INDUSTRIAL FACILITY NONPROCESS ENERGY LIFE CYCLE INFORMATION

A Dissertation By

Khaled Bawaneh

Master of Science, St. Mary's University of Texas, 2007

Bachelor of Science, Muta University, Jordan, 1992

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The following faculty members have examined the final copy of this dissertation for form and content, and recommend that it be accepted in partial fulfillment of the requirement for the degree of Doctor of Philosophy with a major in Industrial Engineering.

Janet Twomey, Committee Chair

Michael Overcash, Committee Member

Bayram Yildirim, Committee Member

Lawrence Whitman, Committee Member

Vinod Namboodiri, Committee Member

Accepted for the College of Engineering

Zulma Toro-Ramos, Dean

Accepted for the Graduate School

J. David McDonald, Dean

DEDICATION

To
My wife, kids, parents, and family

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ABSTRACT

In this study, published information on nonprocess energy use, which includes lighting, heating, cooling, ventilation, humidity control, and particulate control, for industrial buildings has been analyzed and compiled and then represented in power intensity (W/ft^2). More than thirty different sources of data related to industrial building energy use (covering about 82 buildings) were identified and analyzed. The overall objective of this research is to establish benchmark representative ranges (minimum, mean, medium, maximum) of nonprocess energy consumed by an industrial facility. That information will be used in life cycles of industrial products. The industrial manufacturing buildings were classified into six categories according to nonprocess energy use.

This research also investigated the climate zones influence on nonprocess energy use in industrial buildings. The hypothesis tested in this research is: if an industrial building has a characteristic nonprocess energy related to physical dimensions and desired comfort level, then using cooling degrees day (CDD) and heating degrees day (HDD) factors can normalize the measured nonprocess temperature control data for the climate zone differences. The mean, median, standard deviation and total nonprocess energies for current and zone-adjusted nonprocess energy for each facility in this study were calculated.

Finally, five industrial facilities were visited and the energy data for these facilities were collected. The nonprocess power intensity for the various nonprocess energy uses was calculated for each facility, based on the actual facility energy bills and measurements. Four separate analysis techniques were used to estimate the nonprocess energy for these facilities as a means to critically understand this information.

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CHAPTER 1

DISSERTATION OVERVIEW

1.1 Introduction

In 2009 the Energy Information Agency (EIA) reported that the U.S. industrial sector was responsible for 1,655.20 million metric tons of carbon dioxide in the year of 2007 and 1,589.1 million metric tons of carbon dioxide in the year of 2008(Energy Information Administration). While there have been several studies reporting non-process energy for the industrial sector, there is nothing in the literature that prescribes an approach to providing non-process information for life cycle. In this research we address the lack of a methodology for gathering, assessing, and quantifying non-process industrial facility energy for use in life cycle assessment and as a metric for benchmarking improvement. It is vital for any industrial facility to use energy efficiently. This leads to reduction in energy consumption which benefits both the consumer and the utility. Studying the characteristics of industrial facility energy use will allow us to determine the potential reduction and look for efficient ways for energy management.

Accessing information on non-process information is a time intensive and tedious task for several reasons. First, interest in studying non-process energy is low compared to process energy; therefore there are many fewer data resources. Second, non-process energy data are mixed with the process energy, and require some backward calculations to extract the information. Finally, many sources for non-process energy are not well documented, lacking in detail and sufficient transparency, and therefore unusable.

The existing information on industrial buildings nonprocess energy is important for energy improvement, but is often incomplete and not transparent. In this research we provide new methodologies for gathering, assessing, and quantifying nonprocess industrial facility energy as metrics for benchmarking improvement. In addition, the life cycle field for manufactured products does not currently have tools to estimate the nonprocess energy associated with manufacturing facilities. The overall objectives of this research are to estimate and separate the nonprocess energy from process energy for industrial buildings and to integrate these energies with the physical footprint of manufacturing processes for life cycle quantification. Previous analysis of industrial energy use often expressed nonprocess energy as a percentage of total energy but without clear values of actual nonprocess energy. This information is a low value since the actual nonprocess energy is then dominated by the dominator which is unspecified. This places a premium on expressing nonprocess energy as power intensity, W/m^2.

Published information on nonprocess energy use for about 82 buildings, which includes lighting, heating, cooling, ventilation, humidity control, and particle control, for industrial buildings has been analyzed and compiled and then represented in power intensity (W/m^2). The industrial manufacturing buildings were classified into six categories ranging from largely outside facilities (such as refineries) to highly controlled facilities (such as cleanroom facilities). The power intensity for each category was estimated using single to multiple sources. This nonprocess energy was more clearly defined to allow more quantitative improvements.

As a part of this research, energy assessment studies were also conducted for five industrial facilities in Wichita area. Up to four separate analysis techniques were used to estimate the nonprocess energy for these facilities.

Organization of Thesis: The outcome of this research is presented in this thesis according to five articles for journal publication. The remainder of this chapter provides a short synopsis of each paper (journal paper). These chapters of the thesis were all written for submittal to referred journals:

1. Industrial Facilities Nonprocess Energy
2. Climate Zones and the Influence on Industrial Nonprocess Energy
3. Estimating Nonprocess Energy from Building Energy Consumption
4. Analysis techniques to estimate the nonprocess energy for industrial facilities and case studies
5. Assessment of manufacturing process area for nonprocess energy analysis

The final chapter, Chapter 7, draws overall conclusions, and discusses future work for inquiry.

1.2 Industrial Facilities Nonprocess Energy

Approximately 50 published sources covering about 82 industrial buildings in the U.S. were used. The collected data were organized so the characteristics of the different building categories based on type of energy use could be observed. In this study, the information on nonprocess energy use for industrial buildings was compiled and analyzed. The power intensity for lighting, heating, cooling, ventilation, and total nonprocess energy were calculated. This was done for six building categories,

Category 1: Large outside plants and refineries

Category 2: Enclosed buildings with lighting only

Category 3: Industrial buildings with lighting and heating

Category 4: Industrial buildings with lighting, heating, and cooling

Category 5: Industrial buildings with lighting, heating, cooling, and humidity control.

Category 6: Industrial buildings with lighting, heating, cooling, humidity control and particle control.

The available data on nonprocess energy for each source were used to calculate the nonprocess energy for each facility included in this study. The operating hours for each facility were used to calculate the lighting power intensities under the assumption that during nonprocess periods, the lighting is essentially turned off. Heating, cooling, and ventilation are more nearly constant and so 8,760 hours/year are used.

The nonprocess power intensity for building categories 1 and 2, where only lighting is used, was estimated based on the Department of Energy assessment report, the (LBL-29749) report, and ASHRAE Standards for lighting. For example the lighting intensity for the refinery is equal to 4.3 W/m^2 as set by the ASHRAE Standards for outside facilities.

For categories 3, 4, 5, and 6, the results of all sources used in this study were catalogued to estimate the power intensities for each facility.

1.2.1 Results

The collected data were organized and presented so the characteristics of the different building categories. The mean value for each nonprocess energy type was calculated, Figure 1.1.

The mean value for lighting ranges from 0.27 $Watts/ft^2$ in category one buildings to about 1$Watts/ft^2$ in category three and higher buildings. The lighting power intensities for categories one and two, in this case, do not match with the nonprocess energy because the operating hours were used to calculate the lighting power intensity. Heating starts from category three buildings to category five.

The mean value for heating, based on 8,760 hours, ranges from 0.88 $Watts/ft^2$ in category three buildings to 1.75 $Watts/ft^2$ in category five buildings. Heating is the highest among all types of nonprocess energy uses. For cooling, the mean value ranges from 0.62 $Watts/ft^2$ in category four buildings to 1.18 $Watts/ft^2$ in category five buildings. For ventilation, the mean value ranges from 0.14 Watts/ft^2 in category five buildings to 0.20 Watts/ft^2 in category four buildings. The total nonprocess power intensity means, based on 8,760 hours (except as noted for lighting), progress from 0.27 Watts/ft^2 in category one buildings to 4.01 Watts/ft^2 in category five buildings.

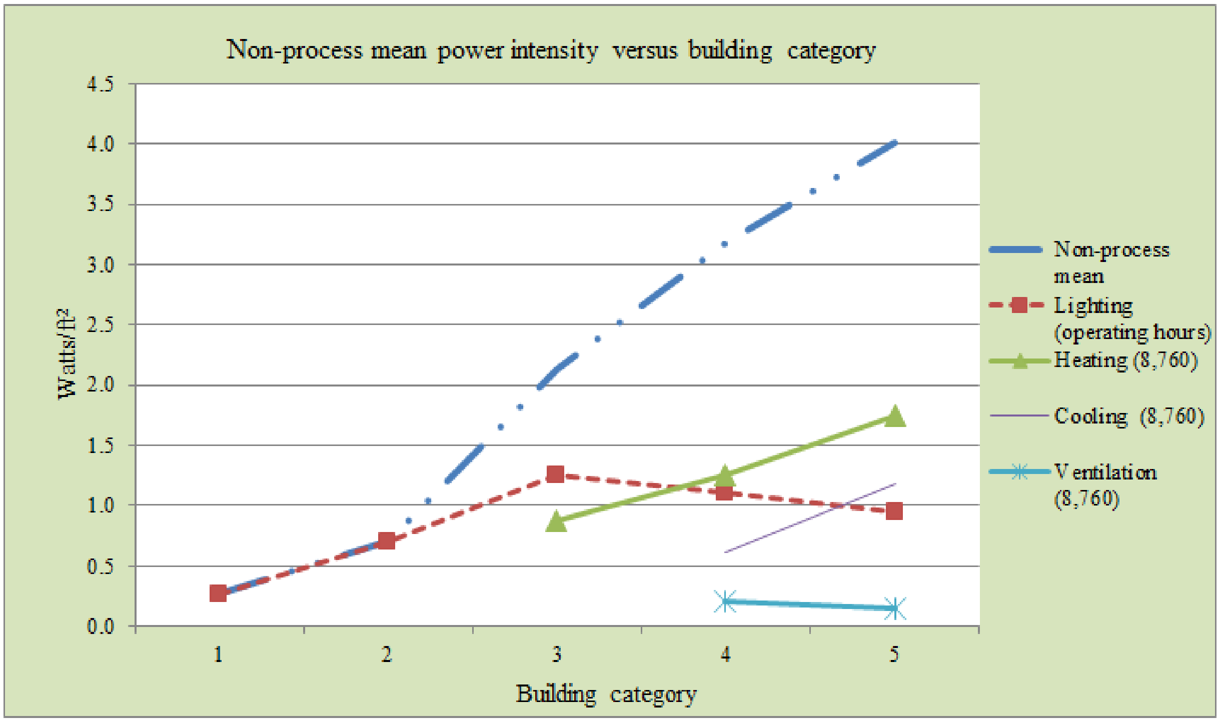

Figure 1.1. The nonprocess power intensities mean values for each building category based on 8,760 hours.

Category six industrial buildings have the highest nonprocess power intensity due to the need for particulate control inside the manufacturing facility, which consumes about 49 % of the annual nonprocess energy use. The power intensity for lighting in category 6 ranges from 1.37 Watts/ft^2 to 1.7 Watts/ft^2. For heating it ranges from 5.3 Watts/ft^2 to 30.5 Watts/ft^2. For cooling the power intensity ranges from 5 Watts/ft^2 to 12.9 Watts/ft^2. For particulate and humidity control, it ranges from to 2 Watts/ft^2, for class 5, to 12.98 Watts/ft^2, for class 1.

1.2.2 Conclusions

This thesis has provided a complete review of nonprocess energy information for industrial manufacturing facilities. The standard deviation of the nonprocess energy ranged from 0.11 for category 2 buildings to 1.29 for category 4 buildings.

The nonprocess energy use by industrial buildings has a general relationship to building category and so this can be used in broader life cycle research. For a manufacturing process, the area can be estimated by direct measurement or by assembling unit process areas to give the total manufacturing sequence area results. These specific areas (dealt with in a subsequent paper) multiplied by the power intensities give nonprocess energy per unit time which with the time to make a product gives nonprocess energy per unit product. In this way the nonprocess energy can then be added to process energy life cycle assessments built from unit process approach.[21, 22]

If instead, life cycle data are collected by annual energy measurement from a manufacturing plant making a specific product, then these nonprocess energies can be subtracted to arrive at direct process energy estimates. In either mechanism to assess life cycle of manufacturing processes, the nonprocess energy estimate portion can be made more transparent from this review paper, thus facilitating energy improvement of process or nonprocess energy consumption.

1.3 Estimating Nonprocess Energy from Building Energy Consumption

Most energy studies in the literature specify solely the relevant to total facility energy consumption and/or energy cost drivers and do not distinguish between process and nonprocess energy for industrial facilities. The main objective of this section of the research is to estimate the overhead energy and to collect the life cycle information of the facility nonprocess energy using a different analysis technique developed in this research. This technique uses a regression of monthly building energy or utilities use versus monthly production and extrapolation to zero production to obtain the nonprocess energy.

1.3.1 Results

In this study, the nonprocess energy consumption for six facilities was calculated using the regression model analysis technique. The nonprocess power intensity for these facilities ranges from 5.7 W/m^2 for case1 to 37.5 W/m^2, Table 1.1. The fraction of nonprocess energy to total facility energy ranges from 10.6 % for case 1 to 56.7 % for case 5 facility.

TABLE 1.1

NONPROCESS ENERGY SUMMARY

	Monthly nonprocess energy consumption, kWh	Fraction of nonprocess to total facility energy at average monthly production	Nonprocess power intensity, W/m^2
Expected mean from literature on nonprocess energy of industrial buildings , std dev, Table 1			Mean of literature values = (30.6 W/m^2), Std dev = (11.8)
Facility type and case study			
Medical textile laundry, 1	23,485	4.9%	5.7
Aluminum extrusion, 2*	503,215	28.3%	50.6
Carpet manufacturing, 3*	218,788	21.9%	56.6
PET recycling, 4*	489,364	32%	72
Aerospace parts, 5	279,057	56.7%	37.5
Aerospace parts, 6 *	195, 459	65%	48.7

Note: * The nonprocess energy for this facility appears to include the standby energy since values are noticeably higher than 30.6 W/m^2

1.3.2 Conclusions

The life cycle of manufactured products in specific plants has advanced by developing unit process tools which reflect the transformation of input materials or chemicals into product. This research has further contributed to the life cycle of products by estimating nonprocess energy to be added to the life cycle process energy to thus obtain more complete energy profile of product manufacturing. An innovative method for the evaluation of the nonprocess energy contribution was developed and tested. This was the regression analysis of monthly energy (electricity and/or natural gas) versus some measures of monthly production. In this regression, the energy when extrapolated to zero production is the estimate of nonprocess energy in the building housing the manufacturing process. The nonprocess power intensity for these facilities ranges from 5.7 Watts/m^2 for the Tampa facility to 72 Watts/m^2. The advantage of this method for assessing the nonprocess energy is that it is raped and uses readily available information and largely nonproprietary information.

Other information has also been collected by the research team that includes an extensive compilation of literature data on heating, cooling, lighting, and ventilation of manufacturing buildings (the traditional source of nonprocess energy requirements. In 4 of the 6 case studies, the regression results indicated that total nonprocess energy significantly exceeded traditional industrial heating, cooling, lighting, and ventilation. This indicated that potential opportunities to reduce this additional nonprocess energy exist thus reducing costs further. This additional nonprocess energy was inferred to be the standby energy of machines that occurs when machines are not in production. To test this hypothesis, one site was used to measure the standby energy of each machine. These were totaled and subtracted from the elevated regression energy intensity result. The corrected nonprocess energy was then in line with the expected values supporting the opportunity for economic improvements by turning off machines. In one case this cost savings might be as high as 20% of the process energy expenditures.

1.4 Climate Zones and the Influence on Industrial Nonprocess Energy Consumption

In this chapter, more than 80 industrial facilities in the U.S. were located and identified. The energy consumption for heating and cooling was estimated for each facility from these literature sources. The hypothesis tested in this research is: if an industrial building has a characteristic nonprocess energy related to physical dimensions and desired comfort level, then using HDD and CDD factors can normalize for the climate zone differences of measured nonprocess temperature control data from various climate zones. That is, if corrected for climate zone differences, do measured nonprocess energy intensities (W/m^2) within each building category become more similar and hence reflecting industrial practices. The five U.S. climate zones and the location for each facility in this study were identified. To investigate how the location influences the amount of heating and cooling at each facility, a baseline analysis of five representative cities in each zone was done to obtain the 5-year average cooling degrees days (CDD) and heating degrees days (HDD). It is postulated that the effect of location in various climate zones can be reduced by a climate zone adjustment factor to a baseline of zone 3 in order to assess the fundamental industrial building need for heating and cooling. That is, if all measured heating and cooling energies were adjusted as if all facilities were in zone 3, would more uniform energy intensities, W/m^2 for heating and cooling emerge?

Cooling degrees days (CDD) and heating degrees days (HDD) are measurements of heating and cooling demands that can be computed from average daily temperatures at a particular location. By subtracting the average daily temperature from a base temperature, the CDD and HDD are determined daily and summed over a year (Garman, Blanco & Erickson, 2000). To calculate the daily HDD with 65 ^{O}F (18.3 ^{O}C) as a base temperature,

Base temperature = 65 ^{O}F (18.3 ^{O}C)

The average day temperature = 50 ^{O}F (10 ^{O}C)

HDD = 65-50 = 15 HDDs (^{O}F) = 15 ×5/9 = 8.3 HDDs (^{O}C)

1.4.1 Results

The effect of CDD and HDD on the industrial building cooling and heating energy estimates were determined from a proposed adjustment of the differences in climatic zones on heating and cooling. The average of zone 3 or the middle U.S. climatic zone is the baseline with average cooling of 1,049 CDDs and the average for heating of 2,425 HDD. The heating and cooling energy intensities, Watts/m^2, for all industrial buildings were adjusted to zone 3 for each building category. Lighting and ventilation were not adjusted as these were assumed to be constant on a daily basis. The adjusted nonprocess energy curves for category buildings 4 and 5 were graphed in Figure 1.2. The mean values for the adjusted nonprocess energy in climate zones 4 and 5 are higher than the current values where low values of HDD were adjusted by a factor of 2.50.

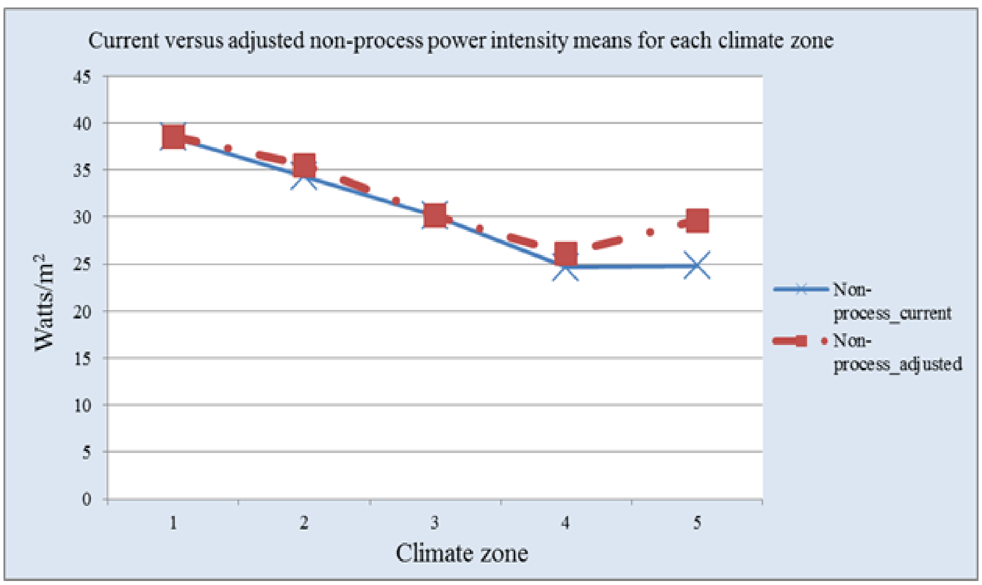

Figure 1.2. Current and adjusted nonprocess power intensities by climate zone for category buildings 4 and 5.

1.4.2 Conclusions

From this study directed at nonprocess industrial building energy, there is no evidence that the use of facility location and the climate adjustment calculation of CDD and HDD were able to have a significant improvement in the uniformity of the nonprocess energy. This implies that the CDD and HDD factors for the U.S. climate zones do not quantitatively reflect zone locations in such a way as to remove this location effect. This indicates that the measured manufacturing building heating and cooling of industrial buildings may reflect other elements than just outside temperature and thus were not as responsive to these climate factor adjustments. The inability to reduce the geographic (that is, climate zone) effects of industrial plant nonprocess energy intensities supports the de-emphasis of this tool in the ASHRAE Handbook.

It is recommended that for life cycle studies, the nonprocess energy estimates should utilize the mean or median energy intensities (W/m^2) from the literature (unadjusted) as estimates for the six building categories. If the life cycle is related to a specific site and building, then currently available tools such as EnergyPlus can be used for improving the nonprocess energy estimates for heating, cooling, and ventilation.

1.5 Analysis Techniques to Estimate the Nonprocess Energy for Industrial Facilities and Case Studies

Five industrial facilities were visited and the energy data for these facilities were collected. The nonprocess energy for each facility was estimated and analyzed. The nonprocess power intensity for the various nonprocess energy uses was calculated for each facility, based on the actual facility energy bills and measurements. Four separate analysis techniques were used to estimate the nonprocess energy for these facilities as a means to critically understand this information:

a) Method 1: direct measurements of nonprocess energy

b) Method 2: direct measurements of process energy, then the nonprocess energy can be calculated by subtracting the process energy consumption from the total facility energy consumption.

c) Method 3: Creating a regression model which relates the material removal (chip weight) with the building energy consumption to estimate the nonprocess energy at zero production

d) Method 4: Using simulation tools to estimate the building nonprocess energy

1.5.1 Results

In this study, the nonprocess energy consumption for five facilities was estimated using the four analysis techniques. The nonprocess power intensity for these facilities ranges from 18.74 W/m^2 for case 3 facility to 33.57 W/m^2 for case 1 facility, Table 1.2. Four analysis techniques were used for case 1 and three for case 2. In case 3 and 4 two analysis techniques were used.

TABLE 1.2

ANNUAL NONPROCESS ENERGY BY METHOD FOR THE FIVE CASE STUDIES

Case #	Facility type	Annual energy consumption, kWh	Nonprocess energy estimate by method, kWh			
			Method 1 (W/m^2)	Method 2 (W/m^2)	Method 3 (W/m^2)	Method 4 (W/m^2)
1	Aerospace parts	5,356,312	2,632,005 (29.50)	2,793,327 (31.31)	3,107,392 (34.8)	2,988,007 (33.57)
2	Aerospace parts	3,424,489	1,250,386 (25.91)	n/a	2,345,508 (45. 19) *	1,149,484 (26.3)
3	Aerospace assembly	1,433,762	633,861 (19.30)	n/a	n/a	606,352 (18.74)
4	Heavy trucks	39,993,613	9,414,099 (23.15)	n/a	n/a	9,002,637 (22.05)
5	Press shop	-	925,934 (25.17)	n/a	n/a	n/a

*: This amount includes standby energy for machines

1.5.2 Conclusions

In this section different methods to extract the nonprocess energy in industrial buildings were used as comparators. The research has indicated that these methods are valuable techniques to assist facility managers in determining energy conservation solutions. It is advantageous to have different methods for estimating the nonprocess energy for the industrial buildings where the facility manager can decide which method to use based on the available information. Also these methods can be used to check the accuracy of each other.

In 1 of the 5 case studies the four different methods were used to estimate the nonprocess energy for the same facility where all needed information are available to use these methods. In the other case studies one to three methods were used for each facility based on the available information for each method. The results of these estimates were close to each other which indicate that any method can be used based on available information. Thus these methods are potentially important step in improving energy use by nonprocess sources.

1.6 Assessment of Manufacturing Process Area for Nonprocess Energy Analysis

The goal of this research is to measure in actual manufacturing plants the relationship of machines (the product manufacturing processes) and the adjacent area. Together these comprise the plant area assigned to a machine or sequence for machines. This is a critical body of information needed to estimate product (from one or a sequence of machines) nonprocess energy as energy intensity (W/m^2) times process area. To understand and investigate the relationship between the manufacturing process (machines converting materials or work pieces into products) area and the nonprocess energy for an industrial facility, buildings physical and energy information for five different facilities was collected and analyzed. The space usage for each facility was grouped into seven categories which are:

a) Category A: space used directly by machines

b) Category B: space used around the machine

c) Category C: space used for raw material and finished product

d) Category D: space used for workstation (controlling all machines)

e) Category E: space used for aisles

f) Category F: Space for offices and break area

g) Category G: unused space due to larger building than necessary for current production

The percentage of each space type to machine area (A) category was calculated after extracting type I space which considered not a part of the building where it is not used. This allows the calculation of area ratios as a potential tool to scale machine area or footprint into that of the manufacturing plant necessary for that machine.

1.6.1 Results

The percentage of nonprocess area (B to F space) to process area (A space) in the five case studies ranges from 500 % in case 5 to 1910 % in case 3 which influences the total energy consumption of the facility. The higher nonprocess area means higher nonprocess energy use in the facility, Table 1.3. In 2 of the 5case studies, the unused space in the facility exceeds machines areas which increase the energy consumption of the facility. This indicated that potential opportunities to reduce this additional nonprocess energy exist thus reducing costs and environmental impact of this energy uses. In case 2, about 45 kW are consumed per hour by the nonprocess area, cost savings might be as high as 30% of this energy if the nonprocess space was reduced.

TABLE 1.3

CASE STUDIES AREA AND NONPROCESS ENERGY DATA SUMMARY

Case #	Percentage of space category area to machines area					Percentage of total non-process area to machine area (C to F)	Percentage of total space category (B to F) to category A space	No-process power intensity (W/m^2)
	B	C	D	E	F			
Case 1	247%	45%	90%	95%	23%	253%	500%	29.2
Case 2	88%	54%	211%	110%	42%	417%	505%	30 .0
Case 3	410%	628%	287%	175%	410%	1500%	1910%	24.8
Case 4	272%	120%	88%	107%	131%	446%	718%	25.9
Case 5	236%	33%	17%	88%	22%	160%	396%	33.7

1.6.2 Conclusions

This thesis has further contributed to the life cycle of products by estimating nonprocess area and related nonprocess energy to be added to the life cycle of industrial facility to obtain more complete energy profile of product manufacturing. The percentage of nonprocess area (B to F space) to process area (A space) in the five case studies ranges from 500 % in case 5 to 1910 % in case 3 which influences the total energy consumption of the facility. The higher nonprocess area means higher nonprocess energy use in the facility. Figure 1.3 shows the effect of the high service area on the annual nonprocess energy for four facilities. For example, case 3 facility has the highest nonprocess area among other facilities which increase the annual energy consumption for this facility. The higher nonprocess area indicates higher annual energy consumption. This means higher carbon dioxide emissions.

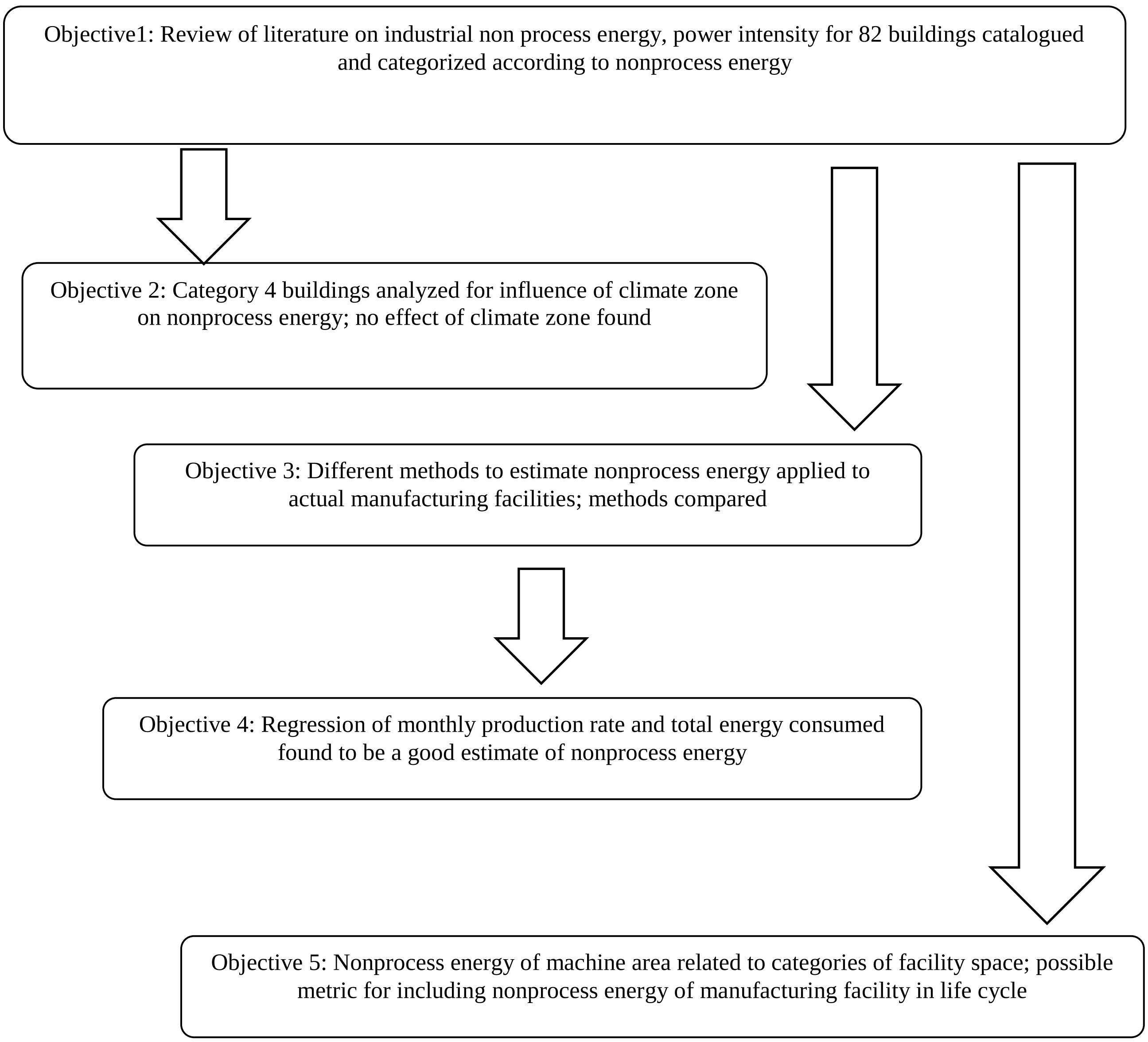

Figure 1.3. Relationships between the 5 dissertation objectives.

CHAPTER 2

INDUSTRIAL FACILITIES NONPROCESS ENERGY

2.1 Abstract

In this study, published information on nonprocess energy use, which includes lighting, heating, cooling, ventilation, humidity control, and particulate control, for industrial buildings has been analyzed and compiled and then represented in power intensity (W/ft^2). More than thirty different sources of data related to industrial building energy use (covering about 82 buildings) were identified and analyzed. Energy receives a lot of consideration in analyzing prospective savings in industrial facilities since the industrial sector consumes more than 30% of the total energy in the U.S. The main objective of this study is to establish representative ranges for nonprocess energy use that can then be used with full process the life cycle for industrial products. The industrial manufacturing buildings were classified into six categories according to nonprocess energy use. The power intensity for each building category was estimated from the available data. Previous analyses of industrial energy use often expressed nonprocess energy as a percentage of total energy but without clear values of actual nonprocess energy. This information is a low value since the actual nonprocess energy is then dominated by the dominator which is unspecified.

KEYWORDS: Industrial building energy, nonprocess energy, energy efficiency

2.2 Introduction

In the last sixty years, industrial energy consumption has doubled. Worldwide, the industrial sector consumed about 175 quadrillion Btu in 2006 and it is expected to consume more than 245.6 quadrillion Btu in 2030.[1] In the U.S., about 28.4 quadrillion Btu was consumed by the industrial sector in the year of 2008 and 27 quadrillion Btu in 2009.[1]

Since the industrial sector consumes more than 30 % of the total U.S. energy consumption at an annual cost of more than $120 billion, energy now receives greater consideration when looking for prospective savings in industrial facilities.[2] The National Association of Manufacturers announced that about 93% of the United States small and medium industrial companies believe that the high energy prices have a negative impact on their bottom line and have negative financial effects on their businesses. So, reducing and controlling energy consumption will have a positive impact on their businesses.[2]

In 2009 the Energy Information Agency (EIA) reported that the U.S. industrial sector was responsible for 1,655.20 million metric tons of carbon dioxide in the year of 2007 and 1,589.[1] million metric tons of carbon dioxide in the year of 2008.[3]

To understand how to reduce industrial facilities energy consumption, the total energy consumed is divided into process energy and nonprocess energy. Process energy includes the energy required for each process function such as, process machinery, heat treatment, furnaces, pumps and motors, conveying systems, and other process loads.[4] The building nonprocess energy includes lighting, heating, cooling, ventilation, humidity control, and particulate control. The focus of this paper is on industrial nonprocess energy. Sources of information on nonprocess energy were located in the published literature (includes government and industrial reports). Using that information is not straight forward. The information is often misleading, incomplete and not transparent. In this paper we address the lack of a methodology for gathering, assessing, and quantifying nonprocess industrial facility energy for use in life cycle assessment and as a metric for benchmarking improvement. It is vital for any industrial facility to use energy efficiently. This leads to reduction in energy consumption which benefits both the consumer and the utility. Studying the characteristics of industrial facility energy use will allow us to determine the potential reduction and look for efficient ways for energy management. The objective of this study is to estimate and separate the nonprocess energy from process energy for industrial buildings and to evaluate the potential environmental impacts in the life cycle for product manufacturing.

2.3 Methodology

The overall objective of this study is to estimate and analyze nonprocess energy use in industrial buildings using data found in published literature and in government or industrial reports. Power intensity is defined in this research, as the power in kW per square foot (kW/ft^2). To understand and quantify the nonprocess from process energy in industrial facilities, the following approach was followed:

1. Published information on nonprocess energy use for industrial buildings has been analyzed and compiled to make sure sufficient data were present.
2. The industrial manufacturing buildings were classified into six categories and the overhead energy use put into these categories.
3. The power intensity for each facility was estimated based on the annual energy consumption, operating hours, and area of the facility.
4. The power intensity for each building category was summarized and in a Summary Table to allow comparison of trends.

Approximately 50 different sources published between 1977 and 2010 were reviewed and evaluated. These sources include Department of Energy publications, Energy Information Administration reports, journals publications, dissertations, academic research reports, industrial manuals, and textbooks. Any information found in these documents pertaining to nonprocess energy was retrieved.

Accessing information on nonprocess information was a time intensive task for several reasons. First, interest in studying nonprocess energy is low compared to process energy; therefore there are many fewer data resources. Second, nonprocess energy data are mixed with the process energy, and require some backward calculations to extract the information.

Finally, many sources for nonprocess energy are not well documented, lacking in detail, and therefore unusable. For example, the PNNL study of nonprocess energy based on Manufacturing Energy Consumption Survey (MECS) for the year 1991.[5] The power intensity watts/ ft^2 for each facility type in this study could not be estimated because the operating hours for each facility were not provided.

The collected data were organized so the characteristics of the different categories based on type of energy use could be observed. In this study, the information on nonprocess energy use for industrial buildings was compiled and analyzed. The power intensity for lighting, heating, cooling, ventilation, and total nonprocess energy were calculated, based on the facility operating hours. This was done for each building category. The operating hours for each facility were used to calculate the lighting power intensities under the assumption that during nonprocess periods, the lighting is essentially turned off. Heating, cooling, and ventilation are more nearly constant and so 8,760 hours/year are used. An analysis was made to determine the influence of the facility location on the nonprocess energy. The results of this analysis indicated that the location of the facility does not have a significant effect on the nonprocess energy.[6]

In the following section, the direct reported data for each study are given.

A. Analysis of Energy Use in the Industrial Sector in California (LBL-29749)

A study was conducted by the Lawrence Berkley Laboratory in California for five different industrial sectors. This study estimated the annual nonprocess energy consumption per square foot (kWh/ft^2) for these five industrial sectors. As shown in Table 2.1, the nonprocess energy values vary from 7 for meat packing facilities to 26 kWh/ft^2 for electronics facilities but were generally about 20 kWh/ft^2.[7]

TABLE 2.1

NONPROCESS ANNUAL ENERGY USE FOR CALIFORNIA INDUSTRIAL BUILDINGS[7]

Space type	Operating hours	Lighting energy use, kWh/ ft^2	Heating energy use, kWh/ ft^2	Cooling energy use, kWh/ ft^2	Total nonprocess energy, kWh/ ft^2
Motor Vehicle plant	3,000	7	9	4.2	20.2
Meat packing	4,000	2	3	2	7
Frozen fruit	6,100	5	8	5	18
Electronics	4,300	7	7	12	26
Instruments	3,500	4	4	12	20

B. Department of Energy Industrial Assessment Center (IAC)

The U.S. Department of Energy initiated the Industrial Assessment Center (IAC) in 2006. The IAC has branches in different States and implements industrial energy assessments through examination of potential savings from energy efficiency improvements, waste minimization, pollution prevention, and productivity improvement. About 14,000 assessments in the U.S. are available in the Department of Energy website. The industrial energy assessments include the SIC number, number of employees, operating hours, annual energy consumption, production rate, facility area, cost of energy, recommended changes, and savings after changes.[8]

The assessment does not distinguish between process and nonprocess energy and mixed the process and nonprocess energy. A sample of these energy assessment results is shown in

Table 2.2. The nonprocess energy for these assessments was not reported and mixed with the total facility energy. The percent ascribed to energy for lighting, heating, etc. was used with the total energy to calculate the nonprocess fraction. Thus other reports and studies were used to separate the nonprocess energy from total facility energy.

TABLE 2.2

IAC ENERGY ASSESSMENTS ENERGY DATA SAMPLE

SIC	Area(ft^2)	Products	Operating hours	Total (kWh)
2631	250,000	Paper Board	8,760	16,336,800
2821	17,000	Thermoplastic hoses	6,240	11,567,208
2435	190,375	Core Veneer	8,400	23,065,269
3496	106,160	Galvanized steel sheet	8,312	75,874,128
2834	1,459,343	Pharmaceutical Pills	6,240	95,904,275
2631	160,000	Recycled paper board	7,200	18,874,575
2911	5,227,200	White Oils, Waxes and Petrolatum	8,760	199,320,747
3728	14,700	aircraft de-icing systems	6,000	12,948,975

C. California Study of Cleanrooms by Lawrence Berkley Laboratory (LBL-2758)

This study in California estimated the energy consumption for heating, cooling, and particulate control in cleanrooms in California. The result of this study is summarized in Table 2.3.[9]

TABLE 2.3

ANNUAL NONPROCESS POWER INTENSITY FOR CALIFORNIA CLEAN ROOMS

Clean room class	Heating, therms/ft^2	Cooling, kWh/ft^2	Fan Energy, kWh/ft^2
1-10	9.13	113	832
100	9.13	113	647
1000	9.13	113	277
10,000	9.13	113	92
100,000	9.13	113	46
Average	9.13	113	455

D. Taiwanese Semiconductors Facility Case Study

In a study conducted in Taiwan for a semiconductor facility, the authors tried to establish energy benchmarking of a typical semiconductor facility. The average energy consumption of semiconductor manufacturing (fab) is equal to 1.432 kWh/cm^2, Table 2.4. The facility consumes about 56.6% of this energy. The process consumes about 43.4% of this energy.[10]

TABLE 2.4

BASIC CONDITIONS OF THE FAB FACILITY

Item	Condition
Location	Hinchu, Taiwan
Temperature	22 ^{o} C
Cleanroom RH	43%
Number of occupants	450
Operating hours/ day	8760
Area	11,182 m^2
Annual energy consumption	233,932,530 kWh

E. English Factory Case Study

The factory was heated by direct gas-fired heaters; the factory floor area was equal to 2,000 m^2. The factory was located in Birmingham, England. The annual energy consumption for this facility was estimated to be equal to 107 kWh/m^2 (0.0095 kWh/ft^2) and the energy consumption for heating was equal to 0.004 kWh/ft^2.[11]

F. Alabama Newspaper Case Study

The Department of Energy reported the annual energy consumption for a newspaper plant in Alabama. The annual production of this facility was estimated to be equal to 36,500,000 newspapers. The approximate area of the facility is equal to 121,000 ft^2. The annual operating hours for this facility were equal to 6,734 hours. The annual energy consumption for this facility was equal to 6,661,250 kWh.[8]

G. The San Francisco State University Case Study

The San Francisco State University conducted a study to estimate the energy consumption in corrugated box facilities. The annual energy consumption for one of these facilities was estimated to be equal to 22,351,340 kWh. The total area of the facility was equal to 370,000 ft^2. The operating hours were equal to 6,240 hours.[12]

H. The Lighting Research Center (LRC) Study

The Lighting Research Center (LRC) conducted a research at Sony Disc Manufacturing in Springfield, Oregon. The team calculated lighting power densities (LPDs) for the facility. The total was 1.34 W/ft^2 (14.4 W/m^2). Other spaces in the facility such as equipment maintenance areas, mechanical and electrical spaces, engineering and controls offices were added to the calculation. The industrial facility's total LPD was 1.04 W/ft^2 (11.2 W/m^2). The research compared these results with the ASHRAE/IES 90.1 1989 whole-building unit lighting power allowance (ULPA) of 2.5 W/ft^2.[13]

I. The Service Facility Case Study

Yimin Zhu conducted a study of a service facility in the southeast region of the United States. The total area of the facility was 1.4 million square feet (about 130,000 m^2). The purpose of this study was to evaluate different energy conservation alternatives for an energy saving plan (cooling, heating, and lighting). Another goal of this study was to reach the energy star designation; the study covered three different space types in this facility which included computer data center, mercantile and services, and offices.[14]

J. ASHRAE 90.1-2004 Standards

The American Society of Heating, Refrigeration, and Air-Conditioning Engineers (ASHRAE) set some standards for workplace design to ensure a suitable lighting design for industrial workplace. ASHRAE 90.1-2004 standards were used to estimate the annual nonprocess energy consumption for the refinery facility in this category.[15] The lighting power density for open areas and outside plants according to ASHARE is equal to or less than 0.5 W/ft^2.

