SUSTAINABLE ENERGY MANAGEMENT SYSTEM FRAMEWORK FOR SMALL AND MEDIUM SIZED MANUFACTURING FACILITIES

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MANUFACTURING FACILITIES

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In loving memory of my father, Dr. Thomas Carter Smith (1953–2016).

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Abstract:

The general significance of the topic stems from the fact that energy consumption by the industrial manufacturing sector in the U.S. accounted for one third of total consumption in 2016 and is expected to grow more than 25% by 2040; small and medium sized manufacturing (SMM) facilities are collectively responsible for a large portion of this consumption. Increasing the energy efficiency of SMM facilities means less energy is used, or energy is used in a more efficiency manner, decreasing the amount of natural resources consumed, reducing emissions, and lowering operating costs - potentially resulting in greater profits and a stronger economy. Based on experience with the Industrial Assessment Center program and data presented in the literature, a typical SMM facility has between 10 and 30% wasted energy.

This wasted energy presents an opportunity for significant savings that could be achieved through systematic energy management. However, formal energy management systems (EnMS), such as ISO 50001, have not yet been widely adopted by SMMs. This is in large part due to numerous barriers faced by SMMs. A significant part of a successful implementation of an EnMS involves data collection and analysis tools such as submetering technology and energy information systems. This dissertation research seeks to provide SMMs with the ability to break through some of the barriers associated with implementation of EnMSs and submetering technology in order to improve their energy management.

This research first makes the connection between the past quality movement and the current energy efficiency movement. Four absolutes to energy management are presented which are used to create an EnMS hierarchy, which describes the stages in an organization's energy management system maturity. An energy management maturity grid, modeled after Crosby's quality management maturity grid, is presented as a tool for SMMs to self-assess the state of their current EnMS. Finally, a methodology is presented to assist an SMM in implementing a formal EnMS in a way that is funded through the energy savings it identifies. This ensures a financially sustainable EnMS which can adapt to an organization's needs over time. This methodology is validated through a conceptual example.

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CHAPTER I

INTRODUCTION

1.1 CHAPTER OUTLINE

1.2 BACKGROUND

ISO 50001 was published in 2011 as an international standard for energy management systems within organizations. A significant part of a successful implementation of the standard involves data collection and analysis tools such as submetering technology and energy information systems. While much published work exists on the benefits of energy management systems, submetering technology, and energy information systems, little has been published on how organizations, specifically small and medium sized manufacturing facilities, should optimally invest in these programs. Being able to use this type of technology in small and medium sized manufacturing facilities in a way that breaks down ‘information silos’ and incorporates existing information systems and improvement efforts would be valuable for organizations seeking to improve their energy efficiency. It is equally important that investments in these undertakings are able to provide acceptable returns on the organization's investment as well as support sustainability efforts/programs.

Reasons for choosing this topic stem from the author's work on industrial energy efficiency projects with manufacturing facilities as part of the Department of Energy's Industrial Assessment Center (IAC) Program, which assists small and medium-sized manufactures (SMM) in saving energy, as well as the author's background in management information systems.

The general significance of the topic stems from the fact that energy consumption by the industrial manufacturing sector in the U.S. accounted for one third of total consumption in 2016 and is expected to grow more than 25% by 2040 according to the U.S. Energy Information Administration (EIA) [1]. Further, SMM's collectively account for 90% of manufacturing facilities in the U.S. and use 50% of energy attributed to the manufacturing sector [2]. The Department of Energy classifies a small to medium sized manufacturing facility as one which has a Standard Industrial Classification (SIC) code for manufacturing of 20-39 and/or a North American Industry Classification System (NAICS) code of 31-33, fewer than 500 employees, annual sales under $100 million, and an annual energy bill between $100,000 and $2,500,000 [3].

Increasing the energy efficiency of manufacturing facilities means less energy is used, or the energy that is used is used in a more efficiency manner, decreasing the amount of natural resources used, reducing emissions, and lowering operating costs, resulting in greater profits and a stronger economy. Throughout this work the word 'energy' is synonymous with electric energy, natural gas consumption, and water consumption.

Implementing formal energy management systems, such as ISO 50001, can be an expensive and time-consuming undertaking, especially when they include an investment in information technologies such as submetering and energy information systems (EIS). Funding for energy management and energy efficiency projects often competes with many other projects that are perceived as more important to the core of an organization's operation. This challenge is compounded by the lack of published examples of these types of systems showing a return on investment. For example, four years after its release, ISO 50001 had only been adopted by 3,520 companies around the world, as compared to 14,106 companies adopting ISO 14001, a standard for environmental management, two years after its release [4].

The majority of SMM facilities that the IAC program works with do not have any formal type of energy management system. These facility's management systems typically range from simply paying their utility bills (if they even see them) to tracking monthly consumption and costs either in an spreadsheet based system or sometimes a larger enterprise resource type system. They may have a rough idea of where their energy is going based on what pieces of equipment are the largest and operate most often, but rarely do these facilities track energy consumption or performance in real time or set energy metrics as part of their normal operating procedures. As a result, these facilities likely have a large amount of undiscovered energy waste.

A few examples of this energy waste commonly seen are: operating equipment longer than needed, not operating equipment in the most efficient manner possible, not using the most efficient type of equipment available to accomplish a job, not tracking energy intensity metrics or energy consumption baselines to identify possible maintenance issues, not recovering waste heat or other process byproducts which have value, and not paying attention to rate schedules, power factor, and/or ratchet clauses, which increase energy costs.

The amount of waste in a facility is difficult to quantify, however based on the past IAC assessment reports since the program's inception, and other research presented in the literature, centers have identified a range of potential energy savings ranging from 5 to >50% [5]. These identified energy savings are at least equivalent to current energy waste in the facility.

In many cases, the SMM clients assisted by the IAC program still view energy as a cost of doing business and not something they actively manage. It is rarely the most expensive resource at a facility, but it is commonly in the top five most expensive resources behind labor, raw materials, management/overhead, etc.[1]. Many clients are currently tracking and managing costs associated with these more expensive resources[2]. In contrast, much of the literature reviewed in this dissertation, and DOE resources such as ISO 50001 and eGuide, often look at energy management with narrow boundaries with respect to other resources and pitch it as being by itself or a stand-alone system. Going forward it is important that energy management systems mature and become integrated with existing management systems for other resources (labor, production, etc.) in order for energy to be managed in an effective manner.

This ideal energy management system 'maturity level' would need to be something that can evolve with time as a facility has more resources to devote to such a system and as technologies change. What may be the ideal system for a facility today may not be appropriate a year from now.

1.3 THE PROBLEM STATEMENT

There is a need for an energy management system "investment" framework that helps SMMs develop a mature energy management system that is financially sustainable and scalable over time.

[1] Based on discussions with clients during the assessment process.
[2] During the assessment, many clients can provide details on their in house labor costs and materials costs.

1.4 THE PURPOSE OF THE STUDY

This research seeks to investigate energy management systems, how they can be more effectively implemented with information technology, and how this can be achieved in a cost effective and sustainable manner. In this work sustainable is defined as financially self-sufficient. The purpose of the research is to develop a model framework to assist SMM facilities in identifying the maturity of their current energy management system (EnMS) and to allow them to justify further investments to increase its maturity. Many of these organizations do not employee dedicated energy management professionals or have any formal energy management systems in place. By helping SMM's determine how to better justify investments related to managing their energy usage, including investments in new technologies, formal energy management systems can develop allowing energy to be thought of as a resource that can be actively managed rather than a lump sum overhead expense.

1.5 THE OBJECTIVES OF THE STUDY

The research has two main objectives:

1. The first objective is to develop a model determining to what extent an investment in an energy management system, including submetering and/or energy information system technology, at a small and medium-sized manufacturing facility is financially justifiable. This would include determining the best way a company's energy management system should evolve and grow over time as their organizational needs change.

2. The second objective is to develop a method for first determining the current maturity of an organization's energy management system and estimate what this system is 'costing' the organization in terms of waste. Such a method would be used as a communication tool with management to prompt improvements.

1.6 EXPECTED OUTCOMES

The major impact of this dissertation is to create a model that can guide any facility using it to design and implement an energy management system – thereby better understanding its processes in relation to energy and its main energy consuming equipment. In other words, to progress toward more effective and efficient energy management from both technical and economic perspectives.

1.7 LIMITATIONS

This research is focused on SMM facilities and is subject to the interaction with IAC clients over a four to five year period. While the proposed methodology would be useful by organizations other than SMMs, this research took a narrow focus based on access to these type of organizations and has limited attempts to generalize beyond SMMs.

1.8 IMPORTANCE OF THE STUDY

This problem is worthy of study for several reasons. More efficient manufacturing facilities will reduce the amount of emissions and natural resources they consume, creating a cleaner environment and prolonging the availability of our natural resources. Being able to better manage a facility's energy and justify expenses incurred by implementing a management system and exploring newer technology will be very important to practicing energy engineers. This is currently not an area specifically addressed in the literature.

By changing the way SMMs think about energy from the common viewpoint of energy as an overhead expense to one that can be actively managed, energy management systems will become more prevalent. This dissertation attempts to provide a means for this paradigm shift to occur.

1.9 CONTRIBUTIONS TO THE FIELD

This dissertation is a contribution to the energy management field because of the achievements listed below.

1. This dissertation creates a link between the quality movement and the current energy efficiency movement.
2. Four absolutes of energy management are presented which shape the methodology presented.
3. An energy management hierarchy is presented, which describes the stages of an energy management system's maturity.
4. An energy management maturity grid is presented which acts as a self-assessment tool to assist organizations in identifying the current state of their energy management system, and what their current system may be costing them in terms of wasted energy.
5. A sustainable (technically and economically) investment methodology for energy management systems is presented which assists an SMM in justifying the creation and growth of an EnMS.

CHAPTER II

LITERATURE REVIEW

2.1 CHAPTER OUTLINE

2.2 GENERAL ENERGY SAVING STRATEGIES

In October of 1973, the United States was in a state of crisis. During a period of decline in U.S. oil production, the Organization for Petroleum Exporting Countries (OPEC), which supplied the U.S. with 15% of its oil, embargoed their oil exports in response to U.S. military actions in the Middle East. This embargo caused the price of oil to increase nearly four times, from $3 per barrel to almost $12 per barrel in one year [6, 7]. These dramatic increases in cost shocked the economy and lead to price increases for other fuels, such as coal. Multiplying the effects of the embargo, many electric utilities had recently started switching from burning coal to oil due to its lesser environmental impacts in order to comply with the Clean Air Act of 1970. As a result, the increase in the cost of oil greatly affected the energy industry causing utility rates to increase by almost 50% by 1977, from 2.2 cents per kWh to over 4 cents per kWh [6].

These price increases had many Americans scrambling to reduce their energy consumption; the manufacturing industry was no exception. This environment gave birth to the modern day energy efficiency movement. Manufactures and consumers alike were forced to look at how they were using energy and what they could do to better manage their consumption. This gave way to innovations such as time clocks, increased the prevalence of energy audits, sparked the Energy Service Company (ESCO) industry, and helped give birth to the DOE's Industrial Assessment Center Program.

Today, there are a wide range of options for general energy efficiency improvements and energy saving strategies coming in the form of equipment upgrades, operational changes, or behavioral changes [8]. Energy savings generally come in the form of kWh, kW or Btu savings, but are also sometimes used to describe energy cost savings that do not actually save any energy – rate schedule changes, reduction in power factor penalties, peak demand shifting, etc.

One of the less common methods used to conserve energy at SMMs is a formal energy management system. This could take many forms, from an in-house home-grown system, to a formal program such as ISO 50001. Energy management systems typically draw on and incorporate multiple energy saving strategies as mentioned above. Such a management system would likely require an energy metering and monitoring program beyond a typical utility provider's revenue meter. This data would often be turned into actionable information through the use of an energy information system. These methods, formal energy management systems, submetering, and energy information systems, are discussed to varying degrees in the literature and are reviewed in Sections 2.2.1, 2.2.2, and 2.2.3.

While the use of these energy efficiency improvements and others have been well established and savings generated by these improvements are generally enough for a respectable payback, energy efficiency improvements are often not implemented at the rates one would expect. This creates what is known as an ‘energy efficiency gap’. Section 2.3 reviews the literature describing the barriers to the implementation of energy efficiency improvements, which create this gap.

In addition to the barriers to energy efficiency, Section 2.4 reviews the ways decisions are made regarding energy efficiency. Of particular interest are the topics of financial analysis related to energy efficiency improvements (Section 2.4.1), activity based costing (Section 2.4.2) which is an accounting method that helps make various cost centers inside the manufacturing process responsible for their energy costs, and how energy improvements are measured (Section 2.4.3).

2.2.1 FORMAL ENERGY MANAGEMENT SYSTEMS

Manufacturing facilities have many different views on energy as it relates to their operations. Some see it as simply an overhead expense and just the ‘cost of doing business’, while others work to actively manage it. Energy management systems (EnMS) are used to provide a structured process for how an organization manages its energy consumption. There are several different approaches to these formal management systems and several definitions of an EnMS, but for the purposes of this work the author defines an EnMS as:

> *“an interacting series of processes that enables an organization to systematically achieve and sustain energy management actions and energy performance improvement [1].”*

Using such a system provides a company with several benefits including improved efficiency, reduction in energy intensity, ability to make fact-based decisions based on energy data, and driving change within an organization among others [1].

Several approaches to energy management systems exist and have been documented in the literature. These approaches have continued to evolve over time as the issue of energy management becomes increasingly important.

2.2.1.1 OVERVIEW OF ENERGY MANAGEMENT SYSTEM STANDARDS

Until recently, no standard for energy management existed. In the early 2000s, researchers at Georgia Tech University made the case for a separate management system specifically for energy [9]. At the time, ISO 9001 for Quality Management and ISO 14001 for Environmental Management were two of the most widely used management systems; however, they did not provide adequate guidance for managing energy consumption. Georgia Tech presented the Management System for Energy (MSE) 2000 standard as an alternative, which was designed specifically for managing energy and became the first energy management standard adopted by the American National Standards Institute (ANSI) in 2005 [9, 10]. In similar fashion, the European Standard on energy management systems, EN 16001, was published in 2009 and was widely adopted in Europe [10, 11]. Its adoption and creation was largely due to climate change related treaties and legislation [11].

In 2011, the International Standards Organization (ISO) published ISO 50001 as the international standard for energy management systems. It was based on the framework of Plan-Do-Check-Act, similar to ISO 9001 and ISO 14001. It also drew upon other existing energy management systems and regulations from around the world such as MSE 2000, EN 16001, and others [12]. ISO 50001:2011 is the current energy management system that is most widely used around the world and has been adopted by the U.S. Department of Energy as the basis for several of their energy programs such as the eGuide, 50001 Ready Navigator, Better Plants, and Superior Energy

Performance programs. In 2012, shortly after being published, EN 16001 was withdrawn due to the publication and success of ISO 50001 [12].

2.2.1.2 ISO 50001 STANDARD FOR ENERGY MANAGEMENT

The ISO 50001 standard is built on the same principles as the ISO 9001 and ISO 140001 standards and uses a Plan-Do-Check-Act (PDCA) continual improvement framework. The main parts of the framework are [13]:

- Plan: Conduct the energy review and establish the baseline, energy performance indicators (EnPIs), objectives, targets and action plans necessary to deliver results that will improve energy performance in accordance with the organization’s energy policy;
- Do: implement the energy management action plans;
- Check: monitor and measure processes and the key characteristics of operations that determine energy performance against the energy policy and objectives, and report the results;
- Act: take actions to continually improve energy performance and the EnMS.

The standard is divided into several sections and sub-sections, with the energy management system requirements starting in section 4. The standard requires top management responsibility, a designated person from management who oversees the system, a written energy policy, conformance with legal requirements, an energy review which details the major energy consuming equipment and prioritize the opportunities for improving energy performance, establishment of an energy baseline, development of EnPIs, development of energy objectives and targets, implementation of the plan, documentation of results, and monitoring progress. These steps are show in Figure II-1 below. Figure II-2 also shows a graphical depiction provided in ISO 50001 of how the different pieces of the system work together.

These sections closely align with other ISO standards such as 9001, 140001, and 22000 (Food Safety Management System). The sections of the standard provide guidance but are intentionally left vague. For example, the standard provides no guidance on the cost of implementing such a system or the amount of resources an organization should dedicate to implementing such a system.

This is not a prescriptive standard but rather a flexible framework. These standards are designed in such a way that provides a framework for creating a system to manage energy consumption and are not specific to any particular industry or type of organization. This allows for each individual organization to tailor their system to fit their individual culture and needs. While these systems could be applied to multiple types of organizations, this literature review will focus on these systems as they have been applied to SMM facilities.

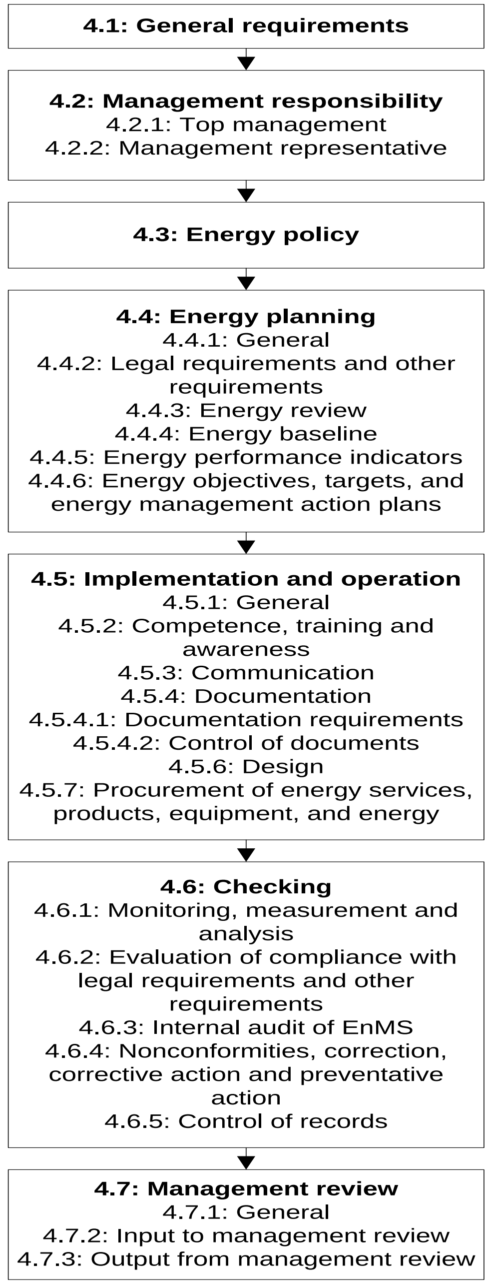

Figure II-1 ISO 50001 Section 4: Energy Management System Requirements

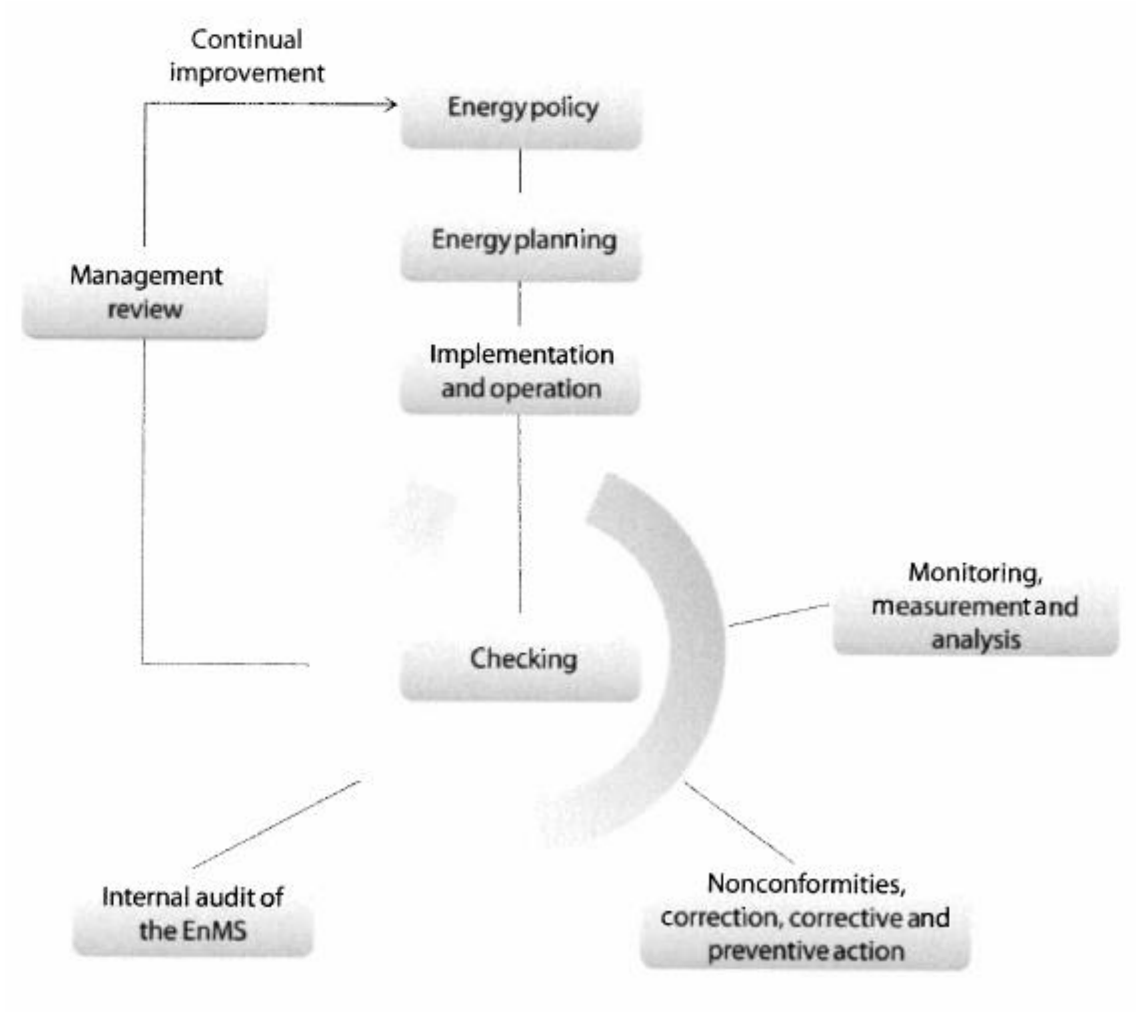

Figure II-2 Energy management system model for ISO 50001 [13]

Two distinct areas in the literature surrounding energy management systems were observed: literature presenting improvements to existing energy management systems, and literature providing analysis and insight from implemented energy management systems.

2.2.1.3 IMPROVEMENTS TO ENERGY MANAGEMENT SYSTEMS

Several articles present ideas for improving energy management systems, some which are independent of ISO 50001, and some which are complementary to ISO 50001.

As mentioned above, in 2005 prior to the creation of ISO 50001, researchers at Georgia Tech University made the case for a separate management system specifically for energy [9]. At this time no standardized energy management system existed. Several larger companies had created in-house systems, but these were not published or developed with replication in mind.

Additionally, ISO 9001 and ISO 14001 did not provide adequate guidance for addressing energy specifically. The research presented the Management System for Energy (MSE) 2000 standard as an alternative [9, 10]. This system differed from the existing management systems due to its more focused approach on improved efficiency rather than compliance with customer specifications or conformance with environmental policy. Many aspects of the MSE 2000 standard were incorporated into ISO 50001.

While the separation of energy management from quality and environmental management systems, as presented in MSE 2000, is needed, the author also believes there is value in having connections between the EnMS and other management systems within the company. Energy consumption is driven by other activities in the organization such as production in manufacturing facilities. Combining data from production and energy management systems would create powerful insights and benefit both systems.

In 2010, a research article presented a case study regarding the development of an energy management system at a Serbian car manufacture [14]. The authors acknowledged that at the time a small number of companies had adopted energy management systems, even in countries with strong commitments to energy efficiency. The authors also mentioned that the International Standards Organization was working on the ISO 50001 standard at the time of the paper's authorship, but had not yet released the standard.

The researchers presented a procedure for the development of an energy management system focused on use in the metalworking industry. It has many similarities with what the ISO 50001 standard ultimately became, however, one key difference is the use of an energy management matrix to assess the status of an organization's existing system. The elements of the energy management system presented are the completion of an energy management matrix, initiation of the energy management system, energy auditing, identification of energy saving measures and action plan development, implementation monitoring and evaluation of energy saving measures. The energy management matrix presented is borrowed from previous researcher's work and is discussed in more detail in Section 2.2.1.3.1.

2.2.1.3.1 ENERGY MANAGEMENT MATRICES

Phillip Crosby introduced the use of maturity matrices during the quality movement with his Quality Management Maturity Grid, presented in his book "Quality is Free" [15]. This grid was powerful because it forced upper management to think about how their organization thought about quality, and most importantly, assigned a dollar amount to what their quality system was costing them. An excerpt of this grid can be seen in Figure II-3.