K. The Southeast Resource Recovery Facility (SERRF) Case Study

This facility is an outside facility which uses lighting only as a nonprocess energy. As reported by the Department of Energy, the annual energy consumption for this facility was estimated to be equal to 9,532,002.50 kWh. The total area of the facility was estimated to be equal to 7, 49,232 ft^2. The site is used to separate the municipal waste to produce energy. The SERRF facility is operated 2,080 hours annually.[8]

L. Nortec Company

Some industrial buildings use humidity control inside these facilities (Nortec, 2009). Humidity is defined as the amount of water vapor in the air. "While relative humidity (RH) is defined as the amount of water vapor in a specific volume of compared to the amount of water vapor the same volume of air with hold at saturation (100 % RH) at a given temperature." A previous study by Nortec Company (the manufacturer of Nortec humidifier) estimated the power consumption for the humidifier is equal to 34 kW assuming that the facility runs 40 hours per week. The annual energy consumption to maintain 40% RH inside the facility is was estimated to be equal 70,720 kWh/yr. The total area of the facility was equal to 6,287ft^2.[16]

M. The Pacific Northwest National Laboratory (PNNL)

The Pacific Northwest National Laboratory (PNNL) analyzed the energy use for lighting, heating, cooling, and ventilation for different manufacturing building in the US. The PNNL study based on Manufacturing Energy Consumption Survey (MECS) for the year 1991.[5] The PNNL study reported the total annual energy consumption for more than 14,000 facilities in the U.S. and the fraction of each energy type use to total nonprocess energy without reporting the operating hours for each facility. The results of this report will be used to calculate the energy consumption for ventilation for industrial facilities.

The literature data for the industrial nonprocess energy were from a variety of building types and so a categorization system was developed to subdivide the information.

2.3.1 Industrial Facilities Classification

A classification scheme was developed with six classes or categories according to the way nonprocess energy is used. The industrial buildings categories are as follows:

1. Category 1: Large outside plants and refineries

Lighting is the only non- process energy use in these facilities.

2. Category 2: Enclosed buildings with lighting only

This category is for lighting only, but enclosed in a building structure, for example, storage places and warehouses and equipment rooms.

3. Category 3: Industrial buildings with lighting and heating

These facilities use heating only but do not use cooling due to the temperate zone in which the plant is situated.

4. Category 4: Industrial buildings with lighting, heating, ventilation, and cooling

Most of the industrial facilities lie in this category where lighting, heating, and cooling are considered the major nonprocess energy uses in these facilities.

5. Category 5: Industrial buildings with lighting, heating, cooling, and humidity control.

In addition to lighting, heating, and cooling, these facilities use humidity control inside the building, for example, in laboratories and circuit board manufacturing facilities.

6. Category 6: Industrial buildings with lighting, heating, cooling, humidity control and particulate control, often known as cleanrooms. Cleanrooms are defined in terms of "classes," which represent the highest allowed number of particles in a specific volume of air. These are six classes, 1, 10, 100, 1,000, 10,000 and 100,000. The name refers to the number of particles greater than or equal to 0.5 micrometers (microns) for each cubic foot of air. For example, for a class 100 clean room there are no more than 100 particles greater than 0.5 micrometer per cubic foot.

Based on the raw data available and complete enough for analysis and the types of manufacturing building, the various nonprocess energy types were grouped.

2.3.1 Calculating the Nonprocess Power Intensity for Each Building Category

The power intensities for heating, cooling, ventilation, and humidity control were based on 8,760 hours/year. The reported operating hours for each facility was used to calculate the lighting power intensities under the assumption that during nonprocess periods, the lighting is essentially turned off. The nonprocess power intensity for building categories 1 and 2, where lighting only is used in these facilities, was estimated based on three sources, the Department of Energy assessments report, the (LBL-29749) report, and ASHRAE Standards for lighting. For categories 3, 4, 5, and 6, the results of all sources described above were used. The intensity for each nonprocess energy type use was calculated as follows:

Power intensity = energy consumption ÷ area ÷ 8,760 (except for lighting which used reported operating hours per year)

For example, the nonprocess power intensities for the motor vehicle plant (LBL-29749 study, Table1) were estimated as follows:

The lighting intensity in the motor vehicle plant =

Lighting energy intensity ÷ operating hours = 7 kWh/ ft^2 ÷ 3,000 = 2.3 Watts/ft^2

The heating intensity in the motor vehicle plant =

9 kWh/ ft^2 ÷ 8,760 = 1.02 Watts/ft^2

For some studies, the nonprocess energy was not reported or was mixed with the total facility energy. For these, the percent ascribed to energy for lighting, heating, etc. was used with the total energy to calculate the nonprocess fraction. Thus other reports and studies were used to separate the nonprocess energy from total facility energy for these studies. For example, the IAC facilities nonprocess energy was calculated using the LBL-29749 report information which provided an analysis of the national average of the energy consumption for lighting, heating, and cooling for industrial facilities types. The LB- 29749 reported the nonprocess energy information for aerospace facilities. The fraction of energy required for lighting is equal to 14 %. For heating, the aircraft facilities heating consume around 20.2%. Cooling consumes around 13 % of the total energy consumption. The nonprocess energy for the aircraft components facilities are calculated as follows:

The annual energy consumption for lighting the aircraft component facility

= 14% (from LBL-29749) × 5,252,912 kWh (from IAC report) = 735, 408 kWh

The power intensity for lighting = 735,408 kWh ÷ 68,000 ft^2 ÷ 5,148 hours = 2.1 W/ft^2

The annual energy consumption for heating the aircraft component facility

= 20.2% (from LBL-29749) × 5,252,912 kWh (provided by IAC) = 1,061,088 kWh

The heating intensity = 1,061,088 kWh ÷ 68,000 ft^2 (provided by IAC) ÷ 8,760 hours

= 1.78 $Watts/ft^2$

The energy consumption for ventilation for these facilities was not reported or mixed with heating and cooling energy. Thus other reports were used to calculate the energy consumption for ventilation in categories 4 and 5 buildings. The PNNL-11499 reported the fraction of ventilation energy consumption from the total nonprocess energy consumption for different types of industrial facilities. For example, the energy consumption for ventilation in the automotive assembly plant was calculated as follows:

The fraction of energy for ventilation to total nonprocess energy for automotive plants = 0.076 of total nonprocess energy (PNNL-11499)

The total nonprocess energy consumption for this facility (LBL-29749 study) = 2,222,000 kWh

The annual ventilation energy consumption for this facility = 0.076 × 2,222,000 = 168,872 kWh

The ventilation intensity for this plant = 168,872 kWh ÷ 110,000 ft^2 ÷ 8,760 = 0.17 W/ft^2

The energy consumption for ventilation was subtracted from cooling and heating, e.g. the new cooling intensity was calculated to be equal to 0.30 W/ft^2

Sources used, number of plants, and summary of calculations for each source used to estimate the nonprocess energy for industrial facilities in this study are summarized in Table 2.5.

TABLE 2.5

SOURCES USED AND CALCULATIONS MADE FOR EACH TO CALCULATE THE NONPROCESS POWER INTENSITY

#	Source	# of Plants	Summary of calculations
A	Analysis of Energy Use in the Industrial Sector in California (LBL-29749)	5	Dividing each energy intensity by annual operating hours for lighting and by 8760 for temperature control
B	Department of Energy Industrial Assessment Centers (IAC)	62	LBL29749 Results for fraction of each energy type use was used to calculate the nonprocess energy for these facilities
C	Lawrence Berkley Laboratory LBL-2758	5	Dividing each energy intensity by operating hours
D	The Taiwan for a semiconductor facility Case Study	1	The power intensity was calculated directly using the facility information(area, production rate, and total kWh)
E	England Factory Case Study	1	Results were given directly
F	Alabama Newspaper Case Study	1	LBL29749 Results for fraction of each energy type use was used to calculate the nonprocess energy for this facility
G	The San Francisco State University Study Case Study	2	Results were given directly
H	The Lighting Research Center (LRC) Study	1	Results were given directly
I	The Service Facility in The Southeast region of The U.S.	1	Results were given directly
J	ANSI/ASHRAE/IESNA Standard 90.1-2004	1	Results were given directly
K	Case Study of the Southeast Resource Recovery Facility (SERRF)	1	ASHRAE Standards were used to estimate the lighting power intensity for this facility
L	Nortec Company Website	1	Information was used to calculate energy consumption for humidity control
M	The Pacific Northwest National Laboratory (PNNL)	not available	Information was used to calculate energy consumption for ventilation

The nonprocess power intensities for energy type use were calculated for all facilities, Table 2.6, except for those with humidity and/or particulate control, Table 2.7. The temperature control energy was broken down to heating, cooling, and ventilation separately and shown in Table 2.8. For particulate control is shown in Table 2.9.

TABLE 2.6

NONPROCESS ENERGY ESTIMATES INDUSTRIAL FACILITIES WITH LIGHTING, HEATING, COOLING, AND VENTILATION

Type	Category	Reference	Operating hours	Lighting, W/ft^2	Temperature control W/ft^2	Nonprocess, W/ft^2
Open area, refinery, outside plants	1	16	8,736	0.40	0.00	0.40
A waste to energy facility	1	8	2,080	0.40	0.00	0.40
Clay/Alumina Brick	1	8	4,080	0.13	0.00	0.13
Clay Construction Brick	1	8	8,736	0.15	0.00	0.15
Equipment room	2	8	2,028	0.80	0.00	0.80
Corrugated boxes facility	2	12	6,240	0.77	0.00	0.77
Packaging	2	17	2,600	0.67	0.00	0.67
Storage room	2	7	2,340	0.56	0.00	0.56
Storage room	3	7	2,340	0.80	0.30	1.10
Assembly facility	3	11	4,160	2.00	1.90	3.90
Metal Glass	3	7	2,080	1.81	0.90	2.71
Assembly facility	3	7	2,860	0.81	0.59	1.40
Assembly facility	3	8	3,224	0.85	0.69	1.54
Newspapers	4	8	5,824	0.77	0.88	1.65
Newspapers	4	8	8,736	0.67	1.53	2.20
Aerospace fasteners	4	8	5,087	0.60	1.10	1.70
Frozen fruit	4	8	6,100	0.59	1.27	1.87
printed circuit boards	4	7	8,112	0.79	1.55	2.34
Textile	4	8	7,904	0.93	1.47	2.40
Microwave component	4	18	2,340	1.07	0.83	1.89
plastics bags	4	9	8,736	0.48	2.05	2.53
Printing	4	8	2,860	0.84	0.65	1.48
Instruments	4	8	3,500	0.55	0.72	1.27

TABLE 2.6 (continued)

Type	Category	Reference	Operating hours	Lighting, W/ft^2	Temperature control W/ft^2	Nonprocess, W/ft^2
Electronics	4	9	4,300	0.78	1.00	1.78
Motor Vehicle plant	4	9	3,000	2.30	1.51	3.81
Metal	4	8	3,380	1.32	0.73	2.05
Aircraft Galleys	4	8	5,740	0.91	1.23	2.13
Automotive Repair	4	8	4,160	0.71	1.11	1.81
Aircraft Engine Parts	4	8	4,250	0.71	1.15	1.86
Aircraft gear repair	4	8	5,824	0.92	1.44	2.36
Aircraft Components	4	8	5,148	0.58	1.49	2.08
Plastic Bottles	4	8	7,200	0.72	1.98	2.70
Printed circuit boards	4	18	6,240	1.43	1.17	2.59
Electronic Parts	4	9	5,500	0.78	1.51	2.30
Automotive Trailers	4	8	6,000	0.46	1.86	2.32
Land-Based Turbines	4	8	5,200	0.42	1.88	2.30
Automotive parts	4	8	6,384	0.62	2.02	2.64
Automotive parts	4	8	6,384	0.57	2.17	2.74
Trucking equipment	4	8	2,340	0.89	0.70	1.59
Jet engine components	4	8	4,800	1.05	1.37	2.43
Aircraft Engines	4	8	8,760	1.06	2.69	3.75
Aerospace components	4	8	6,656	1.06	2.10	3.16
Meat Packing	4	9	2,647	0.45	1.02	1.47
Automotive parts	4	8	6,428	0.73	2.11	2.84
Furniture	4	8	2,000	1.20	0.58	1.78
Furniture	4	8	2,000	1.11	0.60	1.70
Textile products	4	8	6,000	1.19	1.72	2.91
Textile goods	4	8	2,000	1.19	0.57	1.77
Fork lifts	4	8	6,000	0.94	1.87	2.81
Welded Assembly	4	8	4,340	0.94	1.49	2.42
Aircraft Components	4	8	4,400	1.47	1.30	2.77
Rubber chemicals	4	8	8,736	0.77	3.22	3.99
Plastic moldings	4	8	6,120	1.31	1.93	3.24
Aircraft propellers	4	8	4,312	0.89	1.71	2.60
Rubber products	4	8	6,360	0.83	2.66	3.49
Aerospace components	4	8	4,732	0.57	2.02	2.59
Aircraft spare parts	4	8	6,240	0.98	2.28	3.26

TABLE 2.6 (continued)

Type	Category	Reference	Operating hours	Lighting, W/ft^2	Temperature control, W/ft^2	Nonprocess, W/ft^2
Frozen Fruits	4	8	4,368	1.15	1.78	2.93
Aircraft seat manufacturing	4	8	3,736	0.99	1.68	2.67
Frozen Vegetables	4	8	4,368	1.09	2.00	3.09
Aircraft and missile components	4	8	4,160	1.52	1.75	3.27
Apparel	4	8	6,552	2.29	2.21	4.49
Automotive Rubber	4	8	2,286	0.99	1.17	2.16
Aircraft Parts	4	8	2,535	1.30	1.30	2.61
Meat Packing	4	8	3,540	1.77	1.53	3.29
Heavy truck Assembly	4	8	4,980	1.42	2.55	3.96
Aircraft parts	4	8	7,296	2.33	3.12	5.45
Manufactures machine parts	4	9	5,276	2.30	2.34	4.64
Plastic Parts & leather	4	8	6,360	1.14	3.67	4.81
Automotive metal stampings	4	8	8,568	2.10	4.32	6.42
Automotive parts	4	8	4,056	1.22	2.57	3.79
Truck bodies and Trailers	4	8	3,840	2.24	2.11	4.35
Automotive parts	4	8	4,056	2.29	2.23	4.52
Automotive Parts	4	8	5,640	1.20	4.34	5.54

TABLE 2.7

NONPROCESS ENERGY ESTIMATES FOR INDUSTRIAL FACILITIES THAT ALSO INVOLVE HUMIDITY CONTROL AND OR PARTICULATE CONTROL

Type	Category	Reference	Operating hours	Lighting, W/ft^2	Temperature and particle control W/ft^2	Nonprocess, W/ft^2
Blankets	5	7	8,400	0.46	4.01	4.47
Circuit Boards	5	9, 20	2,300	1.43	1.7	3.13
Clean room class 1-10	6	9	8,760	1.71	138.42	140.13
Clean rooms class 100	6	9	8,760	1.71	117.3	119.01
Clean rooms class 1,000	6	9	8,760	1.71	75.06	76.77
Clean room class 10,000	6	9	8,760	1.71	53.94	55.65
Clean room class 10,000	6	9	6,700	1.37	12.72	14.09
Clean room class 100,000	6	19	8,760	1.71	48.69	50.4
Clean rooms class 100,000	6	19	6,700	1.37	34.11	35.48

TABLE 2.8

TEMPERATURE CONTROL BREAKDOWN

Type	Category	Heating, W/ft^2	Cooling, W/ft^2	Ventilation, W/ft^2
Storage Cat	3	0.30	0	0.00
Assembly facility	3	1.90	0	0.00
Metal Glass	3	0.90	0	0.00
Assembly facility	3	0.59	0	0.00
Assembly facility	3	0.69	0	0.00
Newspapers	4	0.43	0.34	0.11
Newspapers	4	0.78	0.57	0.18
Aerospace fasteners	4	0.50	0.52	0.08
Frozen fruit	4	0.83	0.34	0.11
printed circuit boards	4	0.86	0.49	0.19
Textile	4	0.77	0.54	0.16
Microwave component	4	0.52	0.26	0.05
plastics bags	4	1.16	0.68	0.21
Printing	4	0.39	0.18	0.07
Instruments	4	0.27	0.36	0.09
Electronics	4	0.42	0.46	0.12
Motor Vehicle plant	4	1.03	0.30	0.17
Metal	4	0.17	0.47	0.10
Aircraft Galleys	4	0.60	0.48	0.14
Automotive Repair	4	0.67	0.36	0.08
Aircraft Engine Parts	4	0.69	0.37	0.09
Aircraft gear repair	4	0.87	0.41	0.16
Aircraft Components	4	0.77	0.60	0.12
Plastic Bottles	4	1.19	0.64	0.15
Printed circuit boards	4	0.67	0.31	0.18
Electronic Parts	4	0.99	0.40	0.13
Automotive Trailers	4	1.25	0.43	0.18
Land-Based Turbines	4	1.30	0.33	0.25
Automotive parts	4	1.50	0.35	0.17
Automotive parts	4	1.33	0.74	0.09
trucking equipment	4	0.40	0.24	0.06
jet engine components	4	0.71	0.57	0.09
Aircraft Engines	4	1.91	0.49	0.29
Aerospace components	4	1.45	0.43	0.22

TABLE 2.8 (continued)

Type	Category	Heating, W/ft^2	Cooling, W/ft^2	Ventilation, W/ft^2
Meat Packing	4	0.71	0.18	0.14
Machined automotive parts	4	1.65	0.22	0.24
Furniture	4	0.34	0.16	0.08
Furniture	4	0.36	0.17	0.06
Textile finishing products	4	0.76	0.65	0.31
Textile goods	4	0.32	0.18	0.07
Fork lifts	4	1.04	0.59	0.24
Welded Assembly	4	0.74	0.56	0.19
Aircraft Components	4	0.68	0.48	0.14
rubber chemicals	4	1.92	0.93	0.37
Plastic Injection Moldings	4	0.85	0.84	0.23
Aircraft propellers	4	1.23	0.34	0.13
Rubber Products	4	2.06	0.33	0.27
Aerospace components	4	0.85	0.85	0.31
Large Aircraft spare parts	4	1.16	0.79	0.33
Frozen Fruits/Vegetables	4	1.28	0.29	0.21
Aircraft seat manufacturing	4	1.07	0.42	0.19
Frozen Vegetables	4	1.27	0.46	0.27
Aircraft and missile components	4	0.76	0.77	0.22
Apparel	4	0.71	1.14	0.36
Automotive Rubber	4	0.91	0.14	0.12
Aircraft Parts	4	0.87	0.40	0.03
Meat Packing	4	0.88	0.46	0.19
Heavy truck Assembly	4	1.64	0.67	0.24
Aircraft parts	4	1.36	1.31	0.46
Manufactures machine parts	4	1.50	0.54	0.31
Plastic Parts & leather	4	2.50	0.80	0.37
Automotive metal stampings	4	2.41	1.38	0.53
Automotive parts	4	2.00	0.31	0.26
Truck Bodies and Trailers	4	1.19	0.70	0.21
Automotive parts	4	1.24	0.71	0.27
Automotive Parts	4	2.07	1.80	0.46

TABLE 2.9

TEMPERATURE CONTROL, HUMIDITY AND PARTICULATE CONTROL BREAKDOWN

Type	Category	Heating W/ft^2	Cooling W/ft^2	Humidity control W/ft^2	Ventilation W/ft^2	Particle control W/ft^2
Blankets	5	1.301	0.875	0.035	0.042	-
Circuit Boards	5	2.198	1.480	0.163	0.240	-
Clean rooms class 1-10	6	30.54	12.90	-	-	94.98
Clean rooms class 100	6	30.54	12.90	-	-	73.86
Clean rooms class 1,000	6	30.54	12.90	-	-	31.62
Clean rooms class 10,000	6	30.54	12.90	-	-	10.50
Clean rooms class 100,000	6	30.54	12.90	-	-	5.25
Clean room class 100,000	6	5.35	5.14	-	-	2.23
Clean room class 10,000	6	9.47	10.39	-	-	14.04

2.4 Results

The collected data were organized and presented so the characteristics of the different building categories. The mean value for each nonprocess energy type was calculated, Figure 2.1

The mean value for lighting ranges from 0.27 Watts/ft^2 in category one buildings to about 1Watts/ft^2 in category three and higher buildings. The lighting power intensities for categories one and two, in this case, do not match with the nonprocess energy because the operating hours were used to calculate the lighting power intensity. Heating starts from category three buildings to category five.

The mean value for heating, based on 8,760 hours, ranges from 0.88 Watts/ft^2 in category three buildings to 1.75 Watts/ft^2 in category five buildings. Heating is the highest among all types of nonprocess energy uses. For cooling, the mean value ranges from 0.62 Watts/ft^2 in category four buildings to 1.18 Watts/ft^2 in category five buildings. For ventilation, the mean value ranges from 0.14 Watts/ft^2 in category five buildings to 0.20 Watts/ft^2 in category four buildings. The total nonprocess power intensity means, based on 8,760 hours (except as noted for lighting), progress from 0.27 Watts/ft^2 in category one buildings to 4.01 Watts/ft^2 in category five buildings.

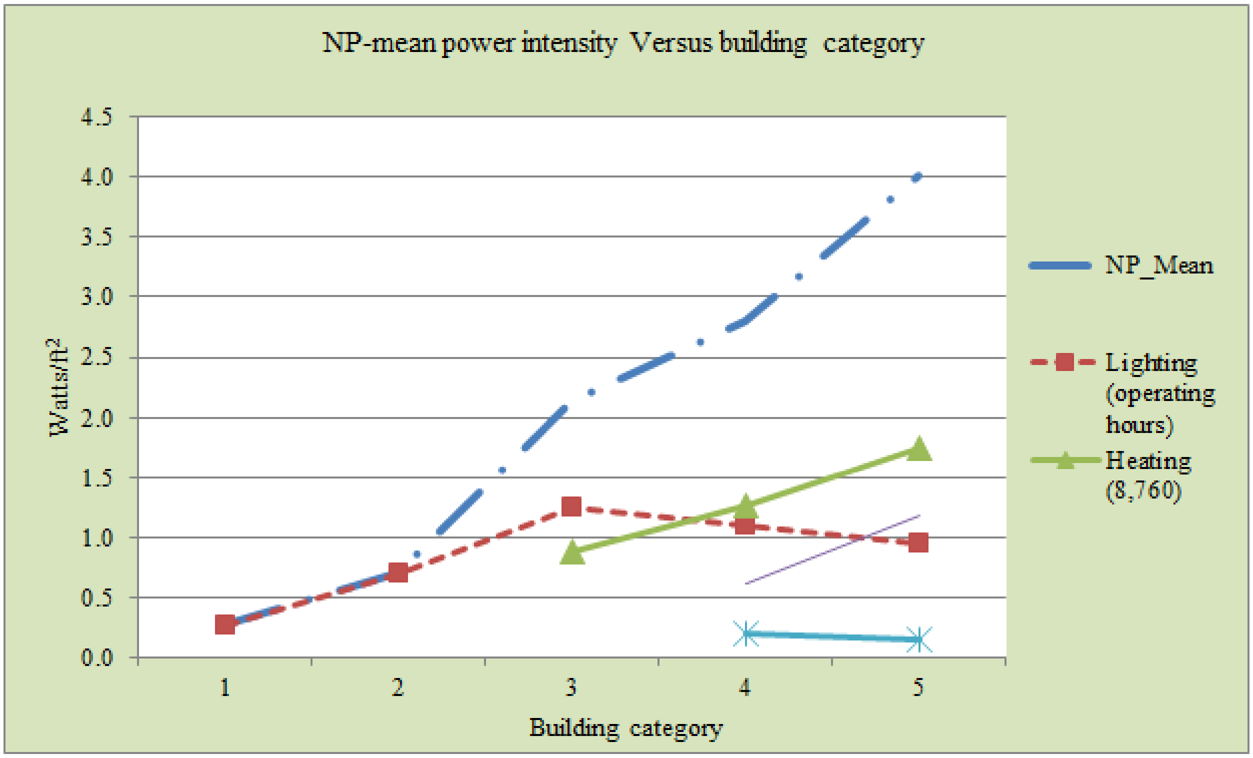

Figure 2.1. The nonprocess power intensities mean values for each building category.

To explore the statistical characteristics for the total nonprocess power intensity and to compare the variability for the nonprocess energy use along with the building category, an interval plot for the mean power intensity was constructed for the nonprocess energy use. The mean nonprocess power intensity plus and minus one standard deviation (μ±1 std dev) is presented for each building category.

As shown in Figure 2.2, the nonprocess power intensity for category one buildings ranges from 0.12 Watts/ft^2 to 0.27 Watts/ft^2. For category two buildings it ranges from 0.59 Watts/ft^2 to 0.81 Watts/ft^2. Category three facilities nonprocess power intensity ranges from 1.53 Watts/ft^2 to 2.73 Watts/ft^2. Category five buildings have the highest nonprocess power intensity interval among other buildings category.

Category six industrial buildings have the highest nonprocess power intensity due to the need for particulate control inside the manufacturing facility, which consumes about 49 % of the annual nonprocess energy use. The power intensity for lighting in category 6 ranges from 1.37 Watts/ft^2 to 1.7 Watts/ft^2. For heating it ranges from 5.3 Watts/ft^2 to 30.5 Watts/ft^2. For cooling the power intensity ranges from 5 Watts/ft^2 to 12.9 Watts/ft^2. For particulate and humidity control, it ranges from to 2 Watts/ft^2, for class 5, to 12.98 Watts/ft^2, for class 1, Table 2.9.

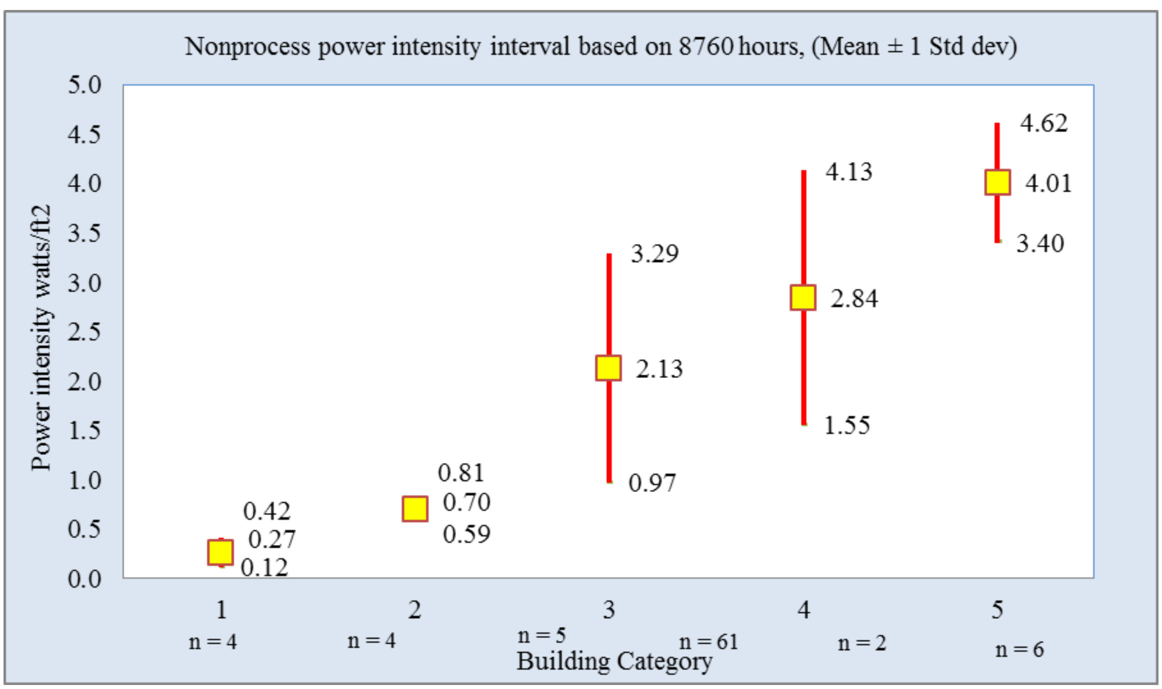

Figure 2.2. Nonprocess power intensity interval.

2.5 Conclusions

This paper has provided a complete review of nonprocess energy information for industrial manufacturing facilities. The standard deviation of the nonprocess energy ranged from 0.11 for category 2 buildings to 1.29 for category 4 buildings, Table 2.10.

TABLE 2.10

NONPROCESS POWER INTENSITY MEANS BY BUILDING CATEGORY

Building category	1	2	3	4	5
Nonprocess, Watts/ft^2	0.27	0.70	2.13	2.84	4.01
Nonprocess standard deviation	0.15	0.11	1.16	1.29	0.61
Lighting (operating hours), Watts/ft^2	0.27	0.70	1.25	1.10	0.94
Heating (8,760) Watts/ft^2	n/a	n/a	0.88	1.02	1.75
Cooling (8,760), Watts/ft^2	n/a	n/a	n/a	0.52	1.18
Ventilation (8,760), Watts/ft^2	n/a	n/a	n/a	0.20	0.14

The literature values for nonprocess energy used in manufacturing buildings are clustered within a reasonable range. The nonprocess energy use by industrial buildings has a general relationship to building category and so this can be used in broader life cycle research. For a manufacturing process, the area can be estimated by direct measurement or by assembling unit process areas to give the total manufacturing sequence area results. These specific areas (dealt with in a subsequent paper) multiplied by the power intensities give nonprocess energy per unit time which with the time to make a product gives nonprocess energy per unit product. In this way the nonprocess energy can then be added to process energy life cycle assessments built from unit process approach.[21, 22]

If instead, life cycle data are collected by annual energy measurement from a manufacturing plant making a specific product, then these nonprocess energies can be subtracted to arrive at direct process energy estimates. In either mechanism to assess life cycle of manufacturing processes, the nonprocess energy estimate portion can be made more transparent from this review paper, thus facilitating energy improvement of process or nonprocess energy consumption.

The most common industrial building is category 4, in which nonprocess electrical use for temperature control and lighting is about 2.6 W/ft^2. The fuel necessary to provide this electricity (based on average U.S. grid) plus energy to deliver the fuel to the electricity generating plant, is a factor of 3.44 times larger, or 8.9 W/ft^2.Using the approximate factor of 0.062 kg CO_2 /MJ fuel combusted, the nonprocess energy for category 4 building about 2 g CO_2 /hr per ft^2.

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CHAPTER 3

ESTIMATING NONPROCESS ENERGY FROM BUILDING ENERGY CONSUMPTION

3.1 Abstract

From this research, an important technique for estimating the nonprocess energy in industrial and manufacturing buildings was examined. The building energy data for six industrial facilities were collected over multiple months in which production varied over these months. This technique then used a regression of monthly building energy or utilities use versus monthly production rate. The nonprocess energy was estimated for each facility as the energy extrapolated to zero production in these regression models. The range of monthly production data was also used to determine a mid-point or average production at each facility and the corresponding average total building energy (process and nonprocess). The energy at zero production as a percentage of the mid-point production energy was thus the nonprocess energy percentage. In addition, the zero production power intensity (W/m^2) was compared to industry average nonprocess energy intensities (heating, cooling, lighting, and ventilation) to interpret the nature and possible improvement in nonprocess energy.

Keywords: Industrial building energy, nonprocess energy, regression

3.2 Introduction

There is a small amount of literature on relating industrial or service building energy to production or activities in those buildings. However a large literature is focused on estimating energy consumption for manufacturing buildings based on design (space, windows, climatic zone, etc). For example, the methodology to estimate building energy consumption using EnergyPlus benchmark models by Fumo, et. al. (2010), contrasts with the capabilities of building energy performance simulation programs by Crawley et. al. (2008), and energy saving studies in industrial facility by Knauglu et. al. (2008). In addition, nonprocess energy is recognized by authors undertaking full manufacturing plant modeling (Herrmann, et. al., 2011 discuss this concept and reviews many of the discrete event simulation (DES) approaches). Weinert, et. al, (2011) also describes detailed plant energy modeling. However, they acknowledge the complexity of such work, but none of these models or papers yet isolates the actual nonprocess energy. Rhamifart, et. al, (2010) examine process and nonprocess energy in a manufacturing facility involving three unit processes. However, the all-inclusive means of reporting energy does not allow isolation of nonprocess energy, as expressed in energy intensity (W/m^2) and thus cannot be scaled to other facilities. These citations reflect the small amount of actual literature focused specifically on nonprocess energy of manufacturing facilities.

Since the goal of this paper is to interpret industrial building energy and production within that building, as a means to understand nonprocess or overhead energy, only the literature related to this nonprocess energy aspect is reviewed below.

Boussabaine (2001) analyzed the energy consumption and cost for 19 sports facilities and proposed a model that incorporates the cost drivers. They found it is possible to predict the total cost of energy over a period of time given the floor area and number of users in sport facilities. The results of this study show that regression can be used to predict the energy and cost of energy for sport facilities (Boussabaine, 2001). One of the most comprehensive studies on energy consumption in industrial buildings was conducted by Vittorio, et. al. (2009). This study provided a methodology to predict the energy consumption for industrial facilities using regression of operations within that building. The study assumed that there is no influence on energy consumption due to climatic variations. Production volume for five different household ovens was used as an energy driver to predict the annual energy consumption for an industrial facility (Vittorio, et. al., 2009). This methodology was used to predict the total energy consumption for the industrial facility but did not separate the nonprocess from process energy. However, the nonprocess energy for this plant could be obtained from their regression equation at zero production.

Electricity consumption in the industrial plant was predicted using multivariate linear regression (Al-Ghandoor and Samhouri, 2009). Electricity consumption was modeled as a function production output, capacity utilization, and number of employees. Their study results showed that the multivariate linear regression can be used to reasonably estimate industrial electricity consumption in an industrial facility. This methodology was used to predict the total energy consumption for many industrial facilities but did not estimate the nonprocess energy for each facility. However, the nonprocess energy for these facilities combined could be obtained from their regression equation at zero production.

The majority of energy studies in the literature focus solely the relevant total facility energy consumption as related to the process and energy cost drivers. Such literature analyses do not distinguish between estimates of process and nonprocess energy for industrial facilities. At this preliminary research stage for nonprocess energy, the objective is to explore a relatively easy, operational concept to estimate nonprocess or overhead energy in a given manufacturing plant. The outcome is to establish whether higher than average nonprocess energy (as determined from other manufacturing literature reviews) can indicate that standby machine energy should be explored for improvement. The goal is not to rigorously establish how to make these improvements, but to suggest that standby or related energy consumption should be evaluated in-depth. For this research objective, only reasonable precision (± 10% - 30%) is needed, given that the method developed herein is reasonable.

Another outcome from better understanding of nonprocess energy intensity as a characteristic of manufacturing buildings is for use in life cycle inventory analysis (leading to carbon footprinting). Currently an estimating technology referred to as unit process life cycle inventory (uplci) has been developed to estimate process energy and material loss for converting raw materials (workpieces) into products (Overcash, et. al., 2009). However, to this process energy must be added the overhead energy and hence tools for estimating this nonprocess energy are needed. The technique developed in this paper will be one mechanism to build a database from actual manufacturing plants of nonprocess energy.

3.3 Methodology

The technique developed herein is based on a regression of monthly building energy or utilities use versus monthly production and extrapolation to zero production to obtain the nonprocess energy. This potentially gives other insights into the basis of this nonprocess energy demand and solutions.

To estimate the nonprocess energy for an industrial facility, the following information was collected:

1- Monthly production rate or chip weight for milling, drilling, and any other machining processes in which material removal occurs
2- Total facility energy consumption on a monthly basis (categorized as electricity, natural gas, etc.)
3- Facility area
4- Facility operating hours

Some of these data are also collected in other energy studies focused on energy improvement (Industrial Assessment Center, 2009). After using the linear regression model to estimate the nonprocess monthly energy (zero production), average monthly production can be estimated as well as average monthly energy.

In order to establish for a given case study whether the plant has higher than average overhead energy use, it was necessary to estimate average manufacturing plant nonprocess energy use. That is, how does the nonprocess energy of a manufacturing plant compare to average overhead energy use for manufacturing plants. For this, an extensive literature review of manufacturing plants nonprocess energy was conducted (Bawaneh, et. al., 2011). The review methodology and results related to building categories (from outdoor production to advanced clean rooms) are given in Bawaneh, et. al. (2011) where the full methodology for energy and energy intensity are given.

The nonprocess energy for different industrial facilities, typically include lighting, heating, cooling, and ventilation. The power intensity (W/m^2) for nonprocess energy use was calculated for each case study herein. All these facilities are referred to as category 4 buildings (that is, providing heating, cooling, lighting, and ventilation) for which the average nonprocess power intensity from the literature ranged from 13.67 W/m^2 to 69.10 W/m^2, Table 3.1. The mean of the

TABLE 3.1

LITERATURE NONPROCESS ENERGY INTENSITY FOR DIFFERENT CATEGORY 4 INDUSTRIAL FACILITIES (Bawaneh, et. al., 2011)

Facility Measured	Lighting, W/m^2	Heating, W/m^2	Cooling , W/m^2	Ventilation, W/m^2	Nonprocess, W/m^2
Instruments	5.92	2.91	3.88	0.97	13.67
Meat packing	4.84	7.64	1.94	1.51	15.82
Printing	9.04	4.20	1.94	0.75	15.93
Trucking equipment	9.58	4.31	2.58	0.65	17.11
Newspapers	8.29	4.63	3.66	1.18	17.76
Furniture	11.95	3.88	1.83	0.65	18.30
Aerospace fasteners	6.46	5.38	5.60	0.86	18.30
Textile goods	12.81	3.44	1.94	0.75	19.05
Furniture	12.92	3.66	1.72	0.86	19.16
Electronics	8.40	4.52	4.95	1.29	19.16
Automotive body repair	7.64	7.21	3.88	0.86	19.48
Aircraft engine parts	7.64	7.43	3.98	0.97	20.02
Frozen fruit	6.35	8.93	3.66	1.18	20.13
Microwave component	11.52	5.60	2.80	0.54	20.34
Metal	14.21	1.83	5.06	1.08	22.07
Aircraft components	6.24	8.29	6.46	1.29	22.39
Aircraft galleys	9.80	6.46	5.17	1.51	22.93
Automotive rubber	10.66	9.80	1.51	1.29	23.25
Newspapers	7.21	8.40	6.14	1.94	23.68
Electronic parts	8.40	10.66	4.31	1.40	24.76
Land-based turbines	4.52	13.99	3.55	2.69	24.76
Automotive trailers	4.95	13.45	4.63	1.94	24.97
Printed circuit boards	8.50	9.26	5.27	2.05	25.19
Aircraft landing gear	9.90	9.36	4.41	1.72	25.40
Textile	10.01	8.29	5.81	1.72	25.83
Welded assembly	10.12	7.97	6.03	2.05	26.05
Jet engine components	11.30	7.64	6.14	0.97	26.16
Plastics bags	5.17	12.49	7.32	2.26	27.23
Aerospace components	6.14	9.15	9.15	3.34	27.88
Printed circuit boards	15.39	7.21	3.34	1.94	27.88
Aircraft propellers	9.58	13.24	3.66	1.40	27.99
Aircraft parts	13.99	9.36	4.31	0.32	28.09
Automotive parts	6.67	16.15	3.77	1.83	28.42

TABLE 3.1 (continued)

Facility Measured	Lighting, W/m^2	Heating, W/m^2	Cooling , W/m^2	Ventilation, W/m^2	Nonprocess, W/m^2
Aircraft seat manufacturing	10.66	11.52	4.52	2.05	28.74
Plastic bottles	7.75	12.81	6.89	1.61	29.06
Automotive parts	6.14	14.32	7.97	0.97	29.49
Aircraft components	15.82	7.32	5.17	1.51	29.82
Fork lifts	10.12	11.19	6.35	2.58	30.25
Machined parts	7.86	17.76	2.37	2.58	30.57
Textile finishing products	12.81	8.18	7.00	3.34	31.32
Frozen fruits/vegetables	12.38	13.78	3.12	2.26	31.54
Frozen vegetables	11.73	13.67	4.95	2.91	33.26
Aerospace components	11.41	15.61	4.63	2.37	34.01
Plastic injection moldings	14.10	9.15	9.04	2.48	34.88
Large aircraft spare parts	10.55	12.49	8.50	3.55	35.09
Missile components	16.36	8.18	8.29	2.37	35.20
Meat packing	19.05	9.47	4.95	2.05	35.41
Rubber products	8.93	22.17	3.55	2.91	37.57
Aircraft engines	11.41	20.56	5.27	3.12	40.36
Automotive parts	13.13	21.53	3.34	2.80	40.80
Motor vehicle plant	24.76	11.09	3.23	1.83	41.01
Heavy truck assembly	15.28	17.65	7.21	2.58	42.63
Rubber chemicals	8.29	20.67	10.01	3.98	42.95
Truck bodies and Trailers	24.11	12.81	7.53	2.26	46.82
Apparel	24.65	7.64	12.27	3.88	48.33
Automotive parts	24.65	13.35	7.64	2.91	48.65
Machine parts	24.76	16.15	5.81	3.34	49.94
Plastic parts & leather	12.27	26.91	8.61	3.98	51.77
Aircraft parts	25.08	14.64	14.10	4.95	58.66
Automotive parts	12.92	22.28	19.38	4.95	59.63
Metal stampings	22.60	25.94	14.85	5.70	69.10
Mean	11.73	11.07	5.69	2.09	30.59
Median	10.55	9.36	4.95	1.94	27.99
Standard deviation	5.55	5.76	3.32	1.17	11.82

results of this literature were about 30 W/m^2 and case studies with higher values from the regression technique than the manufacturing average would then be candidates for a more in-depth study of standby energy use and reduction.