	Stage I: Uncertainty	Stage II: Awakening	Stage III: Enlightenment	Stage IV: Wisdom	Stage V: Certainty
Quality Management	We don't know why we have problems with quality	Is it absolutely necessary to always have problems with quality?	Through management commitment and quality improvement we are identifying and resolving our problems	Defect prevention is a routine part of our operation	We know why we do not have problems with quality

Figure II-3 Excerpt of Crosby's Quality Management Maturity Grid (QMMG) [16]

Crosby's Grid resonated with multiple disciplines resulting in several variations in the fields of medicine, communications, team management, risk management, and even energy management [16]. One of the most prevalent fields where Crosby's grid has been adapted for use is in software development as part of what is known as the Capability Maturity Model (CMM).

The CMM was developed in the late 1980s and early 1990s by work done at the Carnegie Mellon Institute for the U.S. Air Force [17, 18]. Its purpose was assessing the process capability of subcontractors competing on software contracts. Similar to Crosby's grid, the CMM has five levels used to assess an organizations maturity: Initial, Repeatable, Defined, Managed, Optimized [18]. It was eventually adapted to aid in the improvement of multiple business processes, including energy management.

The CMM literature reviewed, that focuses on energy management, generally complemented the ISO 50001 standard. Atunes [19] presents a five level maturity model with the stages of Initial, Planning, Implementation, Monitoring and Improvement. Ngai et al [20] presents a similar CMM based energy management model with the levels of Initial, Managed, Defined, Quantitatively Managed, and Optimizing. The Northwest Energy Efficiency Alliance (NEEA) also presents a CMM based energy management model with six levels of engagement (Unengaged, Engaged, Systematic, Sustaining, Integrated, and World Class) used to rank several energy management components [21]. While these examples presented in the literature follow the CMM framework and provide guidance for implementing an EnMS, they deviate from key aspects of Crosby's original grid critical to communicating the importance of implementing an energy management system. Key shortcomings are the fact that energy is not framed in the context of the larger organization and the amount of waste is not considered or quantified.

Other literature stays truer to Crosby's original grid when applying it to energy management. The most notable previous attempt at creating an energy management maturity matrix following Crosby's original model was prepared by Eclipse Research Consultants[3] for the Buildings Research Energy Conservation Support Unit (BRECSU) in 1993 [22].

The BRECSU matrix (seen in Figure II-4) was created based on research presented in a 1983 UK Department of Energy publication titled *"Energy Conservation Investment in Industry: an Appraisal Of The Opportunities And Barriers"* [23]. Among other things, this research identified that key aspects of an energy management program can become out of sync with one another. This realization led to the creation of an energy maturity matrix presented in the BRECSU publication in which each column dealt with one of six organizational issues: policy, organization, motivation, information systems, marketing, and investment. The ascending rows, labeled from 0 to 4, represented increasingly sophisticated handling of these issues [22]. The ultimate purpose of this matrix was to look at the 'organization profile' after completing the exercise and draw a conclusion about the strength/weakness of the existing energy management system.

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[3]Note: There is some controversy over the original author of the Energy Management Matrix. The GIR 12 sites the origins as P. S. Harris, 'The Armitage Norton Report'. Energy Users Research Association Limited, Bulletin No. 44, February 1984. Attempts to locate this publication were unsuccessful as it is out of print and no digital records exist. However, two former Eclipse research consultants, Ian Cooper and Steven Platt, were contacted. They indicated that they developed the matrix independently of anything the Armitage Norton Report and Peter Harris may have developed, and that he was unduly given credit for its creation in the GIR 12 citation.

BRECSU's matrix forms the basis for the majority of matrices related to energy management, and has been widely used in parts of the world (mainly the EU and Australia) and some published articles cite its success in energy management system implementations [14, 24, 25]. One shortcoming of this matrix, and other CMM type models for energy management, is the lack of an estimation/quantification of what the current state of an energy management system might be costing an organization due to its shortcomings. This is a very important piece of the 'big picture' that was included in Crosby's original grid and must be considered, especially from a top management perspective, in order to help drive change.

Level	Energy Policy	Organising	Motivation	Information systems	Marketing	Investment
4	Energy policy, action plan and regular review have commitment of top management as part of an environmental strategy	Energy management fully integrated into management structure. Clear delegation of responsibility for energy consumption	Formal and informal channels of communication regularly exploited by energy manager and energy staff at all levels	Comprehensive system sets targets, monitors consumption, identifies faults, quantifies savings and provides budget tracking	Marketing the value of energy efficiency and the performance of energy management both within the organisation and outside it	Positive discrimination in favour of 'green' schemes with detailed investment appraisal of all new-build and refurbishment opportunities
3	Formal energy policy, but no active commitment from top management	Energy manager accountable to energy committee representing all users, chaired by a member of the managing board	Energy committee used as main channel together with direct contact with major users	M&T reports for individual premises based on sub-metering, but savings not reported effectively to users	Programme of staff awareness and regular publicity campaigns	Same pay back criteria employed as for all other investment
2	Unadopted energy policy set by energy manager or senior departmental manager	Energy manager in post, reporting to ad-hoc committee, but line management and authority are unclear	Contact with major users through ad hoc committee chaired by senior departmental manager	Monitoring and targeting reports based on supply meter data. Energy unit has ad hoc involvement in budget setting	Some ad hoc staff awareness training	Investment using short term pay back criteria only
1	An unwritten set of guidelines	Energy management the part-time responsibility of someone with only limited authority or influence	Informal contacts between engineer and a few users	Cost reporting based on invoice data. Engineer compiles reports for internal use within technical department	Informal contacts used to promote energy efficiency	Only low cost measures taken
0	No explicit policy	No energy management or any formal delegation of responsibilty for energy consumption	No contact with users	No information system. No accounting for energy consumption	No promotion of energy efficiency	No investment in increasing energy efficiency in premises

Figure II-4 BRECSU'S 1993 Energy Management Matrix

2.2.1.3 Continued

In 2011, just before the publication of ISO 50001, Italian researchers Simona et al wrote a chapter titled “Methodology Development for a Comprehensive and Cost-Effective Energy Management in Industrial Plants” as part of a book titled “Energy Management Systems”. The chapter outlined the transformation of how energy has been viewed historically from quick fixes, to energy conservation projects, to formal energy management systems. The chapter presented a methodology for comprehensive energy management; energy cost and consumption data collection, energy cost and consumption data analysis, energy forecasting at plant level, submetering energy use, tariff analysis and contract renewal, energy budgeting and control, energy monitoring and control, and power plant management optimization. Many of the concepts presented are reflected in ISO 50001, while some are slightly ‘before its time’. It provided an argument for inclusion of submetering into an EnMS, and also recognized that despite the attractive return on investment (from EIS and submetering) they were not being implemented at a rate one would expect, given their benefits. This work presented several formulas for things such as forecasting energy usage at a plant, energy intensity, and power plant optimization. The methodology was verified using a case study. One area lacking from the methodology is guidance on what to spend on implementing such an EnMS.

Also in 2011, just after ISO 50001 was first published, Duglio [11] provided a comparison to the existing EN 16001 standard and the new standard. At the time, EN 16001 was two years old and was a voluntary European Standard. The main differences identified were the increased focus on management responsibility, the addition of the concepts of the energy review, energy baseline, and energy performance indicators, and the sections discussing the consideration of energy performance when making changes to the facility or process and during the procurement of new products, equipment, or energy services. These improvements in the ISO 50001 ultimately lead to its replacement of EN 16001.

In 2014, researchers presented an "Energy Management Maturity model" [26] that could be used as an alternative or complementary method to ISO 50001 for the management of an organization's energy. This model works by using a short questionnaire (40 questions) through a web interface to determine an organization's level of maturity. Answers provided by the organization are to be automatically processed through the website of the model, and a final report assessing the maturity of the organization is obtained, with a set of indicators: a synthetic indicator of maturity, the degree of coverage of levels, and the development of different dimensions. The levels of maturity presented in this work include *Initial* – Organization is uninterested in issue of energy consumption, *Occasional* – Organization shows interest by defining corporate energy policy, *By Projects* – Company develops own strategy with reduction targets, *Managerial* – Recognition that management can be obtained through 'day by day' management instead of 'by projects', and *Optimized* – EnMS is optimized by means of a continuous improvement approach. The work recognizes that the concept of maturity dates back to Phillip Crosby's work, and recognizes that *"The optimal level of maturity is recognized as being the level that delivers the organization's strategic objectives most effectively and efficiently, not necessarily corresponding to the highest level of the defined scale."* This is a very apt insight that is also reflected in this dissertation. This work does not address the waste or financial side of the energy management problem, or address the 'next steps' an organization should take to improve its EnMS. It simply assesses its current maturity.

Also in 2014, researchers at the West Virginia University Industrial Assessment Center developed a software tool [27] that was intended to provide a structured approach for facilitating the implementation of ISO 50001 standard in the manufacturing sector. The tool is similar to the

DOE eGuide (discussed below) but follows a flow chart to guide organizations in implementing a management system. The tool provides no acknowledgement of different levels of system maturity or cost benefit/sustainability aspect.

To assist in the adoption of ISO 50001, the U.S. Department of Energy began creating the eGuide for ISO 50001 shortly after the release of the standard. The eGuide is *"a toolkit designed to help organizations implement an energy management system through an organized step by step process at three different levels: Foundational, ISO 50001 and Superior Energy Performance"* [28]. It provides more detail on how an organization might go about implementing an EnMS, provides resources such as checklists and templates, and allows users to create an account, which can track their organization's progress as they work towards implementing an EnMS. The eGuide attempts to slightly re-organize the content of ISO 50001 into five major steps: 1. Engage management, 2. Plan for energy management, 3. Implement energy management, 4. Measure and check results, 5. Review for continual improvement. The DOE has continued to improve the support it offers for organizations seeking to improve their energy management systems, recently developing a new program based on the eGuide called 50001 Ready Navigator [29]. This newly released program uses many of the same eGuide principles in an online application format that is intended to be more user friendly, and paired with a DOE certificate program.

Figure II-5 demonstrates how level two of the eGuide aligns with the ISO 50001 standard. The eGuide is currently still in its beta test phase and is being assisted by several IAC's (including Oklahoma State University) to work through the steps with selected SMM's. While it takes a fairly narrow view with respect to other resources and pitches itself as being a stand-alone system, most clients have seen value in its use.

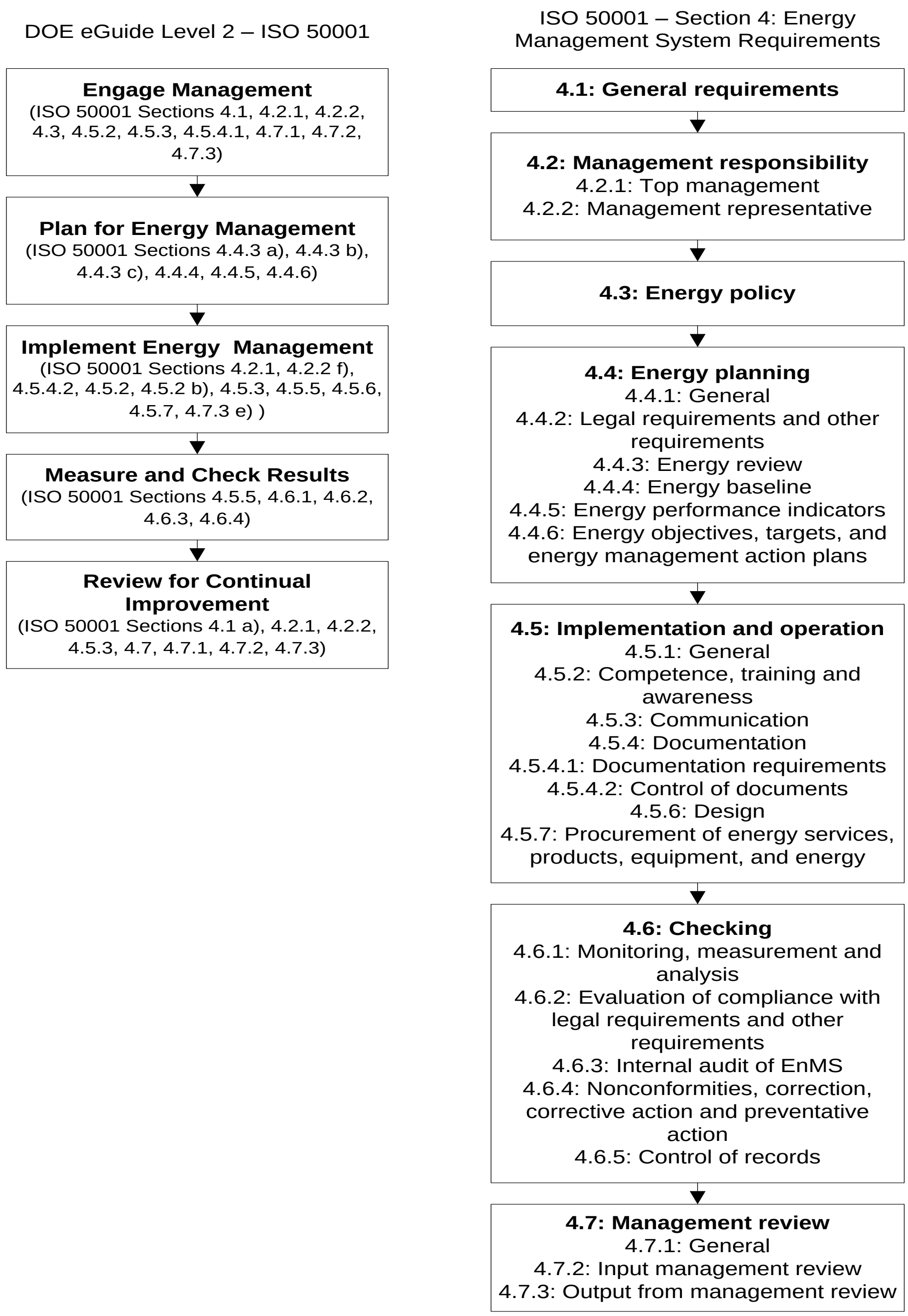

Figure II-5 DOE eGuide level 2 vs ISO 50001 Section 4

In 2017, the DOE introduced the 50001 Ready Navigator, which is described as the "*most recent iteration of the eGuide [30].*" Similar to the eGuide, 50001 Ready Navigator is a web-based tool which is intended to enable "*more effective team collaboration through a simplified and enhanced user interface, streamlined guidance, and the ability to create, store, and share notes* *among users [30]*." Its purpose is to assist facilities in establishing an energy management system. Upon completion, organizations are able to apply for a DOE certificate of recognition.

The Navigator consists of four main sections, 1. Planning, 2. Energy Planning, 3. Continual Improvement, and 4. System Management. Each of these sections have multiple tasks associated with them, all based on sections from ISO 50001 [29]. A comparison between 50001 Ready Navigator and ISO 50001 can be seen in Figure II-6.

The remainder of the literature discussed in Section 2.2.1.4 focuses on the analysis of EnMS, which have been installed in an organization and provides insight from the implementation process.

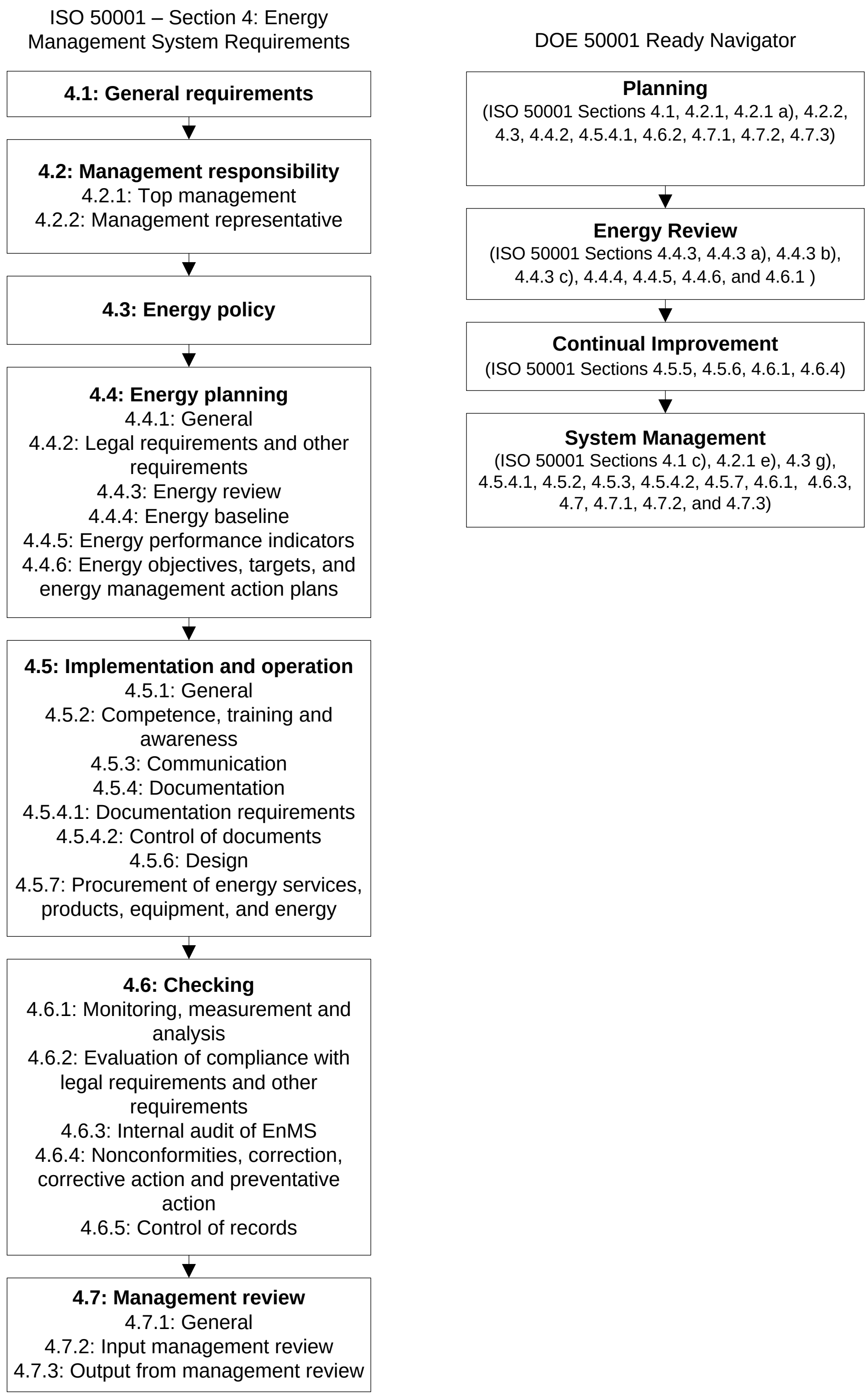

Figure II-6 ISO 50001 Section 4 vs DOE 50001 Ready Navigator

2.2.1.4 ANALYSIS OF ENERGY MANAGEMENT SYSTEM INSTALLATION

As EnMSs have been installed at various organizations, numerous research has been done regarding their effectiveness, and has detailed the insight gained from ‘growing pains’ felt during this process. In 2012, researchers focused on the issue of determining how an organization decides to make a commitment to energy management [31]. The research is based on the experience gained from the implementation of an EnMS at a manufacturing facility. The research lays out several steps needed to demonstrate energy management as something that benefits the organization and positions it as something accepted within an organization. The steps presented in the research include: *Prerequisite* – at least something must be in place, *Finding opportunities* – through an energy assessment or equivalent, *Selling and implementing the initial projects* – when projects deliver, credibility grows, *Demonstrating success* – crucial to have successful project early on, *Expansion to doing more* – create pattern of success, *Selling it to the top* – after small successes, cement practices into organization, operation, and *Next steps* – possibly formal system such as ISO 50001. A valuable insight from the paper is that there are rarely enough resources to do everything. The pieces of energy management with the highest value to the organization should be implemented first. With respect to formal systems such as ISO 50001, the authors suggest the key is to understand what they offer and choose elements that offer the greatest benefit to the company.

Multiple articles have looked at the costs and benefits associated with implementing ISO 50001. In 2013, researchers at Georgia Tech conducted a cost-benefit analysis on an ISO 50001 system implemented at their university [32]. They provided some background on the history of ISO 50001 and Georgia Tech’s role in its creation. Several case studies are discussed which review past ISO 50001 implementation success stories and demonstrated a range of energy savings between 5 and 20% energy savings. The researchers then proceeded to assess the EnMS implementation at Georgia Tech, and through a cost benefit analysis they found the present value of the benefits is 2.5 times the cost of implementation.

The DOE published research regarding the costs and benefits associated with the implementation of an EnMS as part of the Superior Energy Performance Program (a more rigorous system than needed to meet ISO 50001 requirements) [33]. The paper focused on the business value of SEP and ISO 50001 and provided an assessment of costs and benefits associated with SEP implementation at nine large facilities. A questionnaire was developed and sent to staff at each facility ahead of a one-hour phone interview. Qualitative results were determined using the DOE's EnPI tool. Facilities reported that ISO 50001 helped identify operational improvements that previously had gone unnoticed. Energy saving percentages attributable to SEP in the first year after SEP training was 3.8% and 10.1% in the first half of the second year. The study identified the average overall cost per facility to be $319,000 (detailed breakdown seen in Figure II-7).

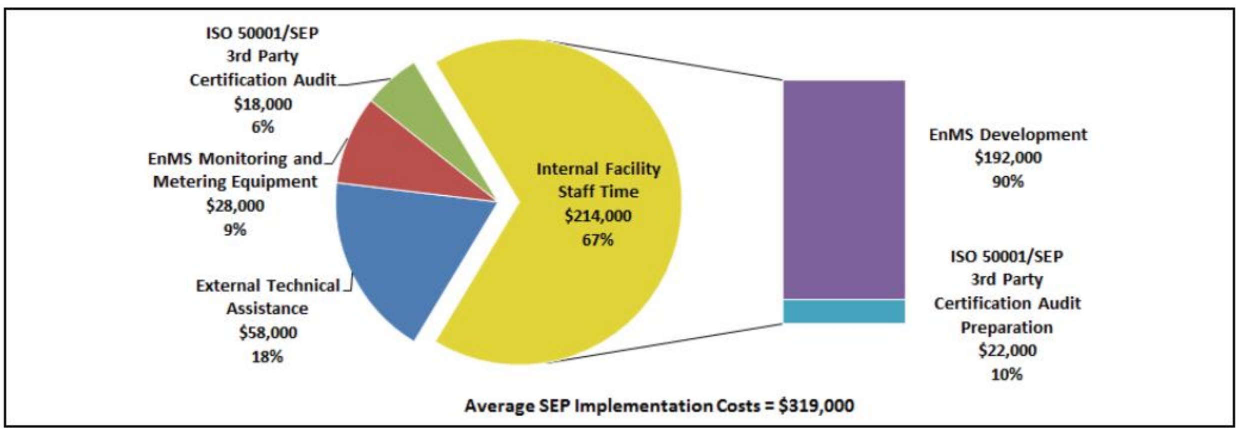

Figure II-7 Average SEP Implementation Cost [33]

The study found the cost of SEP and ISO 50001 certification was marginally higher than ISO 50001 certification alone, but the costs were comparable to other standards. The facilities surveyed indicated the cost of certification was not prohibitive and provided greater confidence in their energy performance results. Data showed SEP participation was expected to have less than a two-year payback for facilities with annual energy consumption greater than 0.27 TBtu, where 0.27 TBtu is equal to 270,000 MMBtu/yr. For comparison, a typical IAC plant's consumption is ~20,000 MMBtu/yr. This study provided interesting insight, but it is hard to know how applicable the results are to SMMs. An additional study of interest would be comparing the improvements in energy savings (if any) at plants using only ISO 50001 versus plants participating in the Superior Plants Program.

An additional study which discussed costs and benefits associated with EnMS was produced by a French research group which published a guide related to energy management systems in the steel industry [12], detailing an overview of EnMS systems, how they are used in various industries, barriers to their use, legislation impacting their use, and the cost of implementing a system. The authors made the argument that the cost of implementing an EnMS should be considered differently from those costs related to investing in an energy efficiency capital project. They reason implementing an EnMS involves changing internal processes and is typically paid back through operational energy savings, whereas the cost of investing in a capital project related to energy efficiency is paid back through the energy savings achieved from its implementation. While similar, the EnMS would be an ongoing system instead of a short-term project.

In 2014, researchers in France performed a study with the hypothesis that the announcement of ISO 50001 certification would be associated with improving a firms market value [4]. To test this, an event study was performed on 120 companies who had achieved ISO 50001 certification and were listed on various stock exchanges. The results of the study were surprising. Market reaction to ISO 50001 adoption was found to be negative, but statistically insignificant. However, the researchers do not believe the standard is a bad investment. They believe that since ISO 14001 was one of the first standards of its kind for improving environmental performance, succeeding initiatives (such as ISO 50001) may have gone unnoticed or resulted in costly environmental management and a reduction in benefits. This is reflected in the number of organizations achieving ISO 50001 certification three years after its released (3,520) compared to those achieving ISO 14001 certification in the same time frame after it release (14,106). This still leaves several questions regarding the low implementation rate of ISO 50001, which may be addressed in part during the discussion of barriers to energy efficiency in Section 2.3.

The majority of the companies that have adopted the standard are based in the EU. In 2015, researchers surveyed ISO 50001 certified companies in Germany (of which 84% were in the manufacturing industry) to determine the success factors for an effective implementation, operation, and certification of an EnMS [34]. The research identified several interesting findings, mainly that EnMS's are most commonly built on existing management structures, tax relief is the largest motivator for implementation in Germany, and that in SMMs EnMSs are often integrated across multiple areas of an organization because personnel capacities for a dedicated energy department are not usually available. The issue of legislation which provides tax relief (up to 25%) as a result of ISO 50001 implementation may explain the concentration of firms that have implemented the standard in Europe. The lack of legislation elsewhere in the world requiring ISO 50001 or providing incentives for its use is a possible explanation for the discrepancy between ISO 14001 and ISO 50001 implementation rates seen in the previous research [4].

2.2.1.5 SECTION SUMMARY

As seen by the research reviewed above, ISO 50001 is the current EnMS standard upon which most management systems are based. There have been several studies assessing the value of using ISO 50001. All agree that the standard has value, however, the standard has not been adopted as widely as previous ISO standards. Many of the regions of the world where the standard is most frequently used have legislation that incentivizes the use of the standard. The studies that assess the costs and benefits of the standard generally focus on large manufacturing facilities, but find the implementation of ISO 50001 pays for itself in a reasonable amount of time. Justifying the cost of implementing the standard is just one of several barriers EnMS faces when companies are determining whether or not to implement. These barriers are discussed in more detail in Section 2.3.

As several of the articles reviewed mentioned, the successful use of a formal energy management system will likely include the use of submetering and/or an energy information system (EIS) on some level to allow for management and scrutiny of energy consumption on a process or sub-system level. These technologies are discussed in more detail in the next two sections.

2.2.2 SUBMETERING

Submetering technology, sometimes referred to as advanced metering, allows for a more in-depth assessment of resource consumption beyond that provided by a traditional utility meter. Utility metering only provides aggregated usage data, where submetering provides a more detailed breakdown of where consumption is taking place within a building or manufacturing facility. For example, rather than receiving consumption data in the form of a utility bill for an entire facility, submetering allows for a breakdown of consumption by floor, process, or system, independent of the utility provider.

The concept and practice of submetering was introduced in the early 1980s [6, 35]. The technology used to submeter has grown since its inception, but its use is not widespread in all industries. While electrical submetering is perhaps the most common and easiest to implement, it is also possible to submeter resources such as natural gas, steam, compressed air, and water through noninvasive means. Noninvasive means are generally preferred due to ease of installation and minimal disruption to operations. Submetering technology can also be used to track things such as temperature, humidity, carbon dioxide, occupancy, and light levels [36]. Submetering has been used in both manufacturing and non-manufacturing environments (commercial spaces, multiple occupant residential settings, college campuses, etc.); however, it has been most common in the later, mainly due to the greater success of cost justification.

The general tone of the literature published regarding submetering technology is positive. The majority of the focus is on commercial and multi-tenant residential spaces and the benefits associated with its use. The majority of articles focus on electrical submetering specifically, but there are mentions of other resources such as water, natural gas, steam, compressed air, etc.

2.2.2.1 CURRENT SUBMETERING CAPABILITIES

Since the 1980s the technology used in submetering systems has become more sophisticated. The three main resources submeter technologies monitor are electricity, natural gas, and water. In addition to these resources, the technology also allows for the monitoring of steam, temperature, humidity, carbon dioxide, and light levels among other things.

Electric submeters commonly consist of a current transducer (CT) type measuring device. CTs come in several different sizes and are commonly either solid core or split core. A solid core CT requires the wire whose load is being monitored to be disconnected and passed through the middle of the CT before being reconnected. A split core CT is able to be closed around the wire which is to be monitored without being disconnected [37]. Data collected by the CT is then received by a controller or logging device. This data is often then sent to a software package or energy information system (EIS) via the Internet for storage and interpretation. EIS will be discussed in more detail later.

Noninvasive natural gas and water submetering can often be accomplished using an ultrasonic type meter. For natural gas, these meters use transducers that produce high frequency sound waves both with and against the flow of natural gas. The velocity of the gas is determined based upon the difference in time between the generation of the sound waves and their reception. This information, along with the size of the meter, allows the volume of gas to be calculated electronically [37]. For water, meters produce ultrasonic frequencies that are refracted at angles across the water, and reflected back to the meter at a wide range of frequencies. The meter then captures these return signals for analysis to determine the flow rate [12]. Similar to an electric submeter, these meters then transfer information to a controller that communicates with the Internet.

Data collected by the electric, natural gas, and water submeters can then be viewed in real-time via the Internet using websites, mobile apps, or other software such as Building Automation Systems (BAS) or Energy Information Systems (EIS), which incorporate the energy data into a larger system. The submetered data can be displayed for analysis using dashboards, gauges, and graphs. This collected data can also be stored to develop operating baselines that can help forecast energy usage and evaluate future improvements effects on the baseline [6].

2.2.2.2 SUBMETERING BENEFITS

Based on the literature reviewed, there is no question submetering has value. The main questions are how much value its use creates, to what extent it should be used in an organization, and how it fits into existing management systems in order to gain the most value. The major benefits identified in the reviewed literature are summarized in Table II-1 below. In the table, the first column contains the benefits discussed in the literature, with the corresponding references in the second column.

Based on Table II-1, it is apparent that the most commonly recognized benefit is cost allocation, followed by using submeters to diagnose problems with systems, generating profiles used to analyze resource consumption, measuring and verifying (M&V) savings from improvement projects, and creating baselines, among others.

The majority of these benefits have been identified in the literature in the application of submetering to the non-manufacturing environment.

2.2.2.3 NON-MANUFACTURING ENVIRONMENT

Building level submetering has been the most common and most widely implemented in multiple occupant residential buildings, commercial spaces with multiple tenants, college campuses, and most recently Federal buildings due to the Energy Policy Act of 2005 [38]. A review of the literature on submetering most frequently discusses it in the context of these settings [5, 6, 35-53].

As identified in Table II-1, cost allocation is the main driver behind non-manufacturing submeter installations. Prior to submetering, many multi-occupant buildings used one master meter, with the utility bill being split equally between all tenants or included in the rent. This resulted in large consumers increasing the bill for everyone, or the landlord potentially losing money when utility rates and consumption increased. With the installation of submetering, tenants are able to be billed based upon their consumption, promoting energy conservation behavior, and saving the landlord money. These savings are used to justify submetering installation in these settings.

Table II-1 Summary of Identified Submetering Benefits in Non-Manufacturing Environment

Benefit	Reference
Cost allocation	[6, 35, 38-40, 43-54]
Diagnostic capability	[35, 38, 40, 41, 43, 46, 49-52, 54]
Usage analysis/consumption profile	[6, 35, 36, 38-41, 46, 48, 52]
Measure and verify savings	[6, 35, 38-41, 43, 45, 46, 48]
Benchmarking consumption/creating baselines	[35, 38-41, 45, 48, 51]
Equipment maintenance/predictive maintenance	[35, 38, 40, 43, 46, 49-51]
Peak demand identification/Peak reduction/ demand response	[5, 6, 35, 38, 40, 41, 43, 50, 51]
Promotes accountability	[40, 41, 43, 45-47, 51, 54]
Identify potential retrofits/ replacements/ improvement opportunities	[36, 38, 40, 43, 45, 46, 54]
Power quality analysis and monitoring	[35, 38, 50, 51, 55]
Promote conservation through awareness	[35, 38-40, 43, 51]
Identify best rate tariff/negotiate lower rates	[35, 38, 39, 41, 51]
Multi-site load aggregation	[6, 35, 38, 40, 46]
Control capability	[41, 49, 50]
Verify utility bills	[38, 41, 50, 54]
Real time pricing/time of use metering	[35, 38, 41, 51]
Load control/comparisons	[5, 6, 35, 41]
Monitoring usage	[38, 41, 51]
Reduce waste/emissions	[40, 50, 51]
Ongoing commissioning/monitoring based commissioning	[40, 43, 45]
Identify major energy users/establish energy use by process	[46, 51]
Gather granular data	[36, 48]
Threshold alarming and notification	[6, 35]
Reduction of costs	[6, 50]
Improved planning	[38, 52]
Emergency response/improved safety	[38, 50]
Savings from 'just metering'	[54]
Savings from enabling automation	[54]
Leak detection	[41]
Increased load factor	[51]
Legal compliance	[48]
Assist in LEED certification	[35]
Improving equipment reliability	[50]
Improving equipment use	[50]

Many jurisdictions such as New York City and Seattle are seeing the value of submetering in commercial spaces and are requiring the technology to be installed in high rise office buildings in the near future [6, 48]. The use of such technology is expected to result in large reductions of energy usage and therefore carbon footprints.

Several disadvantages and barriers to submetering technology in the non-manufacturing environment are also discussed in the literature. These are summarized in Table II-2 below.

Table II-2 Summary of Identified Disadvantages/Barriers to Submetering

Disadvantage/Barrier	Reference
High installation cost	[42, 43, 48, 53]
Increased operating cost	[44, 46, 53]
Increased workload	[36, 44, 53]
Difficult to economically justify	[38, 43, 54]
Not cost effective – spend more than save	[42]
Not fair to tenants	[42]
No uniform standards for cost allocation	[53]

The major concerns surrounding submeter installation is the cost of installation and in some cases the increased cost of operation. In a multiple occupant residential building that previously divided the total bill evenly among all tenants, for example, increasing the number of meters increases the number of bills and paperwork for the building, which increases the number of man hours spent on billing, and adds to the operating cost [44, 46, 53].

The only paper reviewed which had a purely negative view on the use of submetering was written in response to proposed legislation in Ontario allowing landlords to install electric submeters without tenant consent in low income housing [42]. It had a very critical view of submetering in multi-tenant environments stating, “We have found no expert studies that provide a detailed analysis of individual or sub-metering examining, characteristics of the building where individual or submeters are installed, who if anyone is achieving savings, how savings are being achieved (behavioral or energy efficiency), impact on housing and financial security, cost benefit analysis of submetering versus energy efficiency retrofits versus education" [42]. It concluded that tenants would spend more money on submeter installation (through mandated rent increases) than would be saved through their use, and suggested increased education as a more cost effective alternative. It cited that no detailed studies had been completed that examine a cost-benefit analysis of sub-metering versus energy efficient retrofits versus education.

The DOE recognizes the high cost and difficult economic justification of current submetering technology. In order to combat this and promote increased use of submetering, they have created a low cost electric submeter challenge, with the goal of creating a $100 wireless submeter [56] . The challenge has specific requirements regarding accuracy and meter capabilities with the hope of furthering submetering use [57]. To date there has not been a metering solution presented that meets all of the require criteria.

2.2.2.4 MANUFACTURING ENVIRONMENT

In small and medium sized manufacturing facilities, submetering is rarely a tool used in the process of improving energy efficiency. Some utilities estimated that only 2-5% of manufacturing facilities were submetered as of 1999 [54].

While there were less articles focusing on using submetering specifically in manufacturing [6, 35, 49, 51, 52, 58], all of the benefits identified in Table II-1 could be applied in the manufacturing environment. Some of the benefits identified that would be of key interest in the manufacturing environment are identified in Table II-3 below.

Table II-3 Summary of Identified Benefits to Submetering in Manufacturing Environment

Benefit	Reference
Measure and verify savings from improvement projects	[6, 35, 38-41, 43, 45, 46, 48, 59]
Peak demand identification/Load shifting	[5, 6, 35, 38, 40, 41, 43, 50, 51, 59]
Equipment maintenance/predictive maintenance	[35, 38, 40, 43, 46, 49-51, 59]
Diagnostic capability	[35, 38, 40, 41, 43, 46, 49-52, 54]
Benchmarking consumption/creating baselines	[35, 38-41, 45, 48, 51, 59]
Usage analysis/consumption profile	[6, 35, 36, 38-41, 46, 48, 52, 59]
Identify major energy users/establish energy use by process	[6, 35, 36, 38-41, 46, 48, 52, 59]
Power quality analysis and monitoring	[35, 38, 50, 51, 55]
Load control/comparisons	[5, 6, 35, 41]
Control capability	[41, 49, 50]
Leak detection	[41, 59]
Improving equipment use	[50, 59]
Emergency response/improved safety	[38, 50]
Identify future energy savings opportunities	[35, 54]
Verify utility bills	[50, 54]
Allocate energy costs to specific processes	[52-54, 59]

While these articles identify the benefits associated with submetering in the manufacturing environment, there is little reference to the expected savings from its use. Cited cases of expected savings are mainly from the non-manufacturing environment. The author believes this is due to the inherent differences between the non-manufacturing environment and manufacturing environment. In a commercial setting with multiple tenants who are commonly not being billed on actual consumption, there are obvious, easy to calculate savings and paybacks associated with the use of submetering technology for the building owners. These types of environments also allow the costs of metering to be partially or fully passed on to tenants, helping relieve some of the financial burden.

The most applicable example in the literature of a manufacturing facility successfully implementing a submetering system comes from a DOE case study on a large manufacturing facility, Nissan's Smyrna, Tennessee facility [59] . Nissan successfully upgraded an old energy management control system to collect data from new submeters and report the data in a meaningful way. Using submetering the facility was able to measure electricity, natural gas, city water, compressed air, and both high temperature and chilled water. The system provided weekly and monthly reports to the manager of each plant shop to help monitor energy use. In addition to monitoring consumption, upper management made each plant division responsible for its own utility budget, increasing the priority given to energy management. This case study is a rare, but good, example of how submetering can be successfully used in a manufacturing environment. However, many of the barriers faced by SMM organizations were not an issue due to the size of Nissan's operation.

The major challenge in the SMM environment with cost justification of installing this technology is that many of these items are unknowns and would not be quantifiable without the metering data after the fact. This creates uncertainty and likely decreases the adoption rate of the technology, especially with the limited amount of published information directly relating to manufacturing. Incorporating the data produced from submeters into a larger system that can generate actionable information may assist with this.

2.2.2.5 INVESTMENT DECISION SUPPORT

There has been some work in the literature to quantify the value of submeter data in order to calculate a payback and justify an organization's investment. Most notably the U.S. Federal Energy Management Program (FEMP) released a 'Guidance of Electrical Metering in Federal Buildings' to assist Federal buildings in complying with the Energy Policy Act of 2005. This act requires all federal government occupied buildings to implement advanced metering, when cost effective, by 2012 [38]. Because 'when cost effective' is fairly ambiguous, the report provides general thresholds of expected savings based upon the actions taken with the data produced by submetering. FEMP regards cost effectiveness as being based on a ten-year simple payback, assuming an annual savings of at least 2%.

Table II-4 DOE Metering Saving Ranges [38]

Action	Observed Savings
Installation of meters	0-2% the "Hawthorne Effect"
Bill allocation only	2.5-5% Improved awareness
Building tune-up	5-15% Improved awareness, and identification of simple O&M
Continuous commissioning	15-45% improved awareness, identify simple O&M, project accomplishment, and continuing mgmt. attention

Also identified in the report is a formula and sample calculation to identify the minimum annual electric bill required to justify a system based upon desired payback, annual cost, annual savings, and installation cost [38]:

$$Minimum\ Annual\ Electric\ Bill = \left[\frac{\left(\frac{Installation\ Cost}{Desired\ Simple\ Payback\ Period}\right) + Annual\ cost}{Expected\ \%\ Annual\ Savings}\right] \tag{2.1}$$

While this information is helpful, the observed savings are not supported with extensive data. Two case studies are cited: one focusing on submetering in apartments and one focusing on submetering in universities. A building owner outside of the Federal government would likely not rely on this information alone to determine how to invest in submetering technology for their building.

Other articles discuss cost justification calculations using various engineering economic methods such as simple payback period, savings to investment ratio, net present value, and adjusted internal rate of return [40, 53]. However, they do not provide guidance on the expected savings from using submetering technology.

2.2.2.6 APPROACHES TO METERING PROGRAMS

Several articles present general outlines of approaches to undertaking submetering installations. The most detailed method for the design of a metering program is presented by the DOE/FEMP [38, 41]:

- Formalize objectives and goals of metering program.
  - Identify and confirm goals of stakeholders/users
  - Prioritize goals as near-term, mid-term, and long-term
  - Formalize necessary/expected outcomes
- Develop program structure. Identify data needs, equipment needs, analysis methodologies, and responsible staff.
  - Develop data and analysis needs based on necessary outcomes
  - Develop equipment needs based on data needs
  - Take advantage of existing infrastructure
  - Identify responsible staff, preferably a metering "champion"
- Develop criteria for evaluation metering costs, benefits, and impacts to existing systems, infrastructure, and staff.
  - Determine relative economics of proposal
  - Justify with cost/benefit, return on investment, or payback metric
- Develop a prioritized implementation plan targeting manageable successes.
  - Screen opportunities based on success potential
  - Start small/manageable—build off success
- Develop a sustainable plan targeting use, updates, calibration, maintenance, and program reinvestment.
  - Maintain your investment
  - Make this success visible
  - Plan for future implementation/reinvestment

A less detailed method for the process of metering and submetering that addresses the same major issues is presented by the NSTC [40]:

- Determining what should be measured in any particular building or location,

- Measuring the physical properties of flow through the distribution system to determine how much of each resource is being consumed,
- Collecting the data at predetermined intervals and storing those measurements,
- Analyzing the measurements to determine how much of each resource is being used,
- Making informed decisions based on all information provided.

Both of these methods provide a basic, logical approach to planning submetering projects. However, there is still opportunity for improvement. Greater detail can be provided for SMM organizations within the context of a larger energy management system.

There is a clear understanding in the literature that meters alone do not add value; the data they provide must be used to create actionable information. While this information, such as items identified in Table II-1, is definitely valuable, quantifying the value of these items is difficult.

2.2.2.7 SECTION SUMMARY

Submetering is a useful tool that can assist in managing energy in both the non-manufacturing environment and manufacturing environment. However, the adoption of the technology in SMM organizations has been slow. This is likely due in part to the lack of actual cases in the manufacturing environment showing an example of submetering's return on investment. There is a need for further analysis and research on the savings generated from submetering systems, as well as investigation into how such systems can be incorporated into a formal energy management system.

Submetering systems can make the largest impact when combined with a larger energy management system with the purpose of benchmarking performance, providing monitoring and baselines, and tracking performance metrics such as energy intensity. There is an obvious need for greater investment decision support in the manufacturing environment, specifically as part of a larger energy management system. The development of a submetering system that is scalable and can grow as an organization's energy management program grows (ex. at first meter only major equipment, expand as benefits are proven) would greatly help SMMs.

2.2.3 ENERGY INFORMATION SYSTEMS

Because submetering alone does not produce savings, and only data, it is critical to transform this data into actionable energy saving information. This is commonly achieved through an energy information systems (EIS).

An energy information system is defined by Lawrence Berkeley National Laboratory as:

> *"the web-based software, data acquisition hardware, and communication systems used to store, analyze, and display building energy data. They often include analysis methods such as baselining, benchmarking, load profiling, and energy anomaly detection"* [60].

Modern day EIS systems have grown from the computer based energy management systems created in the 1980s. The development of the internet has increased their popularity and decreased the cost of remotely monitoring consumption [61]. Lawrence Berkeley National Laboratory (LBNL) and others have conducted significant research on EIS systems, with the majority of focus being their use in the non-manufacturing environment.

LBNL's most recent work has focused on determining the cost of installing EIS systems and estimating the expected savings generated by such systems in the commercial retail environment [60]. LBNL worked with EIS vendors to identify recently implemented EIS projects and determine their success in reducing energy consumption. The goal of the study was to provide information about EIS in order to inform decision makers on their investments. The key benefits of an EIS system identified by this study were improving operational efficiency, utility billing validation, and information for custom analyses. The study concluded that EIS systems can enable savings between 8 and 17%, but identified more work is needed to explore the relationship between energy savings and the use of EIS.

Previous work by LBNL on EIS has included business case studies on EIS use in commercial settings [62, 63] and the use of EIS for automated demand response [64, 65]. These articles identify the need for further understanding and identification of building consumption before and after implementing an EIS and learning how EIS can be used effectively within organizations.

Other articles focusing on the commercial sector recognize the value of EIS systems for facility managers [66, 67]. EIS systems have been used for modeling and forecasting energy consumption, reviewing building energy consumption trends, detecting and diagnosing faults, and the measurement and verification of energy retrofits and upgrades.

In Europe, energy information systems (also referred to as monitoring and targeting systems) are frequently used for monitoring the reduction of CO_2 emissions [68, 69]. Energy use is captured and emissions data is calculated based on the fuel source used to generate the resources used by the facility.

Several articles have focused on EIS use in the manufacturing environment. They have been used to help understand the embodied product energy, which is a combination of the direct energy and indirect energy used to create an individual product [70]. Other work involves creating energy aware EIS. This entails monitoring energy consumption across processes in order to minimize production time and energy usage, essentially optimizing the production schedule based on energy consumption [71].

Work has been done on using EIS data to classify the energy consumption patterns of various machine states. The work revolves around identifying the operational states within a cycle of a manufacturing process using mathematical models. This allows for modeling energy consumption patterns in industrial machines for the purpose of energy audits and machine scheduling [58].

A final article focused on the use of EIS in the plastics, computing and electronics, and food and related products industry in northern and central California. This work identified that EIS is used for monitoring consumption and load shaping activities [72].

The review of papers identified in this dimension underscored the benefits of EIS systems. However, like submetering, the majority of the focus has been on the non-manufacturing environment. The main gap appears to be the need for further work showing the effectiveness of EIS systems to save energy/money in SMM environments.

2.3 BARRIERS TO ENERGY EFFICIENCY

For the three types of energy saving strategies focused on in this literature review (EnMS, submetering technology, and EIS), abundant evidence and literature exists on their benefits as seen in the previous sections. However, despite the evidence of value, the use of these methods and technology adoption is relatively low in SMM facilities. This disconnect between the lack of energy efficient measures implemented/adopted, despite evidence of cost effectiveness, is often referred to as the ‘energy efficiency gap’ or ‘energy efficiency paradox’ [73-79]. This phenomenon was first observed in 1994 by Jaffe and Stavins [80] and has been a widely studied area by multiple disciplines. The energy efficiency gap has been observed on a global scale and in various industries.

The literature describes the existence of this gap as a result of barriers in multiple aspects of an organization. The definition of barriers applied in this research is based on Sorrel et al [81]: "*barriers comprise all factors that hamper the addition of cost-effective energy-efficient technologies or slow down their diffusion*..."

The majority of the literature reviewed focuses on the barriers leading to the 'energy efficiency gap' in the manufacturing industry. This dissertation does not attempt to add new barriers to the energy efficiency gap literature. It seeks to understand the existing barriers contributing to the energy efficiency gap, and use that data to shape the model presented in this dissertation, in order to address some of the most common barriers observed by SMMs.

The literature has taken several approaches to identifying barriers to energy efficiency. Many studies have relied upon surveys to gather data from organizations, while some have analyzed existing data (like the IAC implementation report database) to gain insight on barriers. The focus of this literature review has been on manufacturing facilities in the United States; however, some applicable international studies and studies focusing on other industry sectors are included.

The majority of the literature classifies barriers into several broad categories (such as behavioral, organizational, economic [82], market related [83], etc.) and then provides multiple barriers within each classification.

While many barriers to energy efficiency exist, the author classified the key barriers to energy efficiency observed in the reviewed literature and of interest to this dissertation as follows: lack of awareness or education regarding energy efficiency improvements, lack of technical skills, other investments deemed more important, lack of access to capital or other financial restraints, perception of already being efficient, project risks, lack of metering, management, organizational, and regulation related barriers. The specific instances of these barriers identified in the literature are summarized and discussed in more detail in Section 2.3.1.

2.3.1 KEY BARRIERS

Lack of awareness and education

Personnel within an organization lacking awareness and education regarding energy efficiency improvement options is commonly referred to as a barrier to energy efficiency as seen in Table II-5. While ignorance may be bliss, it is also expensive. Energy efficiency measures are not always intuitive, and a lack of training or awareness of current best practices results in inefficiency and waste within an organization. As an organization grows its EnMS maturity, part of the process is to increase the training and awareness of its employees and management with regards to energy efficiency measures.

Table II-5 Barriers Attributed to Lack of Awareness and Education

Lack of awareness and education	Reference
Educating consumers	[84]
Ignorant of improvements	[85]
No good overview of existing technologies	[86]
Poor information quality regarding energy efficiency opportunities	[82]
Lack of knowledge about cost of energy savings technologies	[76]
Lack of awareness, education, and training	[77]
Lack of information in energy efficiency and savings technology	[87]
Lack of information	[76, 79]
Awareness of options	[79]
Low diffusion of technologies	[79]
Lack of expertise and competences to identify inefficiencies and opportunities and Implement energy efficient measures	[79]
Low diffusion of technologies	[79]

By empowering employees, and management, to take an active part in improving efficiency and reducing waste through training, an organization is able to take steps towards breaking down this barrier.