3.4 Results

For each case study in this research, the product class and plant location are given. Manufacturing building data on area, operating hours and what utilities were measured as well as the selection of the parameter for monthly production are then described. Results of the regression, utilities at zero production, and calculated energy intensity (W/m^2) are then described. Median monthly production and median monthly utilities are extracted from the Figures to provide a measure of the typical energy use. The nonprocess energy is expressed as a percent of this median monthly utility.

Case Study 1

A medical textile laundry facility is located in Florida. The area of the facility was 5,650 m^2. The operating hours of the facility are 730 hours per month. Electricity, natural gas, and water utilities were measured. Natural gas was measured in cubic feet (CF). CCF is equal to 100 CF of natural gas unit and was converted to kWh, so as to be on comparable terms to electrical use. One CCF is equivalent to 101,156.9 BTU (United States Energy Information Administration, 2009).

1 CCF = 100 CF =101,156 .9 BTU = 106.74 MJ = 29.64 kWh

The energy consumption data in the facility for the years of 2006, 2007 and 2008 are summarized in Tables 3.2, 3.3, and 3.4. The production was equated to kilograms laundered.

TABLES 3.2

TAMPA FACILITY ENERGY CONSUMPTION AND PRODUCTION RATE FOR 2006
(Craig, 2009)

Month	Electric, kWh	Natural gas, MJ	Natural gas, kWh	Water, liter	Kilograms washed
Jan	107,840	1,335,030	370,717	3,765,902	159,437
Feb	113,440	1,343,707	373,126	3,830,616	160,639
Mar	168,960	1,877,111	521,244	5,089,714	213,233
Apr	138,720	1,377,221	382,432	3,901,190	168,713
May	126,542	1,226,496	340,475	3,034,577	159,346
Jun	139,465	1,364,955	378,911	3,412,292	177,807
Jul	124,000	1,085,247	301,356	2,908,915	135,691
Aug	121,920	1,067,460	296,417	3,186,250	140,318
Sep	147,040	1,366,809	379,541	3,752,079	177,875
Oct	110,720	1,190,670	330,630	2,817,872	152,746
Nov	92,960	1,132,500	314,477	2,720,689	136,780
Dec	152,036	1,499,647	416,302	3,799,521	195,766

TABLES 3.3

TAMPA FACILITY ENERGY CONSUMPTION AND PRODUCTION RATE FOR 2007
(Craig, 2009)

Month	Electric, kWh	Natural gas, MJ	Natural gas, kWh	Water, liter	Kilograms washed
Jan	94,720	1,094,683	303,976	2,480,955	139,524
Feb	96,480	1,228,523	341,141	2,758,850	154,924
Mar	140,960	1,532,860	425,651	2,816,560	202,415
Apr	110,080	1,196,418	332,226	2,568,661	154,561
May	117,920	1,135,898	315,421	2,701,734	159,006
Jun	146,560	1,310,735	363,970	3,345,932	194,091
Jul	115,840	950,215	263,860	2,401,996	140,363
Aug	124,640	1,015,833	282,081	2,781,169	148,392
Sep	145,920	1,224,943	340,147	3,322,295	188,194
Oct	113,760	1,054,445	292,803	2,644,058	145,580
Nov	95,520	1,016,050	282,141	2,662,732	144,673
Dec	118,720	1,495,589	415,175	3,616,790	195,225

TABLES 3.4

TAMPA FACILITY ENERGY CONSUMPTION AND PRODUCTION RATE FOR 2008
(Craig, 2009)

Month	Electric, kWh	Natural gas, MJ	Natural gas, kWh	Water, liter	Kilograms washed
Jan	89,280	1,107,698	307,590	2,693,379	140,114
Feb	95,040	1,156,614	321,173	2,821,882	154,969
Mar	120,480	1,398,479	388,335	3,407,205	186,652
Apr	102,560	1,136,115	315,481	2,743,120	147,757
May	114,720	1,109,000	307,952	2,643,048	145,829
Jun	155,360	1,353,059	375,609	3,355,203	176,221
Jul	113,920	1,004,011	278,798	2,381,107	133,042
Aug	120,480	1,074,510	298,374	2,607,355	134,512
Sep	146,240	1,284,488	356,682	3,323,866	165,061
Oct	114,080	1,099,130	305,211	2,533,556	128,411
Nov	103,040	1,065,266	295,718	2,513,531	137,849
Dec	105,440	1,231,126	341,864	3,011,819	152,588

The use of natural gas for drying and sterilizing these medical garments was analyzed, Figure 3.1.

The regression is MJ/month = 7.50*thousand kg laundered/mo + 28,779 MJ/mo,

for which the power at zero laundry production = 28,779 MJ/mo.

The heating power intensity = 7,991 kWh ÷ 5,650 m^2 ÷ 730 = 1.93 W/m^2

The 1.93 W/m^2 is very small compared to typical heating power intensity for similar buildings, Table 3.1, which means that there is essentially no natural gas consumption when zero kilograms are laundered. This is consistent with plant practices of no gas flow to driers and sterilizers when not in an operating shift. As shown in Figure 3.1, the mid-point monthly natural gas consumption for the average production rate is equal about 1.25 million MJ (347,222 kWh). The average monthly laundered amount is equal about 170,000 kilograms. Laundering one kilogram requires around 7.4 MJ.

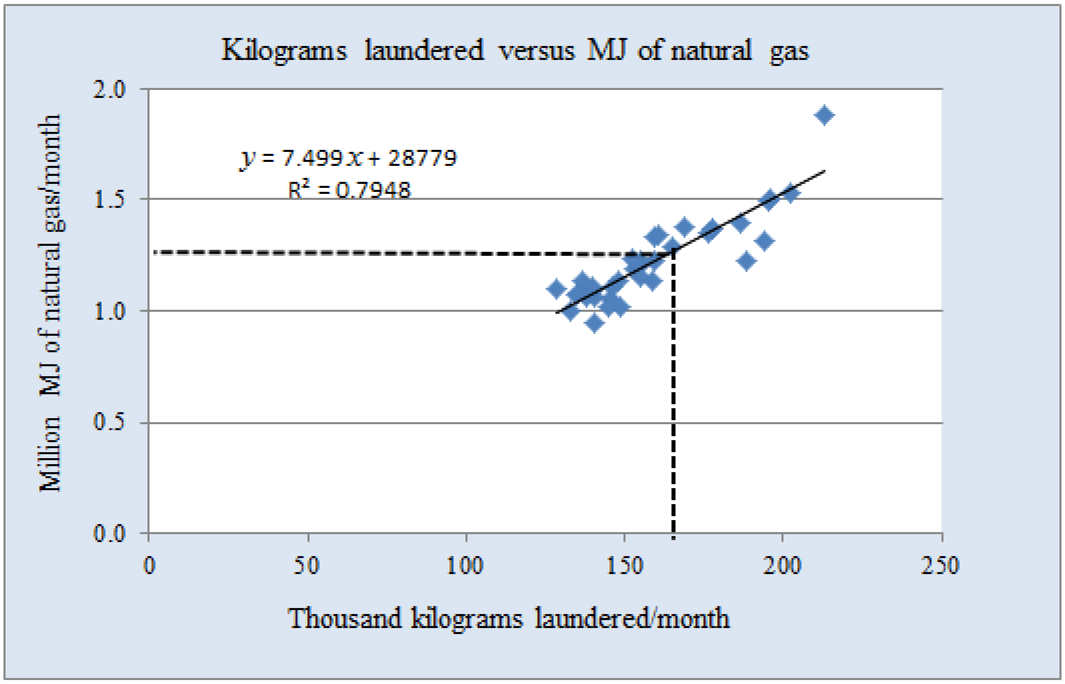

Figure 3.1. Monthly kilograms laundered and monthly natural gas consumption utility for years 2006 to 2008 in commercial laundry (---- shows average monthly natural gas at average monthly production).

The electricity consumption and kilograms washed for each month were also analyzed for the years of 2006, 2007, and 2008, Figure 3.2.

The regression is Mwh/month = 0.659*thousand kg laundered/mo + 15.485 Mwh/mo,

for which the power at zero laundry production = 15,485 kwh/mo.

The electric power intensity for the facility

$15{,}485 \text{ kWh} \div 5{,}650 \text{ m}^2 \div 730 \text{ hours} = 3.75 \text{ Watts/m}^2$

This power intensity is small compared to typical nonprocess power intensity for similar facilities, Table 3.1. Figure 3.2 shows that average monthly mid-point electricity consumption is approximately equal to 130 megaWh for 170,000 kg laundered, so laundering one kilogram of cloths requires approximately 0.76 kWh of electricity.

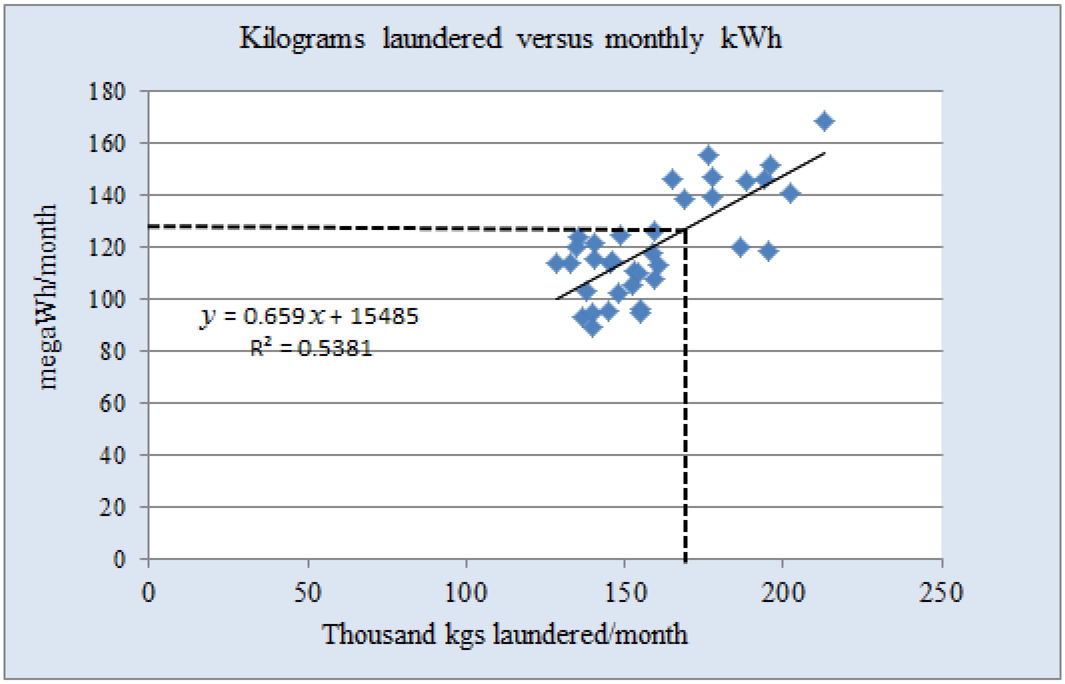

Figure 3.2. Monthly kilograms washed amount with megaWh for the years 2006 to 2008 (---- shows average monthly electricity at average monthly production).

The fraction of nonprocess energy = nonprocess energy consumption ÷ monthly energy consumption for the average production rate

= 15,485 kWh ÷ 130,000 kWh = 11%

Combining natural gas and electricity to obtain the total nonprocess energy, this case study is 5.7 Watts/m^2

Finally, the monthly use of water for the same facility as a utility was collected for the years of 2006 to 2008, Figure 3.3.

The regression is million liters/month = 19.13*thousand kg laundered/mo + 10,844 liters /mo,

for which the power at zero laundry production = 10,844 liters/mo.

Based on this regression model, washing one kilogram of textile requires about 19 liters of water.

This means that if no kgs are laundered, the water consumption will be equal to 10,844 liters monthly. This is very small compared to the average monthly water use at this plant of about 3,400,000 liters, Figure 3.3, so essentially no extra or nonprocess use of water occurred.

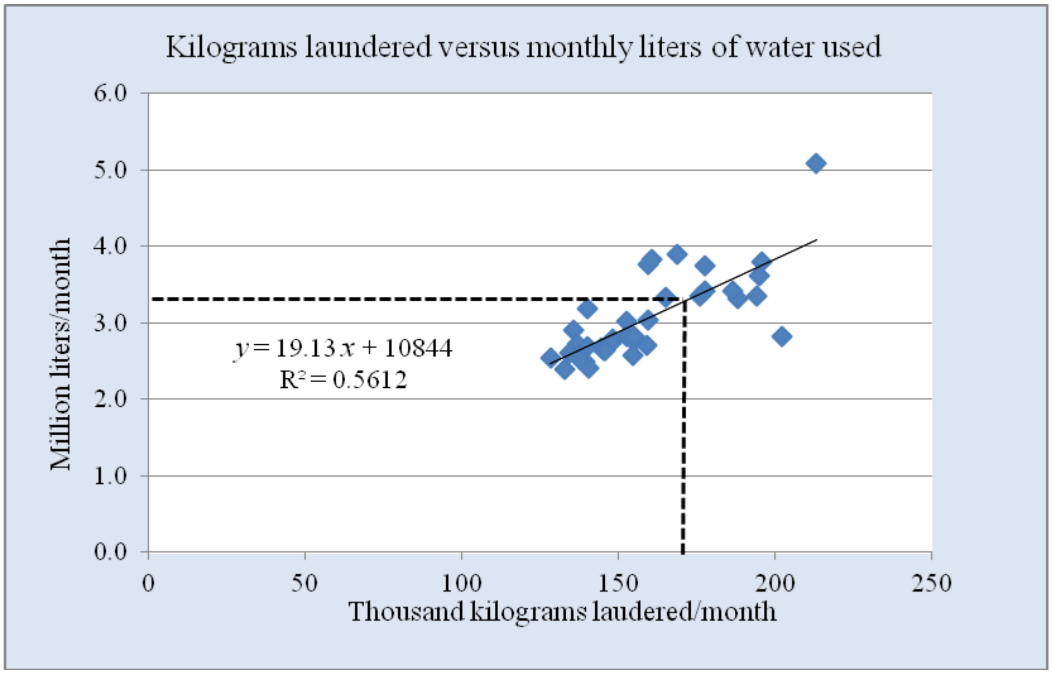

Figure 3.3. Monthly kilograms laundered with liters of water used for the years 2007 to 2008 (---- shows average monthly water liters at average monthly production).

Case Study 2

An aluminum parts facility using extrusion is located in Georgia. The facility area is 13,434 m^2. The operating hours of the facility was 730 hours per month (Ga Tech program, 2009). The monthly energy consumption (electricity and natural gas) and production rate for the years 2006 and 2007 were summarized in Table 3.5.

TABLE 3.5

THE ALUMINUM EXTRUSION FACILITY ENERGY CONSUMPTION AND PRODUCTION RATE (Ga Tech program, 2009)

Month, year	Electricity, kWh	Natural gas, kWh	Extruded weight , kg
Feb,06	800,951	1,615,056	1,256,285
Mar,06	772,041	1,558,881	1,271,813
Apr,06	771,924	1,494,424	1,101,653
May,06	774,302	1,617,435	1,279,954
Jun,06	891,304	1,752,887	1,281,760
Jul, 06	765,272	1,146,593	1,178,407
Aug,06	462,782	939,787	540,772
Sep,06	443,903	1,060,238	638,578
Oct,06	514,732	1,213,280	747,250
Nov,06	561,774	1,334,605	947,611
Dec,06	526,652	1,314,816	757,431
Jan,07	604,818	1,139,334	1,068,784
Feb,07	573,668	1,047,045	914,888
Mar,07	559,913	899,004	888,312
Apr,07	549,651	1,092,316	787,910
May,07	472,439	940,871	657,782
Jun,07	461,547	820,148	596,380
Jul, 07	446,435	1,113,370	936,688

The results of analyzing the relationship between the electricity and production rate of aluminum, based on the regression model are in Figure 3.4.

The regression is Mwh/month = 0.528*million kg extruded/mo + 114.327 Mwh/mo,

for which the power at zero aluminum extrusion production = 114,327 kwh/mo.

The nonprocess power intensity for the facility

$$114{,}327 \text{ kWh} \div 13{,}434 \text{ m}^2 \div 730 \text{ hours} = 11.6 \text{ Watts/m}^2$$

The average monthly electricity consumption for the average production rate is about 605,000 kWh. The average monthly production rate is about 920,000 kilograms of aluminum. This estimates that extruding one kilogram of aluminum requires around 0.527 kWh of energy.

The average monthly electricity consumption for the mid-point production rate = 605,000 kWh (Figure 3.4). The nonprocess electrical use was:

= 114,327 kWh ÷ 605,000 kWh = 18.8%

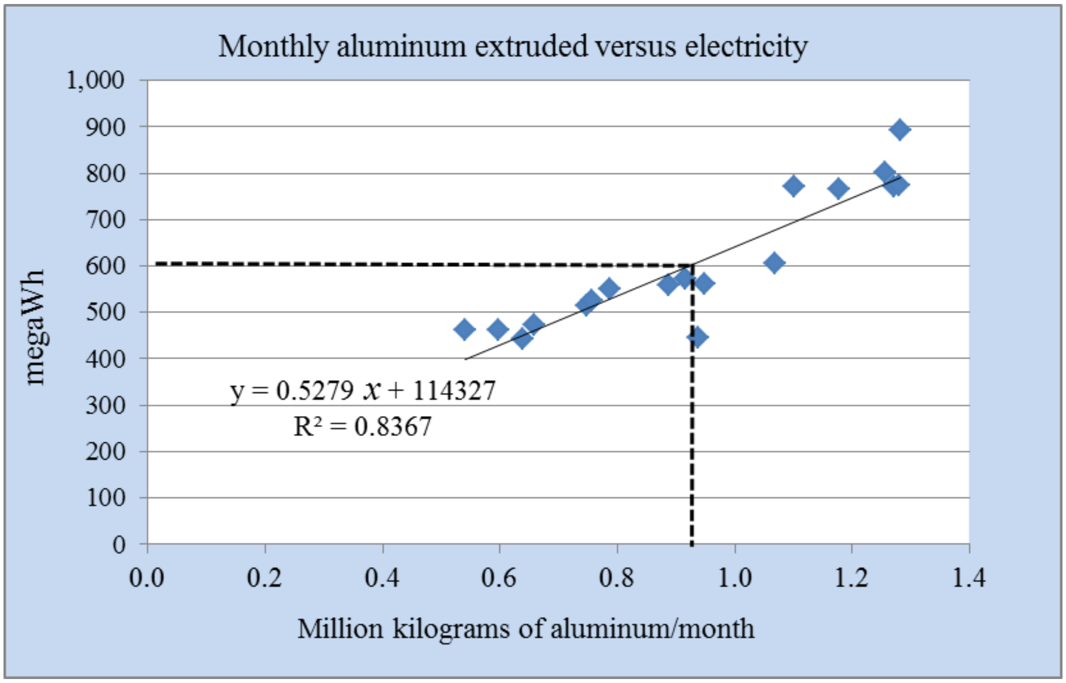

Figure 3.4. Monthly extrusion production rate with electrical energy consumption (---- shows average monthly electricity at average monthly production).

The power intensity for use of natural gas was measured in this facility, Figure 3.5.

The regression is million MJ/month = 3.225*million kg extruded/mo + 1.4 million MJ/mo,

for which the power at zero aluminum extrusion production = 1.4 million MJ/mo.

The heating power intensity = 1.4 million MJ ÷ 13,434 m^2 ÷ 730 hours = 0.142 MJ/m^2

= 39 Watts/m^2

The average monthly natural gas consumption for the average production rate is equal to 4,220,200 MJ. The average monthly production rate is equal to 920,000 kilograms of aluminum. The regression model shows that extruding one kg of aluminum requires about 4.6 MJ of natural gas. The nonprocess natural gas consumption was 1.4 million MJ which accounts for 33% of the average monthly natural gas consumption.

Combining the natural gas and electricity to estimate the nonprocess fraction to mid-point production energy

$$[114{,}327 \text{ kWh} + 388{,}888 \text{ kWh}] \div [605{,}000 \text{ kWh} + 1{,}172{,}000 \text{ kWh}] = 28.3\%$$

The nonprocess power intensity (electricity and natural gas) for this facility = 50.6 Watts/m^2 which compared with the mean values for other industrial buildings implies that standby energy use (probably natural gas) is raising the building nonprocess energy.

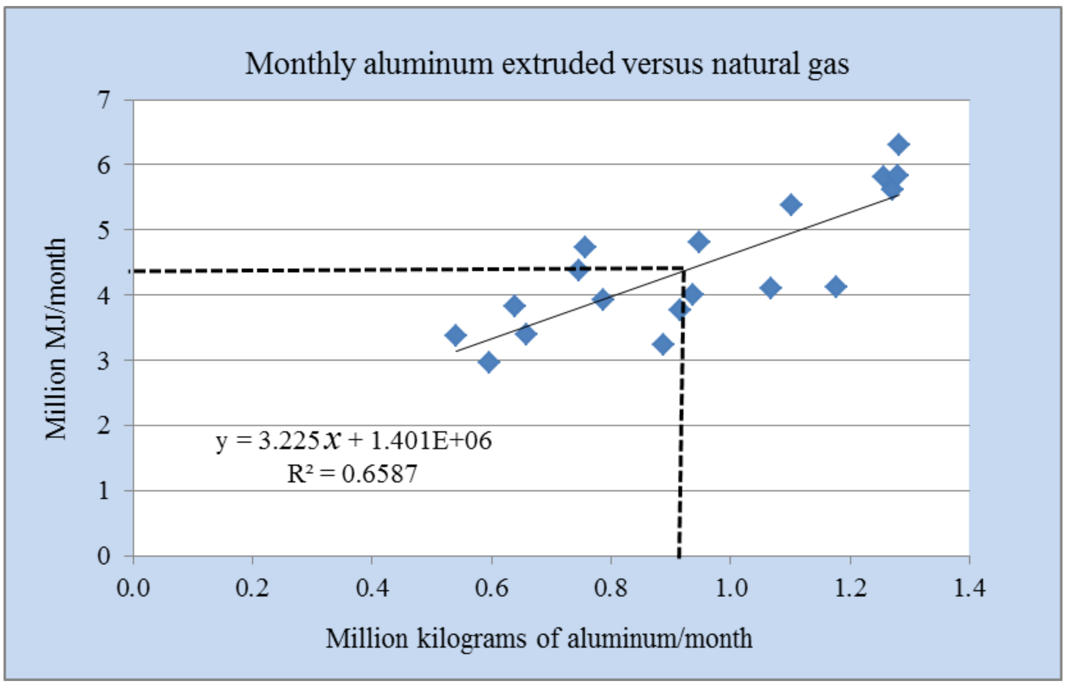

Figure 3.5. Monthly extrusion production rate with natural gas consumption (---- shows average monthly natural gas at average monthly production).

Case Study 3

A carpet manufacturing facility is located in Georgia and has an area of 5,295 m^2. The operating hours of the facility was 730 hours per month. The energy consumption and production rate for a twenty month period was summarized in Table 3.6 and Figure 3.6.

The regression is hundred thousand kwh/month = 1.873*hundred thousand kg carpet/mo + 218,788 kwh/mo,

for which the power at zero carpet production = 218,788 kwh/mo.

The nonprocess power intensity for the facility

$$218{,}788 \text{ kWh} \div 5{,}295 \text{ m}^2 \div 730 \text{ hours} = 56.6 \text{ Watts/m}^2$$

This power intensity is higher than typically found for lighting, cooling, heating, and ventilation (about 18 W/m^2 to 42 W/m^2, Table 3.1). This implies that machines standby energy use may be included and thus an opportunity for reduction.

The average monthly electricity consumption for the mid-point production rate is equal to about 1 million kWh. The mid-point monthly production rate is 415,000 kilograms of finished products, thus producing one kg of carpet requires about 1.87 kWh.

The fraction of the nonprocess energy consumption to the total facility energy consumption can be estimated as follows:

= Average monthly nonprocess energy consumption ÷ monthly mid-point of production energy = 218,788 kWh ÷ 1,000,000 kWh = 21.9 %.

TABLE 3.6

CARPET MANUFACTURING FACILITY MONTHLY PRODUCTION RATE AND ENERGY CONSUMPTION (Bailey, 2009)

Month	Production, kg	Electricity, kWh
Dec 08	242,108	912,000
Jan 09	282,082	454,800
Feb 09	379,055	891,600
Mar 09	462,821	882,600
Apr 09	321,930	964,200
May 09	319,083	801,000
Jun 09	293,928	815,400
Jul 09	289,918	694,200
Aug 09	289,065	797,400
Sep 09	365,088	827,400
Oct 09	291,328	724,800
Nov 09	291,420	746,400
Dec 09	324,582	866,400
Jan 10	329,719	813,000
Feb 10	347,065	857,400
Mar 10	454,191	921,600
Apr 10	419,441	1,072,800
May 10	466,764	1,180,800
Jun 10	568,389	1,316,400
Jul 10	457,319	1,316,400

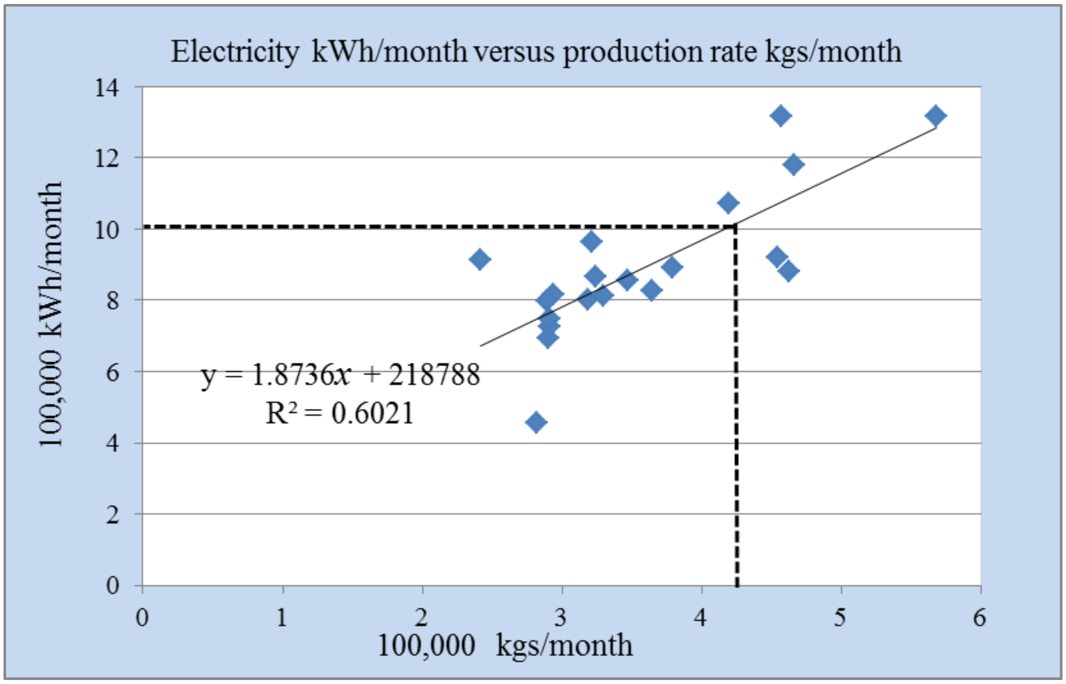

Figure 3.6. Monthly production rate with electricity consumption (---- shows average monthly electricity at average monthly production).

Case Study 4

A plant that recycles PET was analyzed in South Carolina. The area of this facility was 9,290 m^2. The operating level of the facility was 730 hours per month. The electricity consumption and production rate for six months period were summarized in Table 3.7 and Figure 3.7.

TABLE 3.7

FACILITY 5 ENERGY DATA WITH PRODUCTION RATE

Monthly Electricity, kWh	Monthly production rate, kg
1,907,400	1,581,821
1,561,800	1,411,843
1,573,800	1,464,966
1,206,000	872,350
1,664,100	1,245,393
1,810,500	1,504,966

The regression is million kwh/month = 0.84*million kg PET/mo + 489,364 kwh/mo,

for which the power at zero carpet production = 489,364 kwh/mo.

The nonprocess power intensity for the facility

$$489{,}364 \text{ kWh} \div 9{,}290 \text{ m2} \div 730 \text{ hours} = 72 \text{ Watts/m}^2$$

This power intensity is higher than typical results for lighting, heating, cooling, and ventilation (about 18 W/m^2 to 42 W/m^2, Table 3.1) and so this may imply that machines are kept in standby thus increasing the nonprocess energy. The regression tool thus suggests significant standby energy addition to nonprocess energy and upon a revisit the manufacturer confirmed this conclusion.

The average monthly energy consumption for the mid-point production rate is equal to 1.5 million kWh, Figure 3.7. The average monthly production rate for this facility is equal to 1.21 million kg of finished products. The average energy required to produce one kilogram of finished PET is about 1.24 kWh. The fraction of nonprocess energy to total mid-point facility energy is equal to 489,364 kWh ÷ 1,500,000 kWh = 32%

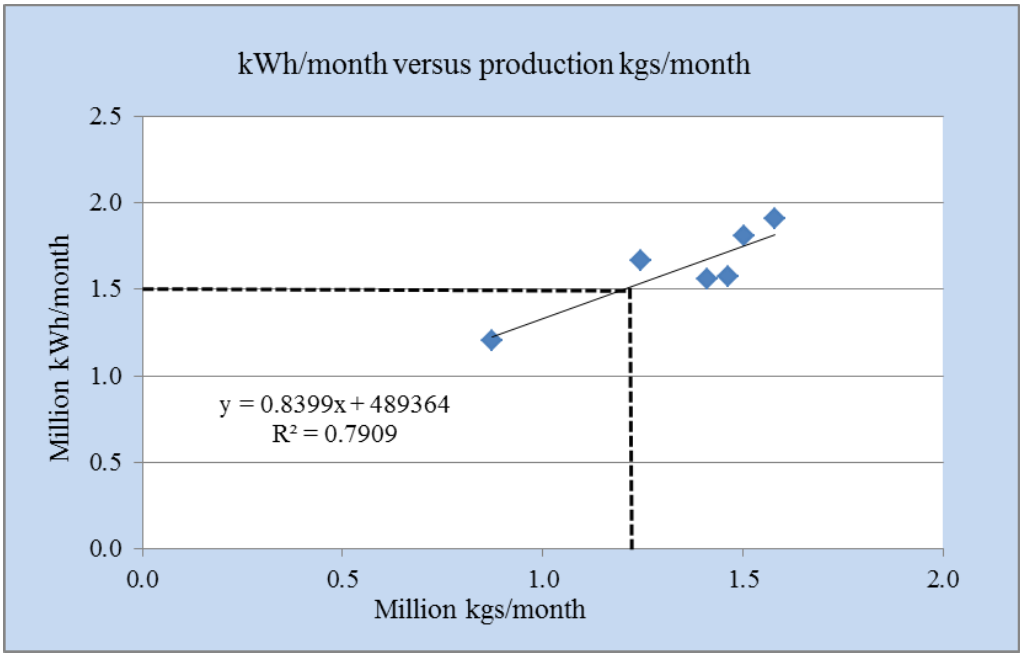

Figure 3.7: Monthly recycled PET production rate with electricity consumption (---- shows average monthly electricity at average monthly production).

Case Study 5

A facility for aerospace parts is located in Kansas. The total area of the facility was 10,172 m^2. The data were collected while the facility was running three shifts a day. Material removed (the principal process in this plant is milling) and plant electrical energy were collected, Table 3.8 and Figure 3.8.

TABLE 3.8

FACILITY 6 MONTHLY CHIP WEIGHT AND ENERGY CONSUMPTION (Bawaneh, et. al., 2011)

Month	Chips weight, kg	Energy consumption, kWh
January	17,100	520,088
February	2,059	428,571
March	9,008	451,264
May	6,241	417,410
June	4,971	462,796
August	9,226	508,980

The regression is million kwh/month = 6.386*thousand kg chips/mo + 413,118 kwh/mo,

for which the power at zero carpet production = 413,118 kwh/mo.

The nonprocess power intensity for the facility

$$413{,}118 \text{ kWh} \div 10{,}172 \text{ m}^2 \div 730 \text{ hours} = 55.6 \text{ Watts/m}^2$$

This power intensity is higher than typical facility lighting, heating, cooling, and ventilation and so this implies that machines are kept in standby even while the plant is operating, thus increasing the nonprocess energy. At this facility a separate study of all the machines was conducted whereby the standby power of each machine was measured, Table 3.9. The monthly standby energy is based on the number of machines, measured power of each machine, and the full monthly operation (3 shifts/d) in which machines are never powered off. The standby energy of all machines is thus summed.

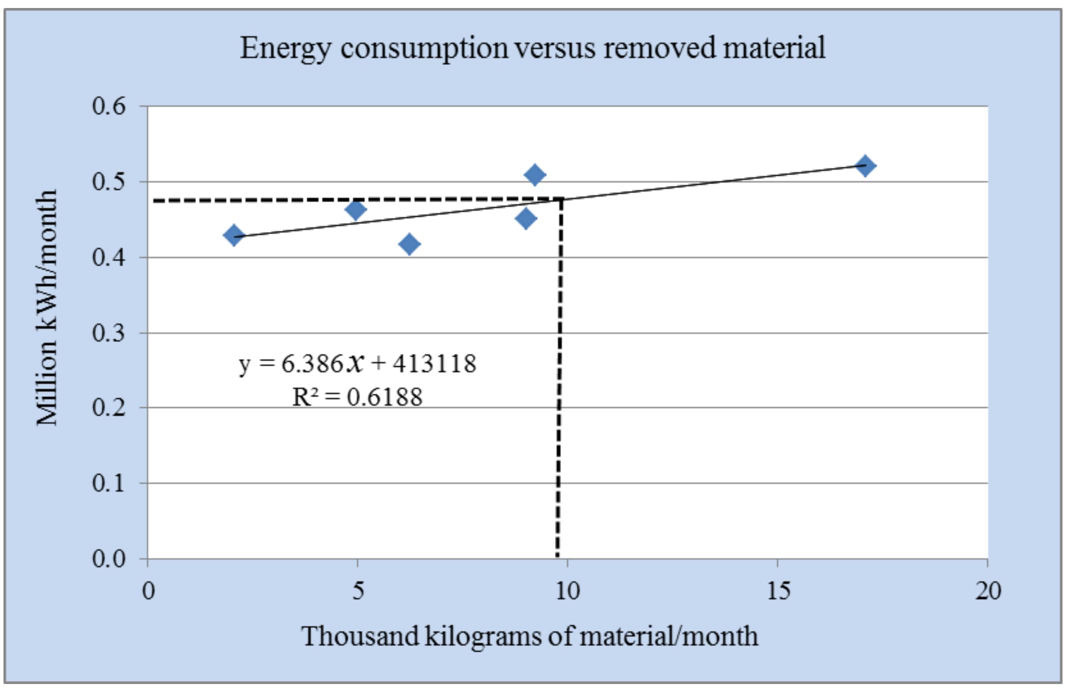

Figure 3.8. Figure 8: Aerospace parts facility energy consumption and removed material regression model (---- shows average monthly energy at average monthly production).

TABLE 3.9

MACHINES ENERGY IN STANDBY MODE (Bawaneh, et. al., 2011)

Machine type	# of machines	Average standby power, kW	monthly standby energy consumption, kWh
Toyoda	3	4	8,928
DMF-330	6	6.1	27,230
DMF-3001	3	10	22,320
FADAL	3	0.73	1,629
FRONTIER-L	2	0.7	1,042
DMV-4020	10	6.5	48,360
MORI-SL254	1	2	1,488
PUMA-2000Y	2	3	4,464
PUMA-2500LT	1	3	2,232
Mag-3	2	11	16,368
Total			134,061

Correcting the monthly energy consumption of the facility for the measured monthly standby energy,

= 413,118 kWh - 134,061 kWh = 279,057 kWh

The nonprocess power intensity for lighting, heating, cooling, and ventilation is

= 279,057 kWh ÷ 10,172 m^2 ÷ 730 hours

= 37.5 Watts/m^2

The resulting nonprocess energy intensity is now in the range of other industrial buildings, Table 3.1. This supports the benefit of detecting elevated nonprocess energy with the regression concept as a means of reducing energy by addressing standby consumption.

The average monthly energy consumption for the mid-point production rate is equal to 490,000 kWh, Figure 3.8. The average monthly removed material rate for this facility is about 9,800 kilogram of material. The average energy required to remove one kg of workpiece material is about 50 kWh. The average monthly energy consumption for mid-point production rate is

490,000 kWh, Figure 3.8, and thus the fraction of nonprocess energy to the total mid-point facility energy is:

279,057 kWh ÷ 490,000 kWh = 56.7%

Case Study 6

Another facility in Kansas also produces aerospace parts. The total area of the facility was 5,502 m^2, working three shifts per day. The monthly removed material weight (from milling and drilling) and monthly electrical energy are given in Table 3.10 and Figure 3.9.

TABLE 3.10

AEROSPACE PARTS FACILITY MONTHLY CHIPS WEIGHT AND ENERGY CONSUMPTION (Bawaneh, et.al. 2011)

Month	Chip weight , kg	Energy consumption, kWh
January	5,300	256,915
February	4,688	255,963
March	5,713	288,428
June	10,650	341,835
August	8,455	298,036

The regression is hundred thousand kwh/month = 13.328*thousand kg chips/mo + 195,459 kwh/mo, for which the power at zero carpet production = 195,459 kwh/mo.

The nonprocess power intensity for the facility

195,459 kWh ÷ 5,502 m^2 ÷ 730 hours = 48.7 Watts/m^2

This nonprocess power intensity is higher than the industrial mean of about 30 W/m^2 for lighting, heating, cooling, and ventilation for this facility where all machines are kept in standby mode during non-production times (Bawaneh, et. al., 2011). If no machines were left in standby during shifts without production and a nonprocess intensity of 30 W/m^2 was achieved (typical of just heating, lighting, cooling and ventilation), this would be about 73,000 kwh/month saved. This is thus a 20% reduction in the electrical expenditures saved by avoiding this standby utilization, a significant product cost savings.

The average monthly energy consumption for the mid-point production rate is about 300,000 kWh, Figure 3.9. The average monthly removed material rate for this facility is 7, 800 kg of material. The average energy required to remove one kg of metal is equal to 38.5 kWh. The fraction of nonprocess energy to the total mid-point facility energy is:

195,459 kWh ÷ 300,000 kWh = 65%

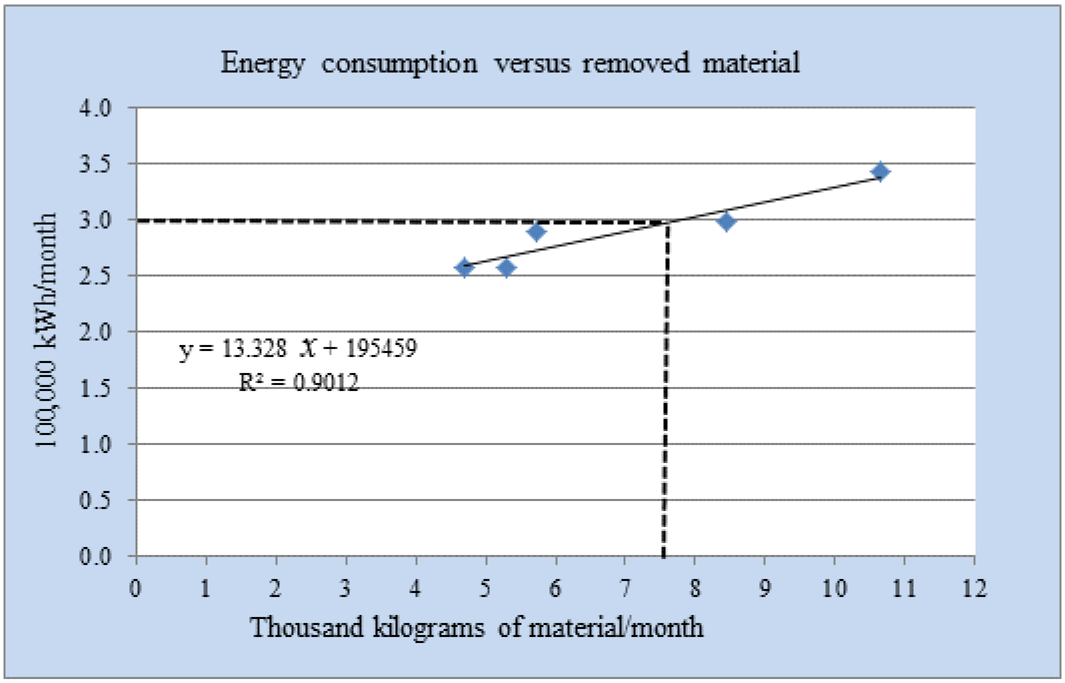

Figure 3.9: Aerospace parts facility energy consumption and removed material regression model (---- shows average monthly energy at average monthly production).