Lack of technical skills

Related to the previous barrier, an organization's personnel lacking technical skills to carry out energy efficiency improvements is another common barrier to energy efficiency as seen in Table II-6. While an organization may understand that implementing an improvement would help improve their energy management, they may lack the in-house ability to install such an improvement. This often increases the cost of the installation and operation of an improvement and, therefore, reduces the likelihood an organization will move ahead with such an improvement. In the case of formal energy management systems, submetering and EIS, if a facility lacks the technical expertise in house and is unsure of the savings that will come from such an investment, it is very unlikely the company will pursue a large initial investment in a project that might provide known benefits and be able to be completed using in-house personnel.

Table II-6 Barriers Attributed to Lack of Technical Skills

Lack of technical skills	Reference
Lack staff for analysis/implementation	[88]
Technical (eg. Lack of availability, reliability, and knowledge of efficient technologies)	[75]
Technical risk	[82]
Lack of technical skills	[82]
Technical risk such as risk of production disruptions	[82]
Shortage of trained and capable technical personnel as most are busy maintaining production	[76]
Technological and financial risks	[89]
Fear of technical risk/cost of production lost	[87]
Lack of trained manpower/staff	[87]
Lack of experience in technology	[87]
Technical options	[79]
Technology related	[79]

In order for the implementation of an improvement or EnMS to succeed, it is important that an organization grows within their technical capabilities, and undergoes training as needed to reduce any gaps in technical skills.

Other investments deemed more important

The literature indicates that sometimes an organization will view other investments as more important than spending money on energy efficiency improvements as seen in Table II-7. The literature identifies energy efficiency improvements often compete for funding with improvements related to quality and production. An interesting insight in the literature is that energy efficiency is often seen as a co-benefit to a larger project, and that energy efficiency may be a side effect of a larger improvement rather than the focus [83]. The use of co-benefits as a driver for energy efficiency will be included in the model presented in this dissertation.

Because energy efficiency projects often compete for funding with projects that may increase the facility's production capacity, demonstrating viability is very important. In one study reviewed, it found that 60% of managers surveyed indicated energy conservation is not a core business activity and is often overlooked since their focus is on daily production issues [76]. Another study found the main driver for energy efficiency investment is reducing the final production cost [77].

It is important to keep both of these items in mind when implementing an EnMS to ensure the activities related to energy efficiency fit into the existing culture or viewpoints as much as possible. For example, in an organization where energy is overlooked for production issues and focus is on the final product cost, using submetering to identify the energy intensity per unit of product and then working to reduce the intensity (and cost) is a logical approach.

Table II-7 Barriers Attributed to Investment Priorities

Other investments more important	Reference
Energy costs are not sufficiently important	[86]
Energy efficiency has a low priority	[79, 86]
Other investments more important	[86]
Lack of time or other priorities	[82]
Other priorities for capital investments	[82]
Energy efficiency often overlooked because it is not a core business activity	[76]
Energy savings not first priority in investment decisions	[76]
Energy bill is often a small portion of the total production costs, incentives to pay attention to rational use of energy are rather weak	[76]
Management finds production more important	[77]
Management concerns about time required to improve energy efficiency	[77]
Management more concerned about production	[77]
Other capital investments are more important	[87]
Values	[79]

Using methods such as activity based costing (discussed in Section 2.4.2) may also help to move energy from an overhead expense to an expense that is more closely monitored and helps to drive efficiency improvements through greater accountability. Increasing energy efficiency's importance ties into the management and organizational culture's attitude towards efficiency.

Management

The views and actions of management are commonly referred to as a barrier to energy efficiency as seen in Table II-8. As mentioned above, if management is more focused on production, or takes a short term thinking approach, this will lead to inefficiencies and waste at an organization. For example, if a standard efficiency piece of equipment is chosen over a high efficiency piece of equipment based on first cost alone, and not the total life cycle cost, management will likely create many opportunities to reduce waste at an organization.

Table II-8 Barriers Attributed to Management

Management	Reference
Indifferent	[85]
Helpless	[85]
Short sightedness of management	[90]
Difficult to implement due to internal organization	[86]
Managerial (eg. Inappropriate program management practices and staff training)	[75, 77, 79]
Short term thinking	[76]
Lack of top management commitment/understanding	[77]
Social, cultural, and behavioral norms and aspirations	[77]
Management finds production more important	[77]

Because management buy-in to energy management is so important, it is one of the first steps in the ISO 50001 process.

Organizational

Organizational culture is another common barrier mentioned in the literature, as seen in Table II-9. Similar to management acting as a barrier, the overall organizational structure can act as a barrier. Change is often hard and met with resistance and because energy efficiency improvements often come in the form of process changes [87], it is sometimes difficult to change the behaviors of personnel. For example, it is much easier to use compressed air for cleaning rather than a broom or less energy intense method. This leads back to education and awareness of why a change is being implemented. As an EnMS is put into place and personnel are included in the process and given responsibility related to energy usage, this would likely help encourage organizational change.

Table II-9 Barriers Attributed to the Organization

Organizational	Reference
Inheritors of inefficiency	[85]
Problems of focus and attention	[90]
Organizational and human factors barriers	[74, 76, 77, 79, 82, 89]
Behavioral barriers	[74, 77, 79, 82]
Institutional (eg. Lack of appropriate technical input, financial support, and proper program design and monitoring expertise)	[74, 75, 79]
Institutional frameworks	[77, 79]
Lack of coordination between company sections	[77]
Lack of coordination between external organizations	[77]
Lack of coordination and slackness	[77]
Resistance to change	[87]
Social, cultural, and behavioral norms and aspirations	[79]
Human dimension	[79]
Internal conflicts	[79]

Already thought of as efficient

Related to organizational culture, often organizations perceive themselves as energy efficient as seen in Table II-10. Because of this, energy efficiency may not be focused on and energy usage may not be scrutinized. As part of an EnMS, continual evaluation of energy usage and performance would help to either confirm existing beliefs of energy efficiency, or identify previously unknown wastes or possibly new developments in technology to further improve energy efficiency. This dissertation presents a tool that allows an organization to perform a 'self-assessment', to identify where energy expenses rank in relation to other costs, and to start to think about how much waste might truly be occurring.

Table II-10 Barriers Attributed to Perception of Efficiency

Already thought of as efficient	Reference
Efficiency blind	[85]
Operating cost blind	[85]
Current installations are sufficiently efficient	[77, 86]
Perception of already being efficient	[79]

Access to capital

One of the most common barriers mentioned in the literature is the lack of capital to undertake energy efficiency improvements as seen in Table II-11. Often times an organization may recognize an improvement as valuable and have the technical ability to carry it out, however, the operating budget may not allow for such an improvement to be completed. SMM facilities often have short payback requirements for energy efficiency improvements and are very first cost sensitive. Researchers using historic data from the IAC implementation database found that historically the longer an improvement's payback, the less likely an organization is to implement it. They found a 10% increase in payback lead to a 0.8% decrease in the probability of implementation, where as an increase in annual savings of 10% lead to a 0.6% increase in the probability of implementation. This indicates that the first cost of an improvement has a 40% greater effect on its implementation relative to future energy savings [88].

Table II-11 Barriers Attributed to Access to Capital

Access to capital	**Reference**
Poor/first cost sensitive	[79, 85, 88]
Short payback period required	[78, 90]
Internal constraints on the budget	[86]
Problems with internal financing	[86]
Cash flow prevents implementation	[88]
Unsuitable return on investment	[88]
Financial (eg. Lack of explicit financing mechanisms)	[75]
Access to capital	[77, 79, 82, 83, 87, 89]
Economic barriers	[79, 82]
Financial and market barriers	[76]
Financing/Financial constraints	[76, 77, 79]
Management concerns about investment costs of energy efficiency	[77]
Investment cost	[78]
Perceived high cost of energy investment	[87]

Because of this, it is important that an EnMS is sustainable in order to compete for funding with other improvements within an organization.

Project risks and uncertainty

Risks and uncertainty surrounding energy efficiency improvements is commonly referred to as a barrier to energy efficiency as seen in Table II-12. While many technologies or improvements related to energy efficiency are fairly 'mature' or tested, some newer technology has less of a track record in the SMM environment. For example, there are few examples in the literature of submetering and EIS being used in SMM facilities, which increases the risk and uncertainty of an organization to invest money in them. Similarly, some articles in the literature cite uncertainty surrounding the future of energy prices as a barrier. If energy prices drop, paybacks increase.

Table II-12 Barriers Attributed to Project Risks and Uncertainty

Project risks and uncertainty	**Reference**
Uncertain	[85]
Uncertainty regarding the quality	[86]
Currently introducing a new technology	[86]
Better to await for experience of colleagues	[86]
Technology will become cheaper	[77, 86]
Maybe new technology will not satisfy future standards	[86]
Project risks	[88]
Possible poor performance of equipment	[82]
Uncertainty and risk	[77, 89]
Technological and financial risks	[82, 89]
New tech may not satisfy future standards	[77]
Risk and uncertainty	[79, 83]
Uncertainty about future energy price	[79, 87]
Credibility and trust	[79]

These risks can be minimized through research and planning. Organizations can avoid fully committing to a new technology by testing it first. For example, prior to completely retrofitting an entire facility with LED lighting, one or two fixtures could be installed for reliability testing.

Lack of energy metering/submetering

The lack of metering at a facility and lack of information regarding historical consumption patterns is commonly referred to as a barrier to energy efficiency as seen in Table II-13. By not having access to accurate information related to how much energy a system is using in order to set a baseline for consumption, the risk and uncertainty relating to some improvements becomes a barrier. While advanced metering is often expensive and may not have an immediate benefit, the long term benefits of such equipment are often invaluable when making decisions related to the metered systems.

Table II-13 Barriers Attributed to Lack of Energy Metering/Submetering

Lack of energy metering/submetering	**Reference**
Difficult monitoring savings achieved by energy management investments	[90]
Lack of submetering/energy metering	[82, 87]
Cost of obtaining information about the energy consumption of purchased equipment	[82]
Difficulties of keeping proper records of energy savings also raised as important obstacles	[76]
Lack of information about energy consumption patterns	[89]
Imperfect information	[83]

Regulation

Governmental regulation and policy (sometimes the lack thereof) is commonly referred to as a barrier to energy efficiency as seen in Table II-14. Many of the areas where EnMS are currently being used in SMM facilities do so as a result of tax related motivation. For example, in Germany facilities receive tax credits for implementing ISO 50001 [86]. A similar practice is observed in the U.S. where utility companies offer incentives or rebates for certain energy efficiency improvements. This practice has helped to reduce the payback of projects that might otherwise be unappealing and encourage the adoption of newer technologies.

Table II-14 Barriers Attributed to Regulation

Regulation	Reference
Better to wait for subsidies	[86]
Lack of enforcement for government regulations	[77]
Government does not give financial incentives	[77, 87]
Policy/Regulation	[77, 79]
Weak policies and legislations	[87]
Misplaced incentives	[79]

While no regulation or government policy in the U.S. currently requires or rewards the use of EnMS, this may be a development in the future that helps increase their use.

2.3.2 SECTION SUMMARY

The key barriers mentioned in this section are addressed in part by the model presented in this dissertation, with the goal of lessening their ability to inhibit an organization's energy management system maturity and continual improvement. By addressing these barriers, the likelihood of success during the implementation of an EnMS increases. By better understanding the common barriers to energy efficiency improvements, the way decisions are made regarding improvements can also be better understood. Section 2.4 reviews the literature surrounding decision support for energy efficiency improvements.

2.4 DECISION SUPPORT FOR ENERGY EFFICIENCY

Given the barriers SMMs face related to energy efficiency improvements, it is important to understand how they ultimately decide to make an investment. Better understanding of some of the drivers behind the measures that do get implemented, as well as understanding how an energy management system might be structured to help improve the decisions made related to energy efficiency, are useful. Many of the barriers discussed earlier ultimately become part of the decision making criteria: Is the level of risk associated with the project acceptable?, Do we have appropriate in-house technical skill to successfully implement this?, Is the payback acceptable?, etc.

Of particular interest to the author are several topics surrounding decision-making processes for energy efficiency improvements: investment criteria, activity based costing, and the measurement and verification of improvements.

As seen in the review of barrier literature, the cost of an improvement project is often a key obstacle. The decision to make an energy efficiency improvement is often a financial one based on the expected costs and benefits of the project in question. Historically however, energy efficiency projects are not always evaluated using the most appropriate methodologies. When evaluating an energy efficiency project, it is most common that organizations use a simple payback methodology. However, as shown in the literature, this is not always the most appropriate tool to assess investment opportunities, more appropriate methods are available. By more appropriately assessing the financial benefits of energy efficiency improvements, management's decision-making process with respect to energy efficiency will be improved.

While it is not uncommon for manufacturing facilities to consider energy as a cost of doing business, it is possible, and has been documented in the literature, that the actual energy cost of making product A is greater than the overhead allotted to that product, and in reality the energy cost of making product B is much less, making product A look profitable. This can be rectified using a method such as activity based costing, as discussed in Section 2.4.2. In such a method different product lines or activity centers are held accountable and 'charged' for the actual energy consumption used to make a product. The author believes this could be an important component of a more advanced energy management system and could help change the way management views and makes decisions regarding energy.

Often times when an energy efficiency improvement is made, the verification of such an improvement is difficult to achieve. For example, if insulation is added to steam lines in a boiler room and the boiler is not the sole user of natural gas in the facility, the drop in natural gas consumption may not show up on the utility bill. This could lead to increased resistance from management to spend money on efficiency improvements. The use of appropriate measurement and verification methods is important to ensure success of an energy management system.

These three sub topics and how they relate to decision support for energy efficiency are reviewed in more detail below.

2.4.1 ENERGY EFFICIENCY INVESTMENT CRITERIA

As identified in the barrier literature, many organizations' energy efficiency improvement projects fail to be implemented due to financial reasons. Using historic data from the Industrial Assessment Center implementation database, researchers found the longer an improvement's payback, the less likely an organization is to implement it with the first cost of an improvement having a 40% greater effect on its implementation relative to future energy savings [88].

Many organizations rely on financial analysis prior to an improvement's undertaking to determine if it is a wise investment. This often involves comparing multiple alternatives (ex. purchasing a standard efficiency motor vs. a high efficiency motor) or comparing the 'do nothing' alternative against the 'do something' alternative (ex. operate the steam system with its existing level of insulation, or operate it with improved insulation). These analyses often require two pieces of information. The first is identifying how much a given improvement will save the organization. This is determined by an engineering analysis for the given improvement to determine the energy (kWh, kW, MMBtu, gallons, etc.) expected to be saved per year. This is then equated to dollars using the average cost of the resource saved. Because this expected savings is based on estimates and calculations, it is important to appropriately measure and verify the savings after an improvement has been carried out. This is discussed in more detail in Section 3.2.

The second piece of information required is how much a given improvement will cost the organization. This might include the cost of planning or designing the improvement, the raw materials needed, labor hours required for installation, possible cost to retrain employees, etc. Once the organization has identified what it plans to save and what the cost to obtain the savings is, they can begin to determine if the investment is appropriate using a variety of different methods.

Below, several engineering economics methods used in the energy management decision-making process are reviewed. Some of these are commonly used, while others are less commonly used for energy efficiency projects but are argued for increased use within the literature.

Simple Payback Period

The payback period, or simple payback period (SPP), is frequently used by organizations when assessing an energy efficiency improvement. This is simply *"the number of years required to recover an initial investment through project returns* [39]*."* Using the two pieces of information mentioned above, the simple payback period is simply calculated by dividing the cost of an improvement by the expected annual savings.

$$SPP = (Initial\ Cost)/\ (Annual\ Net\ Savings) \qquad (2.2)$$

Given the simplicity of simple payback, many organizations rely on this method of financial analysis to make the initial investment decision. It is very popular for a number of reasons as discussed in the "Principles of Engineering Economics"[91]: it is a mathematically simple calculation, it does not require the use of the minimum acceptable rate of return (MARR), it is easily explained and understood, when capital is limited it fits management's attitudes, it hedges against uncertainty of future cash flows, and provides a rough measure of liquidity of an investment. In the IAC program, the U.S. Department of Energy requires any recommendations made to have a simple payback period of five years or less, while many of the IAC clients and other organizations have internal requirements of projects to have even shorter paybacks [92, 93]. This is motivated in part by the barriers energy projects need to overcome; if a project has a shorter payback an organization is willing to accept some of the risks or unknowns that might make a project with a longer payback unappealing.

However, using the simple payback alone has several downfalls and is not always an appropriate standalone method [93]. This is discussed in the literature in several places. Starting with the "Principles of Engineering Economics", SPP does not consider the time value of money (TVOM) and ignores salvage values and MARR. Several articles also point out that the simplicity of using simple payback calculations for decision making is overly simplistic [94]. Some issues they identify are that a specific project's payback is often variable through time, changing with interest rates and the cost of energy. However, project paybacks often do not account for this and are not updated. Payback calculations do not assess the profitability of an investment, only the time for an investor to receive their money back [94].

These papers present several alternative methods that are less used, but provide a more appropriate look at the value provided by an energy efficiency improvement.

Discounted Payback Period

The "Principles of Engineering Economics" presents the discounted payback period (DPBP) as an alternative to SPP. Similar to the SPP, it determines the time required for an investment to be fully recovered, but unlike the SPP, it includes the time value of money and salvage values. The formula for calculating the DPBP is [95]:

$$\textit{Discounted Payback Period (DPBP)} = A + (B / C) \tag{2.3}$$

Where,
A - Last period with a negative discounted cumulative cash flow
B - Absolute value of discounted cumulative cash flow at the end of the period A
C - Discounted cash flow during the period after A.

While this is an improvement over the SPP, the discounted payback period is still intended to be used as only a supplemental tool and not a stand-alone measure of an improvement's economic worth.

Net Present Value

The net present value (NPV) calculation helps provide an estimate *"of the net financial benefit provided to the organization if this investment is undertaken* [93]*"* (relative to the MARR). It is given by the formula:

$$NPV = \sum_{t=1}^{T} S/(1+i)^t - I \tag{2.4}$$

Where S is the discounted sum of the savings, *I* is the investment cost, *i* is the interest rate, and *T* is the useful life of the improvement [93]. A project with a NPV less than zero should not be considered cost-effective because it would represent a financial loss to the organization [39].

Internal Rate of Return

The internal rate of return (IRR) method determines the *"interest rate that yields a future worth (or present worth/annual worth) of zero* [91]*"* or in other words is *"the discount rate at which the present value of a project's costs equal the present value of the project's savings* [93]." It can be determined by setting the NPV equal to zero and solving for *I* [93]. If the computed IRR for a project is greater than the established discount rate for an organization, the project may be considered cost effective [39].

There are a large number of calculation alternatives available for use in estimating an investment's profitability. As discussed above, three of the most common methods are SPP, NPV, and IRR. Based on the literature reviewed NPV is generally considered to be the method that provides the most correct basis for decision [96].

Some additional methods presented in the literature for energy investment decision analysis are presented below.

Life Cycle Costing

An additional alternative to SPP presented in the literature is life-cycle costing (LCC), which according to the ASHRAE Handbook: *"compares the cumulative total of implementation, operating, and maintenance costs. The total costs are discounted over the life of the system or over the loan repayment period. The costs and investments are both discounted and displayed as* *a total combined life-cycle cost at the end of the analysis period. The options are compared to determine which has the lowest total cost over the anticipated project life* [97].*"*

It is a useful tool when comparing multiple alternatives, including the 'do nothing' alternative. In a LCC analysis the total expenses to implement each alternative over a time period, like its useful life, is determined. Both costs and income for the alternative are identified. Costs might include financing expenses, energy expense, maintenance, operations, or equipment replacement. Income might include energy savings, depreciation, productivity improvements, quality improvements, or production improvements. After adjusting for inflation and any anticipated changes the annual cash flow is determined over the life of the alternative and using an assumed interest rate is converted into a total net present value. This then serves as a representation of the money required to operate and maintain the equipment or systems useful life. When comparing alternatives, the one with the lowest cost is the one which requires the least amount of money to own, operate, and maintain over time [92].

Save or Buy Analysis

A newer methodology presented in the literature is called the 'Save or Buy' analysis [94]. This is based on the premises that an organization has committed to doing business, it has committed to using energy, and that all organizations experience energy waste. The article argues that the purchased energy can be divided into the purchased energy used as intended and the purchased energy that is wasted. The portion of the waste that can be avoided in an economic sense is defined as the 'energy at risk'. If the organization continues its operations as usual, it will pay for both the energy at risk and the energy used as intended.

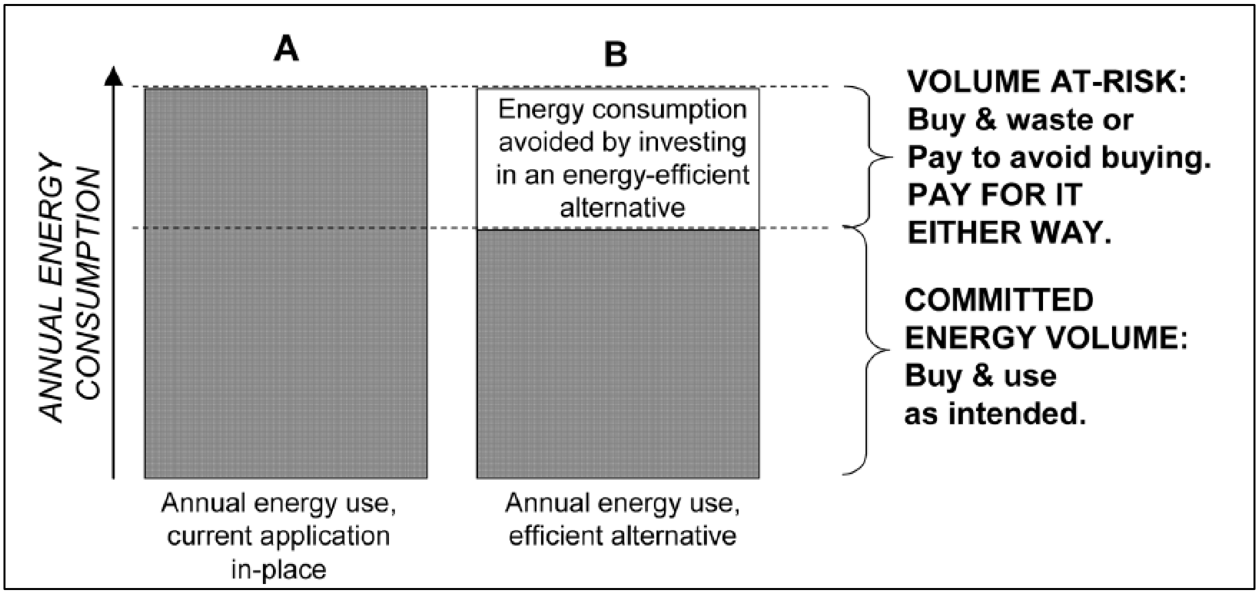

Figure II-8 Energy at Risk [94]

The work presents the ‘save or buy’ method to determine if it is economical to continue buying and wasting a portion of its energy or implement energy efficiency improvements. This method provides a two-step calculation, first calculating the upfront cost to implement an energy saving project as shown in Figure II-9.

$$\text{ANNUALIZED PROJECT COST} = \left(\text{UP-FRONT PROJECT COST}\right) \times \left(\text{CAPITAL RECOVERY FACTOR}\right)$$

$$\text{CAPITAL RECOVERY FACTOR (CRF)} = \frac{i(1+i)^n}{[(1+i)^n]-1}$$

Where:
i = cost of capital or discount rate on future cash flows
n = economic life (years) of remedy (energy improvement project)

Figure II-9 ‘Save or Buy’ Analysis Step 1 [94]

The second step is to determine what it will cost an organization to save a unit of energy based on the project cost identified in Step 1.

$$\text{COST TO SAVE A UNIT OF ENERGY} = \frac{\left(\text{ANNUALIZED PROJECT COST}\right)}{\left(\text{UNITS OF ENERGY SAVED}\right)}$$

Figure II-10 ‘Save or Buy’ Analysis Step 2 [94]

This allows the organization to then compare the current cost per unit of energy versus the cost to save a unit of energy, using the ratio between the two to determine the payback of the project. The article makes a clear point that simple payback is only appropriate to use when the alternative to spending the money on an improvement is to keep the money and do nothing except continue to purchase and waste energy.

In summary, while simple payback period is often used as a method to assess an energy efficiency improvement projects merit, the literature recognizes this as an inadequate choice when used by itself. The literature identifies more appropriate methods such as LCC, NPV, and IRR, as well as newer methods like the ‘Save or Buy” analysis. All of these financial analysis methods provide ways an organization can make decisions regarding energy efficiency improvements. It is important for an EnMS to make use of the most appropriate financial analysis method when deciding whether or not to implement an improvement.

An alternative accounting method known as activity based costing and how it can help motivate energy efficiency improvement decisions is discussed in the next section.

2.4.2 ACTIVITY BASED COSTING

As seen in Section 2.3, many barriers exist to implementing energy efficiency measures in SMMs. One of those most frequently cited barriers is that energy management is not seen as a priority when compared to other day-to-day goals at the facility, such as production or quality. Energy expenses are often seen as an overhead cost and are not often formally managed in SMMs. As a result, the decisions related to energy usage are not given the same priority as decisions related to production.

In a manufacturing facility, overhead costs often account for a large proportion of operating expense in addition to things like labor costs, marketing costs, etc. Overhead commonly consists of items such as material handling, facility rent, tooling costs, maintenance, and energy. Activity Based Costing, or ABC, is an accounting method that assigns manufacturing activities and processes overhead expenses based on the resources they consume, rather than treating overhead costs equally among all activities [98]. ABC takes a relational approach to costing; it believes there is a direct relationship between overhead expenses and the products produced [99, 100]. It aims to assign a total cost to a product that equals the cost of raw materials and other activities required to produce it [101]. This differs from traditional costing, which approaches things like overhead in a way that all processes are treated equally and lacks direct relationship between overhead expense and the actual production process [99, 102]. This traditional method has little accountability associated with the actual end user or process that consumes the resources.

For example, when using traditional costing, the monthly electrical cost for a manufacturing facility might be divided equally among all processes or divided among processes based on their operating hours, regardless of their actual resource consumption. This means a very energy intense process which runs only a short amount of time but causes a spike in kW demand that follows the facility for months may be assigned a smaller portion of the overhead cost as it relates to energy when compared to a less energy intense process that runs a longer amount of time with low kW demand [103].

ABC treats assigning overhead costs differently, assigning cost based upon a processes actual consumption. ABC takes into account more than just energy consumption, but also items such as machine setup, testing, and engineering associated with a specific product or process. This results in more accurate costing, as well as encourages processes with higher costs to improve [98, 103]. By identifying the processes that contribute most to overhead and distributing costs to them accordingly, these ‘expensive’ processes will help drive process improvement in areas that will have the most impact [104]. By utilizing submetered data to provide the information needed to appropriately distribute energy costs by product, improvements resulting in reduced energy consumption would be realized by the appropriate process.

The benefits of Activity Based Costing include improvements in the accuracy of how costs are assigned to processes. Using traditional costing methods often results in over or under costing of products [105]. ABC also results in incentivizing the reduction of overhead cost by process, resulting in energy intensity to be focused on as a means to reduce expenses. ABC could help quantify the value of submetering data. Using a submetering system to provide accurate energy consumption data by process, more accurate costing information would be available. By determining how much a process was being charged before implementing ABC (without submetered data), and comparing it to the cost assigned after implementing ABC (with submetered data), a dollar savings could be able to be assigned to that process. The total energy charged in the facility would be the same; only the proportion ‘costed’ to an individual process would change. However, the adjustment in product pricing as a result from ABC could allow for increased profits. Assigning more accountability for energy consumption would also likely reduce energy consumption, which would be a quantifiable value.

Downsides to using ABC are that it is not currently accepted as an externally published financial statement by either the Financial Accounting Standards Board (FASB) or the Internal Revenue Service (IRS) [106]. This means it cannot be the only cost system used in an organization, requiring a second system to be used and maintained. Implementing ABC in an organization is also more complex and more expensive when compared with traditional costing methods [105, 107]. This is likely due to the increased amount of data processing required to determine how to appropriate costs based on consumption rather than evenly dividing costs amongst processes.

The ABC method’s lack of acceptance by the FASB and IRS [106], as well as its increased cost and complexity to adopt [105], may be a barrier to an organization implementing this method. These items would likely cause people within the organization to resist their implementation. The benefits associated with ABC may not be perceived to outweigh the challenges associated with its adoption. Increasing accountability and ultimately costs for high-energy use processes within an organization may result in push back from managers in those areas. They would likely not welcome the increased stress and accountability for the energy they consume.

The idea of activity based costing dates to the 1980s [104]. It has been received with moderate success and has been implemented in several cases. The appeal of including such a method in an energy management system in a manufacturing environment is that it would move energy from the overhead category into an additional resource that impacts the cost of a product. This would add an additional dimension and motivation to management’s decision-making process regarding energy efficiency. Instead of fixing air leaks being viewed as a good thing to do to lower overhead expense, it is now seen as a way to lower the cost per part of product A by X cents.

Interestingly, the U.S. Department of Energy produced an overview of Activity Based Costing in the late 1990s as part of their cost-estimating guide [108]. However, at the time they did not include a use of ABC as a way to change management's viewpoint on energy management. Their focus was on using ABC as a way to estimate costs for construction projects.

Other literature has focused on demonstrating ABC as a method that is compatible with manufacturing facilities for a variety of purposes other than with a focus on energy [101, 104, 109-112]. One article focused on using ABC to predict energy usage in an automotive manufacturing environment [113]. While this approach has merit, its focus was on the predictive model and less on using ABC to incorporate energy into the decision making process or relate it to EnMS. There is also the previously mentioned Nissan case study [50], which did not mention ABC by name, but mentioned the use of submetered data to attribute energy costs to different departments.

The most relevant article to this dissertation is by Fernandes et al [114], which provided a very detailed overview of how ABC could be used to move energy costs to a driver for energy efficiency. This article detailed the development of an energy allocation system using ABC at a small manufacturing organization. The study identified six cost centers in the facility and divided its electrical energy cost into individual resource costs (lighting, cooling, motors, production machines, and miscellaneous use). For each of these energy-resource cost categories the actual costs were determined through an energy audit. These energy costs were then allocated to the cost pools of each activity based on their cost drivers. The study then compared the costs attributed to each of the six cost centers using a traditional costing method vs. ABC. The findings showed that the traditional costing method produces a significant cost distortion and concludes that ABC provides "*an excellent opportunity to move the cost of energy from overhead to a line item in the* *cost of production, similar to the line item costs for labor and materials....ABC not only identifies the accurate cost of each product but is a true decision-making tool.*"

While this study is older (1997), it is the only paper identified that views ABC in this manner. It was written slightly before its time and before the prevalence of formal energy management systems and submetering technology. The views presented by this paper still have relevance today.

2.4.3 MEASURING IMPROVEMENTS

The final dimension related to energy efficiency decision making is how improvements are measured and verified. In order for an energy management system or energy efficiency program in an organization to be successful, it is important for any improvements made to show real savings. This is part of the decision making process and can even be a barrier to improvements being made, if carried out poorly. While the methods used to conduct measurement and verification (M&V) activities is an active area of research, there is also a nonprofit organization, which produces M&V best practices for industry, that is also important to discuss in addition to the current academic literature.

IPMVP

In 1996, the U.S. DOE published the North American Measurement and Verification Protocol (NEMVP), an effort involving industry experts from Canada, Mexico, and the U.S. The NEMVP was well-received and gained international attention and interest. This led to the republishing of the protocol in 1997 under the name the International Performance Measurement and Verification Protocol (IPMVP). In this new publication, additional information was added regarding new construction projects and water efficiency [115].

In 2001, the IPMVP was adopted as the industry standard approach to M&V, resulting in the formation of a non-profit organization (IPMVP Inc.) dedicated to the continued support of the protocol. The organization's name changed to the Energy Valuation Organization (EVO) in 2004 and has published several versions of the IPMVP protocol over the years, splitting the original 1997 publication into three volumes:

- Volume I is titled "Concepts and Options for Determining Energy and Water Savings",
- Volume II is titled "Concepts and Practices for Improved Environmental Quality",
- Volume III Part I is titled "Concepts and Options for Determining Energy Savings in New Construction", and
- Volume III Part II is titled "Concepts and Options for Determining Energy Savings in Renewable Energy Technology Applications."

Most recently, EVO has published the IPMVP Core Concepts document, which is an abridged version of the IPMVP Volume I. The focus of this review will be on the IPMVP Volume I and Core Concepts documents.

The IPMVP defines Measurement and Verification (M&V) as "*the process of using measurement to reliably determine actual savings* [116]." It commonly consists of activities such as installing metering equipment, gathering data, developing a computation method and reasonable estimates, and reporting results [117]. The protocol presents six fundamentals of the M&V process that any organization should consider when deciding how to determine the appropriate M&V method for their project:

- **Accurate**: M&V reports should be as accurate as the budget will allow. (Ex. A range of methods are available (from making an estimation to fully metering a system). The most accurate method affordable should be utilized.)
- **Complete**: The reporting of energy savings should consider all effects of a project. (Ex. If a measure such as reducing the HVAC set point by using fans is considered, the power

used by the fans should be considered in addition to the reduction in power of the HVAC units.)

- **Conservative**: Where judgments are made about uncertain quantities, M&V procedures should be designed to under-estimate savings.
- **Consistent**: The reporting of a project's energy effectiveness should be consistent between different types of energy efficiency projects, different energy management professionals for any one project, different periods of time for the same project; and energy efficiency projects and new energy supply projects.
- **Relevant**: The determination of savings should measure the performance parameters of concern, or least well known, while other less critical or predictable parameters may be estimated.
- **Transparent**: All M&V activities should be clearly and fully disclosed.

These basic principles guide the framework of the IPMVP's methodology. Determining energy savings is more difficult than one might realize because what is being measured is the amount of a resource not used. Because this cannot be directly measured, the basic goal of measuring and verifying energy savings is to compare the energy usage of an area of interest (a system, building, piece of equipment, etc.) before an improvement or energy conservation measure (ECM) is made to its usage after the improvement has been carried out. This is accomplished using what is called a baseline.

For a set period of time, energy consumption is determined prior to an improvement. This might involve an analysis of utility bills for an entire facility, or metering a specific piece of equipment. After an improvement is made, energy consumption is again determined for the reporting period, or the period of time chosen to verify the savings. The difference in consumption between these two periods is then adjusted as needed (ex. if an improvement in an HVAC system is being made weather may need to be accounted for and baselines may need to be adjusted accordingly). This difference is found to be the savings:

Savings = (Baseline-Period Use or Demand - Reporting-Period Use or Demand) ± Adjustments

The protocol presents four basic options to choose from when deciding how to measure and verify an improvement and determine the baseline and reporting period usage:

Option A - Retrofit Isolation: Key Parameter Measurement

When undertaking an improvement such as a lighting retrofit this option may be an appropriate method to use. In this option:

- Savings are determined by field measurement of the key performance parameter(s) which define the energy use of the ECM's affected system(s) and/or the success of the project.
- Measurement frequency ranges from short-term to continuous, depending on the expected variations in the measured parameter, and the length of the reporting period.
- Parameters not selected for field measurement are estimated. Estimates can be based on historical data, manufacturer's specifications, or engineering judgment. Documentation of the source or justification of the estimated parameter is required. Plausible savings errors arising from estimation rather than measurement are evaluated.
- Savings are calculated using engineering calculation of baseline and reporting period energy from short-term or continuous measurements of key operating parameter(s) and estimated values.

This option is a good place for SMM's to use during the early stages of their EnMS to help show reliable savings while not requiring in-depth technical skills or other resources.

Option B - Retrofit Isolation: All Parameter Measurement

When implementing an improvement such as the installation of a variable speed drive to adjust pump flow this option may be an appropriate method to use. In this option:

- Savings are determined by field measurement of the energy use of the ECM-affected system.
- Measurement frequency ranges from short-term to continuous, depending on the expected variations in the savings and the length of the reporting period.

- Savings are calculated using short-term or continuous measurements of baseline and reporting period energy, and/or engineering computations using measurements of proxies of energy use.

This option would also be appropriate for most SMM's to use during the types of improvements their EnMS would likely identify.

Option C - Whole Facility

When implementing a multifaceted energy management program affecting many systems in a facility simultaneously this option may be an appropriate method to use. In this option:

- Savings are determined by measuring energy use at the whole facility or sub-facility level.
- Continuous measurements of the entire facility's energy use are taken throughout the reporting period.
- Savings are calculated through an analysis of the whole facility baseline and reporting period (utility) meter data.

This option would likely not provide enough detail for a SMM to use during the types of improvements an EnMS would identify. While it would likely be wise for a manufacture to monitor their entire facility's energy usage and set a baseline for the entire operation, using utility data to determine savings from smaller improvements within the production facility would not provide enough detail. In a typical SMM there are enough variables impacting energy usage that could change in a given month to prevent utility meter data alone from providing satisfactory M&V.

Option D - Calibrated Simulation

When implementing a multifaceted energy management program affecting many systems in a facility simultaneously, but where no utility meter existed during the baseline period, this option may be an appropriate method to use. In this option:

- Savings are determined through simulation of the energy use of the whole facility, or of a sub-facility.
- Simulation routines are demonstrated to adequately model actual energy performance measured in the facility.
- This option usually requires considerable skill in calibrated simulation.
- Savings are calculated through energy use simulation, calibrated with hourly or monthly utility billing data. (Energy end use metering may be used to help refine input data.).

This option would also not likely be appropriate for most SMM facilities. Due to the technical skills and resources required, many SMMs would likely not use simulations for the smaller improvements identified through an EnMS. This method may appeal to a facility during a larger capital improvement to predict the likely impacts of a process change.

These four options form the basis of the IPMVP framework. The decision making process to choose between these options is shown graphically in Figure II-11. A SMM would likely follow a similar decision making process when determining the appropriate M&V methods for an energy efficiency improvement resulting from an EnMS.

The documents produced by EVO provide much greater detail of the methods reviewed here, and can be found in their online library.

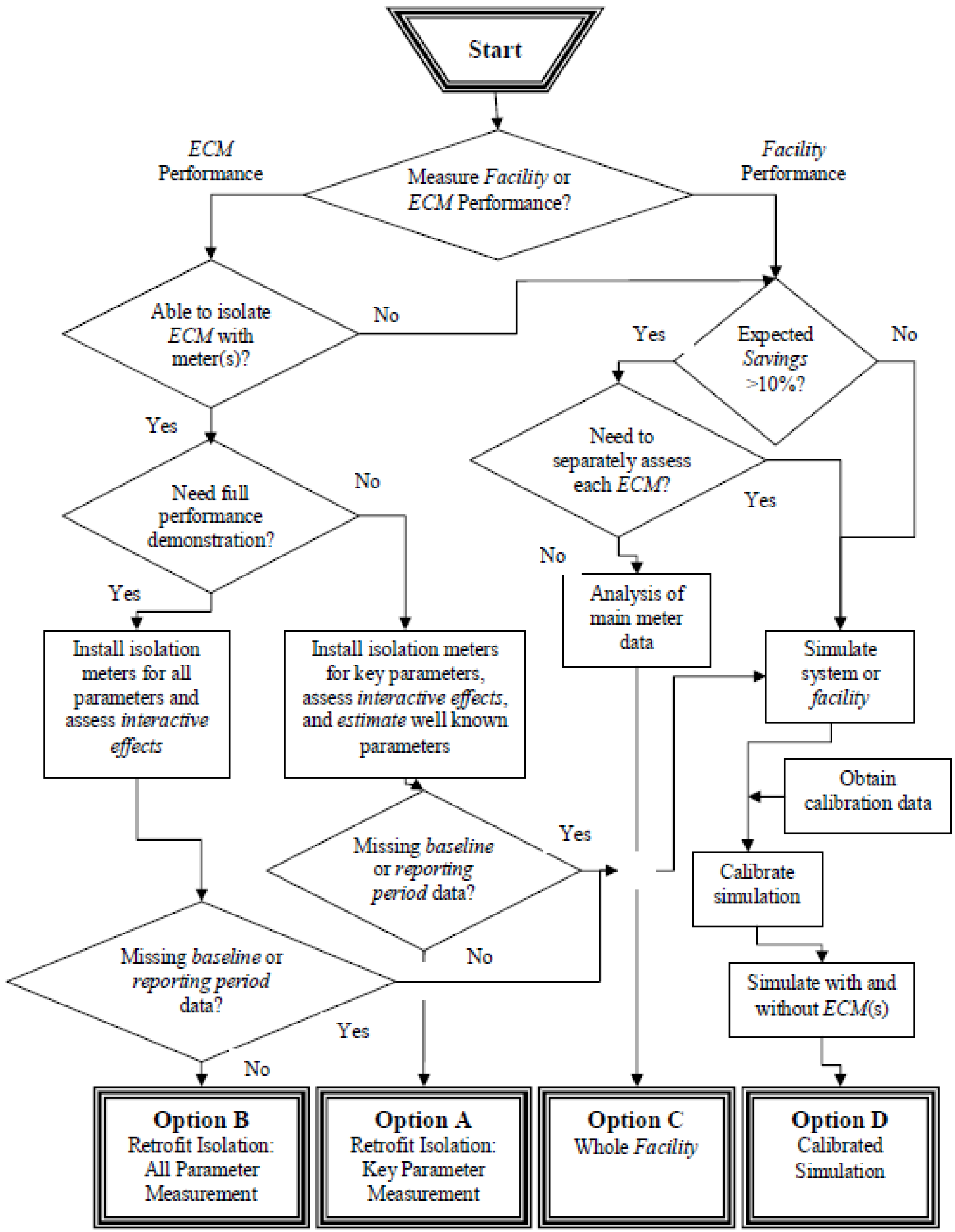

Figure II-11 Simplified Option Selection Process [116]

In addition to the guidelines provided by the IPMVP, the area of M&V is active in literature. Research articles have been written on the areas of submetering, baselines, and, performance indicators.

Submetering

As discussed in detail in section 1.2, submetering in industrial environments is an active area of interest. Its use in SMM facilities is not wide spread yet, but the DOE is attempting to assist in its spread by hosting the submetering challenge, which is an effort to drive the cost of this technology down.

Baselines

Baselines are important for determining the progress made by an improvement. In a manufacturing environment accomplishing this can be difficult as there are many variables that can impact energy usage. Kissock et al discuss a general method for measuring plant-wide industrial energy savings, taking into account weather and production changes [118]. This is accomplished by using multivariable piece-wise regression to characterize baseline energy use and disaggregates savings by taking the total derivative of the energy use equation.

Performance Indicators

In the manufacturing environment, performance indicators are commonly used to set baselines. They are commonly referred to as energy intensity metrics, sometimes called key performance indicators (KPIs) or energy performance indicators (EnPIs), and are disused in ISO 50001 as a way to track energy efficiency improvements.

Energy intensity is generally defined as the energy consumption of a process or system divided by the output of that process or system. This results in a ratio that can be used to track performance over time. In a manufacturing environment this would provide a metric such as kWh/unit of product, MMBtu/unit of product, or kWh/ton of cooling for example.

Tanaka reviews the advantages and disadvantages of measuring energy efficiency performance using several methods applicable to industry and policy makers [119]. The methods of energy performance indicators discussed are absolute energy consumption, energy intensity, thermal efficiency, and the diffusion of energy saving technology. Three criteria are presented to help identify the indicators that are most appropriate to use in a given situation: reliability, feasibility, and verifiability. A case study is then presented showing the decision making process of measuring energy efficiency in the steel industry.

Giacone et al presents a methodology for more precisely measuring industrial energy efficiency [120]. This is accomplished through the use of a matrix equation, which includes the specific energy consumption of each process in a manufacturing facility. A case study is used to demonstrate the methodology's use in both a glass and cast iron melting process.

Bunse et al discusses how energy efficiency can be integrated into the decision making process of manufacturing facilities [121]. This is achieved through the use of key performance indicators and a balanced scorecard method.

While the use of energy intensity is one of the most commonly used methods in industrial settings, it does have some issues and flaws discussed in the literature. Grobler et al discusses the fact that energy intensities have commonly been used as a KPI in industrial facilities to monitor energy performance and savings over time [122]. The article discusses how this method is flawed and describes how the physical characteristics of industrial plants are influenced by controllable and uncontrollable energy drivers and how these drivers should be incorporated into the measurement and verification process. The research describes how the baseline energy usage is linked to the set of conditions surrounding the operation at the time (weather, production level, building occupation, etc.), which the research refers to as the service level. If the service level remains unchanged, the electricity use after an improvement can be directly compared to that of the baseline. If the service level changes, adjustments are required. The authors argue that this is often not accounted for in energy intensity calculations.

Freeman et al also discusses limitations in using energy intensity for measuring industrial performance [123]. They focus more on the issues of energy intensity at a macro level – using it to identify the performance of an industry based on its output compared to the energy used in that industry. They give the example that in the steel industry a decrease in energy intensity may reflect the fact that producers on average are becoming more efficient at producing a ton of finished product, or it may reflect the fact that producers are shifting production toward finished products that require less energy. They also discuss how industry output is measured and the implications that has on energy intensity (ex. using value based measures instead of volume). While the research has merit, it is not completely relevant to this dissertation. The use of energy intensity in this dissertation is on a micro level – by product or system, and less on a macro or industry level.

The focus of this dissertation is not to add to the M&V body of knowledge, but instead apply the existing methods to SMMs in a way that is appropriate and assist in justifying an EnMS.

2.5 CHAPTER SUMMARY

This literature review covered several dimensions related to the areas of interest in this dissertation. The benefits of formal energy management systems to systematically review energy consumption within an SMM were reviewed. It was found that ISO 50001 is the predominant standard for EnMSs, and that they are predominantly used in Europe. This is likely due in a large part to related regulations and government policies such as tax credits. Submetering and energy information systems' technology were reviewed. Combined, the two technologies can collect data on an organization's energy consumption on a granular level, providing the ability for numerous insights that would be difficult to gain otherwise. The majority of the literature in this area focuses on the benefits and cost justification for the non-manufacturing environment. Some research discusses the benefits of such systems in manufacturing environments, but there is a lack of real cases studied in the SMM environment demonstrating savings. As a result there is a low implementation rate of such technology in industry.

Barriers to energy efficiency improvements in the manufacturing environment were reviewed. The literature identifies the most relevant barriers to SMMs and this dissertation as: lack of awareness or education regarding energy efficiency improvements, lack of technical skills, other investments deemed more important, lack of access to capital or other financial restraints, perception of already being efficient, project risks, lack of metering, management, organizational, and regulation related barriers. This dissertation research takes these barriers into consideration during the development of the model presented below.

Finally, the literature related to decision making surrounding energy efficiency improvements is reviewed. The investment criteria that many SMM type organizations use when evaluating and making decisions related to energy efficiency and energy management is reviewed; many organizations rely on the ‘simple payback’ method, even though the literature recognizes this is commonly non-sufficient by itself. Next, an accounting method called Activity Based Costing is reviewed. This method lends itself well to the integration of submetering technology in order to find the ‘true cost’ of a product based on the energy used to produce it. Finally, the various methods used to measure and verify energy improvements are reviewed.

CHAPTER III

METHODOLOGY

3.1 CHAPTER OUTLINE

3.2 INTRODUCTION

This chapter describes the research that was conducted within this dissertation. The primary goal was to develop a sustainable model for implementing energy management systems at SMM facilities. The model demonstrates how such a system can pay for and support itself over time and was developed with the intent of complementing an existing methodology such as that described in ISO 50001.

This research involves a multi-phase process of interaction with IAC clients, review of the current published literature, and model development. Section 3.3 first presents a discussion of several ‘absolutes of energy management’, followed by the presentation of an energy management hierarchy in Section 3.4, and energy management maturity grid in Section 3.5, all of which helped to shape the creation of the model. The model framework is presented in Section 3.6, along with a conceptual example in Chapter IV.

3.3 ABSOLUTES OF ENERGY MANAGEMENT

Based on the author’s experience in the field and the published literature on the subject reviewed above, it is apparent that several absolutes of energy management exist:

- Energy is an expense that can be managed
- Every organization has an energy management system (effective or not)
- Energy improvements should be measured by intensities not Btus, kW, kWh, or dollars
- EnMSs which are not effective, efficient, or sustainable will not succeed

These absolutes are discussed in more detail below.

3.3.1 ENERGY IS AN EXPENSE THAT CAN BE MANAGED

Many organizations, including SMM facilities, view energy as simply the cost of doing business, as shown in the literature. Saving energy (electricity, natural gas, water, etc.) is not always the focus of a manufacturing facility. The focus is typically on getting quality product out the door and making enough money to stay in business, with energy consumption often going unmanaged. However, like any other resource, energy can be managed through a variety of methods. For example, why would an organization not focus on a resource cost that is in the top three plant operating costs (e.g., materials, labor, and energy)? Energy consumption and expense should be a focus that is actively managed in order to help a facility lower its costs and be a good corporate steward. To determine where energy ranks in relation to other expenses at the organization in terms of percentage of annual operating cost, the following equation is introduced:

$$\gamma = \frac{Annual\ Energy\ Cost}{Annual\ Operating\ Cost} = \frac{\epsilon}{\nu} \tag{3.1}$$

Where ϵ represents a SMM's annual energy expense, ν represents a SMM's annual overall operating cost, and γ represents the ratio between these two variables. This provides a multiplier that will be used in the model framework presented in Section 3.6.

3.3.2 EVERY ORGANIZATION HAS AN ENERGY MANAGEMENT SYSTEM

It is clear that every organization has an energy management system (EnMS), effective or not. The scope and extent of energy management systems can and do vary - from simply paying the utility bill without scrutinizing why the consumption being paid for occurred, to a fully sub-metered facility complete with real-time access and energy-related data integrated into the accounting and management information systems, and many variations between these extremes.