3.5 Discussion

In this study, the nonprocess energy consumption for each facility was calculated using the regression model analysis technique. This technique is a regression of monthly building energy or utilities use versus some measure of monthly production. The nonprocess power intensity for these facilities ranges from 5.7 Watts/m^2 for the Tampa facility to 72 Watts/m^2. The fraction of nonprocess energy to total facility energy ranges from 19% to 56.7 %. The monthly nonprocess energy consumption, power intensity, and fraction of nonprocess energy to total facility energy for each facility are summarized in Table 3.11.

TABLE 3.11

NONPROCESS ENERGY SUMMARY FOR INDUSTRIAL BUILDINGS

	Monthly nonprocess energy consumption, kWh	Fraction of nonprocess to total facility energy at average monthly production	Nonprocess power intensity, W/m^2
Expected mean from literature on nonprocess energy of industrial buildings , std dev, Table 3.1			Mean of literature values = (30.6 W/m^2), Std dev = (11.8)
Facility type and case study			
Medical textile laundry, 1	23,485	4.9%	5.7
Aluminum extrusion, 2*	503,215	28.3%	50.6
Carpet manufacturing, 3*	218,788	21.9%	56.6
PET recycling, 4*	489,364	32%	72
Aerospace parts, 5	279,057	56.7%	37.5
Aerospace parts, 6 *	195, 459	65%	48.7

Note: * The nonprocess energy for this facility appears to include the standby energy since values are noticeably higher than 30.6 W/m^2

In discussing the various regression analyses, the measure for goodness of fit for the regression models is the multiple coefficient of determination, R^2. R^2 value measures the % of variation in the dependent variable (energy consumed) that is explained by the model, in this case measure of productivity. Table 3.12 contains the R^2 values for the cases 1 to 6, and the associated F statistic and significance. R^2 values range from 0.538 to 0.901. At an alpha level of 0.05, all models were found to have a statistically good fit except for Case 5 (p-value = 0.063). Case 6 although not significant, shows a trend similar to other cases. From this analysis we can conclude that each model of productivity explains the variability in energy consumed for these cases.

TABLE 3.12

STATISTICAL DATA FOR NONPROCESS ENERGY REGRESSIONS OF CASE STUDIES

Case #	R-square	F-value	P-value
Case 1	0.538	39.61	3.6E-07
Case 2	0.837	81.97	1.1E-07
Case 3	0.602	27.24	5.8E-05
Case 4	0.791	15.13	0.0177
Case 5	0.619	6.49	0.06343
Case 6	0.901	27.36	0.0136

3.6 Conclusions

The life cycle of manufactured products in specific plants has advanced by developing unit process tools which reflect the transformation of input materials or chemicals into products. The research in this paper has further contributed to the life cycle of products by estimating nonprocess energy to be added to the life cycle process energy to thus obtain a more complete energy profile of product manufacturing. An innovative method for the evaluation of the nonprocess energy contribution was developed and tested. This was the regression analysis of monthly energy (electricity and/or natural gas) versus some measures of monthly production. In this regression, the energy when extrapolated to zero production is the estimate of nonprocess energy in the building housing the manufacturing process. The nonprocess energy in which the influences of machine standby energy appear to be small was found to be in the range of 5.7 to 37.5 Watts/m^2. The advantage of this method for assessing the nonprocess energy is that it is rapid and uses readily available information and largely nonproprietary information.

Other information has also been collected by the research team that includes an extensive compilation of literature data on heating, cooling, lighting, and ventilation of manufacturing buildings (the traditional types of nonprocess energy requirements; Bawaneh, et. al, 2011). In 4 of the 6 case studies, the regression results indicated that total nonprocess energy significantly exceeded traditional industrial heating, cooling, lighting, and ventilation. This indicated that potential opportunities to reduce this additional nonprocess energy exist thus being able to reduce costs further. This additional nonprocess energy was inferred to be the standby energy of machines that occurs when machines are not in production. To test this hypothesis, one site was used to measure the standby energy of each machine. These were totaled and subtracted from the elevated regression energy intensity result. The corrected nonprocess energy was then in line with the expected values, supporting the opportunity for economic improvements by turning off machines. In this one case the cost savings might be as high as 20% of the process energy expenditures.

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CHAPTER 4

CLIMATE ZONES AND THE INFLUENCE ON INDUSTRIAL NONPROCESS ENERGY CONSUMPTION

4.1 Abstract

This paper begins with the recognition that climate zones influence nonprocess energy use in industrial buildings. Nonprocess energies are heating, cooling, lighting, and ventilation. Nonprocess energy data have been collected from the literature (about 68 buildings) across a wide range of climate zones. The hypothesis tested in this research is: if an industrial building has a characteristic nonprocess energy related to physical dimensions and desired comfort level, then using cooling degrees day (CDD) and heating degrees day (HDD) factors can normalize the measured nonprocess temperature control data for the climate zone differences. That is, do measured nonprocess energy intensities (W/m^2), if corrected for climate zone differences, within each building category become more similar and hence reflecting the basic building temperature control energy use? The five U.S. climate zones and the location for each facility in this study were identified. To investigate how the location influences the amount of heating and cooling at each facility, a baseline analysis of five representative cities in each zone was done to obtain the 5-year average cooling degrees days (CDD) and heating degrees days (HDD). The reported values of heating and cooling for each facility were then adjusted using this baseline and the climate zones of that facility, so that each facility was then referenced to zone 3. That is, as if all manufacturing facilities were in the same zone 3. The mean, median, standard deviation and total nonprocess energies for current and zone-adjusted nonprocess energy for each facility in this study were calculated. The mean values of current and adjusted heating and cooling remained

close to each other and the standard deviation was not reduced by these adjustments. Thus the hypothesis of using CDD/HDD to quantitatively account for and hence to adjust for different climate zones appears to not be valid. The absence of improvement (reducing the standard deviation) by normalizing heating and cooling energy using adjustment for climate factors using the concept of CDD/HDD implies that some other correction principles are needed for evaluating fundamental needs for industrial building heating and cooling. The inability to reduce the geographic (that is, climate zone) effects of industrial plant nonprocess energy intensities supports the de-emphasis of this tool in the ASHRAE Handbook.

KEYWORDS

Industrial building energy, nonprocess energy, CDD, HDD, climate zones

4.2 Introduction

This paper begins with the recognition that climate zones influence nonprocess energy use in industrial buildings. Nonprocess energies are temperature controls such as heating, cooling, and ventilation. These temperature control energy uses are typically 50%-70% of the nonprocess or overhead energy in industrial buildings (Bawaneh, 2011). These nonprocess energy data have been collected from the literature (about 68 buildings) across a wide range of climate zones and building types. In order to better study a narrower class of industrial buildings, these facilities were subdivided into six building categories,

Category 1: Large outside plants and refineries

Category 2: Enclosed buildings with lighting only

Category 3: Industrial buildings with lighting and heating

Category 4: Industrial buildings with lighting, heating, and cooling

Category 5: Industrial buildings with lighting, heating, cooling, and humidity control.

Category 6: Industrial buildings with lighting, heating, cooling, humidity control and particulate control.

Building categories 4 and 5 are the most common industrial facilities with heating, cooling, ventilation, and lighting (category 4). Adding humidity control is category 5. For the 68 buildings, five are category 3 buildings, sixty two are category 4 buildings, and two are category 5 buildings.

This paper is focused on understanding the body of published literature (50 citations, Bawaneh, Overcash & Twomey, 2011) on nonprocess energy, however, these citations rarely contain enough information to allow the use of detailed transient load models, such as Energy Plus (Fumo, Mago & Luck, 2010). In addition, the goal of this paper is not to design specific buildings, but to put a range on nonprocess energy for manufacturing buildings in general. Thus this literature review focuses only on those few papers published in which cooling degrees day (CDD) and heating degrees day (HDD) concepts have been used to assess or compare industrial building energy use. No body of literature was found describing the relationship of process to nonprocess energy.

The Environmental Protection Agency (EPA) conducted a study to determine if weather can be an important factor in the energy performance of a building. The key drivers of energy consumption in different building types included operational characteristics and climate zone. The variables analyzed included HDD and CDD. Two sample buildings were chosen where these have the same HDD but different CDD. Both buildings had the same operating characteristics rating. The study showed that the energy intensity for the first building with higher CDD (3000) was 2,664 kBtu/m^2 while, the other building with lower CDD (500) had an energy intensity with 2,173 kBtu/m^2. The wide differences in CDD had a very modest effect in the actual cooling intensity, kBtu/m^2. The study concluded that there are numerous weather conditions that may influence energy use such as maximum and minimum temperature values, humidity, and cloud cover.

Another study (Boyd, 2005) presented a method called stochastic frontier regression analysis to describe the energy intensity of a group of industrial plants. The study investigated the impact of CDD and HDD on 101 auto assembly plants in the U.S. The study concluded that plants had increased heating and cooling loads according to climate. The energy consumption per vehicle ranged from 5.5 million British thermal units (MMBTU) to 14.5 MMBTU. Increasing the CDD by 1000 increased the energy consumption by 1.9 MMBTU/vehicle and increasing the HDD by 1000 increased the energy consumption by 1.29 MMBTU/vehicle. Again, these were modest changes in energy (compared to the total) for these significant CDD and HDD changes.

The objectives of this study was to test the hypothesis: if an industrial building has a characteristic nonprocess energy related to physical dimensions and desired comfort level, then using cooling degrees day (CDD) and heating degrees day (HDD) factors can normalize the measured nonprocess temperature control data for the climate zone differences. That is, do measured nonprocess energy intensities (W/m^2), if corrected for climate zone differences, within each building category become more similar and hence reflecting the basic building temperature control energy use. It is postulated that the effect of location in the five U.S. climate zones can be reduced by a using climate zone adjustment factor to give a baseline of one zone (zone 3) in order to assess the fundamental industrial building need for heating and cooling. One important outcome from reducing climate zone differences would be in life cycle studies where nonprocess energy is important and would be more valuable if related to product manufacturing than geographic location.

4.3 Methodology

Cooling degrees days (CDD) and heating degrees days (HDD) are approximate measurements of heating and cooling demands that can be computed from average daily temperatures at a particular location. By subtracting the average daily temperature from a base temperature, the CDD and HDD are determined daily and summed over a year (Garman, Blanco & Erickson, 2000). It should be noted that since the reported building energy data do not include information on heating or cooling equipment, the balance point temperature could not be used and so a simpler set point temperature is used. To calculate the daily HDD with 65 ^{O}F (18.3 ^{O}C) as a base temperature,

Base temperature = 65 ^{O}F (18.3 ^{O}C)

The average day temperature = 50 ^{O}F (10 ^{O}C)

HDD = 65-50 = 15 HDD (^{O}F) = 15 ×5/9 = 8.3 HDD (^{O}C)

Then values for an entire year can be determined as the sum of each day, expressed as HDD or CDD. So CDD and HDD are measures of the deviation (much cooler or much hotter) from a baseline and during how much of the day has this deviation occurred.

To explore the relationship between the nonprocess energy consumption and the five U.S. climate zones, the location for each facility in this study was first identified. As shown in Figure 1, there are five different climate zones in the U.S. and these were used to assign each manufacturing plant to a climate zone.

The building energy data found in the literature (Bawaneh, Overcash & Twomey, 2011) are collected from each building, and thus contain the necessary or measured heating and cooling for that facility. From Figure 4.1 there are two colder areas (zones 1 and 2) and two warmer areas (zone 4 and 5). Since the CDD or HDD data in Figure 1 were not definitive because some entries were just “less than 2000”, an analysis of five representative cities in each zone was done to obtain the baseline 5-year average CDD and HDD (2005-2010), Table 4.1. Between zone 1 and 5 the CDD increased by about 2,700, while the HDD decreased by about 4,000, so the scales of CDD and HDD are not strictly equivalent. The general variations within a zone can be seen in Table 4.1.

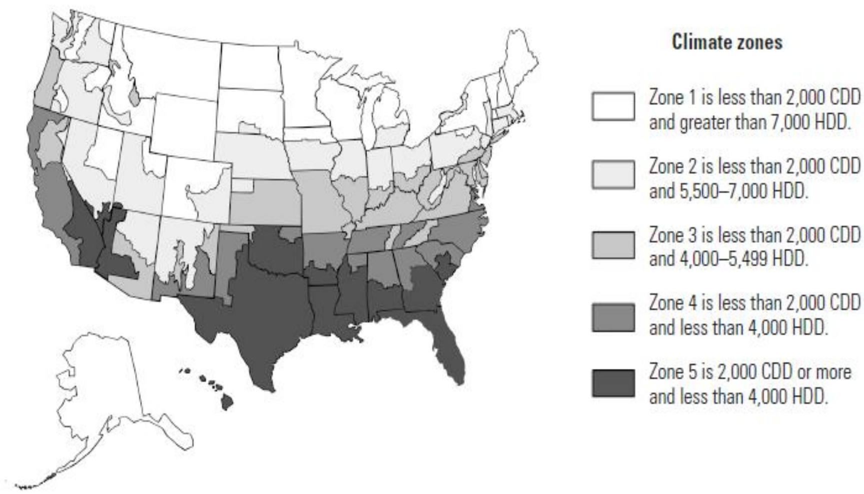

Figure 4.1. U.S. Five climate zones (U.S. Energy Information Administration).

4.4 Results

The effects of CDD and HDD on the industrial building cooling and heating energy estimates were determined from a proposed adjustment for the differences in climatic zones on heating and cooling, Table 4.1. The average of zone 3 or the middle U.S. climatic zone is the baseline of 1,049 CDDs and 2,425 HDD. So as an example, for the data of a given manufacturing plant in zone 1 and data in Table 4.1,

Heating intensity = $W/m^2 \times$ (average HDD for zone 3) ÷ (average HDD for zone 1)

Cooling intensity = $W/m^2 \times$ (average CDD for zone 3) ÷ (average CDD for zone 1)

From Table 1, average CDD and HDD of zones 1 and 3 give

Heating intensity = $W/m^2 \times 2{,}425 \div 4{,}396 = W/m^2 \times 0.55$

Cooling intensity = W/m^2 × 1,049 ÷ 417 = W/m^2 × 2.52

Thus for one facility located in zone 1 with 2.25 Watts/m^2 of heating and 0.77 Watts/m^2 of cooling, the values if adjusted to reflect zone 3 are

Heating intensity = 2.25 W/m^2 × 0.55 = 1.24 W/m^2

Cooling intensity = 0.77 W/m^2 × 2.52 = 1.94 W/m^2

In some cases where the city location of a facility is unknown, but the State is given and if that State includes multiple zones, then the adjusted heating and cooling was calculated based on the fraction of each zone in the State (either 50:50 or 33:67). For example, the adjusted heating and cooling for a facility in Alabama was calculated using Table 4.1 as follows:

Fraction of each climate zone in Alabama which are:

Zone 4: 50% of the state

Zone 5: 50% of the state

Adjusted heating power intensity = W/m^2 × (average HDD for zone 3) ÷ [0.5× (average HDD for zone 4) + 0.5× (average HDD for zone 5)]

= W/m^2 × 2,425 ÷ [0.5× 1,959 + 0.5× 969]

= W/m^2 × 1.66

For multiple zone States, additional adjustment factors are prepared, Table 4.2. Some States have more than two zones, but only the largest two zones were selected and the smaller sections of other zones eliminated.

TABLE 4.1

AVERAGE CDD AND HDD FOR REPRESENTATIVE CITIES AND THE FIVE CLIMATIC ZONES

Zone	City	Average HDD	Average CDD	HDD adjustment factor ratio HDD of zone 3 to HDD of each zone	CDD adjustment factor ratio CDD of zone 3 to CDD of each zone
1	Portland, ME	3,841	314		
1	Bozeman, MT	4,543	442		
1	Madison, WI	4,258	387		
1	Crystal, MN	4,375	508		
1	Fargo, ND	4,965	434		
Average		4,396	417	0.55	2.52
2	Pittsburgh, PA	3,168	541		
2	Lincoln, NE	3,475	811		
2	Chicago, IL	3,514	604		
2	Columbus, OH	3,207	629		
2	Salt lake city, UT	3,266	848		
Average		3,326	687	0.73	1.53
3	Washington, DC	2,214	1,027		
3	Wichita, KS	2,552	1,093		
3	Richmond, VA	2,080	1,101		
3	Cincinnati, OH	2,729	966		
3	St-Louis, MO	2,551	1,061		
Average		2,425	1,049	1	1
4	Raleigh, NC	1,851	1,201		
4	Sacramento, CA	1,699	933		
4	Atlanta, GA	1,774	1,152		
4	Amarillo, TX	2,404	983		
4	Nashville, TN	2,068	1,179		
Average		1,959	1,090	1.24	0.96
5	Dallas, TX	1,247	1,776		
5	Pensacola, FL	940	1,687		
5	Baton Rouge, LA	981	1,797		
5	Mobile, AL	1,050	1,567		
5	Phoenix, AZ	623	2,828		
Average		968	1,931	2.50	0.54

TABLE 4.2

ADJUSTED HEATING AND COOLING FACTORS FOR MULTI ZONE STATES

State	Climate zones	Allocation ratio of area in each State	Adjusted CDD factor	Adjusted HDD factor
Alabama	5,4	50/50	0.69	1.66
Arizona	5,4	50/50	0.98	1.11
Arkansas	4,5	33=5; 67=4	0.77	1.49
Georgia	4,5	50/50	0.69	1.66
Idaho	1,2	33=2; 67=1	2.07	0.60
Illinois	2,3	50/50	1.21	0.84
Indiana	2,3	33=3; 67=2	1.30	0.80
Iowa	1,2	33=1; 67=2	0.37	0.66
Michigan	1,2	33=2; 67=1	2.07	0.60
New Jersey	1,2	50/50	1.21	0.84
New Mexico	3,4	50/50	0.98	1.11
New York	1,2	33 = 2; 67=1	2.19	0.61
Ohio	2,3	33=3; 67 = 2	1.30	0.80
Oregon	2,3	33=3; 67=2	1.30	0.80
Pennsylvania	1,2	33=1;67=2	1.30	0.80
South Carolina	4,5	33=5; 67=4	0.77	1.49
West Virginia	2,3	33=2; 67-3	1.13	0.89

The heating and cooling energy intensities, Watts/m^2, for all industrial buildings were adjusted to zone 3 for each building category. Lighting and ventilation were not adjusted as these were assumed to be constant on a daily basis. The mean, median, standard deviations for the current and adjusted values were calculated, Table 4.3.

TABLE 4.3

CURRENT AND CORRECTED NONPROCESS POWER INTENSITY MEAN VALUES

	Lighting mean, W/m^2	Heating mean, W/m^2		Cooling mean, W/m^2		Ventilation mean, W/m^2	Nonprocess mean, W/m^2	
Zone	No change	Current	Adjusted	Current	Adjusted	No change	Current	Adjusted
1	10.06	18.43	10.16	5.51	13.85	4.50	38.49	38.57
2	10.28	12.99	10.36	7.20	11.01	3.85	34.33	35.51
3	9.96	10.11	10.11	6.28	6.28	3.79	30.13	30.13
4	9.61	7.25	8.98	5.35	5.15	2.41	24.62	26.15
5	9.87	5.86	14.67	7.78	4.23	2.98	24.81	29.63

The adjusted nonprocess energy curves for category buildings 4 and 5 were graphed in Figure 4.2. The mean values for the adjusted nonprocess energy in climate zones 4 and 5 are higher than the current values.

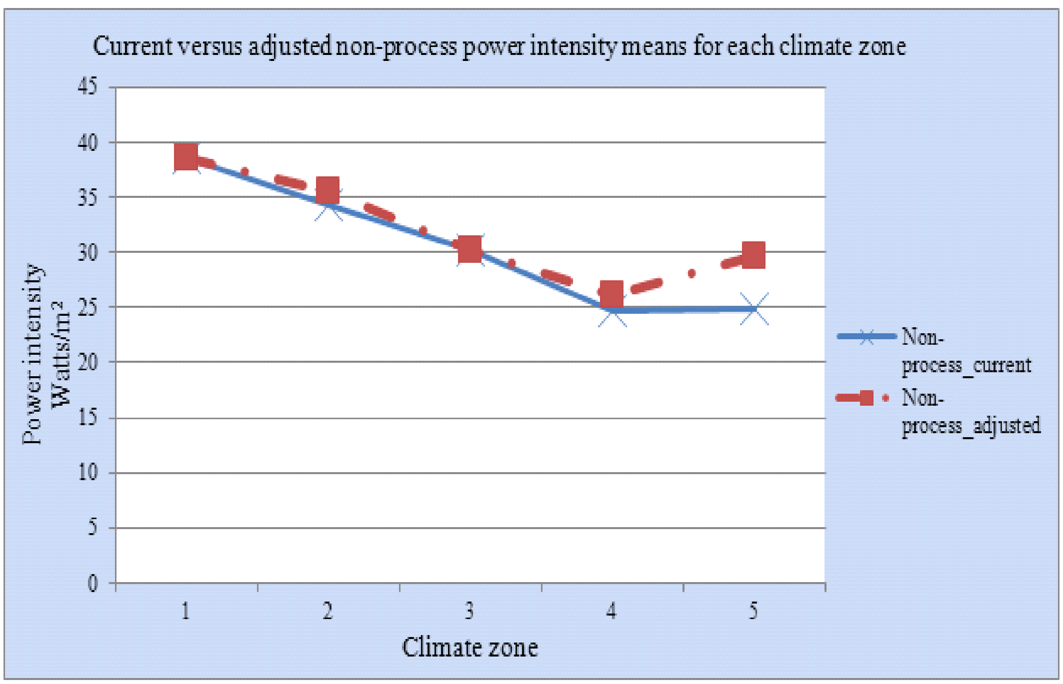

Figure 4.2. Current and adjusted nonprocess power intensities by climate zone for category buildings 4 and 5.

To test the hypothesis of whether across all climate zones, the adjusted HDD and CDD mean values (μ_1) differ from the current measured building mean values (μ_2), an analysis test of hypothesis was conducted at 0.05 level of significance. In this case both n_1 and n_2 are large (greater than 30), so the distribution of the mean will be approximated as a normal distribution (Mendhall & Sincich, 2007). The Minitab software (version 16 by Minitab Company) was used to calculate the confidence interval for the difference between the two means. The null and alternative hypotheses are:

H_o: $\mu_1 - \mu_2 = 0$

H_a: $\mu_1 - \mu_2 \neq 0$

Where,

$\mu_{1:}$ the mean of the current nonprocess power intensities

$\mu_{2:}$ the mean of the adjusted nonprocess power intensities

$\alpha = 0.05$

$n_1 = n_2 = 68$

The confidence interval of the difference between the two means (across all climate zones) was calculated and found to be equal to (-1.03, 5.03). Since zero is included in this interval, we conclude that H_o is not rejected and the difference between the two means is not significant.

The heating and cooling for all buildings were also corrected for each building category, where temperature control is used. Lighting and ventilation were not adjusted. The new mean, median, standard deviation and total nonprocess energies were calculated. Figure 4.3 shows the current and adjusted mean values for the nonprocess energy for each building category. The nonprocess power intensities of category 1 and 2 buildings were not affected because these buildings use lighting only as a nonprocess energy type use. However, in categories 3, 4, and 5 building adjusted nonprocess energies were slightly, but not consistently, different from unadjusted values.

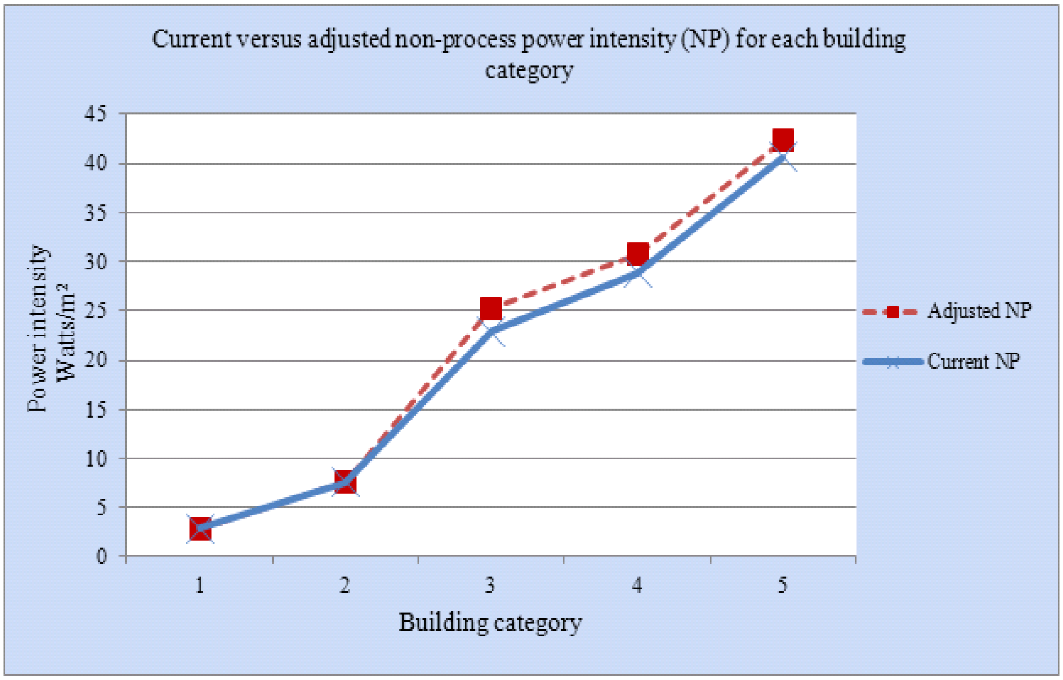

Figure 4.3. Current and adjusted nonprocess power intensity by building category

To determine whether the climate zone adjustment factors could normalize the diverse industrial building heating and cooling intensities to a central or core result, the mean, median, standard deviation and total nonprocess energies for current and adjusted nonprocess energy were calculated. From Table 4.4, the standard deviations for the adjusted heating, cooling, and nonprocess power intensities were not reduced. The higher standard deviation indicates that the adjusted nonprocess energy data are much more scattered with more variability than current data.

TABLE 4.4

STATISTICAL PARAMETERS FOR CURRENT AND ADJUSTED FOR NONPROCESS POWER INTENSITIES FOR CATEGORY 4 AND 5 BUILDINGS FOR ALL CLIMATE ZONES

	Lighting	Heating		Cooling		Ventilation	Total non-process intensity	
	No change	Current	Adjusted	Current	Adjusted	No change	Current	Adjusted
Mean W/m^2	9.98	9.42	11.15	6.10	6.48	3.25	28.75	30.86
Median W/m^2	3.10	8.29	9.85	5.20	5.15	1.54	27.27	29.64
Standard deviation	9.77	4.97	5.87	3.64	4.80	2.95	8.63	9.14

4.5 Future Research and Study Limitations

The current study depended on data found in literature citations and so the effect of building age, level of maintenance, and insulation could not be inferred. Thus this analysis assumes a representative U.S. functioning manufacturing building. Building area is used in these analyses to obtain temperature control (nonprocess) energy intensity, because building volume is rarely reported. In essence, the height is in some typical range of 20 – 40 feet.

Future studies would examine more buildings in categories 3 and 5. In addition, building simulation models applied to manufacturing facilities in different climate zones would study whether the effect of climate zone correction was improved.

4.6 Conclusions

From this study directed at nonprocess industrial building energy, there is no evidence that the use of facility location and the climate adjustment calculation of CDD and HDD were able to have a significant improvement in the uniformity of measured building nonprocess energy. This implies that the CDD and HDD factors for the U.S. climate zones do not quantitatively reflect zone locations in such a way as to remove this location effect. This indicates that the measured manufacturing building heating and cooling of industrial buildings may reflect other elements (see limitations section) than just outside temperature and thus were not as responsive to these climate factor adjustments. The inability to reduce the geographic (that is, climate zone) effects of industrial plant nonprocess energy intensities supports the de-emphasis of this tool in the ASHRAE Handbook.

It is recommended that for life cycle studies, the nonprocess energy estimates should utilize the mean or median energy intensities (W/m^2) from the literature (unadjusted) as estimates for the six building categories. If the life cycle is related to a specific site and building, then currently available tools such as EnergyPlus can be used for improving the nonprocess energy estimates for heating, cooling, and ventilation.

4.7 References

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CHAPTER 5

ANALYSIS TECHNIQUES TO ESTIMATE THE NONPROCESS ENERGY FOR INDUSTRIAL FACILITIES AND CASE STUDIES

5.1 Abstract

In this study, four important techniques for estimating the nonprocess energy in industrial and manufacturing buildings were examined. The building energy data for five industrial facilities were collected and analyzed. The building nonprocess energy includes lighting, heating, cooling, and ventilation. The power intensity for each energy type use was estimated using two or more methods and then analyzed. This nonprocess energy needs to be clearly defined to allow more quantities improvements. The utilization of percentage of nonprocess energy in industrial and manufacturing plants is an important potential source of energy and cost improvements. Previous analysis of industrial energy use often expressed nonprocess energy as a percentage of total energy but without clear values of actual nonprocess energy. This information is a low value since the actual nonprocess energy is then dominated by the dominator which is unspecified.

5.2 Introduction

There is a small literature on relating industrial or service building total building energy or activities in those buildings. However a large literature is focused on estimating energy consumption for buildings based on design (space, windows, climatic zone, etc. For example, the methodology to estimate building energy consumption using EnergyPlus benchmark models by Fumo, et. al. [4] contrasts with the capabilities of building energy performance simulation programs by Crawley et. al. [3] and energy saving studies in industrial facility by Knauglu et. al. [4]. Since the goal of this paper is on using different techniques to estimate the nonprocess energy for industrial buildings, as a means to understand nonprocess or overhead energy, only the literature related to this non process energy aspect is reviewed here.

Yimin Zhu conducted a study of a service facility in the southeast region of the United States. The total area of the facility was 1.4 million square feet (about 130,000 m^2). The purpose of this study was to evaluate different energy conservation alternatives to execute an energy saving plan in this facility for cooling, heating, and lighting. Another goal of this study was to reach the energy star designation; the study covered three different space types in this facility which included computer data center, mercantile and services, and offices [7].

Hashem Akbari and Osman Sezgen, in their analysis, “The Energy Use in Industrial Building in California,” evaluated energy use in two different industrial facilities in California. The goals of this study were to specify how the design of industrial systems affects the energy consumption and to specify how the energy characteristics of an industrial facility affects how much energy consumed for lighting, heating and ventilation. Building and system characteristics with annual energy consumption are shown in Table 5.1. The first case study is a facility for manufacturing of microwave components. The second case study was a facility of manufacturing printed circuit boards [2].

TABLE 5.1

ANNUAL ENERGY CONSUMPTION FOR BOTH FACILITIES

	Facility 1 428 m^2	Facility 2 2,414 m^2
	ELEC kWh/m^2	ELEC kWh/m^2
Energy consumption for lighting	18	117
Energy consumption for HVAC	88	190
Facility Area m^2	428	2,414
Lighting equipment	4-lamp fluorescent light fixtures	Same as facility 1
HVAC equipment	Gas heating	Unit heater and 18 roof cooling units
Lighting system design	Most of the areas have $15w/m^2$	Most of the areas have lighting level of $14Watts/m^2$

An analysis of California data for different industries shows that the percentage of electricity consumption for lighting ranges from 9.5% to 29.1%, for cooling it ranges from 0% to 35%, and for heating the concentration of energy consumption ranges from 5% to 58%. The concentration depends on the industry type, for example, for the motor vehicle facility the energy consumption for heating is equal to 51.6 % of the nonprocess energy consumption. And also for instrument manufacturing facility the energy needed for heating the space is equal to 58% of the total nonprocess energy consumption [1].

A study was conducted by the Lawrence Berkley Laboratory in California for five different industrial sectors. This study estimated the annual nonprocess energy consumption per square foot (kWh/ft^2) for these five industrial sectors. The annual electricity consumption per square foot for each of the five industrial facilities was estimated. The values vary from about 18 for meat packing facilities to 26 kWh/ft^2 for electronics facilities. Lighting use is somewhat seasonal and reflected by hours of operation. For example, Electronics and Motor Vehicles appear to use about 7 kWh/ft^2 [1].

Electricity consumption in the industrial plant was predicted using multivariate linear regression (Al-Ghandoor & Samhouri, 2009). Electricity consumption was modeled as a function production output, capacity utilization, and number of employees. The study results showed that the multivariate linear regression can be used reasonably to estimate industrial electricity consumption in an industrial facility. This methodology was used to predict the total energy consumption for many industrial facilities but did not estimate the nonprocess energy for each facility. However, the nonprocess energy for these facilities combined could be obtained from their regression equation.

Abraham Yezioro, Bing Dong, and Fernanda Leite, in their study "An applied artificial intelligence approach towards assessing building performance simulation tools," presented an approach towards evaluating building performance simulation results to actual measurements, using artificial neural networks (ANN) for predicting building energy consumption. The approach can reduce the cost of data collection and provides credibility in the predicted consumptions. The predicted results using ANN model were compared with other building simulation tools such as eQUEST, EnergyPlus, Energy 10, and Green Studio Web. The results showed a good fitness with the mathematical model with a 0.009 mean absolute error [6].

The Energy Plus simulation software can be used to estimate the annual energy consumption for any building. The knowledge of electric and fuel energy consumption can be useful when considering the use of alternative energy technologies. An approach to estimate how energy is consumed in a building using information from monthly electrical and fuel bills was created to estimate the building energy consumption [3].

The approach comprises of using predetermined coefficients with utility bills to obtain the energy consumption. The coefficients can be obtained by using EnergyPlus simulation model for offices, hospitals, schools, and supermarkets. The study analyzed two building cases and compared the simulated results with actual results and error was found to be equal to 10 %. [3].

These energy studies in the literature focus solely the relevant total facility energy consumption as related to the process and energy cost drivers. Such literature analyses do not distinguish between estimates of process and nonprocess energy for industrial facilities. The main objective this study reported herein is to estimate the overhead energy. Four different techniques were developed herein are based on direct measurement of nonprocess energy, direct measurement of process energy, regression of monthly building energy or utilities use versus monthly production, and extrapolation to zero production, and simulation.

It is vital for any industrial facility to use energy efficiently. This leads to reduction in energy consumption which benefits both the consumer and the utility. Studying the characteristics of industrial facility energy use will allow us to determine the potential reduction and look for efficient ways for energy management. The objective of this study is to estimate and separate the nonprocess energy from process energy for industrial buildings using different analysis techniques and to evaluate the potential environmental impacts in the life cycle for industrial facility energy.

5.3 Methodology

In the energy assessment study, which was conducted by the Department of Industrial and Manufacturing Engineering at Wichita State University, the energy data for five industrial facilities were collected. The objective of this study is to understand and separate the nonprocess energy from process energy in these facilities. Four separate analysis techniques were used to estimate the nonprocess energy for these facilities:

a) Direct measurements of nonprocess energy

To understand and separate the nonprocess from process energy in by direct measurements of the nonprocess energy, the following approach was followed:

1) In the first visit, the following information and documents were collected from the facility separately for each building:
    a) Utility bills
    b) Operating hours
    c) Buildings physical information which includes: blue prints, layout, area, machine configuration.
2) The second step was to collect information on nonprocess energy for each building which includes :
    a) Lighting
    b) Heating
    c) Cooling
    d) Ventilation
3) The nonprocess energy information for each building was used to estimate the energy consumption for each nonprocess energy type use.
4) The nonprocess power intensity (W/ft^2) for each building was estimated separately.

b) Direct measurements of process energy, then the nonprocess energy can be calculated by subtracting the process energy consumption from the total facility energy consumption.

The second technique used to estimate the nonprocess energy for this facility was a direct measurement of process energy. The process energy information was estimated using an energy monitoring device and then, the energy consumption for each machine was calculated.

To understand and separate the nonprocess from process energy by direct a measurement of the process energy, the following approach was followed:

1) The following information and documents were collected from the facility :
    a) Utility bills
    b) Operating hours
    c) Building physical information which includes: blue prints, layout, area, machines configuration, and number of each machine type.
2) The process energy information was estimated using energy monitoring device and then, the power intensity for each machine was calculated.
3) The energy consumption for each machine was calculated. The nonprocess energy can be calculated by subtracting the process energy from the building total energy consumption. The process energy for each building will be analyzed separately.

c) Creating a regression model which relates the material removal (chip weight) with the building energy consumption to estimate the nonprocess energy at zero production

d) Using simulation tools to estimate the building nonprocess energy

5.4 Results

For each case study in this research, one to four different techniques were developed herein are based on direct measurement of nonprocess energy, direct measurement of process energy, regression of monthly building energy or utilities use versus monthly production, and extrapolation to zero production, and simulation.

Case Study 1

The process and nonprocess energy data were collected in this facility. The total area of the facility was 109,488ft^2. The data were collected while the facility was running three shifts a day. The facility consists of two buildings which are analyzed separately:

1- Building 4330 (64,488 ft^2)

2- Building 4226 (45,000 ft^2)

This plant employed more than 350 employees. The monthly utility bills for this plant were documented and analyzed. The annual energy consumption for both buildings of this facility, based on the utility bills, was estimated to be equal to 5,356,312 kWh.

Method 1: Direct Measurements of Nonprocess Energy

The total area of the first building (4330 building) was 64,488 ft^2. The monthly utility bills for this building were documented and analyzed. The annual energy consumption for this building, based on the utility bills, was 3,841,480 kWh. Natural gas was measured in cubic feet (CF) and converted to kWh. One cubic foot of natural gas (CF) is equivalent to 1,028 BTU; one BTU is equivalent to 0.000293 kWh (Natural Gas Organization, 2006). For example, converting 300 (CF) of natural gas for July to kWh is as follows:

$$300 \text{ CF} = 1028 \times 300 = 308{,}400 \text{ BTU}$$

$$308{,}400 \text{ BTU} = 308{,}400 \times 0.000293 = 90.3 \text{ kWh}$$

The monthly energy consumption of this facility is summarized in Table 5.2.

TABLE 5.2

THE MONTHLY ENERGY CONSUMPTION OF 4330 BUILDING

Month	Electricity (kWh)	Natural Gas (CF)	Natural gas (kWh)	Total energy (kWh)
Jul-09	403,320	300	90	403,410
Aug-09	362,520	200	60	362,580
Sep-09	336,960	600	181	337,141
Oct-09	278,760	8,500	2,560	281,320
Nov-09	280,680	7,900	2,380	283,060
Dec-09	241,620	71,700	21,596	263,216
Jan-10	268,980	254,600	76,687	345,667
Feb-10	241,800	165,900	49,970	291,770
Mar-10	269,640	102,600	30,904	300,544
Apr-10	295,560	49,800	15,000	310,560
May-10	304,380	6,100	1,837	306,217
Jun-10	355,860	450	136	355,996
Total	3,640,080	668,650	201,400	3,841,480

The monthly energy cost for the 4330 building ranges from \$ 16,000 for January to \$31,000 for July 2009. The power intensity is the annual energy in kWh divided by 8,760 hrs/yr divided by area (Watts/ft^2). The 4330 building consists of two sections which are: 1) the south section, 2) the north section. The area of the south section was 24,938 ft^2. The area of the north section was 39,551ft^2. The annual energy consumption for lighting, heating, and cooling this facility next analyzed.

1. Lighting

The facility is lit by different types of lamps such as the nominal 400 Watts metal halide lamps and the 2T12 lamps. The 400 Watts metal halide lamps are widely used for lighting large industrial facilities. The actual amount of power which is consumed by the 400 W metal halide lamps ranges from ratings on the bulbs of 400 watts to 499 Watts. The amount of power which is consumed by the T12 lamps is 95 Watts. The power intensity for lighting each area in the facility was estimated and analyzed.

The south area is lit by 2T12 and 4T8 fixtures. The annual energy consumption for lighting the south area was 213,510 kWh with an area of 24,938 ft^2. The north area is lit by 91 nominal 400 Watts metal halide lamps. The area of this section was 39,551 ft^2. The annual energy consumption for lighting the north area, based on 8,760 hours, was 381,743 kWh. The lighting power intensity for this area was estimated to be equal to 1.1 Watts/ft^2, based on 8,760 hours. The annual energy consumption for lighting the CMM Lab, based on 2,600 hours, was 3,328 kWh. The annual energy consumption, power intensity and annual cost for lighting the various sections in the 4330 building were calculated and the results are summarized in Table 5.3.

TABLE 5.3

LIGHTING ENERGY SUMMARY FOR BUILDING 4330

Space type	Area, ft^2	Number and type of Fixtures ,total Watts & operating hours	Annual energy consumption, kWh	Annual cost, based on 8 ¢ per kWh, (dollars)	Power intensity, Watts/ft^2
4330_ south area & de-pore area	24,937	120 (2T12 - total W = 22,800, lit for 8,760 hrs, 12(2T12- total W= 2,280 2,080 hrs.), 18(4T8, total W = 3,888, 2,080 hrs), 1(400 W metal halide – total W = 458, 2,080 hrs)	213,510	17,347	1.2
4330_North area	39,551	91(400 W metal halide – total W = 41,678, lit for 8760 hrs.), 10(2T12-total W= 1900, 8,760 hrs)	381,743	30,539	1.1
4330_CMM Lab	450	10(4T5- total W =1,280, lit for 2,600 hrs.)	3,328	266	2.84
4330_Whole building, area average	64,488		598,581	48,152	1.16

2. Heating

Calculations were made based on the average monthly temperature for Wichita area and number of hours for each heating month (http: //www. climate-zone.com). The average monthly temperatures for Wichita area are summarized in Table 5.4.