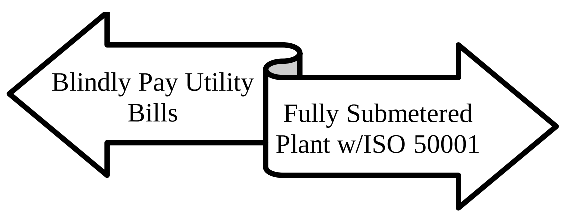

Figure III-1 Energy Management System Spectrum

The majority of SMMs fall somewhere in between these two extremes, with most encountered during the author's experience with the IAC program falling closer to the far 'left' extreme. One of the goals of this research is to provide a means for SMMs to identify where along this spectrum an organization's current energy management system falls, and then identify what steps can be justified to move the organization's management system towards the 'right' side of the spectrum. This research introduces a self-assessment tool in Section 3.5 to assist in identifying where a plant falls on this spectrum.

3.3.3 ENERGY IMPROVEMENTS SHOULD BE MEASURED BY INTENSITIES NOT BTUS, kW, kWh, OR DOLLARS

While it is tempting to expect the utility bill arriving immediately after an energy improvement has been finished to be smaller than the previous bill by an order of magnitude equal to the expected reduction in Btus, kW, kWh, etc. generated by the improvement, this is often a set-up for disappointment. For example, while an improvement might reduce the energy consumed by the current production process through the use of variable speed drives (VSDs), production may increase the month after the improvement was installed, causing energy consumption to actually increase. Similarly, more efficient air conditioning systems may be installed, only to have record high temperatures the following month leading to higher energy usage.

The disappointment associated with these unreasonable expectations may lead management to the opinion that an EnMS system is not working or worthwhile. A more appropriate way to view these types of improvements is through energy intensities. As described in the literature, for a given process, one can define energy intensity, I, as the measure of energy input E divided by the measure of useful output O [123]:

$$I = \frac{Energy\ Input}{Useful\ Output} = \frac{E}{O} \tag{3.2}$$

Such an intensity would typically have units like kWh/unit of product or MMBtu/unit of product (ex. kWh/ton, MMBtu/foot, kWh/reel, etc.). Returning to our first example, if the production process uses a baseline energy intensity measured prior to VSD installation, and again after installation, the reduction in the amount of energy required to produce a unit of product will provide a more accurate measure of success. This intensity improvement should hold constant even if production increases, even though the utility bill may reflect increased energy consumption when compared to a period of slower production. Tracking and measuring these types of intensities is where submetering technology can be effectively utilized. In addition, major swings in co-variables such as ambient temperature, material variation, operating hours, etc. should be considered in the context of recorded energy intensity.

3.3.4 EnMSs THAT ARE NOT EFFECTIVE, EFFICIENT, OR SUSTAINABLE WILL NOT SUCCEED

Some of the frequently cited barriers to energy improvements include lack of technical expertise, competition for funds, time, personnel availability, etc. In order for an energy management system to succeed, meaning it becomes an integrated part of an organization's management philosophy, it must overcome and address these barriers. To help break through these barriers and assist a SMM facility in better managing their energy in a way that fits into their corporate culture and abilities on both an economical and technical level, the method for funding an EnMS is presented in this research.

In order to be sustainable, it is important that an appropriate level of resources are used, both from a financial and personnel standpoint. A new EnMS should be built around the technical expertise and personnel availability at the organization. Financially, the energy management system should be treated similarly to that of an energy service contract with revenue sharing, where the savings generated by projects performed are used to fund the program. If a large amount of savings is identified, then the program should be allowed to grow and advance in maturity. If the amount of savings generated slows, then the energy management program growth should slow as well.

In order to have a sustainable EnMS it is important to set a reasonable initial budget. The first step is estimating the percentage of annual energy purchased that is wasted, and equate this to dollars wasted (μ), as defined in Equation 3.3.

$$\mu = (\epsilon)(\%\, Wasted\ from\ EMMG) \tag{3.3}$$

Dollars wasted are identified by multiplying ϵ, a SMM's annual energy expense, by the percentage of estimated annual energy waste. This can be identified with the assistance of the energy management maturity matrix presented in Section 3.5.

After estimating the amount of money wasted per year, μ, the initial EnMS budget, β_0, should be set based upon a percentage of this waste:

$$\beta_m = (\mu)(X) \tag{3.4}$$

Where *m* is the year of the energy management system's existence, and is equal to '0' for the initial budget; X is the multiplier for the proportion of waste that will be used to set the initial budget. This initial budget would represent money earmarked for the development of an EnMS.

The value for X may vary based on a SMM's own criteria. However, a reasonable amount for X could be equal to 30%. This number is based on the average implementation rate of recommendations in the first year after an IAC assessment has been conducted. Historically, for a given one-day IAC assessment, an average of 3.5 recommendations are implemented out of 7.6 recommended, which is equal to an average of $44,349 of identified savings implemented out of an average of $136,146 identified. This indicates roughly 30% of the identified savings, or waste (in dollars), is being addressed in the first year by SMMs assisted by the IAC program[4].

[4] Data available from https://iac.university/statistics. Accessed 4/19/2017

Therefore, in the first year, it would be reasonable to set the EnMS budget equal to 30% of the identified waste, resulting in a likely one-year simple payback.

When implementing an energy improvement project as identified through the EnMS process it is important to determine the savings generated by the project. The savings generated are often from a combination of areas other than energy alone. To account for this the following equations are presented:

The net annual improvement project savings (S_{ij}) for a given project, *i*, starting in year *j*=1 carried over the useful life of the project, *u* (ex. if project involves installing new HVAC equipment, the useful life according to ASHRAE may equal 15 years). The total number of projects range from *i* = 1 to *g*.

$$TS_{ij} = \sum_{i=1}^{g} \sum_{j=1}^{u} \left[\left(E_{ij} + MA_{ij} + P_{ij} + L_{ij} + IN_{ij} \right) \right] \tag{3.5}$$

$$TC_{ij} = \sum_{i=1}^{g} \sum_{j=1}^{u} \left[\left(PL_{ij} + M_{ij} + I_{ij} - R_{ij} + T_{ij} + O_{ij} + MV_{ij} \right) \right] \tag{3.6}$$

$$S_{ij} = \sum_{i=1}^{g} \sum_{j=1}^{u} \left[\left(TS_{ij} \right) - \left(TC_{ij} \right) \right] \tag{3.7}$$

Where:

TS_{ij}- Total project savings
E_{ij} - Energy savings
R_{ij} - Utility rebate savings
MA_{ij} - Maintenance savings
P_{ij} - Production savings/Production increase
L_{ij} - Labor savings
IN_{ij} - Intangible savings

TC_{ij} - Total project cost
PL_{ij} - Planning cost
M_{ij} - Material cost
I_{ij} - Installation cost
T_{ij} - Training/technical cost
O_{ij} - Operating cost
MV_{ij} - Measurement & Verification cost

Subject to:

- For the expected EnMS revenue of the proposed project, *i*, when added to the projected EnMS year-end budget over the useful life, *u*, of the proposed project, must be greater than 0: $\sum_{j=1}^{u}(\delta_{ij}) + \sum_{j=1}^{u}(\beta_m) \geq 0$ where *j* = 1 and m is equal to the current EnMS year (1, 2, … n):

$$\beta m = \sum_{m=1}^{n}[(\delta_m) + (\beta_{m-1})] \qquad (3.8)$$

In other words, the proposed project cannot deplete the expected EnMS budget.

It is important to note the energy savings from a given improvement will likely decay over the span of its useful life (ex. over the 15 year useful life of a rooftop packaged HVAC unit, its kW/ton consumption will likely start to slowly increase due to things such as age, fouling of its condenser and evaporator coils, mechanical wear, etc.). During the years after an improvement has been implemented, an appropriate M&V methodology should be used to determine the savings achieved in a given year. If this involves metering or sampling, the actual energy savings can be determined, or estimated. To account for this decay during the initial prediction of the expected energy savings, a decay function can be used to provide a conservative estimate of savings over time [124]:

$$E_i(j) = ae^{kj} \qquad (3.9)$$

Where $E_i(j)$ is the energy savings for a given project, *i*, starting in year *j*=1, 'a' is the value of the initial energy savings in year *j*=1, 'k' is the decay rate (k<0, ex. -10%), and 'j' is time that has passed since the initial year.

After the initial prediction, the model uses an input from the selected M&V process to provide 'real' verified numbers from the actual savings occurring during a given year.

Equations 3.3 – 3.8 are based upon the understanding that in a SMM facility there are many interconnected drivers for energy usage and cost, and energy usage or savings are often a part of improvements that take place at the facility, even if sometimes a small part.

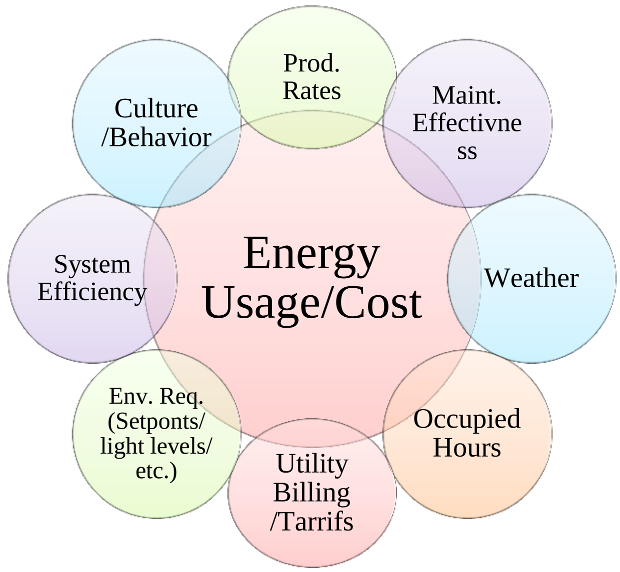

Figure III-2 Relationships Between Energy Usage/Cost And Other Factors

On an annual basis, based on the M&V methodology chosen for the improvement, the SMM would share the 'revenue' or savings generated by the improvement with the energy management system group for their operating budget. The amount of the energy savings shared should be equivalent to the proportion of energy expense determined in Equation 3.1.

For a given improvement project, as noted in Equation 3.5, savings can be generated for an SMM from multiple categories. The EnMS would only claim revenue from the proportion of the project attributed directly to energy savings. Further, the EnMS would only collect a percentage of the net savings after costs for the given year have been deducted at a rate in keeping with the breakdown of savings for the project (ex. if energy savings account for 2% of the total project savings, the energy savings revenue has 2% of the total cost deducted from it) as shown in Equation 3.11.

For all ongoing projects, *i*, within a given year, *j*, of their useful life, the project would generate revenue, δ, for the EnMS equal to:

$$\delta_{ij} = \sum_{i=1}^{g}\sum_{j=1}^{u}\left[(Project\ energy\ savings) - \left((Total\ project\ cost)\left(\frac{Energy\ savings}{Total\ savings}\right)\right)\right]\left(\begin{matrix}Budget\ multiplier\\ from\ Eq. 3.1\end{matrix}\right)$$

$$\delta_{ij} = \sum_{i=1}^{g}\sum_{j=1}^{u}\left[\left(E_{ij}\right) - \left(D_{ij}\right)\right](\gamma) \qquad (3.10)$$

Because saving energy is likely to be only a portion of the motivation behind an improvement (ex. installing new production equipment has a greater throughput but is also more efficient), it is 'fair' to attribute only a portion of the costs for the project to the EnMS based on the ratio of the project's energy savings to total savings. This proportion of the costs would be deducted from the energy savings shared with the EnMS. This is represented by the variable D_{ij} where *I* represents a given project and *j* represents a given year in the projects useful life, *u*:

$$D_{ij} = \sum_{j=1}^{u}\left[\left((Total\ project\ cost)\left(\frac{Energy\ savings}{Total\ savings}\right)\right)\right]$$

$$D_{ij} = \sum_{j=1}^{u}\left[\left(\left(TC_{ij}\right)\left(\frac{E_{ij}}{TS_{ij}}\right)\right)\right] \qquad (3.11)$$

The logic described by these equations will ensure that an organization's EnMS has sustainable growth that does not compete with an organization's 'core' operation and guarantee the EnMS is effective, efficient, and sustainable.

The four absolutes described in this section are used to guide the model framework discussed in Section 3.6 of this dissertation.

3.4 ENERGY MANAGEMENT HIERARCHY

Maslow's 1943 paper, “A Theory of Human Motivation” [125], presented a hierarchy of needs, outlining the basic human needs that must be met before a person can reach self-fulfillment.

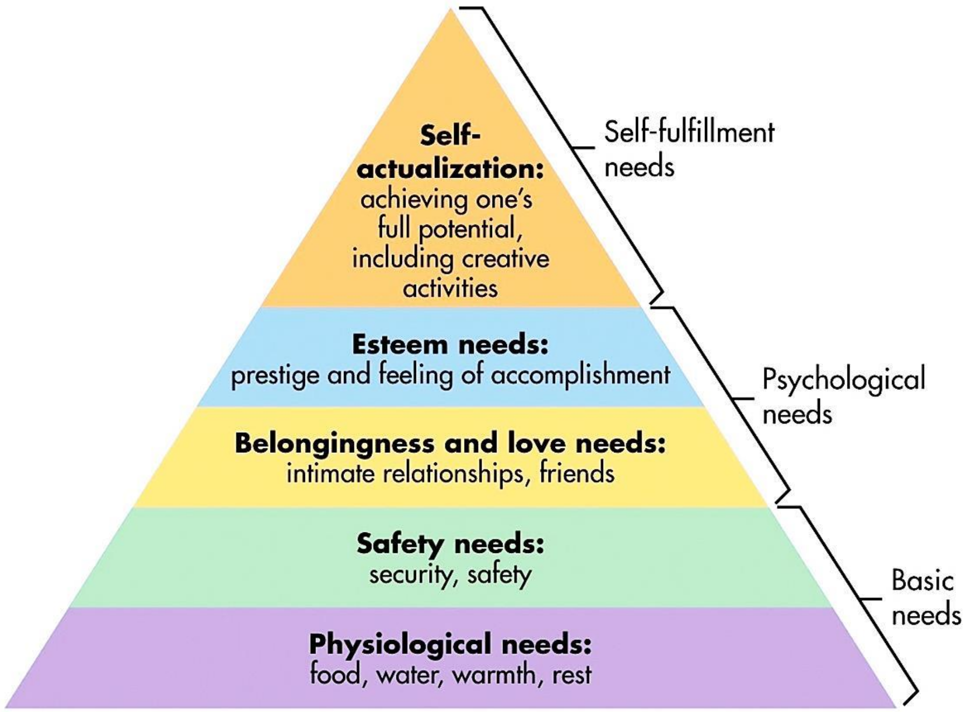

Figure III-3 Maslow’s Hierarchy of Needs [126]

The author believes that energy management systems follow a similar hierarchy. Before a management system reaches its most mature stages, it needs to meet some basic lower level requirements. The levels of this hierarchy are similar to those described by in Crosby’s QMMG. At the bottom the energy management hierarchy is the ‘Uncertainty’ stage, where an organization must be able to pay the utility bill. This is a foundational requirement of being able to manage energy - first being able to purchase energy. At this level of maturity, energy is typically viewed as an overhead expense, simply part of the cost of doing business. The organization has no designated energy manager, energy bills are simply paid, and little or no questions are asked. Effort here is minimal while wastes are largely undiscovered.

Once these conditions have been met, the next stage in the energy management hierarchy is 'Awakening', where energy consumption undergoes increased scrutiny. At this level an organization is essentially realizing to what extent energy ranks in order of resources, such as materials, labor, supplies, overhead, etc. Most efforts here resemble the early days of "zero defects" in the U.S. quality movement where motivational talks and banners (without training and practice) provided little if any real progress. Organizational activities taking place at this level might include low cost or no cost management activities, which typically require minimal personnel time such as:

- Identifying where the organization ranks on energy management maturity grid (described in Section 3.5)
- Beginning to monitor/track monthly energy costs and consumption (using a spreadsheet or other low tech method)
- Determining what energy costs account for as a percentage of total operating costs; Identify where energy 'ranks' with respect to other costs (Eq. 3.1)
- Understanding rate schedules and how organization is being billed
- Documenting all major energy using equipment (make and model numbers, estimated run times, etc.)
- Identifying largest energy using equipment in plant
- Performing in house energy balance (no metering, rough percentage calculation)
    a. Pareto diagram of energy use by system
    b. "Heat Map" of where energy is going in facility
- Beginning to consider implications of actions on energy consumption
- Identifying any equipment being left on when not in need (air compressors/ process equipment/lighting/etc.)
- Identifying energy impact from routine maintenance (condenser coils/air leaks/insulation etc.)
- Increasing employee energy awareness, training (ex. do not use compressed air for cleaning, do not leave equipment on when not needed, etc.)
- Asking for employee suggestions to improve consumption
- Identifying industry/system best practices and compare to current practices (ex. providing fresh air intake for air compressors or recovering waste heat)
- Identifying what current practices are costing the organization (ex. cost of using compressed air for cleaning vs alternative method).

The next stage in the energy management hierarchy is 'Enlightenment'. This is the first real start to a systematic approach to energy as a critical resource that is controllable. Hence, senior leadership commitment, as well as attempts to analyze energy usage within the plant associated with the facility and processes and products, is emerging. Organizational activities taking place at this level might include moderate capital cost and increased personnel time involvement such as:

- Monitor major equipment for short periods of time using short term monitoring (removable data loggers)
- Compare monitored data to the load balance estimation from level two
- Using spot metering, determine energy intensity of major equipment. (kWh/Unit product)
- Attempt to determine things like kW per CFM for air compressors
- Monitor when equipment is running vs. when process is running
- Take monthly 'snap shots' to monitor energy intensity
- Establish consumption baselines
- Set goals/base lines for energy intensity, investigate if reported snapshots are out of range
- Lean principles, etc. "Is current air pressure required to accomplish existing tasks?" "Is there a better way of doing things?" "Why are current set points/ temperatures needed?"
- Install things like occupancy sensors/ programmable thermostats/etc.
- Develop formal energy management system for facility, possibly eGuide Level 1, 50001 Ready Navigator
- Incorporate energy usage considerations in procurement/operating practices

The fourth stage in the hierarchy is 'Wisdom', which extends enlightenment to specific training across the plant whereby an effective energy management system has emerged. The analysis capabilities at this stage have advanced to the point of limited submetering and calculated estimates based on experience. Nevertheless, energy conservation is more or less measurable, controllable, and a major consideration in facilities, processes, and product improvements. Organizational activities taking place at this level might include increased monitoring of energy usage, increased capital investment, and personnel involvement such as:

- Install permanent metering on major energy using equipment
- Monitor energy intensity (EI) in real time – Set reliable baselines
- Investigate immediately if EI out of range – weather related? Process change related? Preventative maintenance?
- Make investments/set goals to reduce EI by process improvements
- Spot meter smaller systems that have not been previously investigated
- Install VFDs, upgrade to more efficient equipment, utilize economizers, etc.
- Increase formal energy management system rigor, possibly implementing eGuide level 2, 50001 Ready Navigator

The final stage of the hierarchy is 'Certainty', which represents a fully functional and sustainable energy management system across the entire organization from end to end. Here, the energy management system is an integral part of the total plant management system. It is a part of, not apart from, the SMM management system as a whole. Energy waste is minimal. Organizational activities taking place at this level might include increased advanced monitoring and moving energy from overhead to an actively managed resource such as:

- Incorporate data from permanent metering with existing management system data (labor, production, etc.)
- Implement Activity Based Costing to help move energy management from overhead category to a resource that is actively managed
- Assign product cost as part of exact energy consumption
- Begin to meter additional processes/ systems beyond major equipment
- Dashboard/weekly reports for EI on processes
- Post weekly reports to make employees/groups aware of their area/process energy performance
- Track energy intensity to determine possible problems and verify success of improvements
- Implement controls in addition to monitoring
- Account for all energy consumed; Submeter to the extent the electric/gas bill can be re-created and verified
- Increase formal energy management system rigor, possibly eGuide level 3, 50001 Ready Navigator

This hierarchy is shown graphically in Figure III-4:

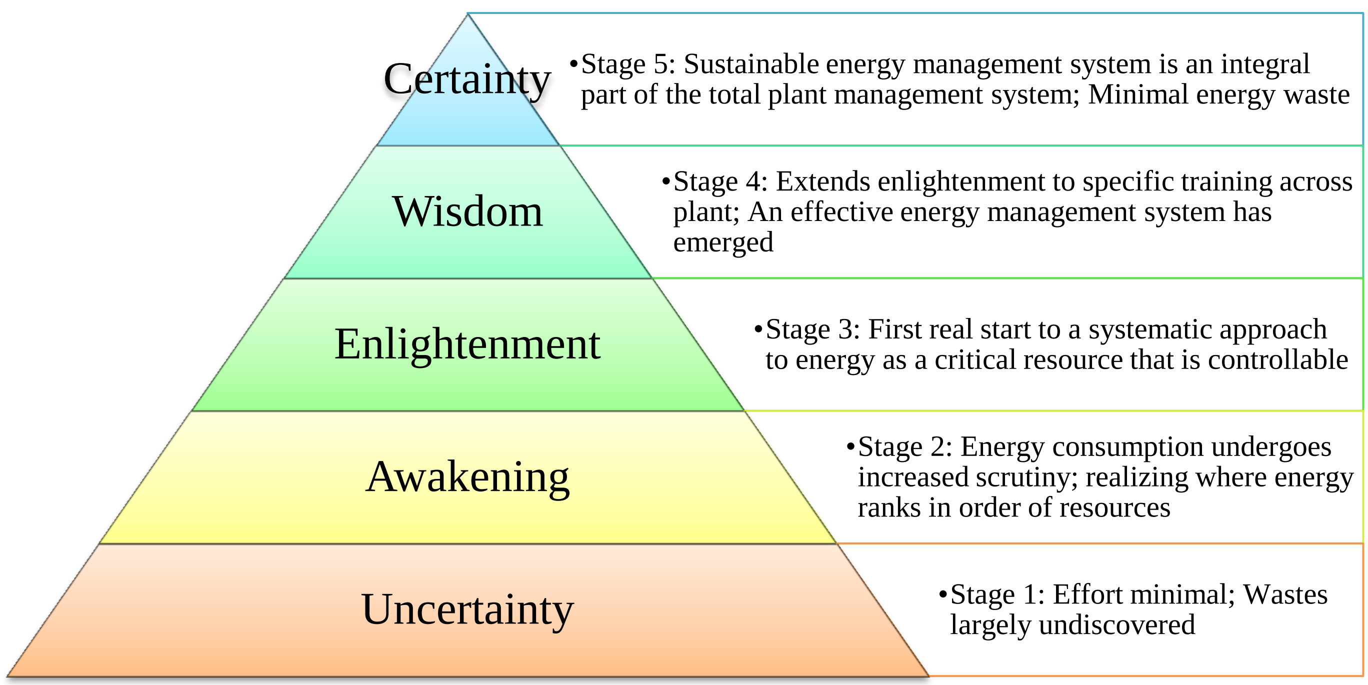

Figure III-4 Energy Management System Maturity Hierarchy

This hierarchy is used to describe the stages of maturity an organization experiences as it works towards improving its energy management system. To help identify what the existing stage of maturity best describes an organization's energy management system, the Energy Management Maturity Grid is presented in Section 3.5.

3.5 ENERGY MANAGEMENT MATURITY GRID (EMMG)

Before a SMM determines what step they should take to improve their current EnMS, it is important that they understand the state of their current 'system'. To assist with this problem, the Energy Management Maturity Grid (EMMG) is presented. This grid was created out of the recognition that there is a parallel between the quality movement from several decades ago and the current energy/sustainability movement today. One of the pivotal "moments" in the quality movement was the recognition of losses with respect to poor/sloppy quality discipline in terms of product design and performance, production processes, customer satisfaction, and the resulting inherent but hidden costs.

It is clear that every organization has a quality management system – some much more efficient than others. Likewise, as described by the second absolute of energy management discussed in Section 3.3.2 above, it is clear that every organization has an energy management system – some more effective than others. For example, on the lower end, simply paying the utility bills would constitute an energy management system.

Because of the parallel between the quality movement in the past and the current energy management movement, the Crosby Quality Management Maturity Grid (QMMG) from the late 1970s and early 1980s has been revisited and superimposed with energy-related counterparts in order to develop an energy management maturity grid. The basis for this super-positioning comes from several decades of experience gained from participating in the U.S. Department of

Energy’s Industrial Assessment Center Program. Experiences in this program have been both qualitative and quantitative.

Phillip Crosby first introduced the Quality Maturity grid in the late 1970s as a way for a facility’s management to self-assess where their organization ranked on the quality management spectrum. The power of the tool lay in its simplicity and its ability to communicate to upper management in a straightforward manner. A key section of the grid estimated the current cost of quality (or lack thereof) as a percentage of sales the organization was experiencing. Because quality problems are directly linked to the bottom line in terms of sales, this was a very powerful motivator for improvements that impact the bottom line.

As discussed in the literature review Section 2.2.1.3.1, several other approaches have been taken during the development of an energy management grid, and other areas of research have used Crosby’s grid as a basis for their fields. While energy management and improving energy efficiency have several parallels with quality, justifying the expenses related to implementing a structured energy management system is often more difficult. While most people agree being more efficient is good, and using less energy will save an organization money, being more efficient does not always link directly with sales like quality does. This often makes communicating the importance of energy management with an organization’s management difficult. In an attempt to emulate Crosby’s approach to quality, and apply it to energy management, an energy management maturity grid was developed to allow management to self-assess their organization’s energy management maturity (see Table III-1).