TABLE 5.4

AVERAGE TEMPERATURES FOR EACH MONTH FOR WICHITA AREA

Month	Days in month	Hours per month	Average temperature, ^{O}F
Jan	31	744	31
Feb	28	672	28
Mar	31	744	31
Apr	30	720	30
May	31	744	31
Jun	30	720	30
Jul	31	744	31
Aug	31	744	30
Sep	30	720	31
Oct	31	744	31
Nov	30	720	30
Dec	31	744	31
Total	365	8,760	

Using ASHRAE standards 90.1, the typical R value for metal buildings in Kansas is equal to 13 $ft^2.°F·h/Btu$. The R-value is a measure of thermal resistance used in the building and construction industry. The building roof is well insulated so, the R-value of the roof was estimated to be equal to 11.78 $ft^2·°F·h/Btu$ (See Tables 5.5 and 5.6) and for walls it was estimated to be equal to 7$ft^2·°F·h/Btu$.

TABLE 5.5

R-VALUE FOR THE ROOF

Building_4330-roof area: 64,488 ft^2	
Layer	R-value
Outside Air	0.17
Membrane	0.44
Roof Insulation	8
Vapor Retarder	0.12
Air Space	0.94
Ceiling Tile	1.5
Inside Air	0.61
Total	11.78

TABLE 5.6

R-VALUE FOR WALLS

Building_4330-walls area: 40,852 ft^2	
Layer	R-value
Outside Air	0.17
Wall Insulation	5
Metal	0.28
Air Space	0.94
Inside Air	0.61
Total	7.00

The power intensity for heating this building was calculated as follows:

$$\text{Heat Flow} = (1/R) \times \text{Area} \times \Delta\theta = \text{BTU/hr (Turner, 2006)} \quad (5.1)$$

Where $\Delta\theta$: the average difference of temperature (outside and required inside temperature)

R: thermal resistance

To calculate the average heat loss during heating hours and the average heat gain during cooling hours, the temperature difference ($\Delta\theta$) is calculated for the roof, walls, and doors. The average monthly temperature for Wichita area was identified. Due to the natural buoyancy of warm air, causing heated air to rise and gather at the ceiling, it was noticed that the difference between the roof and walls temperatures ranges from 6 to 8 ^{o}F. The desired temperature for roof is equal to 75 ^{O}F and 69 ^{O}F for walls. The average monthly temperature difference between the outside and desired inside temperature for walls and the roof was calculated. For example, the average temperature differences for walls and the roof for January were calculated as follows:

Average hourly temperature for January = 30 ^{O}F

Desired inside temperature for the roof = 75 ^{O}F

Desired temperature for walls = 69 ^{O}F

Average temperature difference between outside and inside for the roof in January

= 75 ^{O}F - 30 ^{O}F = 45 ^{O}F

Average temperature difference between outside and inside for walls in January

= 69 ^{O}F – 30 ^{O}F = 39 ^{O}F

The temperature difference between desired and outside was calculated for each month. The difference between outside and desired inside temperature will be used to calculate the average hourly heat loss, then the average monthly required BTUs will be calculated to maintain the inside building temperature. The average temperatures and differences for each month was calculated and summarized in Table 5.7.

TABLE 5.7

FOR HEATING MONTHS, THE AVERAGE TEMPERATURES AND DIFFERENCES BETWEEN DESIRED AND OUTSIDE VALUES

Month	Average hourly temperature, ^{O}F	Difference between desired (69 ^{o}F) and outside temperature (walls) ^{O}F	Difference between desired and outside temperature (roof) ^{O}F
Jan	30	39	45
Feb	36	33	39
Mar	45	24	30
Apr	51	18	24
May	65	4	10
Oct	59	10	16
Nov	41	28	34
Dec	32	37	43

The average heat losses for walls, doors, and the roof for each month were calculated, Table 5.8.

For example, the average heat loss through the roof for January was calculated as follows:

Average hourly heat loss for January = (1/R (roof)) × Roof area × $\Delta\theta$ (difference between desired and average temperature for January, Table 5.7)

$= [1 \div (11.78)\ ft^2 \cdot {}^{\circ}F \cdot h/Btu] \times 64{,}488\ ft^2 \times 45^{o}F$

= 246,348 BTU/hr

Number of heating hours for January = 744 hours

The average heat loss through the roof for January = average hourly heat loss for January × heating hours for January = 246,348 BTU/hr × 744 hours = 183,282,750 BTU

The annual heat loss for the roof = 975,898,528 BTU

TABLE 5.8

MONTHLY AND ANNUAL AVERAGE HEAT LOSSES FOR BUILDING 4330

Month	Roof, Btu/hr (area 64,488 ft^2)	Walls, Btu/hr (area 40,852 ft^2)	Doors, Btu/hr (area 1,800 ft^2)	Roof, Btu/Month	Walls, Btu/month	Doors, Btu/month
Jan	246,348	227,603	43,875	183,282,750	169,336,858	32,643,000
Feb	213,501	192,587	37,125	143,472,948	129,418,740	24,948,000
Mar	164,232	140,064	27,000	122,188,500	104,207,297	20,088,000
Apr	131,385	105,048	20,250	94,597,548	75,634,329	14,580,000
May	54,744	23,344	4,500	40,729,500	17,367,883	3,348,000
Jun	0	0	0	0	0	0
Jul	0	0	0	0	0	0
Aug	0	0	0	0	0	0
Sep	23,266	0	0	17,310,038	0	0
Oct	87,590	58,360	11,250	65,167,200	43,419,707	8,370,000
Nov	186,129	163,408	31,500	134,013,194	117,653,400	22,680,000
Dec	235,399	215,931	41,625	175,136,850	160,652,916	30,969,000
Total (annual, Btu)						(1,951,215,658)

To test whether using the average temperature for each month to calculate the total heat loss for the building differ from using the average temperature for each day, the monthly heat losses for January were calculated using both methods. The total heat losses through the roof, walls, and doors, based on daily average temperatures, were calculated and found to be equal to 383,471,914 Btu. While, the total heat losses based on the average temperature for January, were calculated and found to be equal to 385,262,608 Btu. The difference between both methods is not significant (1.7 Million Btu) with 99.5 % accuracy. So, both methods can be used to estimate the average heat losses for the building.

Total energy required (through walls, roof, and doors, Table 5.8) = 1,951,215,658

BTU/yr. This is 162,601,305 BTU/month as an annual average for heating.

Heater capacity = 250,000 BTU/hr

Heater efficiency = 0.80

Number of heaters = 10

Total energy required = 1,951,215,658 BTU/yr

Total energy that can be produced by the ten heaters =

250,000 BTU/hr × 0.80 × 10 = 2,000,000 BTU/hour

Total fans operating hours = 1,951,215,658 BTU/yr ÷ 2,000,000 BTU/hr = 976 hr/yr

Fans energy = number of hours × number of fans × fan power

= 976 hours/yr× 10 × 0.746 kW = 7,281 kWh/yr

Total energy required = heating energy (BTU) + fans energy (electricity)

= 1,951,215,658 BTU × 0.000293 kWh/Btu + 7,281 kWh = 578,984 kWh

Heating power intensity = Annual energy consumption ÷ total area ÷ operating hours

= 578,984 kWh ÷ 64,488 ft^2 ÷ 8,760 hours = 1.02 Watts/ft^2

3. Cooling

Calculations were made based on the average monthly temperature for Wichita area and number of hours for each cooling month, Table 5.4. The cooling hours for Wichita area were estimated to be equal to 2,928 hours. When the facility runs for three shifts a day, the total cooling hours will be equal to 2,928 annually, Table 5.9. Building 4330 is cooled by ten TRANE roof top coolers with a power of 28.9 kW for each.

TABLE 5.9

FOR COOLING MONTHS, THE AVERAGE TEMPERATURES AND HOURS PER MONTH

Month	Days in month	Hours per month	Average temperature, ^{O}F
Jun	30	720	76
Jul	31	744	81
Aug	31	744	79
Sep	30	720	71
Total	122	2,928	

The average monthly temperature for Wichita area was identified. As shown in Table 5.10, the average monthly temperature difference between the outside and desired inside temperature for walls and the roof were calculated for each month.

Due to the natural buoyancy of warm air, causing heated air to rise and gather at the ceiling. The desired temperature for roof is equal to 67 ^{O}F and 65 ^{O}F for walls. The average monthly temperature difference between the outside and desired inside temperature for walls and the roof were calculated, Table 5.10. For example, the average temperature difference for walls and the roof for August were calculated as follows:

Average temperature for August = 79 ^{O}F

Desired inside temperature for the roof = 67 ^{O}F

Desired temperature for walls = 65 ^{O}F

Average temperature difference between outside and inside for the roof in August

= 79 ^{O}F - 67 ^{O}F = 12 ^{O}F

Average temperature difference between outside and inside for walls in August

= 79 ^{O}F – 65 ^{O}F = 14 ^{O}F

The temperature difference between desired and outside was calculated for each month. The difference between outside and desired inside temperature will be used to calculate the average heat gain, then the average monthly removed BTUs will be calculated to maintain the inside building temperature. The average temperature difference for each month were calculated and summarized in Table 5.10.

TABLE 5.10

FOR COOLING MONTHS, THE AVERAGE TEMPERATURES AND DIFFERENCES BETWEEN DESIRED AND OUTSIDE VALUES

Month	Average hourly temperature, ^{O}F	Difference between desired (65 ^{o}F) and outside temperature (walls)	Difference between desired (67^{o}F) and outside temperature (roof)
Jun	76	11	9
Jul	81	16	14
Aug	79	14	12
Sep	71	6	4

As shown in Table 5.11, the average heat gains for walls, doors, and the roof for each month were calculated. For example, the average heat gain through the roof for August was calculated as follows:

The average hourly heat gain through the roof for August =

(1/R (roof)) × Roof area × Δθ (difference between desired and average temperature for August)

= [1÷ (11.78)] × 64,488 ft^2 × 12 ^{o}F = 65,693 BTU/hr

Cooling hours for August = 744 hours

The average heat gain through the roof for August =

= average hourly heat gain for August × Cooling hours for August

= 65,693 BTU/hr. × 744 hours = 47,298,774 BTU

The annual heat gain for the roof = 153,418,881 BTU

TABLE 5.11

FOR COOLING: MONTHLY HEAT GAINED FOR BUILDING 4330

Month	Roof, Btu/hr (area 64,488 ft^2)	Walls, Btu/hr (area 40,852 ft^2)	Doors, Btu/hr (area 1,800 ft^2)	Roof, Btu/Month	Walls, Btu/month	Doors, Btu/month
Jan	0	0	0	0	0	0
Feb	0	0	0	0	0	0
Mar	0	0	0	0	0	0
Apr	0	0	0	0	0	0
May	0	0	0	0	0	0
Jun	46,532	61,278	11,813	33,503,298	44,120,025	8,505,000
Jul	76,642	93,376	18,000	57,021,300	69,471,531	13,392,000
Aug	65,693	81,704	15,750	47,298,774	58,826,700	11,340,000
Sep	20,529	33,557	6,469	15,273,563	24,966,332	4,812,750
Oct	0	0	0	0	0	0
Nov	0	0	0	0	0	0
Dec	0	0	0	0	0	0
Total (annual, Btu)						(388,531,273)

Total annual heat gained through the roof, walls, and doors = 388,531,273 BTU/yr.

Total cooling capacity = 40,000 BTU (1 unit capacity) × (number of coolers) ×

Efficiency = 40,000 BTU/hr. × 10 × 0.80 = 320,000 BTU/ hr.

Total operating hours for coolers = 388,531,273 BTU ÷ 320,000 BTU/ hr. = 1,214

hours/yr

Total annual energy consumption = Cooler power × number of coolers × 1,214 hours

= 28.9 kW × 10 × 1,214 hr = 350,892 kWh

Cooling power intensity = Annual energy consumption ÷ total area ÷ operating hours

= 350,892 kWh ÷ 64,488 ft^2 ÷ 8,760 hours = 0.62 Watts/ft^2

The nonprocess power intensity for each energy type use was estimated for this building. The ventilation energy is included with the heating and cooling energy in this facility. The power intensity and annual energy consumption for this building are summarized in Table 5.12.

TABLE 5.12

NONPROCESS POWER INTENSITY FOR BUILDING 4330

Energy type use	Annual energy, kWh	Power intensity, Watts/ft^2
Lighting	601,909	1.16
Cooling	350,892	0.62
Heating	578,984	1.02
Total (nonprocess)	1,531,785	(2.71)

The second building of the facility is the 4226 building. The total area of this building was 45,000 ft^2. The monthly utility bills for this building were documented and analyzed. The annual energy consumption for this building, based on the utility bills, was 1,514,831 kWh.

The power intensity is the annual energy in kWh divided by 8,760 hrs/yr divided by area (Watts/ft^2). The power intensity for the whole building, which includes process and nonprocess energy, was estimated to be equal to 3.9 Watts/ft^2. The annual energy consumption for lighting, heating, and cooling this facility next analyzed.

The nonprocess power intensity for each energy type use was estimated for this building. The power intensity and annual energy consumption for this building are summarized in Table 5.13.

TABLE 5.13

NONPROCESS POWER INTENSITY FOR BUILDING 4226

Energy type use	Annual energy, kWh	Power intensity, Watts/ft^2
Lighting	425,911	1.08
Cooling	254,093	0.65
Heating	420,220	1.07
Total (nonprocess)	1,100,220	2.79

Method 2: Direct Measurements of Process Energy

The process energy for building 4330 was measured and analyzed. All machines types, number of machines, and process types in this facility were collected, Table 5.14. An energy monitoring device was installed on each machine type for different periods. The facility is running 8,760 hours annually. All machines are running during the operating hours or kept in standby mode during non-production hours. The average power for each machine was calculated for different periods. This power average includes the three modes (standby, partial, full). The average annual energy consumption for all each machine can be calculated by multiplying the average power for one machine by the total number of machines then by the facility operating hours. The average annual energy consumption for each machine can be calculated as follows:

The average annual energy consumption for each machine type =

The average power for one machine (measured) × facility operating hour’s × number of machines

TABLE 5.14

BUILDING 4330 MACHINES SUMMARY

Machine type	# of machines	Process type
Toyoda	3	Milling
DMF-330	6	Milling
DMF-3001	3	Milling
FADAL	3	Milling
FRONTIER-L	2	Lathe
DMV- 4020	10	Milling
MORI-SL254	1	Lathe
PUMA-2000Y	2	Lathe
PUMA-2500LT	1	Lathe

The energy monitoring device was installed on each machine type for different periods to measure the average energy consumption for this machine and then to estimate the annual energy consumption for all machines. The energy monitoring device was set to collect 20 readings every second. For example, the device was installed on FADL CNC machine. Around 5,750 power data points were collected during the 10 minutes period. The average power for this machine is 0.725 kW, when the machine in standby mode, and when the machine was milling the average power is 1.25 kW. The mean value of the collected data was equal to 1.07 kW and median was equal to 1.19 kW. The standard deviation for this data is equal to 0.35. Figure 5.1 shows the power for three modes, which are:

1) Basic or standby energy mode: where the machine is idle or down
2) Full mode or tip energy mode: when the machine in machining, milling drilling, etc.
3) Partial mode; where the machine is changing tool or axis is moving

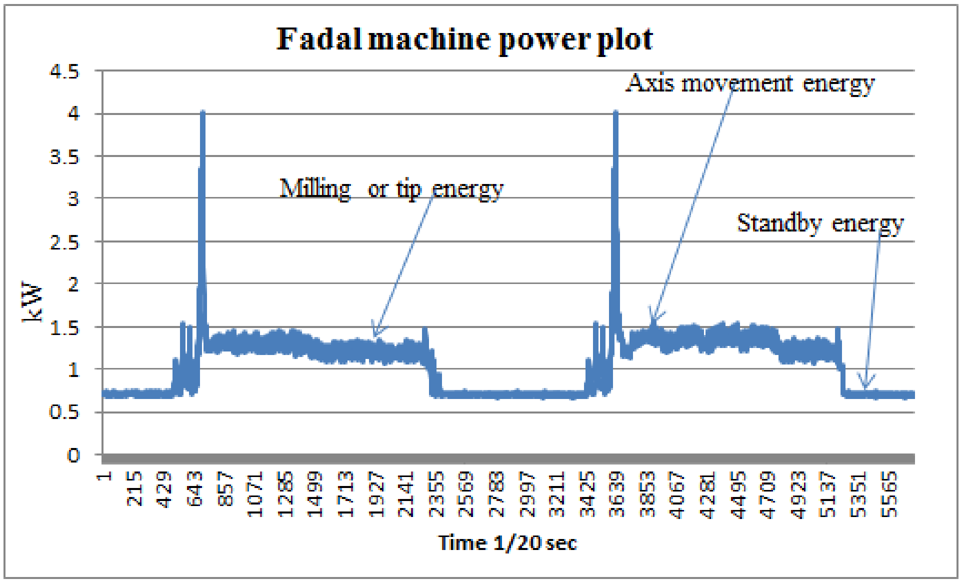

Figure 5.1. Power plot for Fadal CNC machine.

The average energy consumption for the Fadal machine was estimated as follows:

The average power during the study period = 1.07 kW

The average annual energy consumption for Fadal machine = average power × facility annual operating hours =

1.07 kW × 8760 = 9,373 kWh

The annual energy for the Fadal machine, study period, modes found, time for each mode, were calculated and summarized in Table 5.15.

TABLE 5.15

FADAL MACHINE MODE TIMES AND ENERGY

Machine: Fadal			
Study period : 626 sec			
Mode type	Time (sec)	% to total study time	Average power, kW
Standby mode	288	0.46	0 .725
Partial Mode	182	0.29	0.44
Full Mode	156	0.25	0.81
Average power for the three modes			1.07
Average annual energy/machine (kWh)			(9,373)

The same methodology was followed to estimate the energy consumption for DMF-330 machine. The data were collected for 23 hours long while the equipment was installed on this machine. The collected data were documented and analyzed. Around 1,650,240 readings were collected during the 16 hours period.

The average energy consumption for this machine was estimated to be equal to 7.37 kWh. The annual energy for the DMF-330 machine, study period, and modes found, were calculated and summarized in Table 5.16.

TABLE 5.16

DMF-330 MACHINE MODE TIMES AND ENERGY

Machine: DMF -330	Average power, kW
Study period: 23 hrs.	
Mode type	
Standby mode	6.1
Partial Mode	3.3
Full Mode	5.24
Average power during the study period kW	7.37
Average annual energy/machine (kWh)	(64,561)

Figure 5.2 shows the power plot for the first seven minutes and the power for each mode during this period.

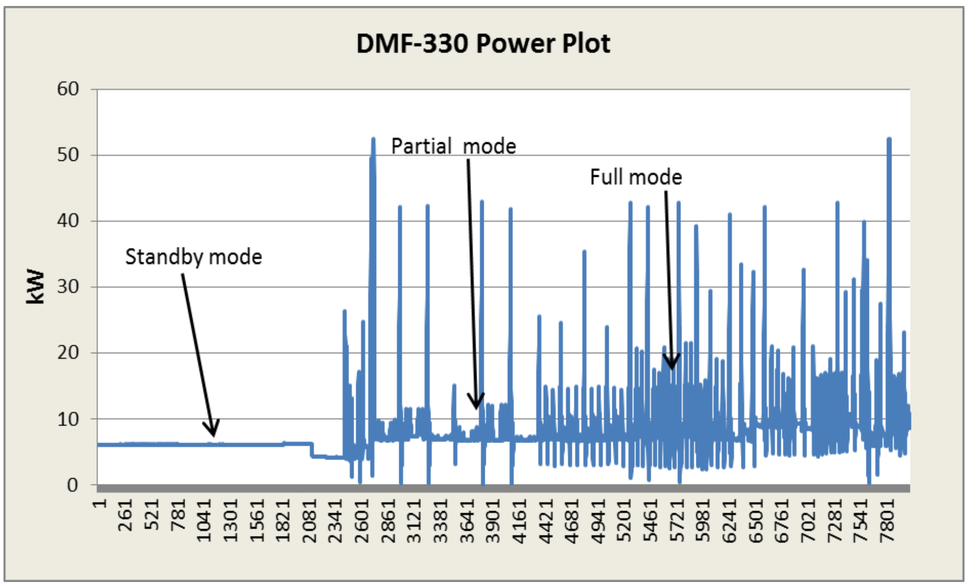

Figure 5.2. DMF-330 power plot.

The energy data for FRONTIER lathe machine were collected and documented. The data were collected during 59 hours period. The collected data were analyzed; the average power for this machine was estimated to be equal to 2.83 kW. The average energy consumption and the annual energy consumption for the FRONTIER machine during the study period are summarized in Table 5.17.

TABLE 5.17

FRONTIER MACHINE MODE TIMES AND ENERGY

Machine: Frontier	
Study period: 59 hrs.	
Average standby mode, kW	0.70
Average power for the three modes, kW	2.83
Average annual energy/machine, kWh	24,791

The energy data for the FADAL (DMV- 4020) milling machine was collected and the average energy consumption for this machine was estimated to be equal to 11.35 kWh. The average energy consumption and the annual energy consumption for the FADAL (DMV-4020) machine during the study period are summarized in Table 5.18.

TABLE 5.18

DMV- 4020 MACHINE ENERGY DATA

Machine: DMV- 4020	
Study period: 7.2 hrs.	
Standby mode, kW	6.5
Average power , kW	11.35
Average annual energy/machine, kWh	99,426

The energy data for the MORI-SL254 machine were collected and the average energy consumption for this machine was estimated to be equal to 2.65 kWh. The average energy consumption and the annual energy consumption for the MORI-SL254 machine during the study period are summarized in Table 5.19.

TABLE 5.19

MORI-SL254 MACHINE ENERGY DATA

Machine: MORI-SL254 Study period: 72 min	
Average standby mode power, kW	2
Average power for the three modes , kW	2.65
Average annual energy/machine, kWh	23,214

The energy data for the PUMA-2000Y machine were collected and the average energy consumption for this machine was estimated to be equal to 3.75 kWh. The average energy consumption and the annual energy consumption for the PUMA-2000Y machine during the study period are summarized in Table 5.20.

TABLE 5.20

PUMA-2000Y MACHINE ENERGY DATA

Machine: PUMA-2000Y	
Study period: 120 min.	
Average standby mode power, kW	3
Average power for the three modes, kW	3.75
Average annual energy/machine, kWh	32,850

The energy data for the PUMA-2000Y machine lathe machine were collected and the average energy consumption for this machine was estimated to be equal to 2.7 kWh. The annual energy consumption for the PUMA-2500L machine, study period, and average power for standby mode, were calculated and summarized in Table 5.21.

TABLE 5.21

PUMA-2500L MACHINE ENERGY DATA

Machine: PUMA-2500L	
Study period: 90 min.	
Average standby mode power, kW	2
Average power for the three modes, kW	2.7
Average annual energy/machine, kWh	23,652

The energy data for the DMF-3001 machine were collected and the average energy consumption for this machine was estimated to be equal to 13.7 kWh. The annual energy consumption for this machine, study period, and average standby mode power, were calculated and summarized in Table 5.22.

TABLE 5.22

MACHINE: DMF-3001 MACHINE ENERGY DATA

Machine: DMF-3001	
Study period: 102 min.	
Average standby mode power, kW	10
Average power for the three modes, kW	13.7
Average annual energy/machine, kWh	120,012

The energy consumption for each machine type in building 4330 was calculated. The number of each machine type was identified. The annual energy consumption for all machines was calculated by multiplying the average energy consumption for each machine type by the number of machine. Table 5.23 shows the average power for each machine, study period, and number of machines, total energy for machines, and the total annual process energy for the building, based on 8,760 annual hours.

TABLE 5.23

BUILDING 4330 MACHINES ENERGY SUMMARY (BASED ON 8,760 HOURS)

Machine type	# of machines	Average power, kW	Study period, min	Total machine energy, kWh/yr.	Total energy, kWh/yr. (All machines)
Toyoda	3	9.06	55	79,366	238,097
DMF-330	6	7.37	1,380	64,561	387,367
DMF-3001	3	13.7	102	120,012	360,036
FADAL	3	0.72	23	4,993	14,980
FRONTIER-L	2	2.83	3,540	24,791	49,582
DMV-4020	10	11.35	432	99,426	994,260
MORI-SL254	1	2.65	72	23,214	23,214
PUMA-2000Y	2	3.75	90	32,850	65,700
PUMA-2500LT	1	2.7	120	23,652	23,652
Others	2	2.5		21,900	43,800
Total, (kWh)					(2,200,687)

As shown in Table 5.24, the annual process energy for building 4330 was calculated to be equal to 7,922,474 MJ (2,200,687 kWh). The annual nonprocess energy for this building can be calculated as follows:

Nonprocess energy = total building energy – process energy = 3,841,480 kWh - 2,200,687 kWh = 1,640,793 kWh

TABLE 5.24

BUILDING - 4330 ENERGY SUMMARY (8,760 hrs /yr)

Energy use type	MJ/yr.	kWh/yr.
Annual process energy	7,922,474	2,200,687
Annual building energy	13,829,328	3,841,480
Annual nonprocess energy	5,906,854	1,640,793

The process energy for building 4226 was measured and analyzed. An energy monitoring device was installed on the Mag-3 machine for 27 hours period. There are two MAG-3 machines in this building. The facility is running 8,760 hours annually. All machines are running during the operating hours or kept in standby mode during non-production hours.

The average power for the Mag-3 machine was calculated during the 27 hours period. This average includes the three modes (standby, partial, full). The average annual energy consumption Mag-3 machines can is calculated as follows:

The average annual energy consumption for Mag-3 machines =

The average power for one machine (measured) × facility operating hour's × number of machines

The energy monitoring device was installed the Mag-3 machine for 27 hours period to measure the average energy consumption and then to estimate the annual energy consumption for this machine. The energy monitoring device was set to collect 15 readings every second. Around 1,450,000 power data points were collected. As shown in Figure 5.3, the average power for the standby mode was estimated to be equal to 11 kW.

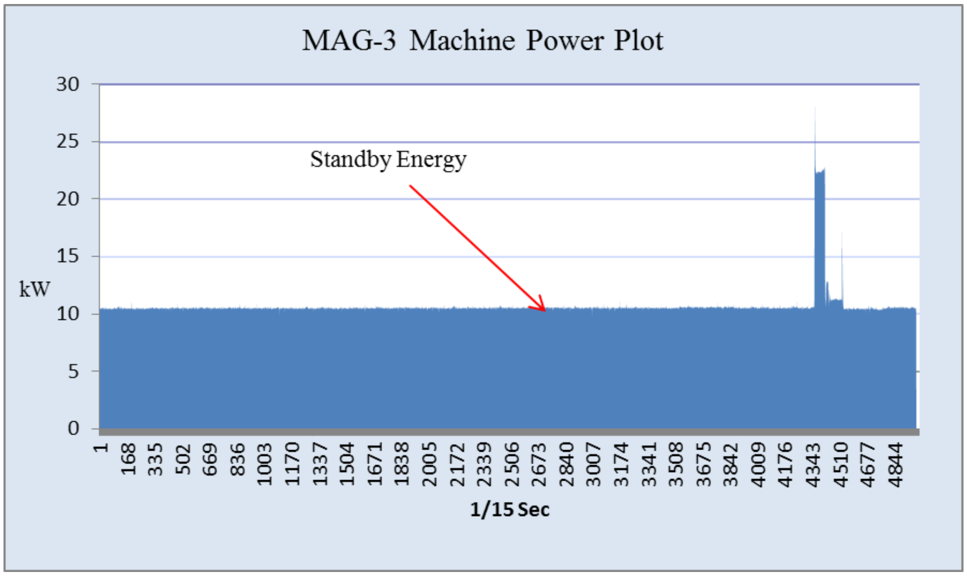

Figure 5.3. Basic mode power data for MAG-3 CNC machine.

For the full mode, the average power was estimated to be equal to 26 kW. Figure 5.4 shows a sample data points of the full mode power data.

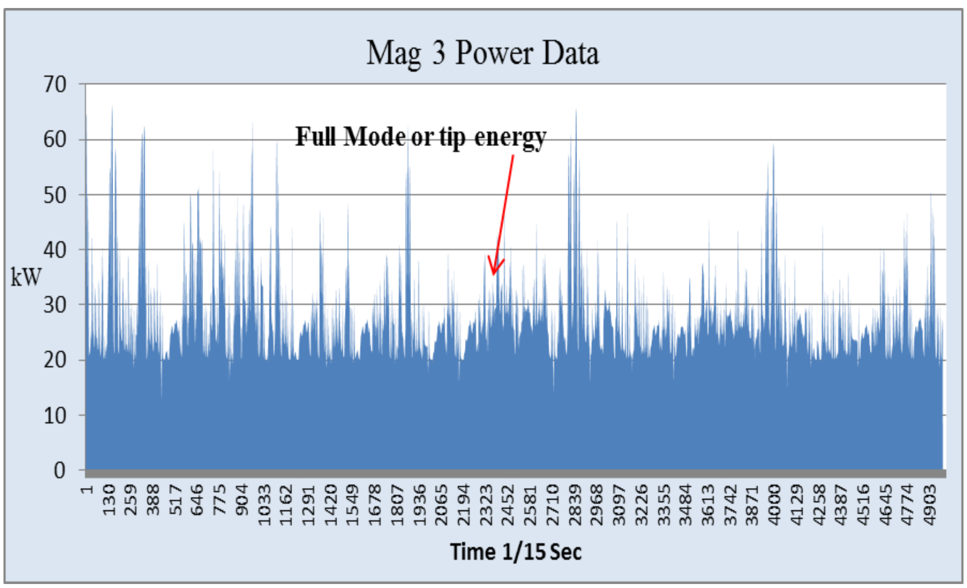

Figure 5.4. Full mode power plot for MAG-3 CNC machine.

The annual energy consumption for the MAG-3 machine was estimated. The annual energy consumption for the Mag-3 machine was calculated as follows:

The annual energy consumption for the Mag-3 machine

= 19.53 (average power for the three modes) × 8,760 (facility operating hours) = 171,083 kWh

The study period, average standby mode power during the study period, and the annual energy consumption for the Mag-3 machine are summarized in Table 5.25.

TABLE 5.25

MAG-3 MACHINE MODE TIMES AND ENERGY

Machine: MAG-3	
Study period: 27 hrs.	
Average standby mode power, kW	11
Average power for the study period, kWh	19.53
Annual machine energy, kWh	171,083

Table 5.26 shows the average annual energy process consumption, study period, and number of machines, for the building 4226.

TABLE 5.26

BUILDING 4226 PROCESS ENERGY SUMMARY (BASED ON 8,760 HOURS)

Machine type	# of machines	Average energy consumption/ machine, kWh	Study period (hrs.)	Total machine energy, kWh/yr.	Total energy kWh/yr. (All machines)
MAG-3	2	19.53	27	171,083	342,166
Other (Comp + chip process)	1	2.29	-	20,131	20,131
Total					362,297

As shown in Table 5.27, the annual process energy for building 4226 was calculated to be equal to 362,297 kWh. The annual nonprocess energy can be calculated as follows:

Nonprocess energy = total annual building energy – annual process energy

= 1,514,831 kWh - 362,297 kWh = 1,152,534 kWh

TABLE 5.27

BUILDING - 4226 ANNUAL ENERGY SUMMARY

Energy use type	MJ	kWh
Annual process energy	1,304,268	362,297
Total annual building energy	5,453,392	1,514,831
Annual nonprocess energy	4,149,124	1,152,534

Method 3: Using Regression to Estimate Nonprocess Energy

The nonprocess energy can also be estimated from the relationship between the amount of energy which are consumed by the plant monthly and the removed material weight for material subtractive processes in production (such as milling, drilling, etc.).

The facility uses two chip processing machines, one machine for each building. The removed chip by machines includes different material types which are aluminum, titanium, brass, and steel. These materials are mixed and not separated. The mixed chip then transferred to a chip processing machine inside the facility where it is compressed to reduce its volume. Then the produced chip is send to a contractor for recycling on a monthly basis. The chip weight information for both buildings of this facility was provided by the contractor who buys this chip. As shown in Table 5.28, the amount of removed material ranged from 520,087 Ib of material for January, 2010 to 417,409 Ib for May, 2010.

TABLE 5.28

CASE 1 FACILITY MONTHLY CHIP WEIGHT AND ENERGY CONSUMPTION

Month	Chips weight, Ib	Energy consumption, kWh	kWh/Ib
January	37,700	520,088	13.79
February	4,540	428,571	94.39
March	19,860	451,264	22.72
May	13,760	417,410	30.33
June	10,960	462,796	42.22
August	20,340	508,980	25.02

A regression model was created using the facility energy consumption and removed material on monthly basis. The energy consumption and chip mass for both buildings (4330 and 4226) were combined to create this model. As shown in Figure 5.5, the R^2 value for the regression model was equal to 0.61.

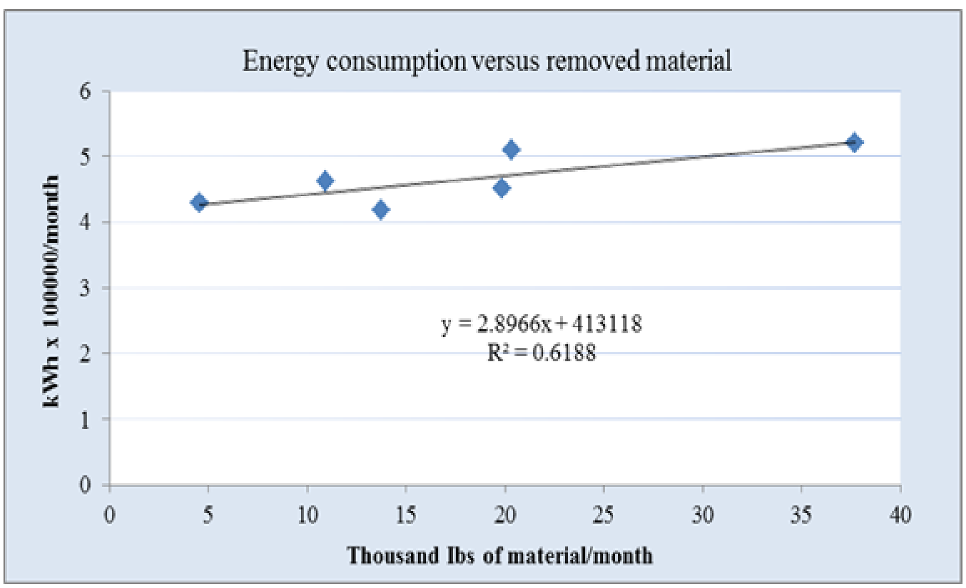

Figure 5.5. Case 1 energy consumption and removed material regression model.

Based on the regression model which was created, the monthly energy consumption for the facility can be estimated as follows:

When x = 0 (which means all machines are down or idle) then,

y = 413,118 kWh/month (this includes nonprocess energy and basic or standby energy for all machines)

Average annual energy consumption, based on regression model = 413,118 kWh × 12 months = 4,957,416 kWh

The nonprocess energy estimate, based on regression model is much larger than normal and other methods results such as method1 and method 2. As shown in Table 5.29, the difference between method 1 and regression model result is large.

TABLE 5.29

NONPROCESS ENERGY COMPARISON TABLE (METHOD 1 TO METHOD 3)

Method	Annual nonprocess energy (kWh)
Method1(direct estimate of nonprocess energy)	2,632,005
Method 2(direct estimate of process energy)	2,793,327
Method 3 (regression)	4,957,416
Difference (method 3- method 1)	2,325,411
Difference (method 3- method 2)	2,164,089

The regression model nonprocess energy estimates is much larger than the actual nonprocess energy for this building which indicates that the standby energy for all machines is included in this result where all machines are kept in standby mode while non-production times.

So to calculate the nonprocess energy for this facility, using regression results, the basic energy consumption for all machines must be calculated and subtracted from the regression result to estimate the building nonprocess energy. As shown in Table 5.30, the standby energy consumption for each machine is calculated from method 2, based on 8,760 hours. The total standby energy will be subtracted from the annual energy result of regression model.

TABLE 5.30

STANDBY ENERGY CONSUMPTION FOR MACHINES, BUILDINGS 4330 AND 4226 BASED ON 8760 HOURS (SEE METHOD 2)

Machine type	# of machines	Average standby energy consumption, kWh	Annual standby energy consumption, kWh
TOYODA	3	4	105,120
DMF-330	6	6.1	320,616
DMF-3001	3	10	262,800
FADAL	3	0.73	19,184
FRONTIER-L	2	0.7	12,264
DMV-4020	10	6.5	569,400
MORI-SL254	1	2	17,520
PUMA-2000Y	2	3	52,560
PUMA-2500LT	1	2	17,520
MAG-3	2	11	192,720
Other	4	8	280,320
Total			1,850,024

The monthly nonprocess energy consumption for this facility, using regression model results, can be calculated as follows:

Average annual nonprocess energy consumption =

Average annual energy consumption of the facility when zero material removed (y = 0) – standby energy consumption

= 4,957,416 kWh - 1,850,024 kWh = 3,107,392 kWh

Nonprocess power intensity =

Monthly energy consumption ÷ area ÷ monthly operating hours

Nonprocess power intensity = 3,107,392 kWh ÷ 109,488 ft^2 (both buildings) ÷ 8760 hours= 3.2 Watts/ft^2

Method 4: Using Simulation to Calculated the Nonprocess Energy

In 2009, the Department of Energy released a new version of EnergyPlus Simulation Software for modeling building overhead energy. The new EnergyPlus Simulation Software includes capabilities such as natural ventilation, water use, photovoltaic systems, and thermal comfort. In this study, the e-Quest-3.64 simulation software was used to test the facility nonprocess energy consumption.

The building energy simulation software (e-Quest-3.64) usually used to study the effect on the building energy consumption by changing some factors. This software was designed to explore the energy behavior of proposed and existing buildings, and their associated lighting, heating, and cooling. The following information was collected to estimate the energy consumption using the e-Quest-3.64 software (http://doe2.com/equest/):

1. The building orientation and location
2. The characteristics of building’s material (R-values, height, dimensions)
3. The area weather information
4. Heating and cooling sources and equipment

Buildings physical information which includes area, R-values for roof and walls, heating, cooling, and lighting equipment were used as inputs to simulate the annual energy consumption for this facility configuration. Table 5.31 shows the parameters which were used as inputs for the simulation software to simulate the annual nonprocess energy for this facility.

TABLE 5.31

BUILDING PARAMETERS INPUTS

Parameter	Building - 4330	Building - 4226
Area (ft^2)	64,488	45,000
Roof- R value ($ft^2 \bullet {}^\circ F \bullet h/Btu$)	11. 78	11. 78
Walls-R- value ($ft^2 \bullet {}^\circ F \bullet h/Btu$)	7	7
Building Height (ft.)	35	35
Lighting density, W/ft^2	1	1
Heating equipment	Gas fired	Gas fired
Cooling equipment	Electric	Electric
Operating hours	8,760	8,760
Year of study	2010	2010
Building location	Wichita, KS	Wichita, KS

The annual nonprocess energy consumption for each building was estimated separately. The simulated energy results are summarized in Table 5.32.

TABLE 5.32

SIMULATED ENERGY RESULTS FOR THE FACILITY

Building	Annual on-process energy consumption, kWh
Building 4330	1,892,936
Building 4226	1,095,071
Total	2,988,007

Case Study 2

The facility produces aerospace parts. The process and nonprocess energy data for this facility were collected. The total area of the facility was 59,218 ft^2. The data were collected while the facility was running three shifts a day. The facility consists of four sections which are:

1) Mag-3 area (29,318 ft^2)

2) 3-Axis area (9,600 ft^2)

3) Sheet metal & shipping area (10,494 ft^2)

4) Offices (5,000 ft^2)

This plant employed more than 200 employees. The monthly utility bills for this plant were documented and analyzed. The annual energy consumption this facility, based on the utility bills, was equal to 3,540,189 kWh. Three separate analysis techniques were used to estimate the nonprocess energy for this facility:

a) Direct measurements of nonprocess energy

b) Using simulation tools to estimate the building nonprocess energy

c) Creating a regression model which relates the chip weight with the building energy consumption to estimate the nonprocess energy.

Method 1: Direct Measurements of Nonprocess Energy

The total area of this facility is 59,218 ft^2. The monthly utility bills for this building were documented and analyzed. The annual energy consumption for this building, based on the utility bills, was equal to 3,540,189 kWh.

The monthly electricity cost consumption for the facility ranges from $13,144 for January to $25,101 for June 2009. The natural gas cost ranges from $141 in August 2009 to $3,409 in December 2009.

The power intensity is the power in kW or Watts divided by area, square foot or square meter (Watts/ft^2). The power intensity for the whole facility, which includes process and nonprocess intensities, was estimated and found to be equal to 6.84 Watts/ft^2. The facility was categorized, based on the nonprocess energy usage, as category four building where lighting, heating, cooling, and ventilation are used in this facility. The energy consumption for lighting, heating, and cooling this facility was estimated and analyzed.

1. Lighting

The facility is lit by the 400 watts metal halide (MH), 2T12, 2T8, and 6T5 lamps. The power intensity for lighting each area in the facility was estimated and analyzed. The Mag-3 area is lit by 32 400 Watts metal halide lamps and 30 (2T12) fixtures; the lighting power intensity for this area was estimated to be equal to 0.70 Watts/ft^2. The annual energy consumption, power intensity, and annual cost for lighting each area in this facility were calculated and summarized in Table 5.33.

TABLE 5.33

LIGHTING ENERGY SUMMARY FOR THE FACILITY

Space type	Area, ft^2	Number and type of Fixtures & total Watts	Annual energy consumption, kWh	Annual cost, based on 8 ¢ per kWh, dollars	Power intensity, Watts/ft^2
Mag-3 area	29,318	32 (400 W total W= 14,656), 30(2T12, total W= 5,760)	178,844	14,308	0.70
3-Axis machine shop	9,600	12 (400 W total W= 5,496,), 34(2T8, total W= 4,080)	83,885	6,711	1.00
Sheet metal & shipping	10,494	22 (400 W total W= 10,076), 16(2T12, total W= 1,920), 10(2T5, total W= 640)	51,555	4,124	0.56
Offices	5,000	41(6T5, total W= 8,364)	73,269	5,861	1.67

2. Heating

Calculations were made based on the average monthly temperature for Wichita area and number of hours for each heating month. The annual energy consumption for each section was calculated then the power intensity was calculated also. For example, the total energy required for heating the Mag-3 area is calculated as follows:

Annual heating energy for the mag-3 area = 349,320 kWh (see case 1)

Heating power intensity = Annual energy consumption ÷ total area ÷ 8760 hours

= 349,320 kWh ÷ 29,318 ft^2 ÷ 8,760 hours = 1.36 Watts/ft^2

The same methodology was followed to estimate the heating energy for other sections, Table 5.34.

TABLE 5.34

HEATING ENERGY DATA FOR CASE 2 FACILITY

	Mag-3 section	3-Axis section	Sheet metal section	Offices
Annual Heating, kWh	349,320	99,637	69,677	20,160
Power intensity, W/ft^2	1.36	1.18	1.66	1.01

3. Cooling

Calculations were made based on the average monthly temperature for Wichita area and number of hours for each cooling month, Table 5.3. The cooling hours for Wichita area were estimated to be equal to 2,928 hours, when the facility runs for three shifts a day, the total cooling hours will be equal to 2,928 annually. The Mag- 3 machine shop is cooled by six Rheem roof top coolers with a power of 31 kW for each. The annual energy consumption for cooling the Mag-3 area was calculated as follows:

The annual cooling energy for the mag-3 area = 186,715kWh (see case 1)

Cooling power intensity = Annual energy consumption ÷ total area ÷ 8,760

= 186,715 kWh ÷ 29,318 ft^2 ÷ 8,760 hours = 0.73 Watts/ft^2

The annual energy consumption for cooling other areas in the facilities is summarized in Table 5.35.

TABLE 5.35

COOLING ENERGY DATA FOR CASE 2 FACILITY

	Mag-3 section	3-Axis section	Sheet metal section	Offices
Annual cooling, kWh	186,715	55,653	42,660	10,098
Power intensity, W/ft^2	0.73	0.66	1.02	0.78

4. Ventilation

The power intensity for ventilation in the mag-3 area was estimated as follows:

Total energy required = fan power × number of fans × operating hours

$= 0.186$ kW $\times 15 \times 8760$ hours $= 24{,}506$ kWh

Ventilation power intensity = Annual energy consumption ÷ total area ÷ operating hours

$= 24{,}506$ kWh ÷ 29,318ft^2 ÷ 8,760 hours = 0.1 Watts/ft^2

The nonprocess power intensity for each energy use type was estimated for this area. The nonprocess power intensity and annual energy consumption for each section were estimated and summarized in Table 5.36.

TABLE 5.36

NONPROCESS ANNUAL ENERGY AND POWER INTENSITY FOR CASE 2 FACILITY

Energy type use	Mag-3, kWh	3-Axis, kWh	Sheet metal, kWh	Offices, kWh	Total annual, kWh	Power intensity, W/ft^2
Lighting	178,844	83,886	51,555	73,269	387,554	0.75
Cooling	186,715	55,653	42,660	10,098	295,126	0.57
Heating	349,320	99,637	69,677	20,160	538,794	1.04
Ventilation	24,506	1,683	1,683	1,040	28,912	0.06
Total nonprocess (for the whole facility)	739,385	240,859	165,575	104,567	(1,250,386)	(2.41)

Method 2: Using Simulation to Calculated the Nonprocess Energy

In 2009, the Department of Energy released a new version of EnergyPlus Simulation Software for modeling building overhead energy. The new EnergyPlus Simulation Software includes capabilities such as natural ventilation, water use, photovoltaic systems, and thermal comfort. In this study, the e-Quest-3.64 simulation software was used to test the facility nonprocess energy consumption.

The building energy simulation software (e-Quest-3.64) usually used to study the effect on the building energy consumption by changing some factors. This software was designed to explore the energy behavior of proposed and existing buildings, and their associated lighting, heating, and cooling. The following information was collected to estimate the energy consumption using the e-Quest-3.64 software (http://doe2.com/equest/):

1. The building orientation and location

2. The characteristics of building’s material (R-values, height, dimensions)

3. The area weather information

4. Heating and cooling sources and equipment

Buildings physical information which includes area, R-values for roof and walls, heating, cooling, and lighting equipment were used as inputs to simulate the annual energy consumption for this facility configuration. Table 5.37 shows the parameters which were used as inputs for the simulation software to simulate the annual nonprocess energy for this facility.

TABLE 5.37

BUILDING PARAMETERS INPUTS

Parameter	
Area (ft^2)	59,218
Roof- R value (ft^2•°F•h/Btu)	11. 78
Walls-R- value (ft^2•°F•h/Btu)	7
Building Height (ft.)	35
Lighting density, W/ft^2	0.75
Heating equipment	Radiant
Cooling equipment	Electric
Operating hours	8,760
Year of study	2011
Building location	Wichita, KS

The natural gas consumption for heating months and the electricity consumption for cooling months are shown in Figure 5.6. The annual nonprocess energy consumption for the facility using simulation was equal to 1,149,484 kWh.

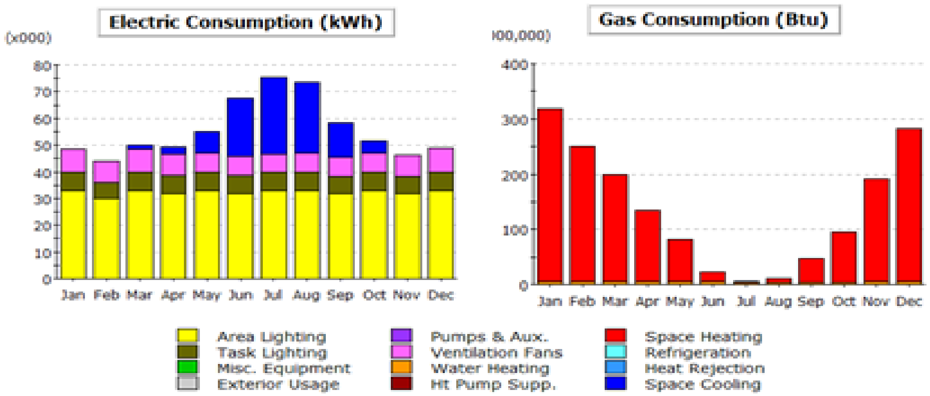

Figure 5.6. Annual energy consumption using simulation.

Method 3: Using Regression Model to Estimate Nonprocess Energy

The nonprocess energy can also be estimated from the relationship between the amount of energy which are consumed by the plant monthly and the removed material weight for material removal processes in production (such as milling, drilling, etc.). As shown in Table 5.38, the amount of removed material ranged from 10,335 Ib of material for February, 2009 to 23,480 Ib for June, 2009. The removed chip by machines includes different material types which are aluminum, titanium, brass, and steel. The chip weight information for this facility was provided by the facility manager.

TABLE 5.38

MONTHLY CHIP WEIGHT AND ENERGY CONSUMPTION

Month	Chip weight Ib	Energy consumption
January	11,684	256,915
February	10,335	255,963
March	12,596	288,428
June	23,480	341,835
August	18,640	298,036

A regression model was created using the facility energy consumption and removed material on monthly basis. As shown in Figure 5.7, the R^2 value for the regression model was equal to 0.90.

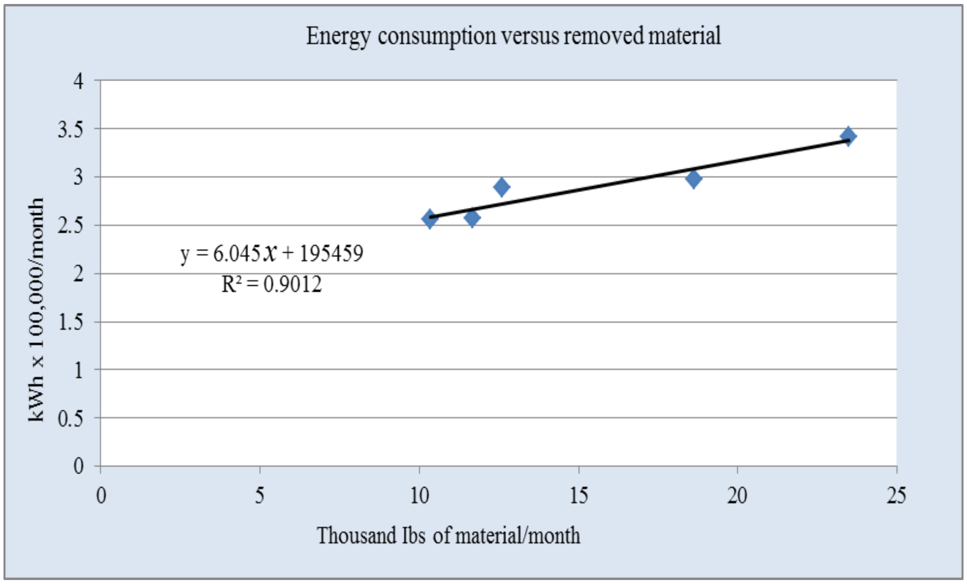

Figure 5.7. Energy consumption and removed material regression model.

Based on the regression model, the nonprocess energy for the facility can be estimated as follows: when $x = 0$ (which means no production) then,

y = 195, 459 kWh (this includes nonprocess energy and basic or standby energy for all machines)

Average annual energy consumption, based on regression model = 195, 459 kWh × 12 months = 2,345,508 kWh

The nonprocess energy consumption, based on regression, is equal to 2,345,508 kWh. The nonprocess energy estimate, based on regression model is much larger than normal and other methods 1&2. The regression model nonprocess energy estimates is much larger than the actual nonprocess energy for this facility which indicates that the standby energy for all machines is included in this result where the machines are kept in standby mode in no-production times.

Case Study 3

The facility produces aerospace parts. The process and nonprocess energy data for this facility were collected. The total area of the facility is 40,000 ft^2. The data were collected while the facility was running three shifts a day. The facility consists of four sections which are:

1) Machine shop (2, 347 ft^2)

2) Production area & engineering lab (18,454 ft^2)

3) Warehouse & shipping area (9,035 ft^2)

4) Offices & quality control section (9,945 ft^2)

This plant employed more than 160 employees. The monthly utility bills for this plant were documented and analyzed .The annual energy consumption this facility, based on the utility bills, was estimated to be equal to 1,414,937 kWh. Two separate analysis techniques were used to estimate the nonprocess energy for this facility:

a) Direct measurements of nonprocess energy

b) Using simulation tools to estimate the building nonprocess energy

Method 1: Direct Measurements of Nonprocess Energy

The power intensity is the power in kW or Watts divided by area, square foot or square meter (Watts/ft^2). The power intensity for the whole facility, which includes process and nonprocess intensities, was estimated and found to be equal to 4.1 Watts/ft^2. The facility was categorized, based on the nonprocess energy usage, as category four building where lighting, heating, and cooling are used in this facility. The energy consumption for lighting, heating, and cooling this facility next analyzed.

1. Lighting

The facility is lit by different types of lamps such as the nominal 400 Watts metal halide lamps and the 2T12 lamps. The 400 Watts metal halide lamps are widely used for lighting large industrial facilities. The actual amount of power which is consumed by the 400 W metal halide lamps ranges from ratings on the bulbs of 400 watts to 499 Watts. The amount of power which is consumed by the T12 lamps is 95 Watts. The power intensity for lighting the facility was estimated and analyzed, Table 5.39.

The lighting power intensity for the whole facility was estimated based on operating hours and lighting bulbs power. For example the lighting power intensity for the machine shop can was estimated as follows:

The Machine Shop is lit by 4T5 fixtures with 54 watts for each lamp. The total number of fixtures used to light the machine shop is 18 fixtures. The area of the machine is equal to 2,347 ft^2. The lighting power intensity for machine shop was estimated as follows:

Watts = watts for each lamp × number of lamps

54 × 18 × 4 = 3,888 Watts

Annual lighting energy consumption =

Lighting power × operating hours =

3,888 watts × 2,600 hours ÷ 1,000 kW/watts = 10,109 kWh

The power intensity for lighting the machine shop =:

= annual energy consumption ÷ Total area of the machine shop ÷ operating hours =

9097.97 ÷ 2600hrs ÷ 2,340 ft^2 = 1.66 $Watts/ft^2$

TABLE 5.39

LIGHTING BULBS AND ANNUAL ENERGY FOR THE FACILITY

Bulb type	Number of bulbs	Bulb Watts	Total Watts	Annual energy (based on 2,600 hours), kWh
400 W metal halide	46	458	21,068	54,777
T5	620	34	19,840	54,808
T12	6	95	576	1,498
T8	270	54	14,580	37,908
Total for facility				148,990
Power intensity (W/ft^2)				1.43

2. Heating

Calculations were made based on the average monthly temperature for Wichita area and number of hours for each heating month. The same methodology used in case1, method 1was used to estimate the annual energy and power intensity for each section in this facility, Table 5.40.

TABLE 5.40

FACILITY HEATING ENERGY SUMMARY

Space type	Area, ft^2	Annual heating, kWh	Power intensity, W/ft^2
Machine shop	2,347	39,751	1.93
High flow test area	1,220	10,964	1.03
Engineering lab	2,671	16,795	0.72
Production area #1	4,500	32,888	0.83
Production area #2	2,250	20,514	1.04
Motors assembly area	1,750	11,204	0.73
New stock area	2,265	15,929	0.80
Old stock area	3,850	29,350	0.87
Shipping room	270	1,163	0.49
Repair room	2,250	15,750	0.80
Quality control area	1,075	12,647	1.34
Offices	8,870	55,411	0.71
Maintenance & Shipping	2,650	7,020	0.30

3. Cooling

Calculations were made based on the average monthly temperature for Wichita area and number of hours for each cooling month. The cooling hours for Wichita area were estimated to be equal to 2,928 hours. When the facility runs for three shifts a day, the total cooling hours will be equal to 2,928 annually. The building is cooled by one roof top coolers with a power of 27.7 kW.

The annual energy consumption for cooling and the power intensity for each section in this facility were estimated and summarized in Table 5.41.

TABLE 5.41

FACILITY COOLING ENERGY SUMMARY

Space type	Area, ft^2	Cooling, kWh	Power intensity, W/ft^2
Machine shop	2,347	11,883	0.58
High flow test area	1,220	8,948	0.84
Engineering lab ovens room	2,671	52,281	2.23
Production area #1	4,500	12,347	0.45
Production area #2	2,250	11,346	0.58
Motors assembly area	1,750	24,735	1.61
New stock area	2,265	21,761	1.10
Old stock area	3,850	39,104	1.16
Shipping room	270	1,163	0.49
Repair room	2,250	717	0.04
Quality control area	1,075	6,769	0.72
Offices	8,870	23,021	0.30
Maintenance area & Shipping	2,650	4,680	0.32
Whole facility	40,266	219,246	0.62

4. Ventilation

The power intensity for ventilation in the machine shop was estimated as follows:

Total energy required = fan power × number of fans × operating hours

= 0.373 kW × 3 × 2,340 hours = 2,618 kWh

Ventilation power intensity = Annual energy consumption ÷ total area ÷ operating hours

= 2,328 kWh ÷ 2,347ft^2 ÷ 2,340 hours = 0.48 Watts/ft^2

The annual nonprocess energy consumption and the power intensity for each section in this facility were calculated. The nonprocess power intensity and annual energy consumption for each section are summarized in Table 5.41.

TABLE 5.41

NONPROCESS POWER INTENSITY FOR THE FACILITY

Space type	Lighting, kWh	Heating , kWh	Cooling, kWh	Ventilation , kWh
Machine shop	10,109	39,751	11,883	2,618
Compressors room	4,763	0	0	4,694
Engineering lab ovens room	14,476	16,795	52,281	0
Production area #1	24,903	32,888	12,347	6,240
Production area #2	11,183	20,514	11,346	0
Motors assembly area	8,750	11,204	24,735	2,080
New stock area	9,287	15,929	21,761	0
Old stock area	10,010	29,350	39,104	0
Ovens room #2	1,991	0	0	0
Paint room	1,280	0	0	2,896
Shipping room	1,065	1,163	1,163	3,200
High flow test area	4,763	10,964	8,948	0
Repair room	8,775	15,750	717	0
Quality control area	4,655	12,647	6,769	0
Offices	23,175	55,411	23,021	0
Maintenance area & Shipping	9,805	7,020	4,680	0
Total annual non – process energy (W/ft^2)	148,990 (1.43)	269,386 (0.77)	218,755 (0.63)	21,728 (0.064)

Method 2: Using Simulation to Calculated the Nonprocess Energy

Buildings physical information which includes area, R-values for roof and walls, heating, cooling, and lighting equipment were used as inputs to simulate the annual energy consumption for this facility configuration. Table 5.42 shows the parameters which were used as inputs for the simulation software to simulate the annual nonprocess energy for this facility.

TABLE 5.42

BUILDING PARAMETERS INPUTS

Parameter	
Area (ft^2)	40,266
Roof- R value (ft²•°F•h/Btu)	11. 78
Walls-R- value (ft²•°F•h/Btu)	7
Building Height (ft.)	35
Lighting density, W/ft^2	1
Heating equipment	Gas fired
Cooling equipment	Electric
Operating hours	8,760
Year of study	2010
Building location	Wichita, KS

The natural gas consumption for heating months and the electricity consumption for cooling months are shown in Figure 5.8. The annual nonprocess energy consumption for the facility using simulation was equal to 606,352 kWh.

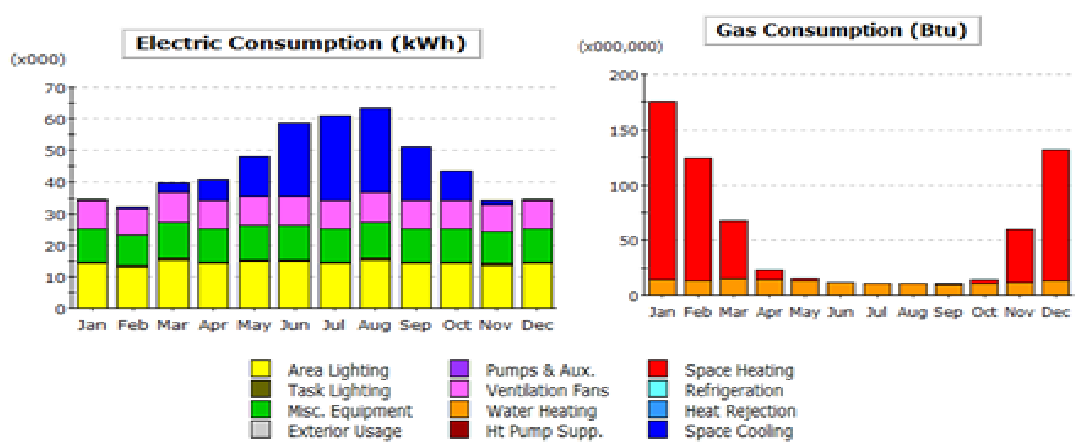

Figure 5.8. Simulation energy summary.

The annual nonprocess energy consumption for each building was estimated separately. The simulated energy results are summarized in Table 5.43.

TABLE 5.43

SIMULATED ENERGY RESULTS FOR THE FACILITY

Energy type	Method 1, kWh	Simulation, kWh
Lighting	148,990	177,860
Heating	269,386	191,312
Cooling	218,755	237,180
Ventilation	21,728	-
Total (kWh)	658,859	606,352

Case Study 4

The facility produces different plastic and metal products. The process and nonprocess energy data for this facility were collected. The total area of the facility was estimated to be around 1.3 million ft^2. The data were collected while the facility was running three shifts a day. The facility consists of four sections which are:

1) Press shop (45,000 ft^2)

2) Warehouse section (400,000 ft^2)

3) Sheet metal & shipping area (100,000)

4) Offices (100,000)

5) Plastic molding area (500,000)

This plant employed more than 900 employees. The monthly utility bills for this plant were documented and analyzed. The annual energy consumption for both buildings of this facility, based on the utility bills, was estimated to be equal to 88.65 million kWh. Two separate analysis techniques were used to estimate the nonprocess energy for this facility:

a) Direct measurements of nonprocess energy

b) Using simulation tools to estimate the building nonprocess energy

Method 1: Direct Measurements of Nonprocess Energy

The total area of this building was estimated to be equal to 1.3 million ft^2. The monthly utility bills for this building were documented and analyzed. The annual energy consumption for this building, based on the utility bills, was estimated to be equal to 88.65 million kWh.

The monthly energy consumption of this facility is summarized in Table 5.44.

TABLE 5.44

ANNUAL ENERGY CONSUMPTION FOR CASE STUDY 4

Energy Type	Annual Energy Consumption	Power intensity Watts/ft^2
Electricity million kWh	43.15	
Natural Gas million BTU	155,305	
Total Annual Energy Consumption, million kWh	88.65	9.88

In this study, the nonprocess energy for the machine shop and warehouse will be estimated and analyzed. The total area of the press shop was estimated to be equal to 45,000 square feet**.** The press shop uses 29 press machines inside this area. The press shop includes two work stations. There are different types of machines used in the press shop. These machines are used to produce different parts necessary for coolers, grills, lights and propane cans. The process and nonprocess energy data for this shop were collected and analyzed. The annual energy consumption for lighting, heating, and cooling this facility next analyzed.

1. Lighting

The press shop is lit by two kinds of lamps, the 400 watts metal halide lamps and the 2T12 96 Watts lamps which are used for task lighting. The 400 Watts metal halide lamps are widely used for lighting large industrial facilities. The actual amount of power which is consumed by the 400 W metal halide lamps ranges from ratings on the bulbs of 400 watts to 499

Watts. The amount of power which is consumed by the T12 lamps is equal to 96 Watts. The power intensity for lighting each area in the facility was estimated and analyzed. The press shop facility is lit by150 (400 W) lamps and 20 2T12 fixtures used as task lighting. The lamps and fixtures used for the press shop area and the power for each fixture are shown in Table 5.45.

TABLE 5.45

PRESS SHOP LIGHTING ENERGY SUMMARY

Type	Number of lamps	Total Watts	Annual, based on 4,000 annual hours, kWh	Power intensity, Watts/ft^2
400 W metal halide	150	68,700	274,800	
2T12 (F96)	40	3,840	15,360	
Total			287,160	1.60

The east warehouse is lit by two types of fixtures, 2T12 and 6T8 fixtures. The power intensity for lighting the east warehouse was estimated to be equal to 0.30 Watts/ft^2. The lighting energy consumption and power intensity for the east warehouse are summarized in Table 5.46.

TABLE 5.46

EAST WAREHOUSE LIGHTING ENERGY SUMMARY

Fixture type	Number of pulps	Watts/ pulp	Total Watts	Annual hours	Annual consumption, kWh	Power intensity, Watts/ft^2
6T8	1710	32	54,720	8,760	479,347	
2T12	92	96	8,832	8,760	77,368	
Total					556,716	0.30

The middle warehouse is lit by three types of fixtures, 2T12, 6T8, and 400 watts metal halide lamps. The power intensity for lighting the middle warehouse was estimated to be equal to 0.6 Watts/ft^2. The lighting energy consumption and power intensity for the middle warehouse are summarized in Table 5.47.

TABLE 5.47

MIDDLE WAREHOUSE LIGHTING ENERGY SUMMARY

Fixture type	Number of pulps	Watts/pulp	Total Watts	Hours/yr.	Annual consumption, kWh	Power intensity, Watts/ft^2
6T84	246	32	7,872	8,760	68,959	
2T128	312	96	29,952	8,760	262,380	
400W	147	458	67,326	8,760	589,776	
Total					921,114	0.60

2. Heating

Calculations were made based on the average monthly temperature for Wichita area and number of hours for each heating month.

The same methodology used in case 1 was used to estimate the heating energy consumption for each section in this facility, Table 5.48.

TABLE 5.48

FACILITY HEATING ENERGY SUMMARY

Space	Annual heating energy , kWh	Heating power intensity, W/ft^2
Press shop	543,437	1.38
East warehouse	1,656,746	0.84
Middle warehouse	1,330,548	0.87

3. Cooling and Ventilation

The press shop is cooled by 80 Dayton air circulation fans. The power for each fan is equal to 0.5 hp. The annual energy consumption for cooling and the power intensity for were calculated as follows:

Cooling annual energy consumption for the press shop = 0.5 hp × 80 × 0.746 kW/hp ×

2,184 hours = 65,171 kWh

Cooling power intensity for the press shop = 65,171 kWh ÷ 45,000 ÷ 8,760 = 0.17 Watts/ft^2

The power intensity for ventilation in the press shop area was estimated as follows:

Total energy required = fan power × number of fans × operating hours

= 0.37 kW ×10 × 8,760 hours = 32,412 kWh

Ventilation power intensity = Annual energy consumption ÷ total area ÷ operating hours

= 32,412 kWh ÷ 45, 000 ÷ 8,760 hours = 0.082 Watts/ft^2

The same methodology was followed to estimate the energy consumption for cooling and ventilating the other sections. The annual energy consumption for cooling and ventilation are summarized in Table 5.49.

TABLE 5.49

ANNUAL NONPROCESS ENERGY FOR THE PRESS SHOP

Space	Cooling energy, kWh	Ventilation energy , kWh
Press shop (W/ft^2)	58,725 (0.17)	32,412 (0.082)

Case Study 5

The total area of the facility was estimated to be around 500,000 ft^2. The facility is running three shifts a day. The facility consists of the following sections:

1) Production area (275,000 ft^2)

2) Warehouse (200,000 ft^2)

3) Offices and cafeteria (25,000 ft^2)

The annual energy consumption for this facility, based on the utility bills, was estimated to be equal to 39,993,613 kWh. This plant employed more than 450 employees with an approximate annual production of 10,000 units.

Two separate analysis techniques were used to estimate the nonprocess energy for this facility:

Method 1: Direct measurements of nonprocess energy

The total area of this facility was estimated to be equal to 500,000 ft^2. The monthly utility bills for this building were documented and analyzed. The annual energy consumption for this building, based on the utility bills, was estimated to be equal to 39,993,613 kWh. The power intensity for the whole facility, which includes process and nonprocess energy, was estimated to be equal to 9.1Watts/ft^2. The annual energy consumption for lighting, heating, and cooling this facility next analyzed.

1. Lighting

The facility is lit by different kinds of lamps such as the 400 watts metal halide lamps and the 4T5 lamps. The lamps, fixtures, watt usage and energy consumption for each fixture are shown in Table 5.50.

TABLE 5.50

LIGHTING FIXTURES IN THE CASE 5 PLANT

Fixture	Fixture Wattage	Bulb watts	Number of fixtures	Annual energy consumption, kWh
D20 W Incandescent	40	40	12	4,205
40W FL	56	56	8	3,924
Dual 40W FL	112	56	225	220,752
Quad 40W FL	224	56	175	343,392
Triple 40W FL	168	56	347	510,673
Dual 96W FL	210	105	4	7,358
400w MH w/ballast	458	458	886	3,554,703
Total	1,268		1,657	4,645,008

The annual energy consumption for lighting was equal to 4,645,008 kWh. The power intensity is the energy in kW or Watts divided by square foot (Watts/ft^2). The power intensity for lighting was estimated to be equal to 1.06 Watt/ft^2.

2. Heating

Calculations were made based on the average monthly temperature for Wichita area and number of hours for each heating month. The same methodology was used to estimate the energy consumption for this facility:

Total energy required = heating energy (BTU) + fans energy (electricity)

10,032,940,191 BTU × 0.000293 kWh/Btu + 23,163 kWh = 3,697,722 kWh

Heating power intensity = Annual energy consumption ÷ total area ÷ operating hours

= 3,697,722 kWh ÷ 500,000ft^2 ÷ 8,760 hours = 0.84 Watts/ft^2

2. Cooling

Calculations were made based on the average monthly temperature for Wichita area and number of hours for each cooling month, Table 3. The cooling hours for Wichita area were estimated to be equal to 2,928 hours. When the facility runs for three shifts a day, the total cooling hours will be equal to 2,928 annually.

The annual energy consumption for cooling the facility = energy for cooling the first office area + energy consumption for the second office area + energy for the production area = 613,738 + 63,135 + 48,721 = 725,594 kWh

The power intensity for cooling the facility = 725,594 kWh ÷ 500,000 ft^2 ÷ 8,760 = 0.17 Watts /ft^2.

The nonprocess power intensity for this facility was estimated to be equal to 2.15 Watts/ft^2. The nonprocess power intensity for the facility was estimated for each energy type use. The power intensity for lighting the facility was estimated to be equal to 1.06 Watts/ft^2. For heating, the power intensity was estimated to be equal to 0.84 Watts/ft^2. For cooling, the power intensity was estimated to be equal to 0.17 Watts/ft^2.The nonprocess power intensity for the facility is summarized in Table 5.51.

TABLE 5.51

NONPROCESS ENERGY FOR THE FACILITY

Energy type use	Annual energy, kWh	Power intensity, Watts/ft^2
Lighting	4,645,008	1.06
Heating	3,697,722	0.84
Cooling	725,594	0.17
Ventilation	209,119	0.05
humidity control	136,656	0.03
Total (nonprocess)	(9,414,099)	(2.15)

Method 2: Using Simulation to Calculated the Nonprocess Energy

The building energy simulation software (e-Quest-3.64) usually used to study the effect on the building energy consumption by changing some factors. This software was designed to explore the energy behavior of proposed and existing buildings, and their associated lighting, heating, and cooling.

Buildings physical information which includes area, R-values for roof and walls, heating, cooling, and lighting equipment were used as inputs to simulate the annual energy consumption for this facility configuration. Table 5.52 shows the parameters which were used as inputs for the simulation software to simulate the annual nonprocess energy for this facility.

TABLE 5.52

BUILDING PARAMETERS INPUTS

Parameter	
Area (ft^2)	500,000
Roof- R value (ft^2•°F•h/Btu)	11. 78
Walls-R- value (ft^2•°F•h/Btu)	7
Building Height (ft.)	35
Lighting density, W/ft^2	1.
Heating equipment	Natural gas
Cooling equipment	Electric
Operating hours	8,760
Year of study	2011
Building location	Wichita, KS

The annual nonprocess energy consumption for the facility was estimated using simulation was equal to 9,642,262 kWh, Figure 5.9.

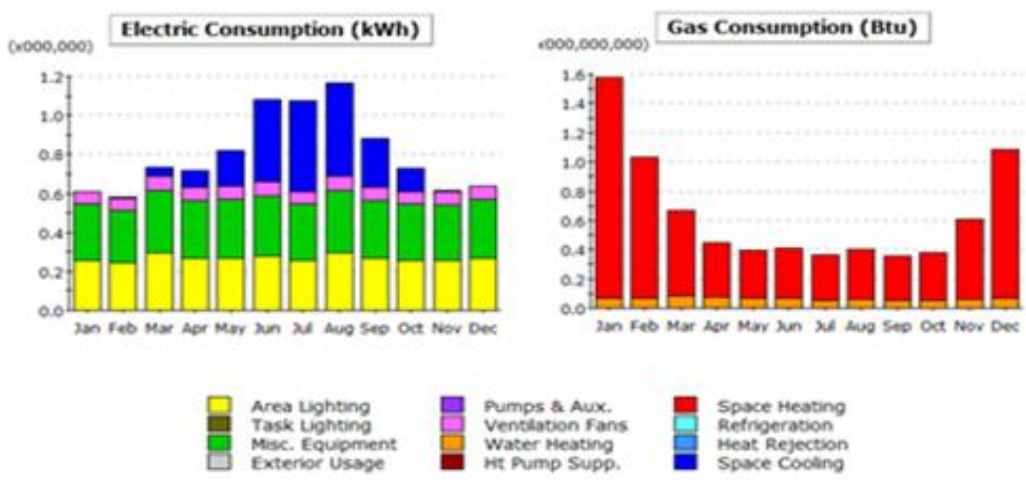

Figure 5.9. Annual nonprocess energy consumption for case 5 facility.

The facility produces about 10,000 units annually. The energy consumption for each unit was calculated. The energy consumption for each unit can be calculated as follows:

Annual energy consumption for the facility = 39,993,613 kWh

Annual production rate = 10,000 units

Energy consumption for each unit = 39,993,613 kWh ÷ 10,000 units = 3,999 kWh

Table 5.54 shows the annual nonprocess energy consumption for this facility using direct measurement of nonprocess energy (method 1) and simulation (method 2).

TABLE 5.54

ENERGY SUMMARY BY METHOD

Method	Annual energy , kWh	Power intensity, Watts/ft^2
Method 1	9,414,099	2.15
Method 2	9,642,262	2.20

5.6 Discussion and Conclusions

Five industrial facilities were visited and the energy data for these facilities were collected. The nonprocess energy for each facility was estimated and analyzed. The nonprocess power intensity for the various nonprocess energy uses was calculated for each facility, based on the actual facility energy bills and measurements. Four separate analysis techniques were used to estimate the nonprocess energy for these facilities as a means to critically understand this information:

a) Method 1: direct measurements of nonprocess energy

b) Method 2: direct measurements of process energy, then the nonprocess energy can be calculated by subtracting the process energy consumption from the total facility energy consumption.

c) Method 3: Creating a regression model which relates the material removal (chip weight) with the building energy consumption to estimate the nonprocess energy at zero production

d) Method 4: Using simulation tools to estimate the building nonprocess energy

In this study, the nonprocess energy consumption for five facilities was estimated using the four analysis techniques. The nonprocess power intensity for these facilities ranges from 1.65 W/ft^2 for case 3 facility to 3.23 W/ft^2 for case 1 facility, Table 5.55. Four analysis techniques were used for case 1 and three for case 2. In case 3 and 4 two analysis techniques were used.

TABLE 5.55

ANNUAL NONPROCESS ENERGY BY METHOD FOR THE FIVE CASE STUDIES

Case #	Facility type	Annual energy consumption, kWh	Nonprocess energy estimate by method, kWh			
			Method 1 (W/ft^2)	Method 2 (W/ft^2)	Method 3 (W/ft^2)	Method 4 (W/ft^2)
1	Aerospace parts	5,356,312	2,632,005 (2.70)	2,793,327 (2.90)	3,107,392 (34.8)	2,988,007 (3.23)
2	Aerospace parts	3,424,489	1,250,386 (2.40)	n/a	2,345,508 (45. 19) *	1,149,484 (4.2)
3	Aerospace assembly	1,433,762	633,861 (1.80)	n/a	n/a	606,352 (1.65)
4	Press shop	-	925,934 (2.33)	n/a	n/a	n/a
5	Heavy trucks	39,993,613	9,414,099 (2.15)	n/a	n/a	9,002,637 (2.20)

*: this amount includes standby energy for machines

In this study different methods to extract the nonprocess energy in industrial buildings were used as comparators. The research has indicated that these methods are valuable techniques to assist facility managers in determining energy conservation solutions. It is advantageous to have different methods for estimating the nonprocess energy for the industrial buildings where the facility manager can decide which method to use based on the available information. Also these methods can be used to check the accuracy of each other.

In 1 of the 5 case studies the four different methods were used to estimate the nonprocess energy for the same facility where all needed information are available to use these methods. In the other case studies one to three methods were used for each facility based on the available information for each method. The results of these estimates were close to each other which indicate that any method can be used based on available information. Thus these methods are potentially important step in improving energy use by nonprocess sources.

5.7 References

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CHAPTER 6

ASSESSMENT OF MANUFACTURING PROCESS AREA FOR NONPROCESS ENERGY ANALYSIS

6.1 Abstract

In this paper, the actual manufacturing plants relationship of machines (the product manufacturing processes) and the adjacent area was measured. Together these comprise the plant area assigned to a machine or sequence for machines. This is a critical body of information needed to estimate product (from one or a sequence of machines) nonprocess energy as energy intensity (W/m^2) times process area. The relationship between the manufacturing process (machines converting materials or workpieces into products) area and the nonprocess energy for an industrial facility was investigated and analyzed. The building area information and energy data for five industrial facilities were collected and analyzed. The building nonprocess energy includes lighting, heating, cooling, ventilation. The space usage was grouped into seven categories. The percentage of each space type to machine area category was calculated this allows the calculation of area ratios as a potential tool to scale machine area or footprint into that of the manufacturing plant necessary for that machine**.** This paper has further contributed to the life cycle of products by estimating nonprocess area and related nonprocess energy to be added to the life cycle of industrial facility to obtain more complete energy profile of product manufacturing.

6.2 Introduction

There is a very small literature on relating industrial nonprocess or service building energy to manufacturing process area in those buildings. However a large literature is focused on planning for efficient utilization of resources and reducing material handling cost. For example, Tools of Soft Computing as Applied to the Problem of Facilities Layout Planning by Karray, et. al. [7]. Design & Evaluation of Engine Assembly Line Layouts by Mardani & Jalili [8] and The Construction Goals and Spatial Layout Project of the Offshore Three Green Gorges in China [6].

The plant layout should meet all of the plant requirements with lowest cost at the planning stage. These requirements include: process flow, equipment configuration, utilities, support services, shipping, safety, and material handling. Block layout is a simple approach to setup a plant space involving production with variety of equipment by combining tasks or equipment into blocks or groups [9].

Knowledge of processes and processes are essential to arrange blocks. An example of typical assembly facility area distribution which includes different departments and area are shown in Table 6.1 [9].

TABLE 6.1

TYPICAL PLANT AREA DISTRIBUTION [9]

Function	Area, m^2
Shipping	334
Storage	1,003
Offices	1,905
Aisles	1,338
Machines	6,002
Assemble	2,072
Packaging	557
Painting	1,421
Total	14,660

Sule Dilleep, in his book “Manufacturing facilities location, planning, and design” described the conventional method of developing a plant layout. The first step of developing a plant layout is to determine the required area. The second step is to draw the relationship chart (rel-chart) which describes the relationship between work centers. Then, the rel chart is transformed to a graphical representation and the work centers are presented by nodes. Then the evaluation chart is created by converting the nodal representation to semi-scaled grid or blocks. For example, 100 square foot could equal to 1 block. The departments are placed within the grid and then the templates are arranged as a graphical representation. Changes can be made to minimize the waste space [10].

The typical clearance around machine can be calculated using the following formula:

$$5\times l + 4 \times w \tag{6.1}$$

Where, l and w represent the length and width of the machine.

For example, for a lathe machine with 8 m × 3 m ($l\times w$)

The required clearance is equal to $5\times 8 + 4 \times 3 = 52$ m^2

Thus the overall area is 2.2 times the machine area.

The aisle width ranges from 1 m for personnel to 3.6 m for a forklift and depends on the type of traffic or vehicles needed inside the facility [10].

An example of area needed for a small manufacturing plant is shown in Table 6.2. Each department is given a number to represent this department in the block chart.

TABLE 6.2

SPACE REQUIREMENTS FOR A SMALL MANUFACTURING PLANT [10]

Department	Area, m^2
(1) Production	446
(2) Warehouse	283
(3) Office	223
(4) Accounting	107
(5) Food service	70
(6) Maintenance	93
(7) Locker room	56
(8) Shipping and receiving	177

As shown in Figure 6.1, the grid representations, the production area requires 446 m^2 which can be represented by 12 blocks (each block area equals 6.08 m× 6.08 m). The office area is represented by 6 blocks, with an area of 223 m^2. The total area of the plant is represented by 40 blocks which equal to 1,486.5 m^2.

8	8	2	2	2
8	8	2	2	2
3	8	2	2	4
3	1	1	1	4
3	1	1	1	4
3	1	1	1	6
3	1	1	1	6
3	5	5	7	7

Figure 6.1: Grid representation of a small plant [10]

The computer layout design (COMLANDII) is an interactive tool for plant layout design [10]. The user can determine the number of departments, number of products, and relationships between departments. The square matrix is setup based on the number of departments and the program rejects any invalid values. The nodal diagram is used as a guide and the block diagram is created by the program. The user can make changes and evaluate alternative arrangements. Computerized layout algorithms are classified based on the way the final layout is generated using construct algorithms and improvement algorithms. The constructive algorithms are involved in successive selection and placement of departments until the final layout design is completed. The improvement type requires complete existing layout then the departments can be interchanged to improve the layout [5].

There are many construction algorithms tools that can be used in plant layout such as, CORELAP (computerized Relationship Layout Planning), ALDEP (Automated Layout Design Program), RAM Comp, and PLANET. CRAFT (computerized Relative Allocation of Facilities Techniques) is an improvement algorithm which can be used to improve an existing layout design [5].

The most recent plant layout software is CATIA Plant Layout 1which enables optimization of the plant layout design. This software deals with spatial organization and plant components. The CATIA Plant Layout 1 enables design changes using a set of modifications tools [3]. There are many plant layout software programs which can be used in layout designs such as, PLANTWIZE, CADWORKS, FACTORYCAD, and many others [2].

Diaz, et. al. [4] conducted a life-cycle energy consumption analysis of two machines “Bridgeport mill” and “Mori Seiki Dura Vertical 5060” and analyzed the effect of the facility characteristics on the energy consumption for both machines. The life cycle analysis included the manufacturing phase of machines, transportation, use phase in different environments, and end of life.

The major findings of this study were that the effects of HVAC and lighting could be minimized when machines are more closely packed together. Fitting more machines onto the same floor space lowers the nonprocess energy consumption. For example, the lighting energy consumption for Bridgeport machine in a small shop was equal to 1,100 MJ /yr (5 W/m^2). While it is equal to 2,400 MJ/yr. for the same machine in another facility with larger area, Table 6.3.