3.5.1 DEVELOPMENT OF THE EMMG

Similar to Crosby's approach, the proposed grid has six measurement categories and five stages of maturity (as described in the energy management hierarchy). The categories were developed based on energy management principles and best practices such as ISO 50001 implies.

3.5.1.1 EMMG MEASUREMENT CATEGORIES

The six measurement categories used in the EMMG are:

1. Management understanding and attitude
2. Energy management organization status
3. Improving energy intensity & solving energy related problems
4. Amount of waste as a percentage of utility bill
5. Energy management improvement actions
6. Summation of company energy management posture.

Five of the measurement categories are fairly straightforward, 'Management understanding and attitude' is a measure of how management views energy in their decision making process. 'Energy management organization status' is a measure of how energy is viewed by the organization as a whole. 'Improving energy intensity & solving energy related problems' is a measure of how energy and energy intensity is considered when addressing problems and making long-term decisions. 'Energy management improvement actions' is a measure of what steps, if any, the organization is making to create a formal EnMS. 'Summation of company energy management posture' is a measure of the overall company attitude, summarized by the first five measures.

The forth measurement category, ‘Amount of waste as a percentage of utility bill’, estimates the amount of waste as a percentage of the facility’s current utility bill. This is achieved based on historical data from DOE research and historical IAC program data.

Based on experience from the Oklahoma State University’s Industrial Assessment Center (IAC), the amount of recommended savings (energy waste) in a typical facility can range from 50% at the high end of the spectrum to 5-10% at the lower end of the spectrum, with the majority of plants having around 20-30% in reasonable opportunities for reducing their energy waste. Figure III-5 represents the percentage of recommended savings in electricity (kWh, kW, fees) and natural gas in relation to the total energy cost for a given IAC client. It is important to note that the recommended savings are based only upon those opportunities that are both economically feasible (typically a simple payback of 5 years or less) and practically feasible (recommendations with a high likelihood of implementation).

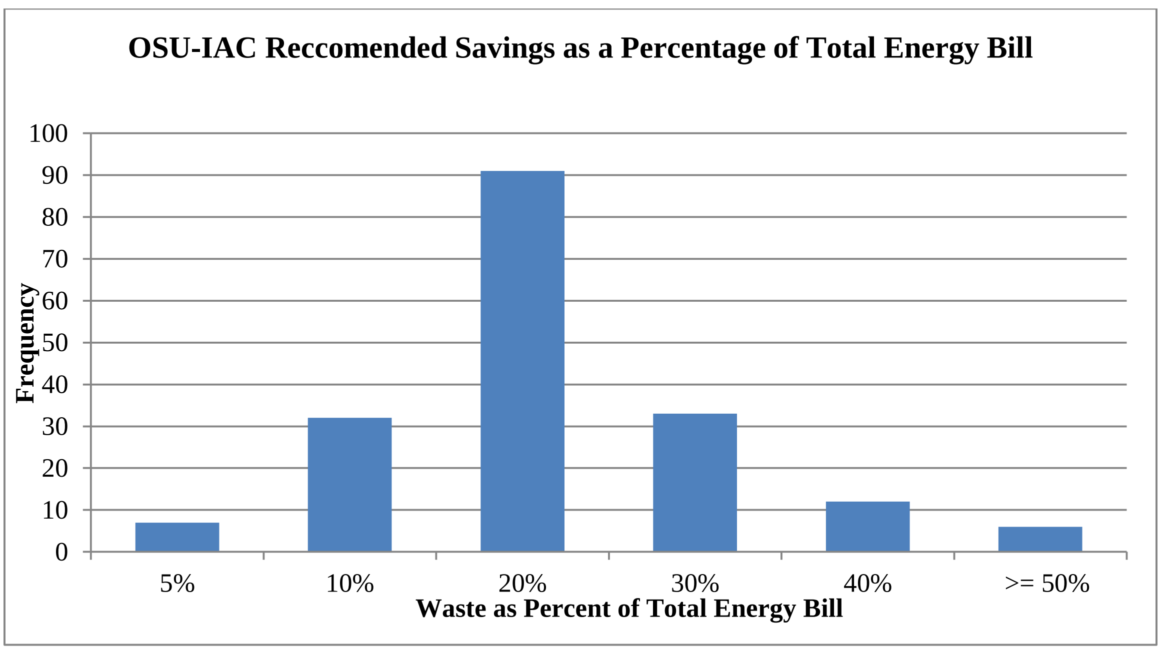

Figure III-5 Historic IAC Savings Opportunities as a Percent of a Facility’s Total Utility Bill [5]

These identified energy savings are equivalent to at least a fraction of the current energy waste in the facility; the true amount of opportunity in a typical IAC client facility is likely larger than what is identified in a one day assessment due to time and other constraints. It is important to note that these recommended energy savings are classified by the specific areas of a facility's energy related costs. The IAC program defines these parts as follows: energy savings related to the manufacturing process (App 1), savings related to process support (App 2), savings related to buildings and grounds (App 3), and administrative related savings (App 4). Figure III-6 shows what percentage of the savings identified by the IAC program is attributed to these four areas across the history of the entire IAC program at all centers, beginning in 1993 when application codes were first introduced.

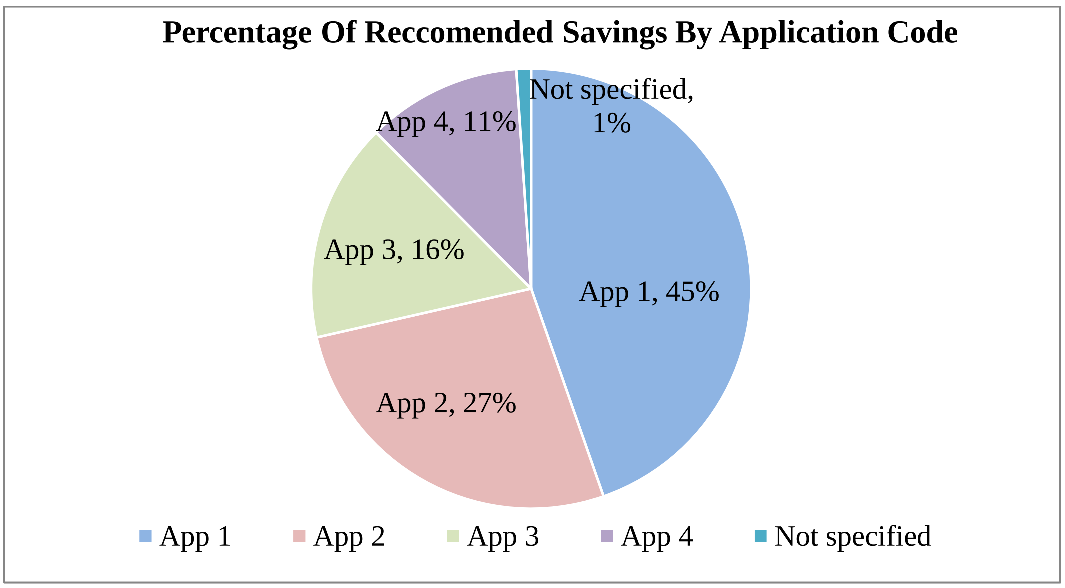

Figure III-6 Percentage Savings Identified by Application Code [53]

This illustrates that over half (55%) of the savings identified are in areas not directly related to the process, even though the processes are undoubtedly the main consumers of energy at facilities. It is likely that a more in depth assessment at a SMM, or a formal energy management system operating over time, would identify an even larger quantity of energy savings, shifting the distribution in Figure III-5 to the right.

According to Lawrence Livermore National Laboratory, in 2016 the U.S. as a whole was estimated to be only 32% energy efficient, wasting 66.4 quads of the total 97.3 quads produced [127]. The majority of this waste is attributed to losses in the electricity generation process, but the manufacturing industry also contributes. As a whole, the industrial sector wastes approximately 51% of the energy it consumes [127]. There is also other evidence that supports large amounts of waste at many manufacturing facilities. The U.S. DOE's Office of Energy Efficiency and Renewable Energy Industrial Technologies Program conducted a survey in 2004 that found a typical manufacturing facility loses 32% of the energy input into the plant through inefficient systems and processes [128].

These research results and the historical IAC data mentioned above are reflected in the energy management maturity grid below with the first maturity stage estimating that facilities with little energy management effort have greater than 50% waste, and the last maturity stage estimating that facilities have 5-10% actual waste.

3.5.1.2 EMMG STAGES

Essentially the EMMG, Stage I: Uncertainty, describes many plants or organizations where energy bills are simply paid and little or no questions are asked. Effort here is minimal while wastes are largely undiscovered.

Stage II: Awakening, is essentially realizing to what extent energy ranks in order of resources, such as materials, labor, supplies, overhead, etc. Most efforts here resemble the early days of "zero defects" in the U.S. where motivational talks and banners (without training and practice) provided little if any real progress.

Stage III: Enlightenment, is the first real start to a systematic approach to energy as a critical resource that is controllable. Hence, senior leadership commitment, as well as attempts to analyze energy usage within the plant associated with the facility, processes, and products, is emerging.

Stage IV: Wisdom, extends enlightenment to specific training across the plant whereby an effective energy management system has emerged. The analysis capabilities at this stage have advanced to the point of limited submetering and calculated estimates based on experience. Nevertheless, energy conservation is more or less measurable, controllable, and a major consideration in facilities and process and product improvements.

Stage V: Certainty, represents a fully functional energy management system across the entire organization from end to end. Here, the energy management system is an integral part of the total plant management system. It is a part of, not apart from, the management system as a whole.

3.5.2 DISCUSSION

Similar to the QMMG, the purpose of using the energy management maturity grid is to allow for comparisons between different levels of maturity within an organization in terms of energy and encourage action. Using the energy management maturity grid, a manager who is not professionally trained in the energy management business can determine where the operation in question stands from an efficiency standpoint.

As discussed by the UK Department of Energy, it is possible for different aspects of the energy management system to be out of sync (ex. have certain measurement categories more or less mature than others). For example, an organization may have advance metering in place, but not use the data generated to impact decisions or calculate energy intensity. Conversely, an organization may have an energy focused management system without the use of advanced metering, operating solely on "educated guesses" and calculations or estimations. While both of these examples 'out of sync' are better than having all categories at the lower levels of maturity, they both open the door to allow more waste than necessary into the system.

The EMMG overview simplifies the evolution and growth of the energy management system. We can state for certain that every organization currently has an energy management system, some effective and some ineffective. Every organization must start where they are currently at – and move forward from there. As progress occurs and the system matures, the next question is how far (and how fast) does one progress or move the system?

The answer is complex and different for each organization. It depends on the nature of the business. It is clearly possible, with today's technologies, to evolve beyond cost effectiveness in any management resource-related system, such as finance, labor, and energy.

Nevertheless, experience gained in developing the more mature systems within an organization provides guidance. In other words, the extent of cost effectiveness is a moving target. For example, energy costs, especially electricity, tend to move up, while technology related cost for monitoring and analyses (via software) tend to move down. So in the end, the process of maturation is a never-ending journey, as opposed to a specific destination.

The model framework presented in this research attempts to provide further guidance for how to advance an organization's energy management system in a sustainable manner.

Table III-1 Energy Management Maturity Grid

Energy Management Maturity Grid
Rating Tool

Measurement Categories	Stage I: Uncertainty	Stage II: Awakening	Stage III: Enlightenment	Stage IV: Wisdom	Stage V: Certainty
Management understanding and attitude	No comprehension of energy as a management tool. View energy as a cost of doing business.	Recognizing that energy management may be of value but not willing to provide money or time to make it all happen.	Going through energy improvement program to learn more about energy management; becoming supportive and helpful.	Participating. Understanding principles of energy management reasoning. On-going energy conservation projects.	Integration. Consider energy management an essential part of company management system.
Energy management organization status	Energy management is hidden in maintenance or engineering departments; energy considered 'just the cost of doing business'.	An energy management leader is appointed but main emphasis is still on getting the product out the door.	Energy-sustainability management group reports to top management, focus is on compliance.	Energy sustainability manager is an officer of company; effective performance indicators, reporting and improvement actions. Focus on compliance and improvements.	Energy sustainability manager leading efforts; Systems which are integrated across organization with financial and quality systems.
Improving energy intensity & solving energy related problems	Improvements are made based on patchwork basis with little concern for efficiency. React and fix current problems.	Teams are set up to attack major improvements. Long-range solutions are not solicited.	Thought is given to energy efficiency when seeking solutions. Life cycle savings considered over first cost.	Energy efficiency is considered in initial design. All functions are open to suggestion and improvement.	Innovative energy efficient solutions implemented; energy intensity is a focus.
Amount of waste as % of utility bill	Estimated: unknown Actual: 50%	Estimated: 30% Actual 40%	Estimated: 20% Actual: 30%	Estimated: 10% Actual: 20%	Estimated: 5-10% Actual: 5-10%
Energy management improvement actions	No organized activities. No understanding of such activities.	Trying obvious "motivational" short-range efforts.	Implementation of first energy management step[1] with thorough understanding and establishment of each step.	Implementation of ISO 50001[2]	Energy improvement is a normal and continued activity[3].
Summation of company energy management posture	"We don't know why our energy costs are what they are."	"Is it absolutely necessary to consider energy consumption a given?"	"Through management commitment and energy improvement -- we are reducing our consumption."	"Identifying energy improvement opportunities are a routine part of our operation."	"We know where our energy goes and why it goes there."

1. Might include DOE eGuide level 1 or components of 50001 Ready Navigator
2. Might include DOE eGuide level 2 or components of 50001 Ready Navigator
3. Might include DOE eGuide level 3 or components of 50001 Ready Navigator

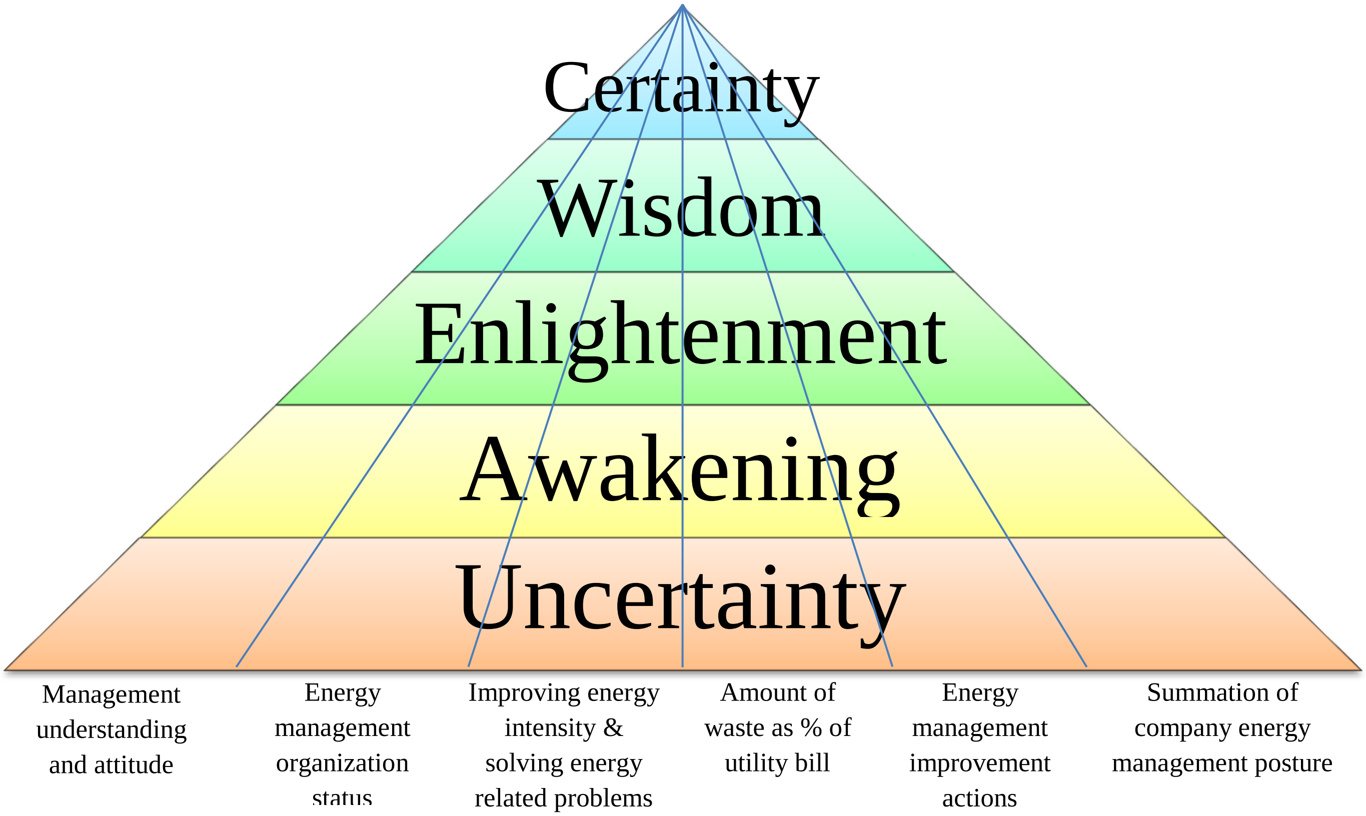

Figure III-7 Energy Management System Maturity Hierarchy with Measurement Categories

3.6 FRAMEWORK FOR SUSTAINABLE ENERGY MANAGEMENT SYSTEM

Energy management systems (EnMS) have been presented as a way to formally manage and control the energy used in an organization. Figure III-8 presents the layout of ISO 50001, as well as the DOE eGuide level two and DOE 50001 Ready Navigator, both slightly reorganize the layout of ISO 50001 into more manageable steps:

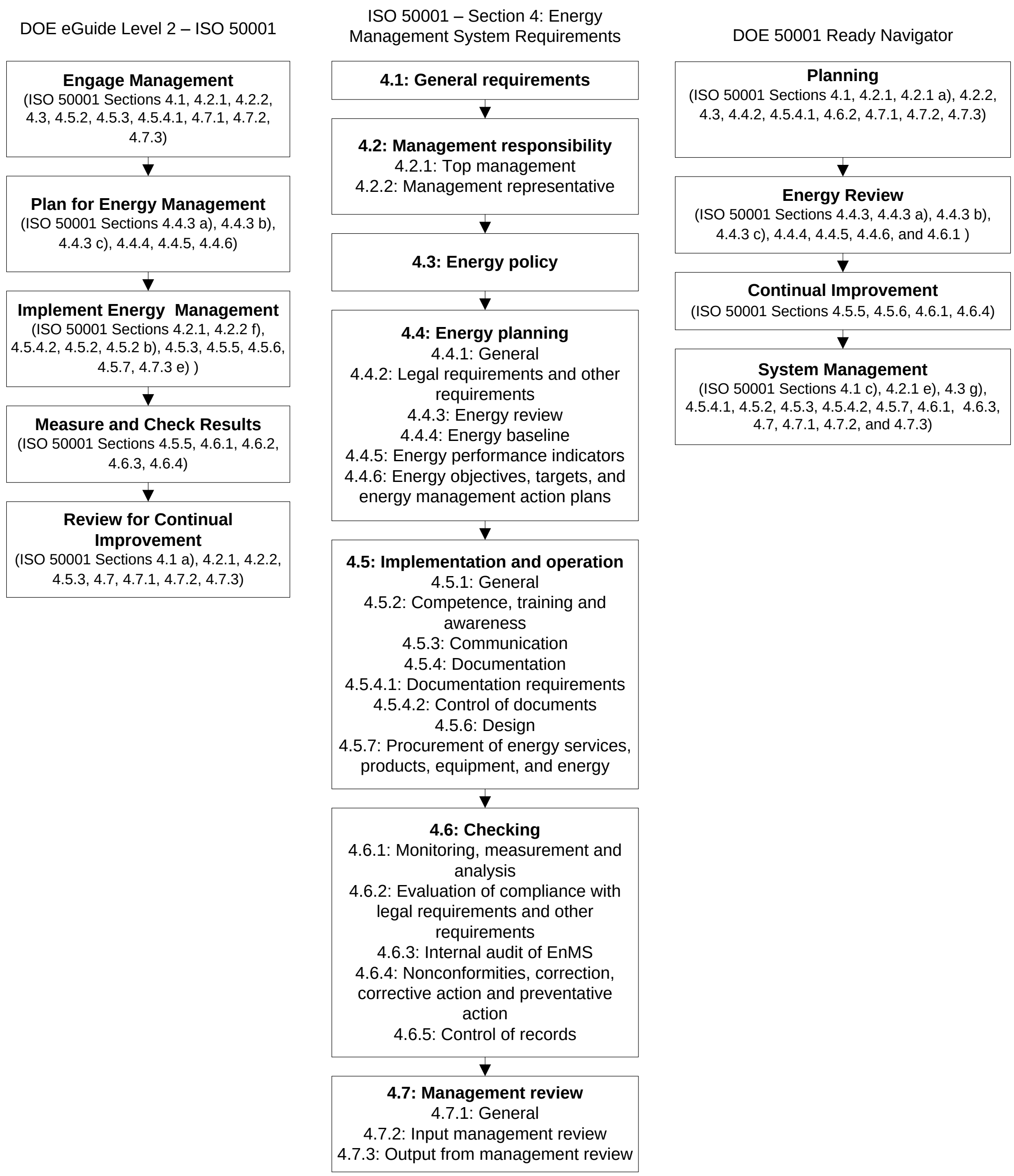

Figure III-8 DOE eGuide Level 2 Vs. ISO 50001 Section 4 Vs. 50001 Ready Navigator

There are often barriers as to why an organization is not managing its energy as effectively as it could, which include lack of technical expertise, competition for funds, time, personnel availability, etc.

To help break through these barriers and assist a manufacturing facility in better managing their energy in a way that fits into their corporate culture and abilities on both an economical and technical level, the method for funding an EnMS is presented below, using equations presented in the sections above.

It is important that an appropriate level of resources be used. As mentioned earlier, to achieve this, the energy management system should be treated similarly to that of an energy service contract with revenue sharing, where the savings generated by projects performed should be used to fund the program. If a large amount of savings is available, then the program should be allowed to grow and advance in maturity. If the amount of savings generated slows, then the energy management program funding should slow as well.

First, an organization needs to determine the state of their current energy management system and what opportunities are on the table. This is achieved in part with the energy management maturity grid. From this grid, the facility will be able to determine the percentage of waste that is likely at their facility. This will give the organization an estimate of the amount of money they could potentially save and allow for a reasonable initial budget/investment to be determined.

To further investigate this potential savings, the plant needs to next identify the major energy consuming equipment, perform an energy balance, and begin the process of forming an energy management system. The steps presented below parallel and compliment the EnMS described in ISO 50001 and present a means for the work described above to be applied in an SMM.

Step 1

Determine where energy ranks in relation to other expenses at the organization in terms of percentage of annual operating cost.

$$\gamma = \frac{Annual\ Energy\ Cost}{Annual\ Operating\ Cost} = \frac{\epsilon}{\nu} \tag{3.1}$$

Step 2

Use the energy management maturity matrix to estimate the percentage of annual energy purchased that is wasted and equate this to dollars wasted.

$$(\mu) = (\epsilon)(\%\ Wasted\ from\ EMMG) \tag{3.3}$$

Step 3

Determine a reasonable initial EnMS budget.

$$\beta_0 = (\mu)(X) \tag{3.4}$$

For example, $\beta_m = (\mu)(0.30)$, Where *m* is the year of the of the energy management systems existence, and is equal to '0' for Step 3. X is the multiplier for the proportion of waste that will be used to set the initial budget. As discussed above, a reasonable amount could be equal to 30% of the annual waste identified in Equation 3.3. This budget would represent money earmarked to fund the activities required in Step 4, such as to install metering equipment.

Step 4

Begin to work through energy management system steps as described in eGuide, 50001 Ready Navigator, or ISO 50001.

A logical first step would be conducting an energy assessment, similar to those conducted by IACs, performed to identify opportunities. This could be achieved using qualified in-house personnel, or brining in an outside consultant.

An important next step is establishing reliable energy intensity metrics and baselines, which might be part of an energy assessment. Long-term success of an EnMS will require reliable data to ensure targets and goals are being achieved. To ensure reliable data for decision-making it would make sense to spend some of the initial EnMS budget on permanent submetering of major energy users in the facility, in addition to other activities.

To assist manufactures in the justification of installing submetering equipment in their facility, when the energy management system budget allows, the following methodology is proposed:

4.1. Determine major energy using equipment. Group equipment into systems if logical (ex. rather than having three individual hydraulic pumps, possibly group these into one system for simplicity)

- Ensure equipment is optimally tuned/ operating in a normal condition
- Spot measure with short term energy monitoring, (ex. install data loggers for 5-day period)
- Extrapolate energy usage to an annual basis and create an energy balance
- Create a Pareto diagram showing energy use by system or end use

4.2. Determine cost of operating major equipment/ systems based on estimated consumption from Step 1 and energy unit costs from a utility analysis.