TABLE 6.3

MACHINE FOOTPRINT AND ANNUAL NONPROCESS ENERGY CONSUMPTION [4]

	Community shop, area 149 m^2		Job Shop, area 232 m^2		Commercial Facility, area 69,677 m^2	
	Bridgeport	Mori Seki	Bridgeport	Mori Seki	Bridgeport	Mori Seki
Machine Workspace area (m^2)	7	7.5	7	7.5	7	7.5
HVAC, MJ/yr. machine (W/m^2)	3,200 (14)	7,600 (32)	2,900 (13)	6,900 (29)	5,200 (24)	13,000 (55)
Lighting MJ/yr. machine, (W/m^2)	11,00 (5)	2,600 (11)	1,000 (4.5)	2,500 (10.6)	2,400 (10.9)	5,800 (24)

The goal of this research is to measure in actual manufacturing plants the relationship of machines (the product manufacturing processes) and the adjacent area. Together these comprise the plant area assigned to a machine or sequence for machines. This is a critical body of information needed to estimate product (from one or a sequence of machines) nonprocess energy as energy intensity (W/m^2) times process area.

6.3 Methodology

To understand and investigate the relationship between the manufacturing process (machines converting materials or workpieces into products) area and the nonprocess energy for an industrial facility, the following information was collected:

1) Buildings physical information which includes:

   a) Blue prints

   b) Plant layout

   c) Plant area

   d) Machine configuration

2) Building energy information which includes:

d) Utility bills

e) Operating hours

3) Information on nonprocess energy for each building which includes :

e) Lighting

f) Heating

g) Cooling

h) Ventilation

The nonprocess energy information for each building was used to estimate the energy consumption for each nonprocess energy type used. The nonprocess power intensity (W/m^2) for each building was estimated also. The space usage was grouped into seven categories which are:

a) Category A: space used directly by machines

b) Category B: space used around the machine

c) Category C: space used for raw material and finished product

d) Category D: space used for workstation (controlling all machines)

e) Category E: space used for aisles

f) Category F: space for offices and break area

g) Category G: unused space due to larger building than necessary for current production

The percentage of each space type to machine area (A) category was calculated after extracting type I space which considered not a part of the building where it is not used. This allows the calculation of area ratios as a potential tool to scale machine area or footprint into that of the manufacturing plant necessary for that machine**.**

6.4 Results

Case Study 1

This facility produces aerospace parts. The process and nonprocess energy data for this facility were collected. The total area of the facility was 5,992 m^2. The data were collected while the facility was running three shifts a day. This building consists of two sections which are: 1) south (2,317 m^2), Figure 6.2 and, 2) north. (3,675 m^2).

Figure 6.2. South area layout.

The facility uses six types of machines (labeled as area A). To analyze the facility machines layout and to compare the space usage for machines and the space usage for other services, the dimensions of each machine were measured and the space usage for other services were also measured for this facility, Table 6.4.

TABLE 6.4

SPACE REQUIREMENT FOR EACH MACHINE IN THE BUILDING

Machine type	# of machines	Individual Machine area, m^2 (A)	Total area, m^2 (A)	Service area around individual machine, m^2 (B)	Total service area, m^2 (B)	Machine & service area m^2	Percentage of A and B area to A area
DMF-3001	3	59	178	104	312	491	276%
DMF-330	6	36	217	117	702	920	424%
DMV-4020	10	30	302	71	706	1,008	334%
PUMA-2500LT	1	28	28	33	33	60	214%
PUMA-2000Y	1	22	22	31	31	53	241%
MORI-SL254	2	21	42	39	78	120	286%
Toyoda	3	20	60	93	279	339	565%
FRONTIER-L	2	19	37	28	56	93	251%
Chip processing machine	1	17	17	28	28	45	265%
FADAL	3	4	11	12	36	47	427%
Total			914		2,260	3,175	347%

The seven area categories were developed in this research to categorize the type of space usage. For example, space which used directly by machine is category A space type. Space type B represents space around the machine which is used by operators, maintenance purposes, and machine setup. All space types which are used for raw materials and finished products are categorized as category C space. As shown in Table 6.5. Category C is subdivided into two space types. The first type is used for storing raw materials and parts such as racks and shelves. The second category C space type is space used for heavy metal sheets and finished raw materials on the floor. Space D represents space used for work completion and maintenance that is where parts are taken for work completion, quality control area where products are inspected for quality and maintenance area where some tools necessary for machining and maintenance purposes are stored. Space E represents the space used for aisles. Category F space represents service space such as offices and break rooms. Unused space is considered as category G space.

To compare the space used by machines with the total facility space Table 6.5 was prepared. The machines area usage, which includes machines area and area around machines, was 3,175 m^2; this area represents around 53 % of the total building area. The area usage for category c was 411 m^2. Category D area was 827 m^2. The area usage for aisles and walkways was 867 m^2 and consist of 14% of the facility area. Category F, the office and service areas occupy around 3% of the total area. Category I (unused space) space area for this facility was 507 m^2.

TABLE 6.5

SPACE USAGE FOR THE BUILDING

Description	Total area m^2	Percentage to total area	Space category	Space category/A	Ratio of cumulative space category ,B to I) to machine area (A)
Machines	915	0.15	A	100%	100%
Space around the machine	2260	0.38	B	247%	247%
Shelves & storage	411	0.07	C	45%	292%
Workstations, maintenance areas	827	0.14	D	90%	382%
Aisles	867	0.14	E	95%	477%
Offices & break room	207	0.03	F	23%	500%
Unused space	507	0.08	G	55%	555%

The ratio of each space category to space A category was graphed in Figure 6.3. These ratios ranged from office space to machines space ratio 23 % to the ratio of space around machines to machines area with a value of 247%.

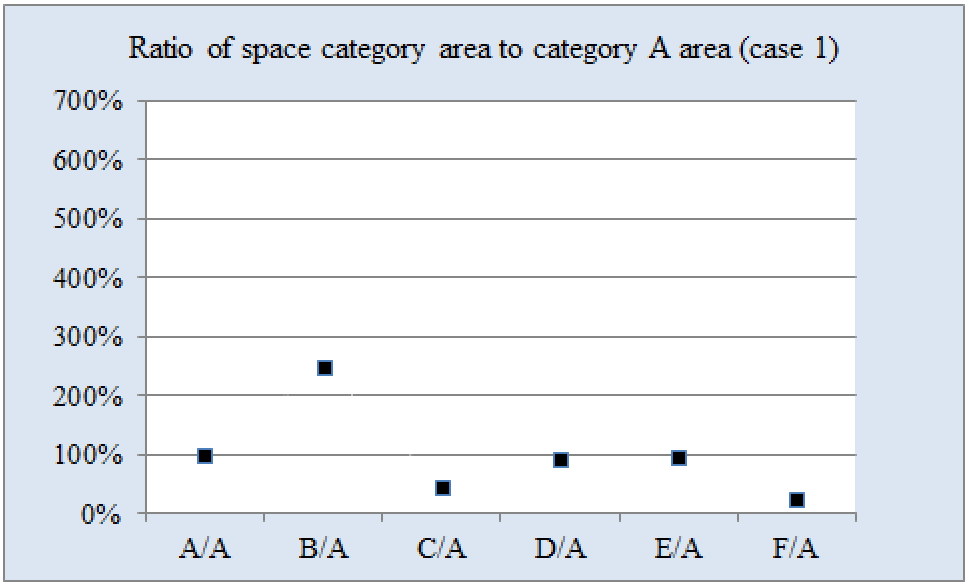

Figure 6.3. Ratio of each space category to category A space.

Figure 6.4 shows the accumulative ratio of space categories (from B to F) to A space category. The ratio of cumulative space category (B+C+D+E+F) which represents the total facility area expect machines area was equal to 500% of category A area.

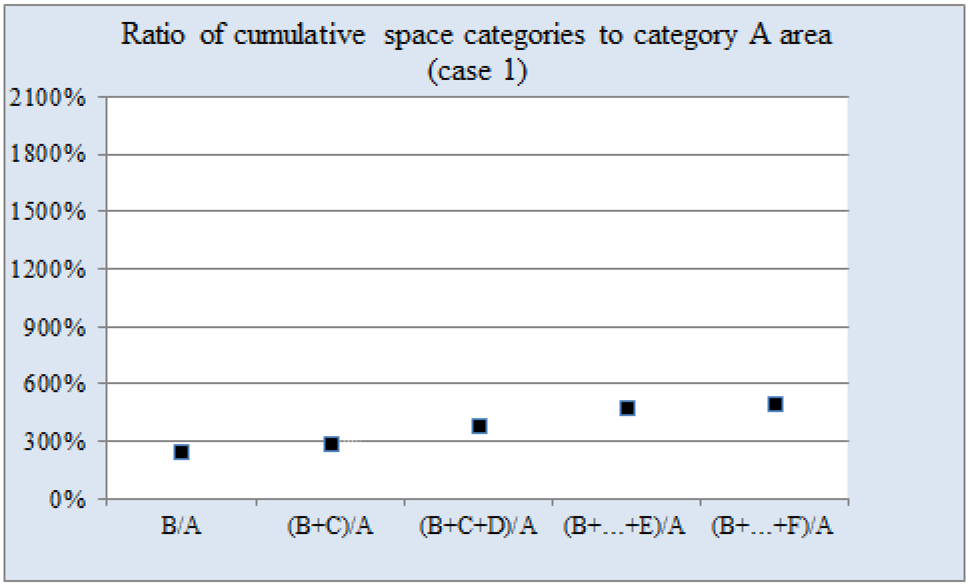

Figure 6.4. Ratio of cumulative space category to category A space.

Analysis was then used to scale these plant areas to the individual machines, Table 6.6. Space category A and B differ from machine to machine, and so category A and B space types were estimated for each machine separately. For other space categories in which the same space is used by all machines the total space was divided by the total number of machines in the facility. For example, category D space for each machine was calculated as follows:

Total space for category D = 827 m^2

Total number of machines in the facility = 32

Category D space required for each machine = 827 $m^2 \div 32 = 26$ m^2

The same methodology was used to estimate the space requirement for categories C, E, and F for each machine.

The total number of machines in this facility is equal to 32. The number of machines by type ranges from 10 DMV- 4020 CNC machines to one PUMA-2000Y machine. In this facility, machines occupy 915 m^2 as category A space type. However, the space around machines occupies most of the facility space with 2,260 m^2. For category A space, DMF-3001 CNC machines occupy around 59 m^2, the highest area among all machines in this facility. Fadal Machine occupies 4 m^2 as category A space which is the lowest among all machines in the facility.

TABLE 6.6

MACHINES SPACE USAGE BY CATEGORY

Building total area 5,991 m^2		Ratio of space category area to machine area					Ratio of total area for each machine/machine area (A)
Machine type	A, m^2	B/A, (B area, m^2)	C/A, (C= 13 m^2)	D/A, (D= 26 m^2)	E/A, (E= 27 m^2)	F/A, (F= 6 m^2)	
DMF-3001	59	176% (104)	22%	44%	46%	10%	298%
DMF-330	36	325% (117)	36%	72%	75%	17%	497%
DMV-4020	30	237% (71)	43%	87%	90%	20%	434%
PUMA-2500LT	28	118% (33)	46%	93%	96%	21%	325%
PUMA-2000Y	22	141% (31)	59%	118%	123%	27%	394%
MORI-SL254	21	186% (39)	62%	124%	129%	29%	450%
Toyoda	20	465% (93)	65%	130%	135%	30%	739%
FRONTIER-L	19	147% (28)	68%	137%	142%	32%	433%
Chip processing machine	17	165% (28)	76%	153%	159%	35%	479%
FADAL	4	300% (12)	325%	650%	675%	150%	1494%

The ratio of each space category to space A category for each machine type was graphed in Figure 6.5. These ratios increase when category A space decreases. For example, category A area for Fadal machine is the lowest among all machines and has the highest ratio between space categories and A space category. DMF machine has the highest space A category with the lowest ratio of space category with A space.

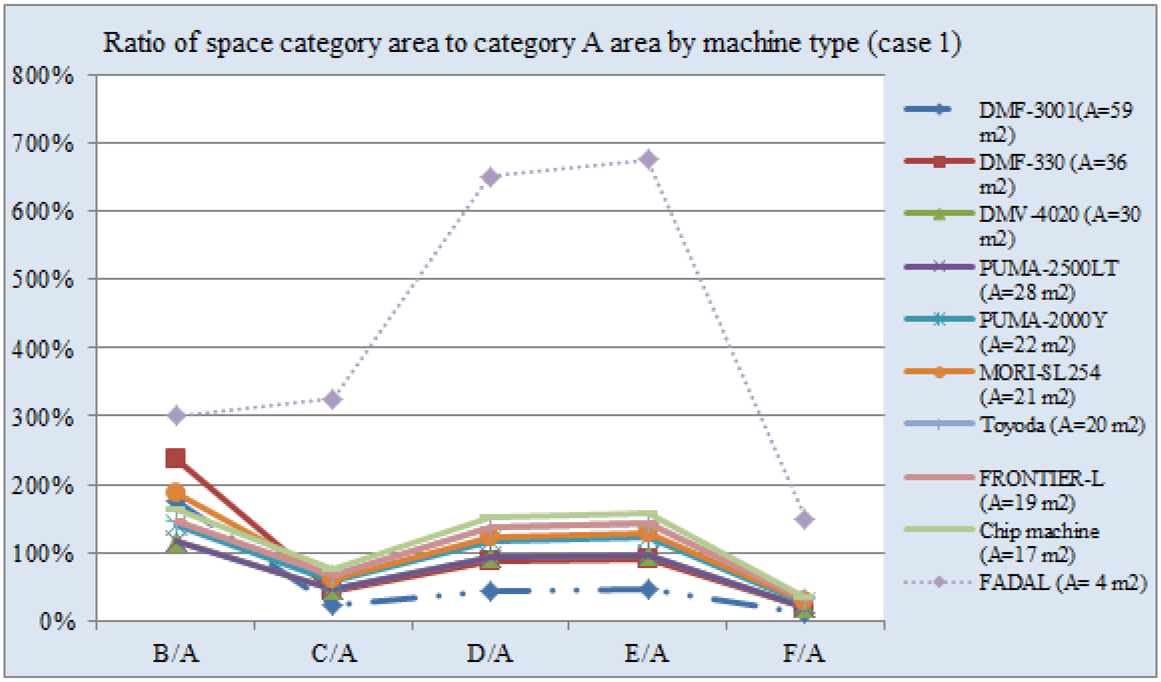

Figure 6.5. Space category to space A ratio by machine type.

The cumulative space category area to category A area was calculated for each space category, Table 6.7. The cumulative space ratio to category A space ranged from 325 % for B/A ratio for DMF-3001 which has the Highest space A value among other machines to 2500 % for FADAL machine which has the lowest space category value among all machines.

TABLE 6.7

RATIO OF CUMULATIVE SPACE CATEGORY TO CATEGORY A SPACE BY MACHINE TYPE

Machine type	B/A	(B+C)/A	(B+C+D)/A	(B+…+E)/A	(B+…+F)/A
DMF-3001	176%	198%	242%	288%	298%
DMF-330	325%	361%	433%	508%	525%
DMV-4020	237%	280%	367%	457%	477%
PUMA-2500LT	118%	164%	257%	354%	375%
PUMA-2000Y	141%	200%	318%	441%	468%
MORI-SL254	186%	248%	371%	500%	529%
Toyoda	465%	530%	660%	795%	825%
FRONTIER	147%	216%	353%	495%	526%
Chip processing machine	165%	241%	394%	553%	588%
FADAL	300%	625%	1275%	1950%	2100%

Figure 6.6 shows the ratio of cumulative of space categories (from B to I) to category A space for each machine type. The ratio of cumulative space category (B+C+D+E+F) which represents the total related area of each machine type ranged from 298 % for DMF-300 to 2100% for FADAL machine.

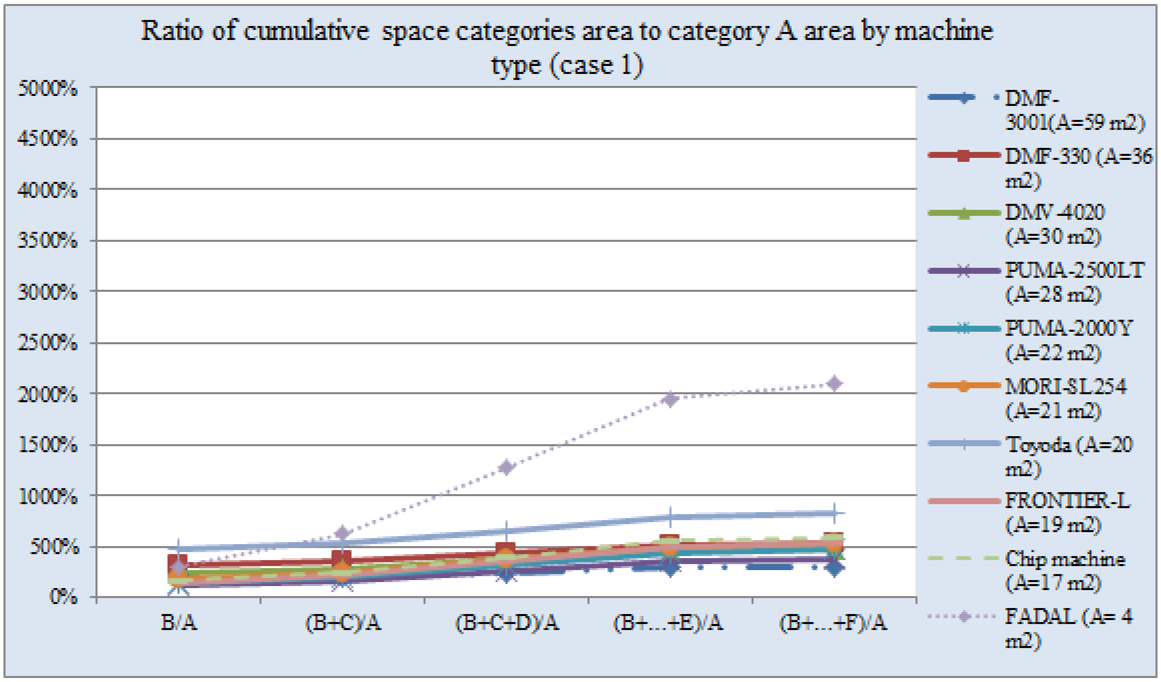

Figure 6.6. Space category to space A ratio by machine type.

The nonprocess power intensity for each energy type use was estimated for this building. The energy consumption for heating and cooling was estimated by using direct estimation of heating and cooling loads during the year. The ventilation energy is included with the heating and cooling energy in this facility. The power intensity and annual energy consumption for this building are summarized in Table 6.8 [1].

TABLE 6.8

NONPROCESS POWER INTENSITIES

Energy type use	Annual energy, kWh	Power intensity, Watts/m^2
Lighting	601,909	11.47
Cooling	350,892	6.67
Heating	578,984	11
Total nonprocess	1,531,785	29.20

The total area for each space was estimated. Then the percentage of each space type to total machines area was calculated. The related nonprocess energy for each space type was calculated, Table 6.9. The nonprocess power ranged from category B (15 kW) to category F (2.76 kW). The nonprocess energy consumption increases when the facility space increases in other words the facility area decide the nonprocess energy consumption not the process operations inside the facility. Placing more machines onto floor space lowers the nonprocess area which leads to nonprocess energy consumption.

TABLE 6.9

PERCENTAGE OF EACH SPACE TYPE AREA TO MACHINES AREA AND RELATED POWER

Space category	% area to machines area	Total related lighting power, kW	Total related heating power, kW	Total related cooling power, kW
A	100%	10.49	10.09	6.12
B	247%	25.92	24.93	15.11
C	45%	4.74	4.56	2.76
D	90%	9.48	9.12	5.53
E	95%	9.94	9.56	5.80
F	23%	2.37	2.28	1.38

Case Study 2

This facility produces aerospace parts. The process and nonprocess energy data for this facility were collected. The building consists of one section where two MAG-3 CNC machines are used in this building. The area of this building was 4,182 m^2.

To analyze the facility machines layout and to compare the space usage for machines and the space usage for other services, the dimensions of the MAG-3 machine was estimated and the space usage for other services was estimated for this building, Table 6.10.

TABLE 6.10

MAG-3 MACHINES SPACES REQUIREMENTS

Machine type	MAG-3 CNC
# of machines	2
Individual Machine area, m^2 (A)	98
Total area, m^2 (A)	195
Service area around individual machine, m^2 (B)	158
Total service area, m^2 (B)	316
Machine & service area m^2	511
Percentage of A and B area to A area	181%

The machines area usage, which includes machines area and area around machines, represents around 20 % of the total building area. The area usage for category c was 242 m^2. Category D area was 943 m^2. The area usage for aisles and walkways was 492 m^2 and consist of 12% of the facility area. Offices and service areas (Category F) occupy around 4% of the total area. Category G (unused space) space area for this facility was 1,491 m^2, Table 6.11.

TABLE 6.11

BUILDING SPACE USAGE

Description	Total area, m^2	Fraction to total area	Space category	Space category/ A	Ratio of cumulative space category ,B to I) to machine area (A)
Machines	445	0.11	A	100%	100%
Space around machines	390	0.09	B	88%	88%
Material and stocking area	242	0.06	C	54%	142%
Workstations	943	0.23	D	212%	354%
Aisles	492	0.12	E	111%	464%
Offices and cafeteria	188	0.04	F	42%	507%

The ratio of each space category to space A category was graphed in Figure 6.7. These ratios ranged from 42 % for office space to the ratio of unused space to machines area with a value of 335%.

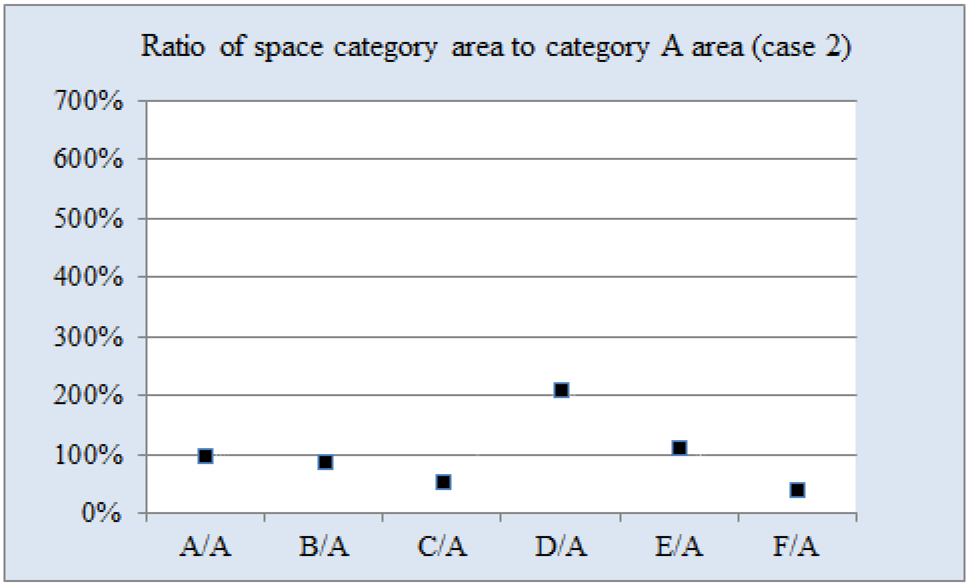

Figure 6.7. Ratio of each space category to category A space.

Figure 6.8 shows the accumulative ratio of space categories (from B to I) to category A space. The ratio of cumulative space category (B+C+D+E+F) which represents the total facility area expect machines area was equal to 507 % of category A area.

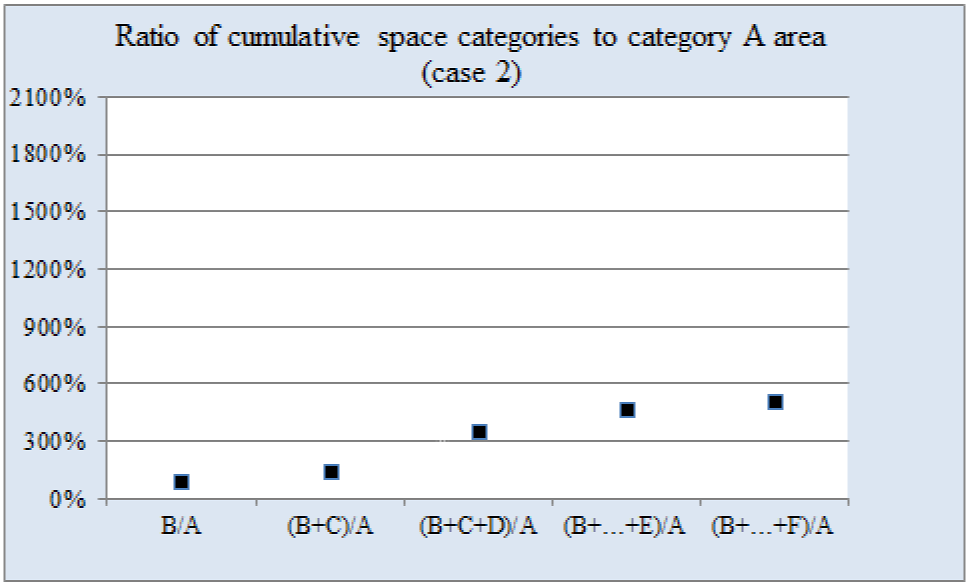

Figure 6.8: Ratio of cumulative space category to category A space.

The total number of machine in this facility is equal to 4. Approximately, 11% of the facility space is used by machines. In this facility, machines occupy 445 m^2 as category A space type. However, the space around machines occupies 390 m^2. The unused space for this facility is much higher than normal because only three machines are used inside the facility**.** The cumulative ratio of space category to category A space ranges from 1017% for the conveyer to 1605 % for chip processing machine, Table 6.12.

TABLE 6.12

MACHINES SPACE USAGE

Building total area 4,181 m^2 / Machine type		Ratio of space category area to machine area					Ratio of total area for each machine/machine area (A)
	A, m^2	B/A, (B area, m^2)	C/A ([B+C]/A) (C=236m^2)	D/A ([B+C]/A) (D=60 m^2)	E/A ([B+C+D]/A) (E=123m^2)	F/A ([B+..F]/A) (F=47m^2)	
Conveyer	204	98% (B=158)	116% (214%)	29% (216%)	60% (276%)	23% (299%)	299%
Mag-3	98	161% (B=220)	241% (402%)	61% (463%)	126% (589%)	48% (637%)	637%
Chip processing machine	46	122% (B=56)	421% (543%)	25% (568%)	205% (773%)	38% (811%)	811%

The ratio of each space category to space A category for each machine type was graphed in Figure 6.9. These ratios increase when category A space decreases. For example, category A area for the chip processing machine is the lowest among all machines and has the highest ratio between space categories and A space category.

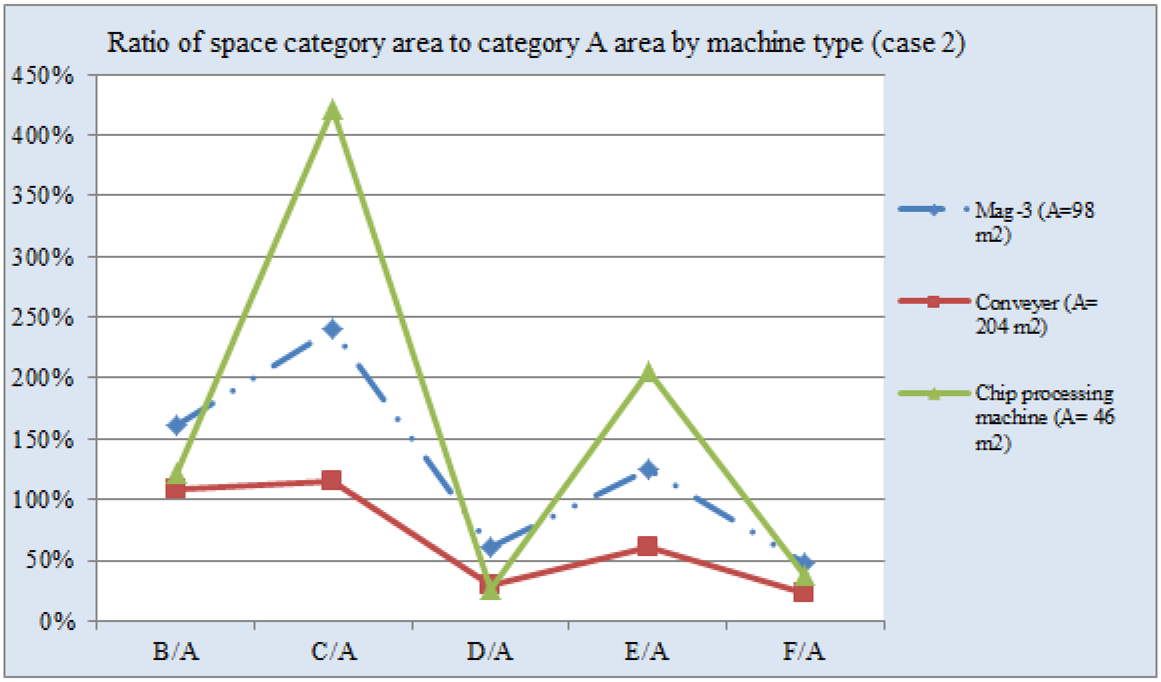

Figure 6.9. Space category to space A ratio by machine type.

Figure 6.10 shows the ratio of cumulative of space categories (from B to F) to category A space for each machine type. These ratios of cumulative ranged from 299 % for conveyer to 811 % for chip processing machine.

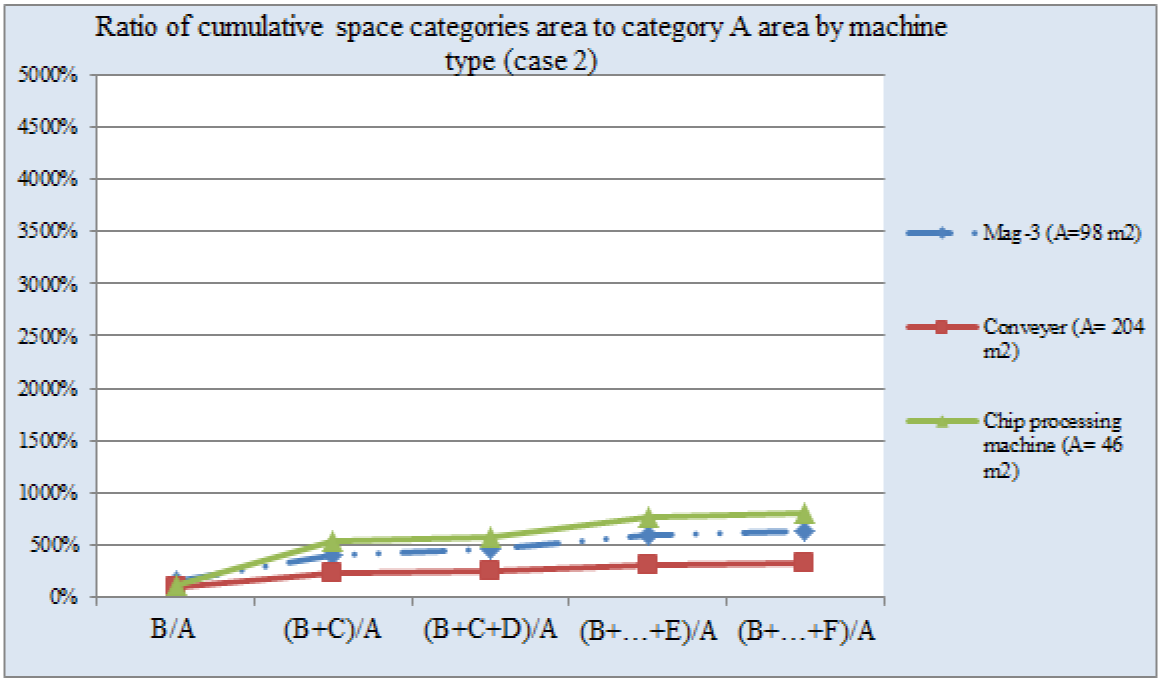

Figure 6.10. Space category to space A ratio by machine type.

The nonprocess power intensity for each energy type use was estimated for this building. The ventilation energy is included with the heating and cooling energy in this facility. The power intensity and annual energy consumption for this building are summarized in Table 6.13 [1].

TABLE 6.13

NONPROCESS POWER INTENSITIES

Energy type use	Annual energy, kWh	Power intensity, Watts/m^2
Lighting	425,911	11.63
Cooling	254,093	1.83
Heating	420,220	11.52
Total (nonprocess)	1,100,220	30

The total area for each space was measured. Then the percentage of each space type to total machines area was calculated. The related nonprocess energy for each space type was calculated, Table 6.14.

TABLE 14

PERCENTAGE OF EACH SPACE TYPE AREA TO MACHINES AREA AND RELATED POWER

Space category	% area to machines area	Total related lighting power, kW	Total related heating power, kW	Total related cooling power, kW
A	100%	5.18	5.13	3.12
B	88%	4.54	4.49	2.73
C	54%	2.81	2.78	1.69
D	211%	10.96	10.86	6.60
E	110%	5.72	5.67	3.45
F	42%	2.19	2.167	1.32

Case Study 3

The facility is a press shop which produces different metal products. The process and nonprocess energy data for this facility were collected. The total area for this press shop is equal to 4,182 m^2. The press shop uses four types of machines. There are eight Verson press machines in the press shop. Each Verson machines uses two containers one for finished parts and one for scrap materials.

To analyze the press machines layout and to compare the space usage for machines and the space usage for other services, the dimensions of each machine were measured and the space usage for other services was measured also. Number of each machines type, space requirement for each machine in this building were measured and summarized in Table 6.15.

TABLE 15

SPACE REQUIREMENT FOR EACH MACHINE

Type	Individual machine area, m^2	# machi nes	Total machi nes' area m^2	Service area around individual machine, m^2	Total space around machines, m^2	Machine s & space area, m^2	Percentag e of A and B area to A area
South land press machine	18.6	2	37.2	37.2	74.3	111.5	300%
Verson press machine (model 16908)	7.4	8	59.5	26	208.1	267.6	450%
Drilling machine	7.3	2	14.6	15	30	44.6	305%
Verson press machine (med)	3.7	6	22.3	13	78	100.3	450%
Verson press machine (small size)	3	14	41.6	11.1	156.1	197.7	475%
Drilling machine	1.9	6	11.1	1.9	11.1	22.3	201%
Total						744	

As shown in Table 6.16, the machines area usage was equal 186.3 m^2, and fraction of this area equals around 4 % of the total area. The area usage for aisles and walkways consist of 28% of the facility area. The office and service areas occupy around 3% of the total area. Raw materials and finished goods space occupy around 15% of the total building area.

TABLE 6.16

SPACE USAGE BY CATEGORY FOR THE PRESS SHOP

Description	Total area m^2	Fraction to total area	Space category	Space category /A	Ratio of cumulative space category ,B to I) to machine area (A)
Machines	186.3	0.04	A	100%	100%
Space around the machine	557.6	0.13	B	299%	299%
Raw materials and finished products	643	0.15	C	345%	644%
Work station and maintenance	764	0.18	D	410%	1054%
Aisles	1,171	0.28	E	628%	1682%
Offices and cafeteria	534	0.13	F	287%	1969%
Unused space	325	0.08	G	175%	2144%

The ratio of each space category to space A category was graphed in Figure 6.11. These ratios ranged from 175 % for offices to the ratio of aisles to machines area with a value of 628%.

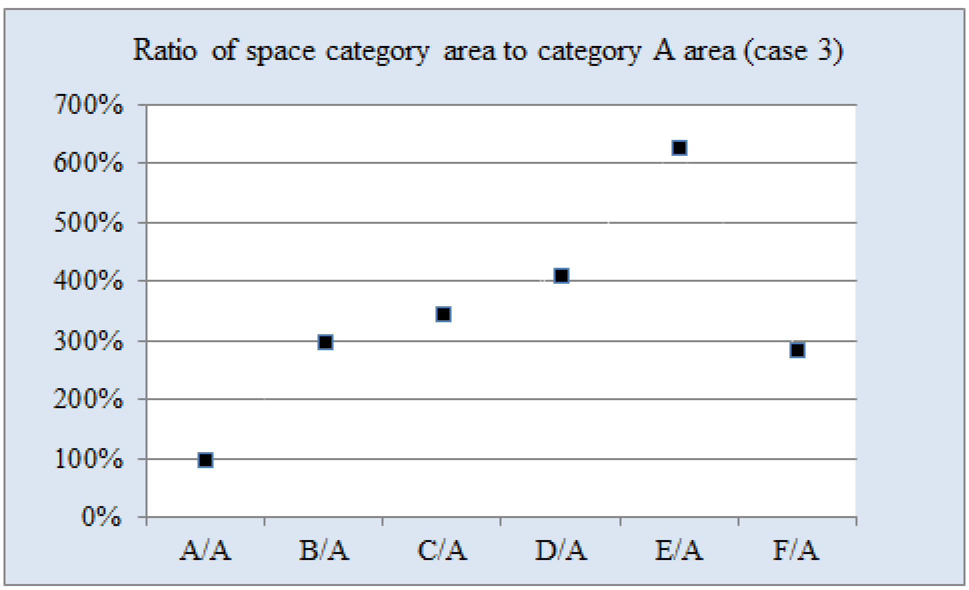

Figure 6.11. Ratio of each space category to category A space.

Figure 6.12 shows the accumulative ratio of space categories (from B to F) to A space category. The cumulative ratio of non-machine to machine area uses for this facility is equal to 1969%.

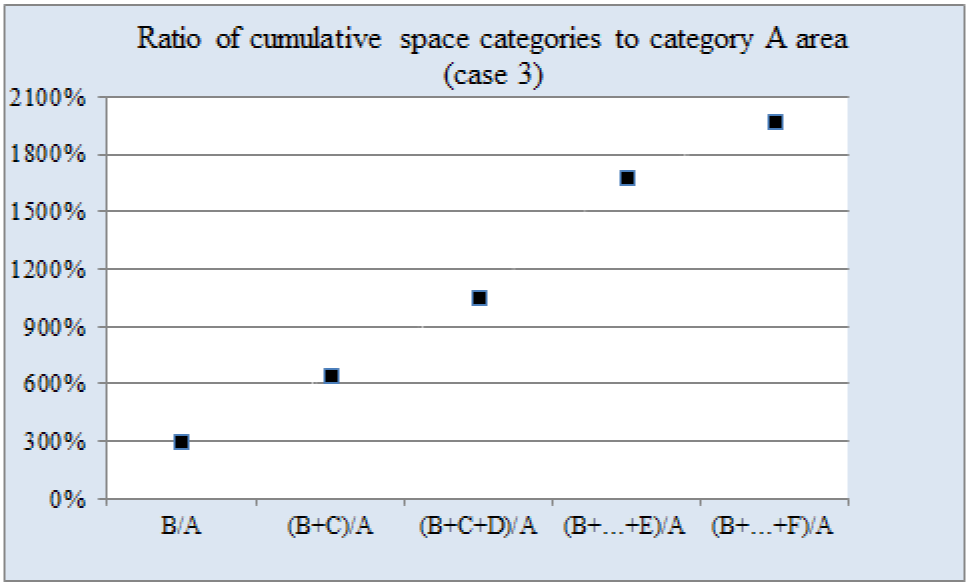

Figure 6.12. Ratio of cumulative space category to category A space.

Table 6.17 shows the space distribution for the press shop; the space required around each machine was estimated. The space usage for each machine by category ranges from 1.9 m^2 for category A space to 30.8 m^2 for category B space for Southland press machine.

TABLE 6.17

MACHINES SPACE USAGE BY CATEGORY

Press Sop : total area 4,180 m^2		Ratio of space category area to machine area						Ratio of total area for each machine/machine area (A)
Machine type	# of machines	A, m^2	B/A, (B area, m^2)	C/A,(C =16.9 m^2)	D/A ,(D=20.1 m^2)	E/A ,(E=30.8 m^2)	F/A ,(F=14 m^2)	
South land press machine	2	18.6	200% (B= 37.2)	91%	108%	166%	75%	640%
Verson press machine	8	7.4	351% (B=26)	228%	272%	416%	189%	1457%
Drilling machine	2	7.3	200% (B=14.6)	232%	275%	422%	192%	1321%
Verson press machine small size	6	3.7	351% (B=13)	457%	543%	832%	378%	2562%
Verson press machine med size	14	3	370% (B=11.1)	563%	670%	1027%	467%	3097%
Drilling machine	6	1.9	105% (B=2)	889%	1058%	1621%	737%	4411%
Total	38							

The ratio of each space category to space A category for each machine type was graphed in Figure 6.13. These ratios increase when category A space decreases. Category A area for the southland press machine the highest among all machines and has the lowest ratio between space categories and A space category.

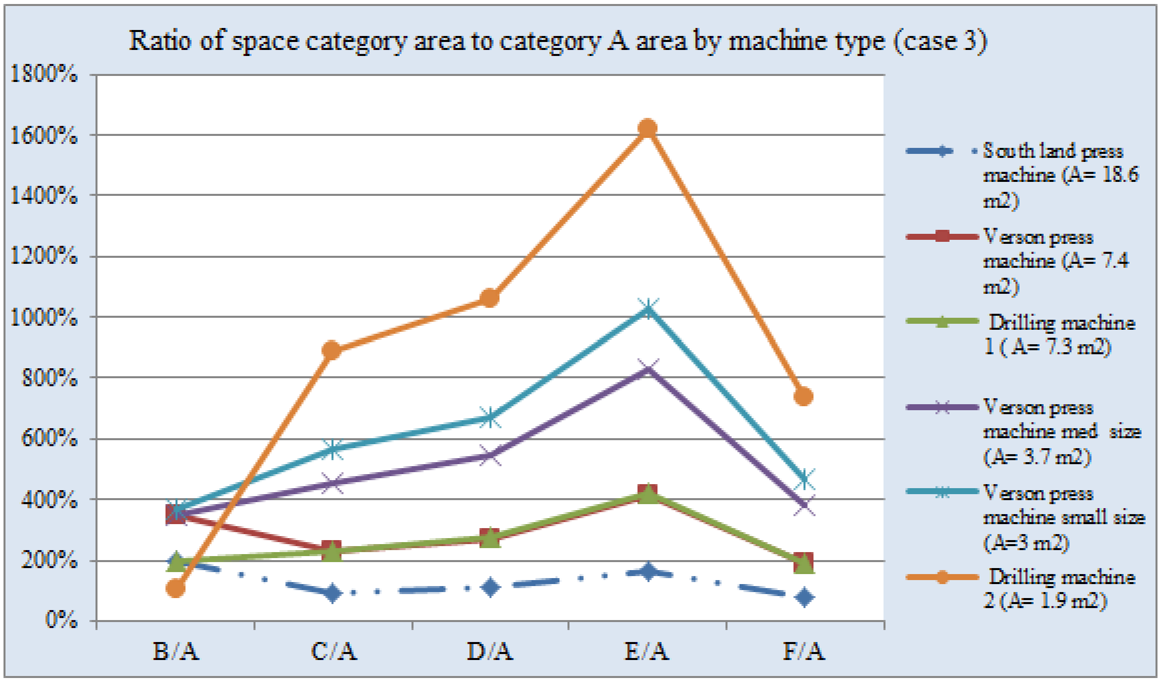

Figure 6.13. Space category to space A ratio by machine type.

The cumulative space category area to category A area was calculated for each space category, Table 6.18. The cumulative space ratio to category A space ranged from 640 % for southland press machine to 4411 % for drilling machine.

TABLE 6.18

RATIO OF CUMULATIVE SPACE CATEGORY TO CATEGORY A SPACE BY MACHINE TYPE

Machine type	B/A	(B+C)/A	(B+C+D)/A	(B+…+E)/A	(B+…+F)/A
South land press machine	200%	291%	399%	565%	640%
Verson press machine	351%	580%	851%	1268%	1457%
Drilling machine	200%	432%	707%	1129%	1321%
Verson press machine small size	351%	808%	1351%	2184%	2562%
Verson press machine med size	370%	933%	1603%	2630%	3097%
Drilling machine	105%	995%	2053%	3674%	4411%

Figure 6.14 shows the ratio of cumulative of space categories (from B to F) to category A space for each machine type. The ratio of cumulative space category to category A space ranged from 640 % for southland press machine to 4411 % for drilling machine.

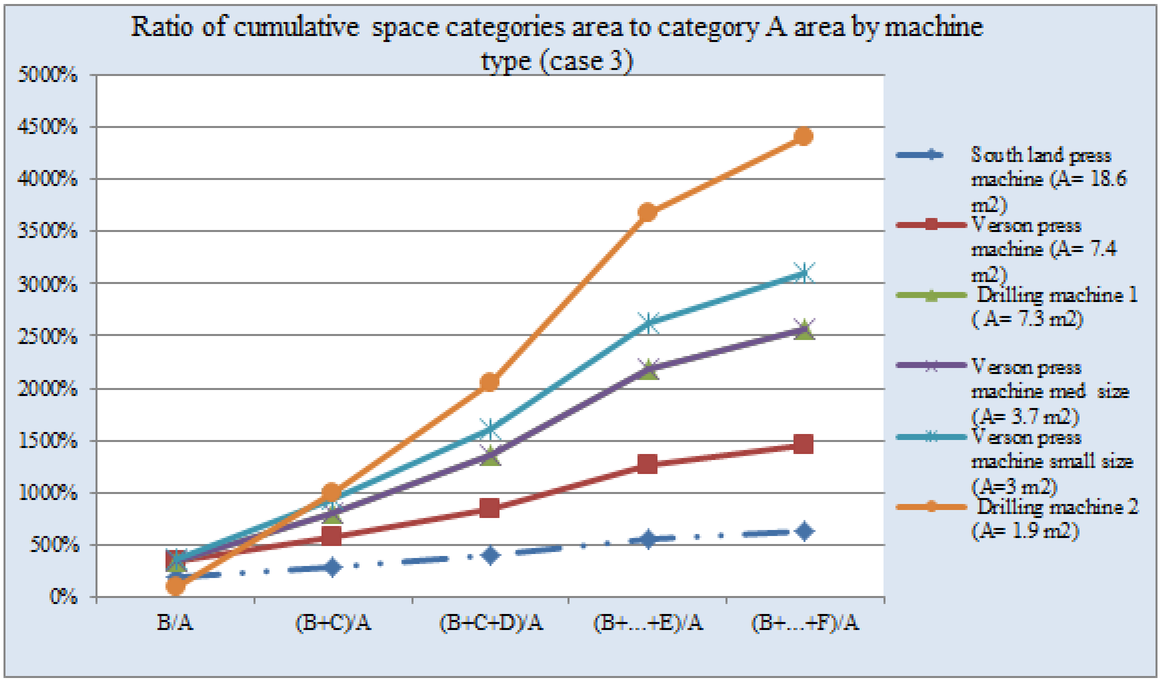

Figure 6.14. Space category to space A ratio by machine type.

The nonprocess power intensity for each energy type use was estimated for this building. The power intensity and annual energy consumption for this building are summarized in Table 6.19 [1].

TABLE 6.19

NONPROCESS POWER INTENSITIES

Energy type use	Annual energy, kWh	Power intensity, Watts/m^2
Lighting	274,800	11.6
Cooling	58,725	1.9
Heating	543,437	14.8
Ventilation	32,412	0.88
Total (nonprocess)	909,374	24.8

The total area for each space was measured. Then the percentage of each space type to total machines area was calculated. The related nonprocess energy for each space type was calculated, Table 6.20.

TABLE 6.20

PERCENTAGE OF EACH SPACE TYPE AREA TO MACHINES AREA AND RELATED POWER

Space category	% area to machines area	Total related lighting power, kW	Total related heating power, kW	Total related cooling power, kW	Total related ventilation power, kW
A	100%	2.16	2.75	0.35	0.16
B	288%	6.23	7.95	1.02	0.47
C	345%	7.46	9.51	1.22	0.57
D	410%	8.86	11.31	1.45	0.67
E	628%	13.58	17.33	2.22	1.03
F	287%	6.19	7.91	1.01	0.47

Case Study 4

The facility produces aerospace parts. The nonprocess energy data for this facility were collected. The total area of the facility was 5,501m^2. The data were collected while the facility was running three shifts a day. The facility consists of four sections which are:

1) Mag-3 area (2,724 m^2)

2) 3-Axis area (892 m^2)

3) Sheet metal & shipping area (975 m^2)

4) Offices (910 m^2)

The facility uses five types of machines. To analyze the facility machines layout and to compare the space usage for machines and the space usage for other services, the dimensions of each machine were measured and the space usage for other services was measured for this facility, Table 6.21.

TABLE 6.21

SPACE REQUIREMENT FOR EACH MACHINE

Machine type	# of machines	Individual Machine area, m^2 (A)	Total area m^2, (A)	Space around the machine, m^2 (B)	Total service area , m^2 (B)	Machine & service area, m^2	Percentage of A and B area to A area
DMC& Mori	3	14.5	43.6	83.6	250.8	294.4	300%
FADAL	10	13.9	139.4	46.5	464.5	603.9	433%
A88	3	11.1	33.4	29.7	89.2	122.6	367%
A99-Makino	1	46.5	46.5	120.8	120.8	167.2	360%
VMC	10	18.6	185.8	37.2	371.6	557.4	300%
Mag-3	2	83.6	167.2	148.6	297.3	464.5	278%
Drilling	4	3.7	14.9	5.2	20.8	35.7	240%
Autobahn	7	7.4	52.0	33.4	234.1	286.1	550%
Cutting machine	3	3.7	11.1	13.0	39.0	50.2	452%
Total			693.9		1,888	2,582	372%

The machines area usage, which includes machines area and area around machines, was equal to 7,469 m^2; this area occupies around 44 % of the total building area. The area usage for aisles and walkways consist of 13% of the facility area. The office and service areas occupy around 16% of the total area. raw materials area occupy around 14% of the total shop area. The fraction of the space used for each space type, space category ratio to category A area, and cumulative ratio are summarized in Table 6.22.

TABLE 6.22

SPACE USAGE BY CATEGORY

Description	Total area m^2	Fraction to total area	Space category	Space category/A	Ratio of cumulative space category ,B to I) to machine area (A)
Machines	694	0.12	A	100%	100%
Space around machines	1,888	0.32	B	272%	272%
Raw materials and finished products	836	0.14	C	120%	393%
Workstations	611	0.10	D	88%	481%
Aisles	744	0.13	E	107%	588%
Offices and cafeteria	910	0.16	F	131%	719%
Unused space	139	0.02	G	20%	739%

The ratio of each space category to space A category was graphed in Figure 6.15. These ratios ranged from 20 % for unused space to machines space to the ratio of space around machines to machines area with a value of 272%.

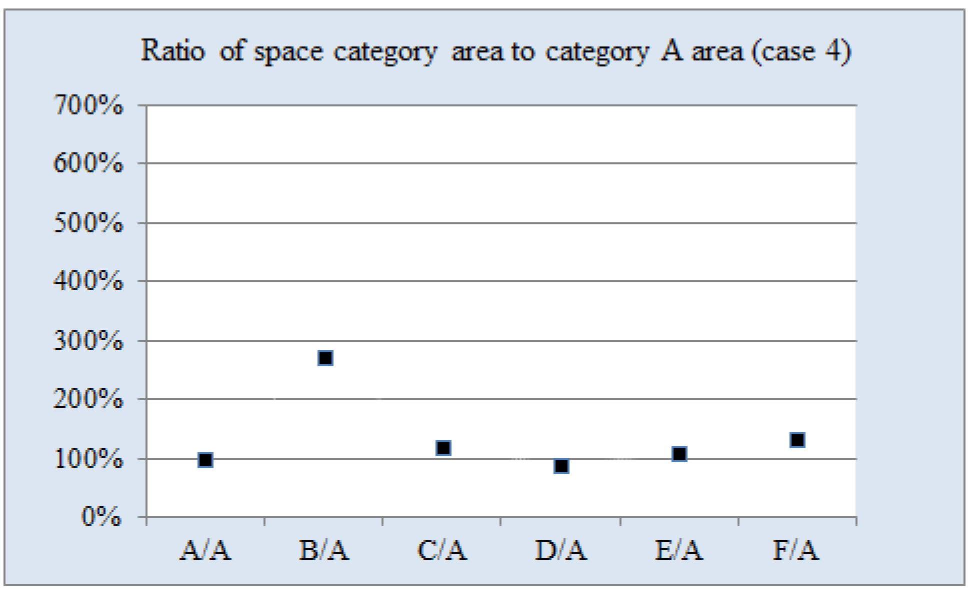

Figure 6.15. Ratio of each space category to category A space.

Figure 6.16 shows the accumulative ratio of space categories (from B to F) to A space category. The cumulative ratio of non-machine to machine area uses for this facility is equal to 719%.

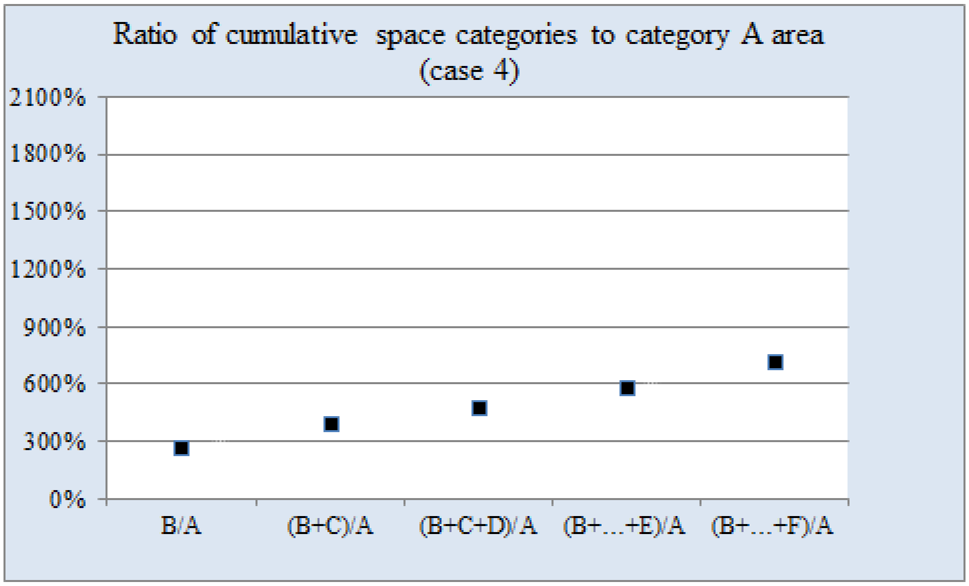

Figure 6.16. Ratio of cumulative space category to category A space.

The total number of machines in this facility is equal to 43. The number of machines by type ranges from 10 VMC- CNC machines to one A99-Makino machine, so around 10% of the facility space is used by VMC- CNC machines. In this facility, machines occupy 694 m^2 as category A space type. However, the space around machines occupies most of the facility space with 1,888 m^2. For category A space, Mag-3 CNC machines occupy around 83.6 m^2, the highest area among all machines in this facility. Small cutting and drilling machines occupy 3.7 m^2 for each. The space usage for each machine including all space category ranges from 3.7 m^2 for drilling machine to 83.6 m^2 for Mag-3 CNC machine, Table 6.23.

TABLE 6.23

MACHINES SPACE USAGE BY CATEGORY

Facility area 5,501 m^2			Ratio of space category area to machine area					Ratio of total area for each machine/machine area (A)
Machine type	# of machines	A, m^2	B/A, (B area, m^2)	C/A (C= 19.4 m^2)	D/A(D = 14.2 m^2)	E/A(E= 17.3 m^2)	F/A(F= 22.7 m^2)	
Mag-3	2	83.6	178% (B=148.6)	23%	17%	21%	27%	270%
A99-Makino	1	46.5	260% (B=120.8)	42%	31%	37%	49%	425%
VMC	10	18.6	200% (B=37.2)	104%	76%	93%	122%	613%
DMC& Mori	3	14.5	577% (B=83.6)	134%	98%	119%	157%	1107%
FADAL	10	13.9	335% (B=46.5)	140%	102%	124%	163%	888%
A88	3	11.1	268% (B=29.7)	175%	128%	156%	205%	960%
Autobahn	7	7.4	451% (B=33.4)	262%	192%	234%	307%	1491%
Drilling	4	3.7	141%(B= 5.2)	524%	384%	468%	614%	2219%
Cutting machine	3	3.7	351% (B=13)	524%	384%	468%	614%	2430%

The ratio of each space category to space A category for each machine type was graphed in Figure 6.17. Category A area for the Mag-3 machine is the highest among all machines and has the lowest ratio between space categories and A space category.

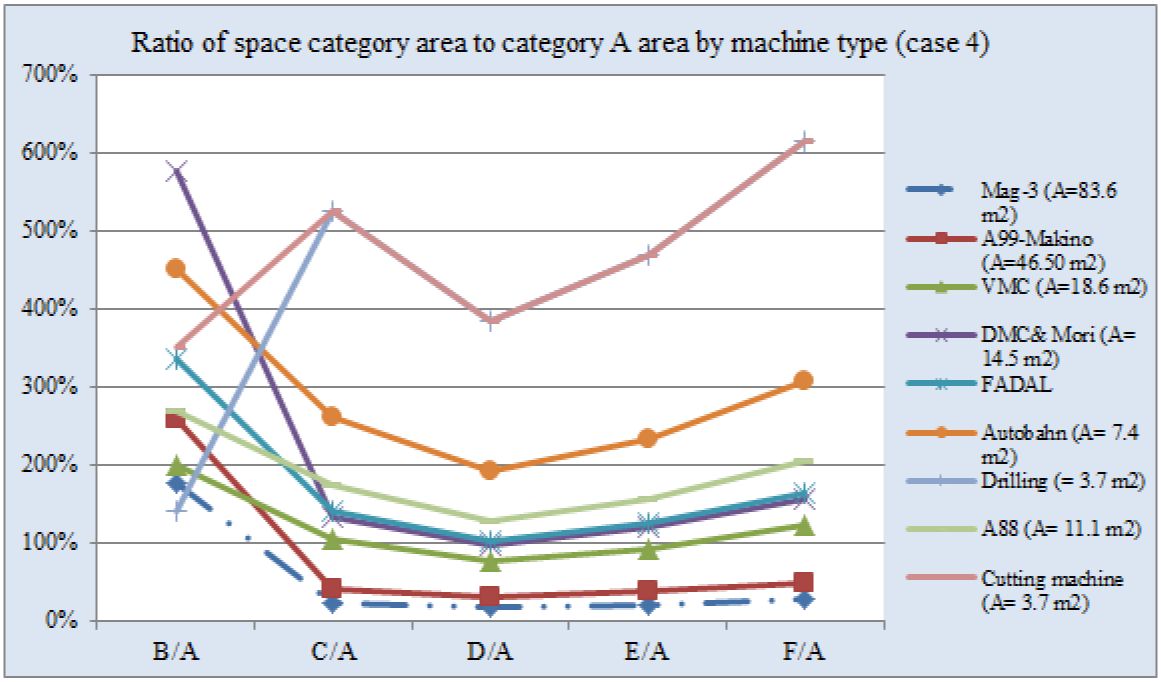

Figure 6.17. Space category to space A ratio by machine type.

The cumulative space category area to category A area was calculated for each space category, Table 6.24. The cumulative space to category A space ratio ranged from 270% for Mag-3 machine to 2430 % for the cutting machine.

TABLE 6.24

RATIO OF CUMULATIVE SPACE CATEGORY TO CATEGORY A SPACE BY MACHINE TYPE

Machine type	B/A	(B+C)/A	(B+C+D)/A	(B+…+E)/A	(B+…+F)/A
Mag-3	178%	201%	218%	239%	270%
A99-Makino	260%	302%	332%	369%	425%
VMC	200%	304%	381%	474%	613%
DMC& Mori	577%	710%	808%	928%	1107%
FADAL	335%	474%	576%	701%	888%
A88	268%	442%	570%	726%	960%
Autobahn	451%	714%	905%	1139%	1491%
Drilling	141%	665%	1049%	1516%	2219%
Cutting machine	351%	876%	1259%	1727%	2430%

Figure 6.18 shows the ratio of cumulative of space categories (from B to F) to category A space for each machine type. The ratio of cumulative space category to category A space ranged from 639 % for Mag-3 machine to 4959 % for cutting machine.

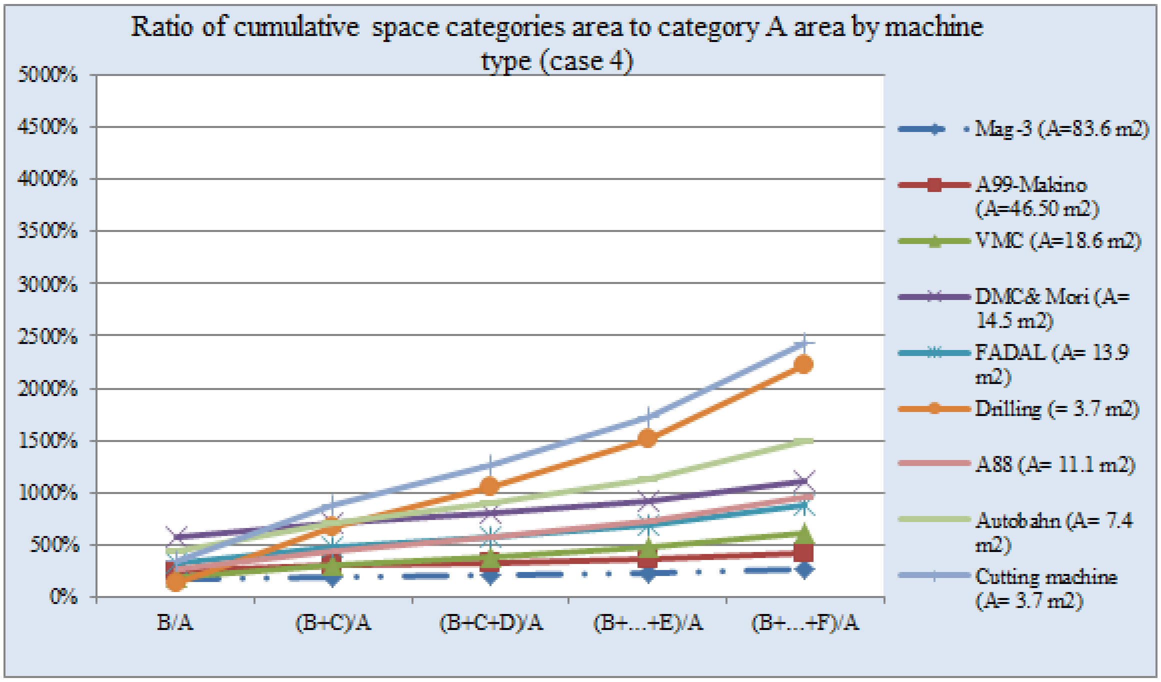

Figure 6.18. Space category to space A ratio by machine type.

The nonprocess power intensity for each energy type use was estimated for this building. The power intensity and annual energy consumption for this building are summarized in Table 6.25 [1].

TABLE 6.25

NONPROCESS POWER INTENSITIES

Energy type use	Total annual, kWh	Power intensity, W/m^2
Lighting	387,554	8.10
Cooling	295,126	6.10
Heating	538,794	11.20
Ventilation	28,912	0.60
Total nonprocess	1,250,386	25.90

The total area for each space was estimated. Then the percentage of each space type to total machines area was calculated. The related nonprocess energy for each space type was calculated, Table 6.26.

TABLE 6.26

PERCENTAGE OF EACH SPACE TYPE AREA TO MACHINES AREA AND RELATED POWER

Space category	% area to machines area	Total related lighting power, kW	Total related heating power, kW	Total related cooling power, kW	Total related ventilation power, kW
A	100%	5.60	7.77	4.25	0.45
B	272%	15.24	21.13	11.58	1.22
C	120%	6.75	9.36	5.13	0.54
D	88%	4.93	6.84	3.75	.40
E	107%	6.00	8.33	4.56	0.48
F	131%	7. 35	10.18	5.589	0.58

Case Study 5

The facility produces aerospace parts. The process and nonprocess energy data for this machine shop were collected. The area of the machine shop is equal to 218 m^2. There are two Harding CNC machines in the machine shop.

The machine shop uses 4 types of machines. To analyze the facility machines layout and to compare the space usage for machines and the space usage for other services, the dimensions of each machine were measured and the space usage for other services was also measured, Table 6.27.

TABLE 6.27

SPACE REQUIREMENT FOR EACH MACHINE IN THE MACHINE SHOP

Machine type	# of machines	Individual Machine area, m^2 (A)	Total area, m^2 (A)	Area around the machine, m^2 (B)	Total service area, m^2 (B)	Machine & service area, m^2	Percentage of A and B area to A area
Harding CNC	2	9.3	18.6	27.9	55.8	74.4	400%
Drilling	5	3.3	16.5	5.6	28	44.5	270%
Lathe	3	2.2	6.6	5.1	15.3	21.9	332%
Total	10		41.7	38.6	99.1	140.8	338%

As shown in Table 6.28, the machines area usage, which includes machines area and area around machines, was 141 m^2; this area occupies around 19 % of the total building area. The area usage for aisles and walkways consist of 17% of the facility area. The office and service areas occupy around 4% of the total area. Storage racks and raw materials occupy around 6% of the total shop area.

TABLE 6.28

SPACE USAGE BY CATEGORY FOR THE MACHINE SHOP

Description	Total area, m^2	Fraction to total area	Space category	Space category/ A	Ratio of cumulative space category ,B to I) to machine area (A)
Machines	41.7	0.19	A	100%	100%
Space around the machine	99.1	0.45	B	238%	238%
Raw materials and finished products	13.9	0.06	C	33%	271%
Workstations	7	0.03	D	17%	288%
Aisles	37	0.17	E	89%	376%
Offices and cafeteria	9.2	0.04	F	22%	399%
Unused area	11.1	0.05	G	27%	425%

The ratio of each space category to space A category was graphed in Figure 6.19. These ratios ranged from 17% for category F to 238% for category B space.

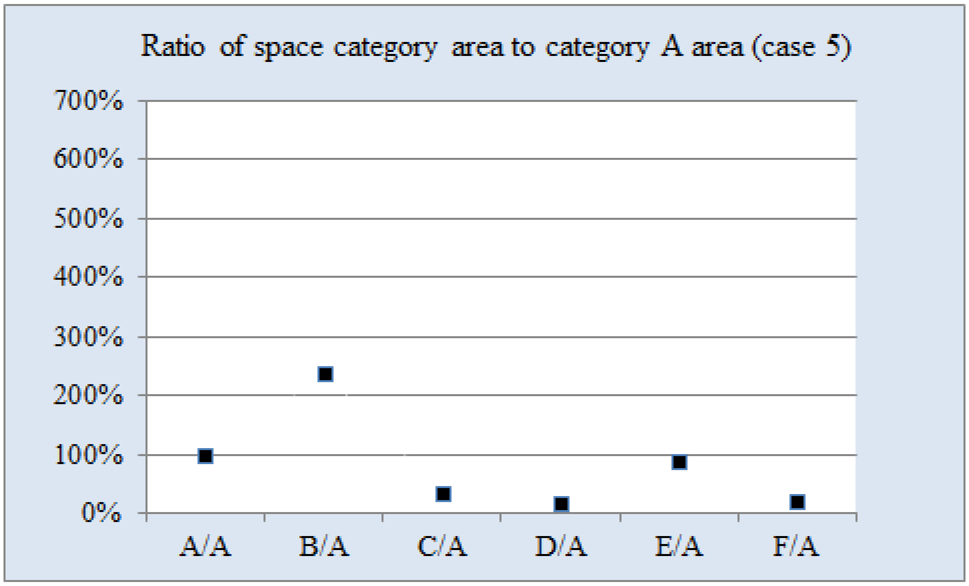

Figure 6.19. Ratio of each space category to category A space.

Figure 6.20 shows the accumulative ratio of space categories (from B to F) to A space category. The cumulative ratio of non-machine to machine area uses for this facility is equal to 399 %.

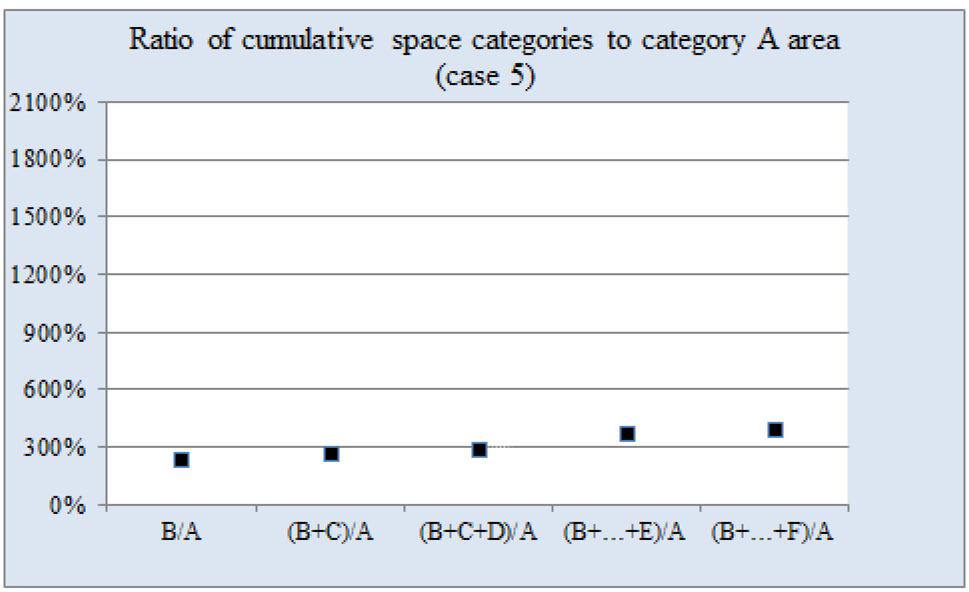

Figure 6.20. Ratio of cumulative space category to category A space.

The total number of machines in this shop is 10. Around 19% of the shop space is used as category A space. Harding CNC machines occupy 9.3 m^2 as category A space which is the highest among all machines in the facility. The space usage for each machine including all space category ranges from 0.7 m^2 for workstations to 27.9 m^2 for category B space for Harding CNC machine, Table 6.29.

TABLE 6.29

MACHINES SPACE USAGE BY CATEGORY

Machine shop total area 218 m^2			Ratio of space category area to machine area					Ratio of total area for each machine/machine area (A)
Machine type	# of machines	A, m^2	B/A, (B area, m^2)	C/A ([B+C]/A) (C= 1.4 m^2)	D/A ([B+C+D]/A) (D= 0.7 m^2)	E/A ([B+…+E]/A) (E= 3.7 m^2)	F/A ([B+...+F]/A) (F= 0.92 m^2)	
HARDING milling machine	2	9.3	300% (B= 27.9)	15% (315%)	8% (323%)	40% (362%)	10% (372%)	372%
Drilling machines	5	3.3	170% (B = 5.6)	42% (212%)	21% (233%)	112% (345%)	28% (373%)	373%
Lathe machines	3	2.2	232% (B= 5.1)	64% (296%)	32% (3286%)	168% (496%)	42% (537%)	537%
Total	10							

The ratio of each space category to space A category for each machine type was graphed in Figure 6.21.

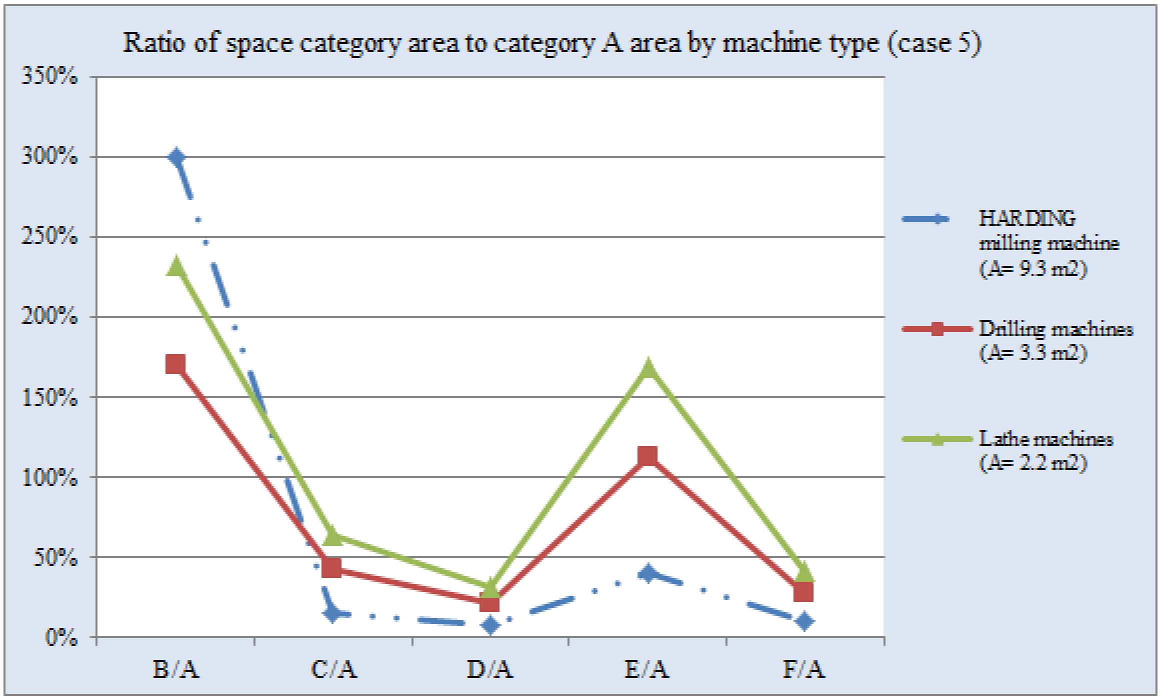

Figure 6.21. Space category to space A ratio by machine type.

Figure 6.22 shows the ratio of cumulative of space categories (from B to F) to category A space for each machine type. The ratio of cumulative space category to category A space ranged from 372 % for Harding machine to 537 % for lathe machine.

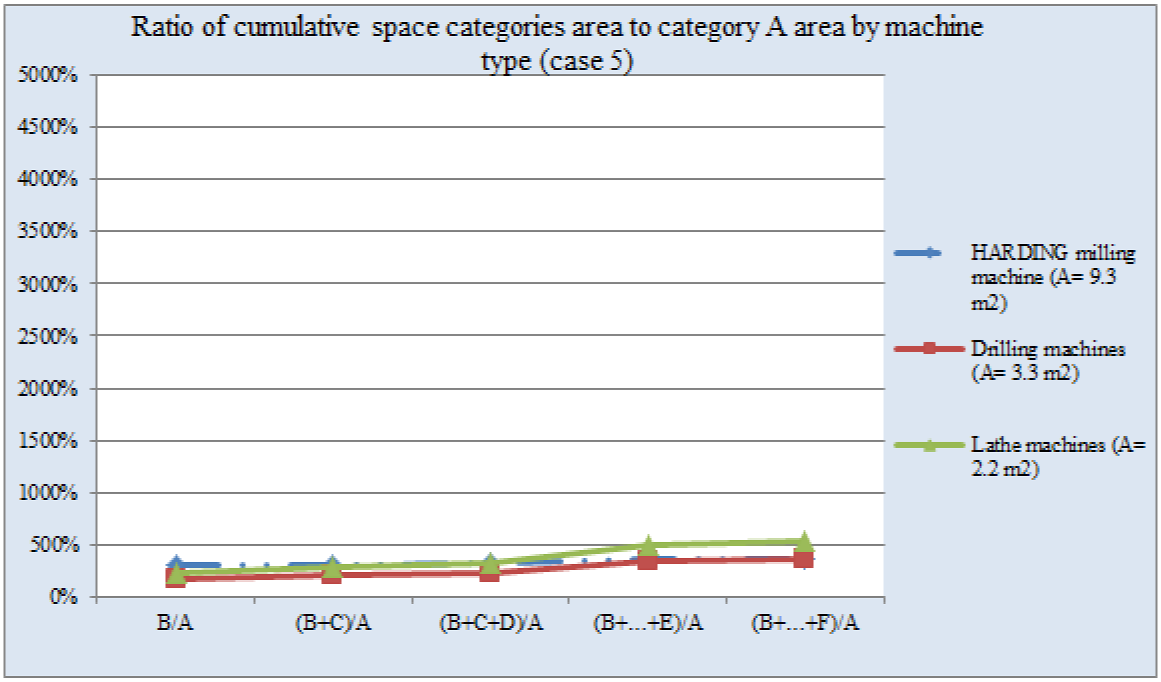

Figure 6.22. Space category to space A ratio by machine type.

The nonprocess power intensity for each energy type use was estimated for this building. The power intensity and annual energy consumption for this building are summarized in Table 6.30 [1].

TABLE 6.30

NONPROCESS POWER INTENSITIES

Energy type use	Total annual, kWh	Power intensity, W/m^2
Lighting	10,109	17.9
Cooling	11,883	6.2
Heating	39,751	20.8
Ventilation	2,618	1.4
Total nonprocess	64,361	33.7

The total area for each space was estimated. Then the percentage of each space type to total machines area was calculated. The related nonprocess energy for each space type was calculated, Table 6.31.

TABLE 6.31

PERCENTAGE OF EACH SPACE TYPE AREA TO MACHINES AREA AND RELATED POWER

Space category	% area to machines area	Total related lighting power, Watts	Total related heating power, Watts	Total related cooling power, Watts	Total related ventilation power, Watts
A	100%	750	874	261	58
B	236%	1,768	2,059	616	136
C	33%	249	290	87	19
D	17%	125	145	43	10
E	88%	664	773	231	51
F	22%	166	193	58	13

6.5 Conclusions

This paper has further contributed to the life cycle of products by estimating nonprocess area and related nonprocess energy to be added to the life cycle of industrial facility to obtain more complete energy profile of product manufacturing. The percentage of nonprocess area (B to F space) to process area (A space) in the five case studies ranges from 500 % in case 5 to 1910 % in case 3 which influences the total energy consumption of the facility. The higher nonprocess area means higher nonprocess energy use in the facility, Table 6.32. In 2 of the 5case studies, the unused space in the facility exceeds machines areas which increase the energy consumption of the facility. This indicated that potential opportunities to reduce this additional nonprocess energy exist thus reducing costs and environmental impact of this energy uses. In case 2, about 45 kW are consumed per hour by the nonprocess area, cost savings might be as high as 30% of this energy if the nonprocess space was reduced.

TABLE 6.32

CASE STUDIES AREA AND NONPROCESS ENERGY DATA SUMMARY

Case #	Percentage of space category area to machines area					Percentage of total non-process area to machine area (C to F)	Percentage of total space category (B to F) to category A space	No-process power intensity (W/m^2)
	B	C	D	E	F			
Case 1	247%	45%	90%	95%	23%	253%	500%	29.2
Case 2	88%	54%	211%	110%	42%	417%	505%	30 .0
Case 3	410%	628%	287%	175%	410%	1500%	1910%	24.8
Case 4	272%	120%	88%	107%	131%	446%	718%	25.9
Case 5	236%	33%	17%	88%	22%	160%	396%	33.7

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CHAPTER 7

CONCLUSIONS AND FUTURE WORK

7.1 Conclusions

In this chapter, the results of this dissertation are summarized and how this research provided valuable nonprocess energy information for different facilities. A major contribution of this work is to the field of product life cycle analysis manufacturing phase. There is a considerable gap in information for the manufacturing phase of life cycle. Recently, the life cycle of manufactured products in specific plants has advanced by developing unit process tools which reflect the transformation of input materials or chemicals into product (Overcash, et. al., 2009). This research has further contributed to the life cycle of products by estimating nonprocess energy to be added to the life cycle process energy to thus obtain more complete energy profile of product manufacturing.

One of the major findings in this study is that the lighting power intensity for the industrial facilities for category 1 to category 5, which are included in this study, ranges from 0.13 Watts/ft^2 to 2.56 Watts/ft^2. For heating, the power intensity ranges from 0.17 Watts/ft^2 to 2.99 Watts/ft^2. Cooling power intensity ranges from 0.14 Watts/ft^2 to 2.25 Watts/ft^2. The power intensity for ventilation ranges from 0.03 Watts/ft^2 to 0.65 Watts/ft^2.

As described in chapter 4, four innovative methods for the evaluation of the nonprocess energy contribution were developed and tested. These different methods to extract the nonprocess energy in industrial buildings were used as comparators. The research has indicated that these methods are valuable techniques to assist facility managers in determining energy conservation solutions. It is advantageous to have different methods for estimating the nonprocess energy for the industrial buildings where the facility manager can decide which method to use based on the available information. Also these methods can be used to check the accuracy of each other.

In 1 of the 5 case studies the four different methods were used to estimate the nonprocess energy for the same facility where all needed information are available to use these methods. In the other case studies one to three methods were used for each facility based on the available information for each method. The results of these estimates were close to each other which indicate that any method can be used based on available information. Thus these methods are potentially important step in improving energy use by nonprocess sources.

In this study, the effect of CDD and HDD on the industrial building cooling and heating energy estimates were determined from a proposed adjustment of the differences in climatic zones on heating and cooling. From this study directed at nonprocess industrial building energy, there is no evidence that the use of facility location and the climate adjustment calculation of CDD and HDD were able to have a significant improvement in the uniformity of the nonprocess energy. This implies that the CDD and HDD factors for the U.S. climate zones do not quantitatively reflect zone locations in such a way as to remove this location effect. This indicates that the measured manufacturing building heating and cooling of industrial buildings may reflect other elements than just outside temperature and thus were not as responsive to these climate factor adjustments. The inability to reduce the geographic (that is, climate zone) effects of industrial plant nonprocess energy intensities supports the de-emphasis of this tool in the ASHRAE Handbook.

This research has further contributed to the life cycle of products by estimating nonprocess energy to be added to the life cycle process energy to thus obtain more complete energy profile of product manufacturing. An innovative method for the evaluation of the nonprocess energy contribution was developed and tested. This was the regression analysis of monthly energy (electricity and/or natural gas) versus some measures of monthly production. In this regression, the energy when extrapolated to zero production is the estimate of nonprocess energy in the building housing the manufacturing process. The nonprocess energy in which influences that machine standby energy was not included was found to be in the range of 6.6 to 37.5 Watts/m^2. The advantage of this method for assessing the nonprocess energy is that it is raped and uses readily available information and largely nonproprietary information.

This research has contributed to the life cycle of products by estimating nonprocess area and related nonprocess energy. The percentage of nonprocess area (B to F space) to process area (A space) in the five case studies ranges from 500 % in case 5 to 1910 % in case 3 which influences the total energy consumption of the facility.

7.2 Future Work

Using information on nonprocess energy is not straight forward. The information is often misleading, incomplete and not transparent. In this paper we address the lack of a methodology for gathering, assessing, and quantifying nonprocess industrial facility energy for use in life cycle assessment and as a metric for benchmarking improvement. It would be valuable if more data from different locations were collected and validated.

Further study which includes different types of facilities such as large energy-intensive industries, specifically chemical manufacturing and refining from different locations can be great value in the field of the industrial nonprocess energy.

Data on process/nonprocess energy captured for each category of facilities should be collected over an entire year. The data would provide better a validation of the concepts developed from this research.

The approach and methods develop in this this thesis can be generalized to other sectors of the economy, such as the commercial sector. The healthcare industry, in particular, has no way to parse out process from nonprocess energy when the only data available is an energy bill.

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