4.3. Determine which pieces of equipment/systems listed in Step 4.1 most impact the process (ex. a large blower motor could be using a significant amount of energy, but may not be as critical to the process as a motor used for mixing).

4.4. For the largest energy consumers, budget a percentage of the piece of equipment or system's annual energy consumption towards submetering.

A possible starting point may be to budget 15% of the equipment or system's annual consumption if it is a process critical piece of equipment, and 10% of its annual consumption if it is a major energy user but not deemed process critical.

The logic behind this is if a piece of equipment (ex. air compressor) begins to drift from its 'optimal' or baseline performance, it will begin to consume more energy over time. Spending 10% of the equipment's operating cost seems like a reasonable amount to avoid continued unmanaged energy usage resulting from problems that are not immediately noticed, which could likely increase that equipment's operating cost by at least 10%. Research shows that for various types of equipment, lack of routine maintenance may allow energy consumption to increase by as much as 50% [129].

If a piece of equipment is critical to production, monitoring its energy usage and performance would justify a larger percentage (ex. 15%) of its annual consumption, due to the increased costs/losses that would occur if the equipment failed and halted production.

This percentage of the annual bill per piece of equipment/system (10% or 15%) would then set the budget for advanced metering.

$$\textit{Metering budget per system} = (\textit{Annual energy cost})(\textit{Budget multiplier}) \quad (3.12)$$

If the metering budget per identified piece of equipment is large enough to purchase metering equipment then it is acceptable, otherwise the equipment should not be included in the current metering plan. The sum of the cost of the metering equipment installed should not exceed 10% of the total facility's annual utility bill. Equipment for the most critical systems should be given preference. Once the 10% threshold is reached, the remaining equipment should not be metered at this time. It is also possible for the submetering cost to be included as the measurement and verification cost for a given improvement.

This process should be reviewed on an annual basis as part of Step 7 below to determine if the amount of equipment metered should be expanded.

Step 5

When implementing an energy improvement project as identified through the EnMS process in Step 4, determine the total savings generated from the project using the following equations as described above:

$$TS_{ij} = \sum_{i=1}^{g} \sum_{j=1}^{u} \left[\left(E_{ij} + MA_{ij} + P_{ij} + L_{ij} + IN_{ij}\right)\right] \tag{3.5}$$

$$TC_{ij} = \sum_{i=1}^{g} \sum_{j=1}^{u} \left[\left(PL_{ij} + M_{ij} + I_{ij} - R_{ij} + T_{ij} + O_{ij} + MV_{ij}\right)\right] \tag{3.6}$$

$$S_{ij} = \sum_{i=1}^{g} \sum_{j=1}^{u} \left[\left(TS_{ij}\right) - \left(TC_{ij}\right)\right] \tag{3.7}$$

Step 6

On an annual basis, based on the M&V methodology chosen for the improvement, share the 'revenue' or savings generated by the improvement with the energy management system group for their operating budget. The amount of the energy savings shared should be equivalent to the proportion of energy expense determined in Step 1 using Equation 3.1.

The EnMS would only claim revenue from the proportion of the project attributed to energy savings and would only collect a percentage of the net savings after costs for the given year have been deducted at a rate in keeping with the breakdown of savings for the project (ex. if energy savings account for 2% of the total project savings, the energy savings revenue has 2% of the total cost deducted from it). From the energy savings generated, a proportion of the total implementation cost equivalent to the ratio of energy savings to total project savings would be deducted.

For all ongoing projects, i, within a given year, j, of their useful life, the project would generate revenue, δ, for the EnMS equal to:

$$\delta_{ij} = \sum_{i=1}^{g} \sum_{j=1}^{u} \left[\left(E_{ij} \right) - \left(D_{ij} \right) \right] (\gamma) \tag{3.10}$$

Step 7

Use the energy management system budget, βm, to advance the organization's energy management maturity level as funding allows. Possible levels of energy management maturity, starting with foundational levels and working towards more advanced levels, are described above in Section 3.4. After a facility assesses where they stand on the energy management maturity grid, or energy management hierarchy, they should determine what it would take to advance the energy management system forward to the next level. This should be done both in terms of dollars and management activities. Next, the facility needs to determine if the money in the EnMS budget is enough to achieve that goal.

For the chosen ‘next step’, the SMM should identify the costs involved to complete this step (planning, materials, installation, training, etc.) and then identify the anticipated savings associated with the step (energy, maintenance, production, etc.). They should then determine the revenue expected to be shared with the EnMS and the ongoing operating expense. If the existing EnMS budget is capable of supporting the other ongoing projects in addition to the new proposed project, proceed. If not, the improvement should wait until the EnMS budget allows you to proceed, or select a project that is able to be supported. This is described in the sub-steps below:

7.1 Determine the projected EnMS revenue (δ) and projected end of year balance (βm), based on the existing projects and expected revenue generated.

7.2 Identify the potential next step(s) for the EnMS program (possibly from descriptions in Section 3.4 above).

7.3 Determine costs and savings for the proposed next step using the same process as Step 5.

$$TS_{ij} = \sum_{i=1}^{g} \sum_{j=1}^{u} \left[\left(E_{ij} + MA_{ij} + P_{ij} + L_{ij} + IN_{ij} \right) \right] \quad (3.5)$$

$$TC_{ij} = \sum_{i=1}^{g} \sum_{j=1}^{u} \left[\left(PL_{ij} + M_{ij} + I_{ij} - R_{ij} + T_{ij} + O_{ij} + MV_{ij} \right) \right] \quad (3.6)$$

7.4 Determine the proportion of the costs that would be deducted from the energy savings, *D*, for the proposed next project, *i*. For each year, *j*, over the useful life, *u*, of the proposed project, determine the operating cost of the proposed next step:

$$D_{ij} = \sum_{j=1}^{u} \left[\left(\left(TC_{ij} \right) \left(\frac{E_{ij}}{TS_{ij}} \right) \right) \right] \quad (3.11)$$

7.5 Determine the proportion of the net savings that will be generated as revenue for the EnMS for the proposed next project, *i*, in each year, *j*, over the useful life, *u*,

$$\delta_{ij} = \sum_{i=1}^{g} \sum_{j=1}^{u} \left[\left(E_{ij} \right) - \left(D_{ij} \right) \right] (\gamma) \tag{3.10}$$

Because this step is a projection into the future, it is important to include a consideration of the decay of energy savings across time, as described in Equation 3.9.

7.6 Determine if the expected EnMS revenue of the proposed project, *i*, when added to the projected EnMS year-end budget over the useful life, *u*, of the proposed project, is greater than 0: $\sum_{j=1}^{u} \left(\delta_{ij} \right) + \sum_{j=1}^{u} (\beta_m) \geq 0$, where $j = 1$ and *m* is equal to the current EnMS year (1, 2, … n) and:

$$\beta m = \sum_{m=1}^{n} [(\delta_m) + (\beta_{m-1})] \tag{3.8}$$

7.7 If these constraints are met, the SMM should proceed with the next step to improve their EnMS. If not, a more suitable next step should be identified, or the SMM should determine what changes need to be made to make the proposed project viable.

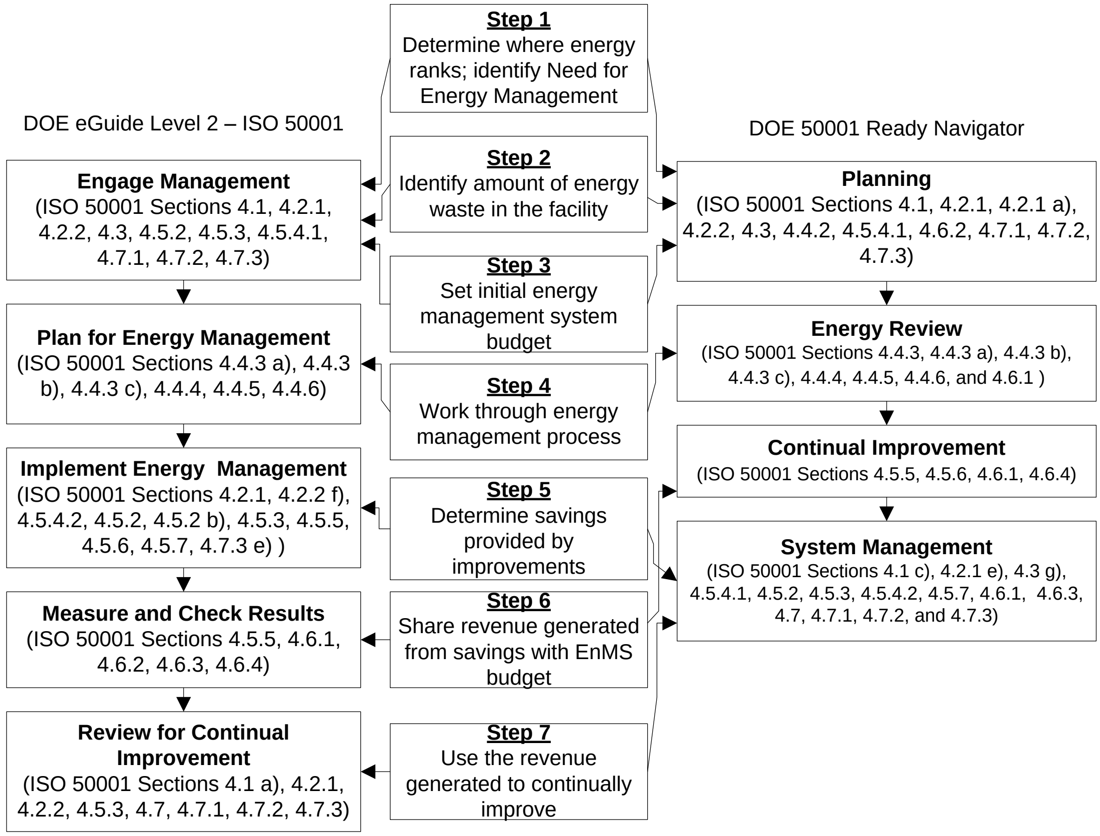

Figure III-9 Depiction of Where Model Would Fit into ISO 50001/eGuide/50001 Ready Navigator

Once the EnMS is established (Steps 1-5) the organization would repeat Steps 6 and 7 across time, growing the system as savings allowed and slowing growth as the generated savings slowed.

The next chapter of this dissertation presents a conceptual validation of this model.

CHAPTER IV

VALIDATION

4.1 CHAPTER OUTLINE

4.2 INTRODUCTION

To validate the model framework presented in this dissertation a conceptual application is presented below. This example was designed based on reasonable numbers observed during site visits to manufacturing facilities but does not use actual data from any particular organization. The example follows a SMM through the steps of the framework presented in Chapter III, first identifying an initial budget and initial improvements, and then following several iterations of the process showing the organization's EnMS maturing in a sustainable manner. The background for the scenario is described below.

4.3 SCENARIO BACKGROUND

ACME Injection Molding Inc. is a fictitious SMM organization created for the purpose of this example. We will assume that it produces a wide range of injection molded consumer products; their production loads are typically seasonal and they have several product lines. ACME's facility is approximately 200,000 sqft, of which 50,000 sqft includes the company's headquarters, office area, sales team, and data center. Production occurs 5 days per week, 24 hours per day; the office area is operated 5 days per week, 8 hours per day. The entire facility is heated and cooled year-round.

The facility currently pays $0.114/kWh and $10/kW. ACME's electric utility rate schedule includes a ratchet clause where the monthly demand charge is based on either the current month's measured demand, or 70% of the highest measured demand established during the past eleven months, whichever is greater. The majority of the production equipment is electric, with exception for space heating during the winter. The facility pays $5.651/MMBtu for natural gas, including transportation costs. For simplicity this example assumes a static energy cost for electricity and natural gas. In reality this cost would likely increase over time. This would not impact the performance of the presented methodology.

The facility has a total annual operating expense of $10,000,000 with the three major annual operating expense categories being as follows: 1. Labor: $6,000,000, 2. Raw materials: $1,500,000, 3. Energy: $1,000,000

ACME Inc. recently signed a large contract with a major retailer who values sustainability in its manufacturers and uses it as part of a screening process for who they do business with. As a result, ACME Inc.'s management made the decision to begin investigating the implementation of a formal EnMS six months ago and is currently in the early stages of scrutinizing its energy consumption and improving its energy management. This example follows the organization through several improvements over time to demonstrate how the methodology presented in this dissertation might be used in an organization's decision-making process. ACME Inc.'s energy consumption data for the period January 20XX to December 20XX is provided below:

Table IV–1 ACME Inc. Annual Electricity Consumption Summary

Electricity Consumption from January 20XX to December 20XX
Electricity Provider: Friendly Utility Company

Month	Energy Consumption Charge			Demand Charge				Electrical Service Charge ($)	Franchise Fee ($)	State Sales Tax ($)	Total Cost ($)
	Electricity Consumption (kWh)	kWh Cost ($/kWh)	Energy Charge ($)	Actual (kW)	Billed (kW)	kW Cost ($/kW)	Demand Charge ($)				
Jan	328,668	0.09	29,580	4,289	4,289	10.00	42,887	2,297	2,991	5,053	82,809
Feb	426,388	0.09	38,375	2,403	3,002	10.00	30,021	2,343	2,830	4,802	78,370
Mar	401,245	0.09	36,112	2,494	3,002	10.00	30,021	2,262	2,736	4,656	75,786
Apr	423,112	0.09	38,080	3,000	3,002	10.00	30,021	2,420	2,821	4,789	78,131
May	447,979	0.09	40,318	3,283	3,283	10.00	32,831	2,440	3,024	5,105	83,717
Jun	486,839	0.09	43,816	3,690	3,690	10.00	36,903	2,628	3,334	5,589	92,269
Jul	469,839	0.09	42,286	3,465	3,465	10.00	34,653	2,615	3,182	5,352	88,088
Aug	448,974	0.09	40,408	3,291	3,291	10.00	32,915	2,667	3,040	5,130	84,158
Sep	434,109	0.09	39,070	2,668	3,002	10.00	30,021	2,547	2,866	4,858	79,361
Oct	403,244	0.09	36,292	2,910	3,002	10.00	30,021	2,365	2,747	4,674	76,099
Nov	436,379	0.09	39,274	2,686	3,002	10.00	30,021	2,158	2,858	4,847	79,158
Dec	324,649	0.09	29,218	2,055	3,002	10.00	30,021	1,944	2,447	4,206	67,837
Total	**5,031,427**		**452,828**	**36,236**	**39,034**		**390,338**			**59,059**	**965,784**

Average Cost of Electricity w/o Demand ($)	0.114
Average Demand Cost / kW ($)	10.00

Table IV-2 ACME Inc. Annual Natural Gas Consumption Summary

Natural Gas Consumption January 20XX to December 20XX

Natural Gas Provider: Friendly Gas Corp.

Month	Units Billed (MMBtu)	Customer Fuel Cost ($/MMBtu)	Customer Fuel Cost ($)	Franchise Fee ($)	Distribution Charge ($)	State Tax ($)	Franchise Tax ($)	Total Natural Gas Usage Cost ($)
Jan	925	3.25	3,007	380	767	208	184	4,546
Feb	779	3.25	2,532	306	683	176	168	3,866
Mar	682	3.25	2,216	330	684	161	156	3,547
Apr	487	3.25	1,583	323	657	128	153	2,844
May	150	3.25	488	337	659	74	165	1,722
Jun	110	3.25	358	305	613	64	140	1,479
Jul	97	3.25	317	285	659	63	155	1,479
Aug	487	3.25	1,583	250	634	123	157	2,747
Sep	195	3.25	633	128	587	67	157	1,573
Oct	390	3.25	1,266	173	657	105	136	2,337
Nov	779	3.25	2,532	247	587	168	130	3,665
Dec	974	3.25	3,166	267	618	203	159	4,412
Total	6,055		19,680					34,216

Average Natural Gas Cost with Transportation ($/MMBtu)	**5.651**

Table IV-3 ACME Inc. Total Annual Energy Consumption Summary

Total Energy Consumption January 20XX to December 20XX

Month	**Total Energy Usage & Cost**					
	Energy (MMBtu)			**Cost ($)**		
	Electricity	**Natural Gas**	**Total MMBtu**	**Electricity**	**Natural Gas**	**Total ($)**
Jan	1,121	925	2,047	82,809	4,546	87,355
Feb	1,455	779	2,234	78,370	3,866	82,236
Mar	1,369	682	2,051	75,786	3,547	79,333
Apr	1,444	487	1,931	78,131	2,844	80,975
May	1,529	150	1,679	83,717	1,722	85,440
Jun	1,661	110	1,771	92,269	1,479	93,748
Jul	1,603	97	1,701	88,088	1,479	89,567
Aug	1,532	487	2,019	84,158	2,747	86,904
Sep	1,481	195	1,676	79,361	1,573	80,935
Oct	1,376	390	1,766	76,099	2,337	78,436
Nov	1,489	779	2,268	79,158	3,665	82,823
Dec	1,108	974	2,082	67,837	4,412	72,249
Total			**23,223**			**$ 1,000,000**

Total Energy Cost / MMBtu	**$ 43.060**

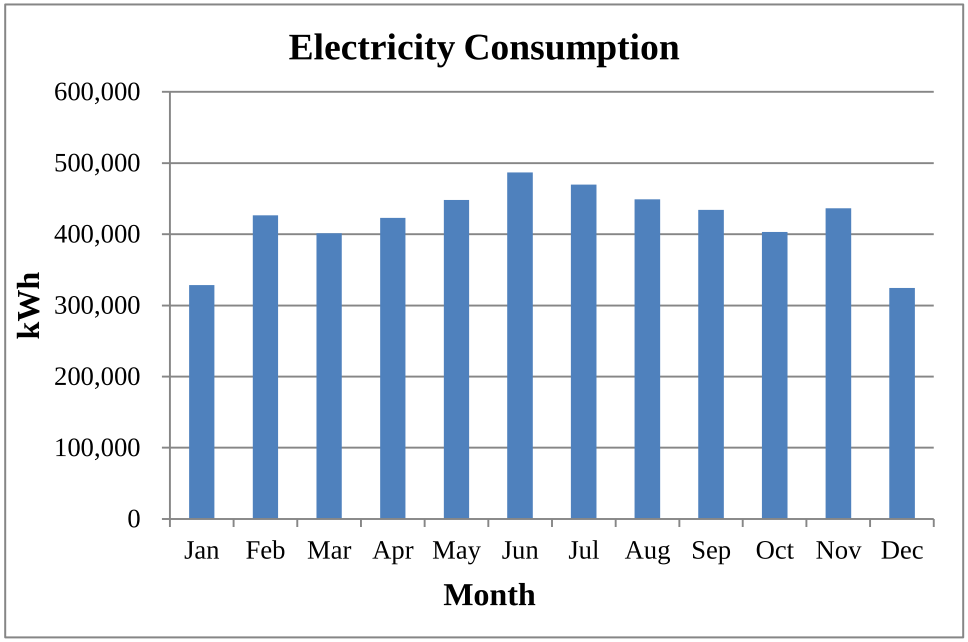

Figure IV-1 Annual Electricity Consumption

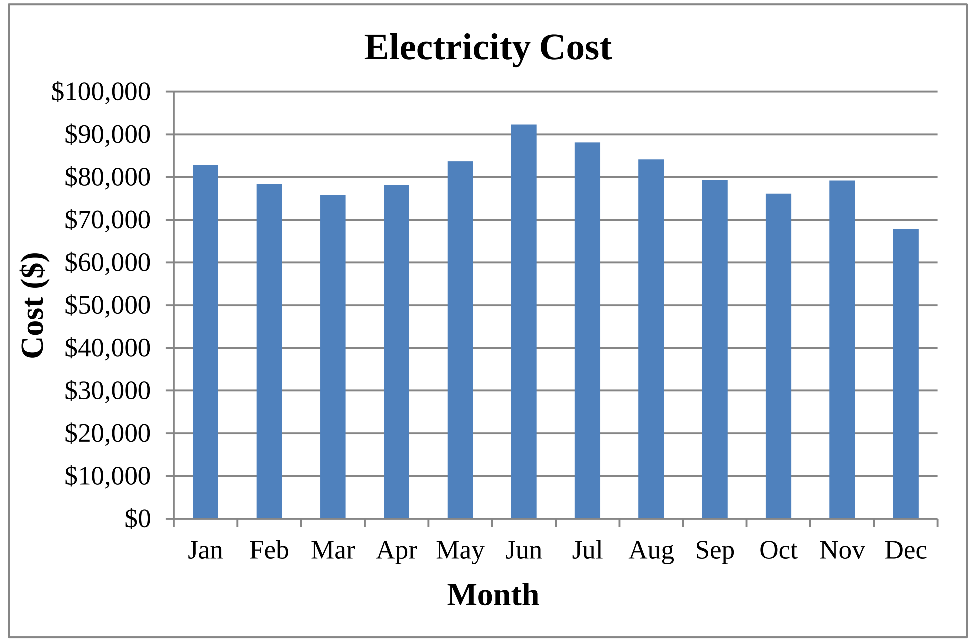

Figure IV-2 Annual Electricity Consumption Cost

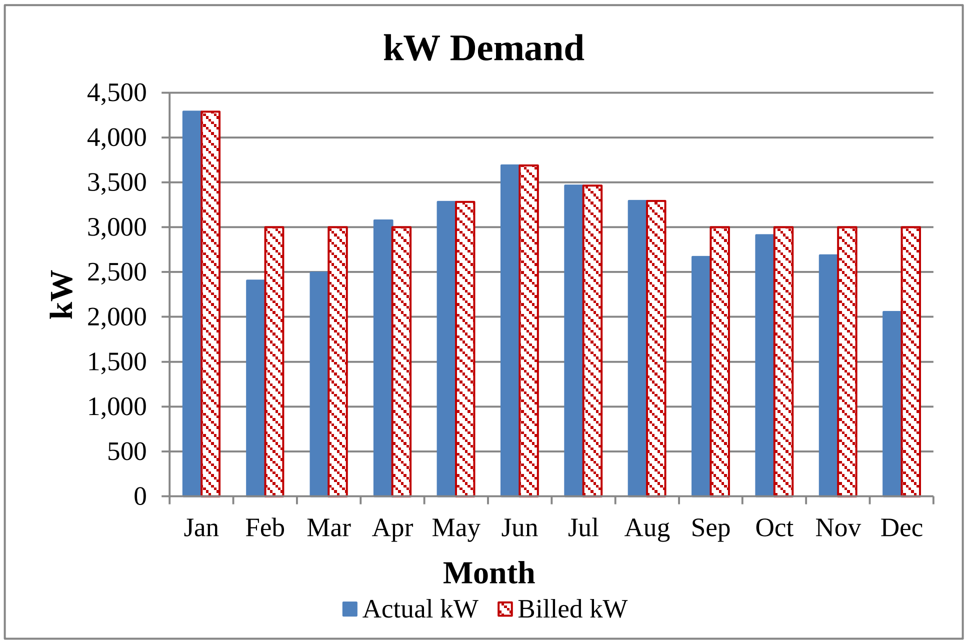

Figure IV-3 Annual Metered vs Billed kW Demand

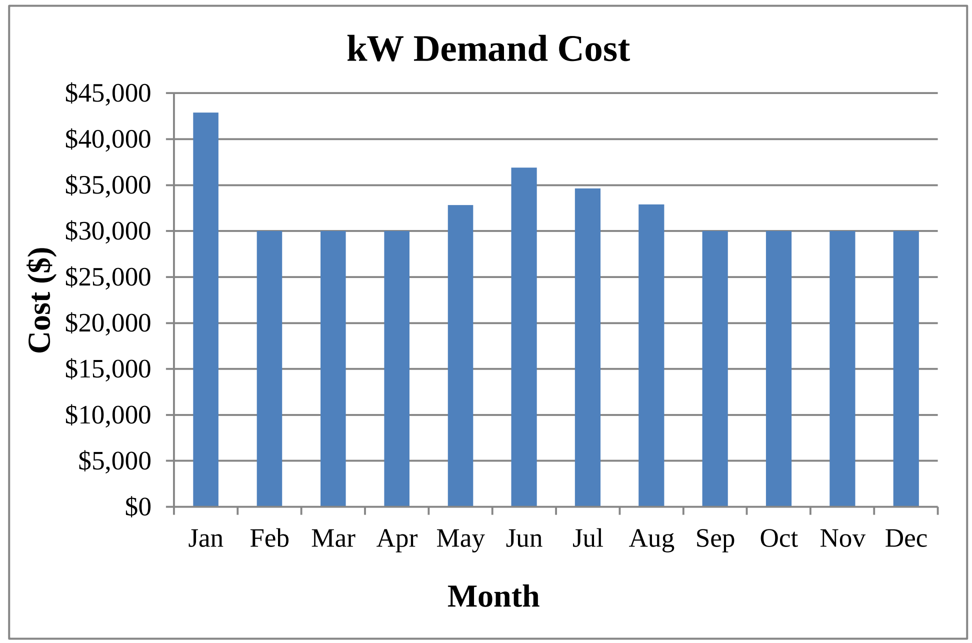

Figure IV-4 Annual kW Demand Cost

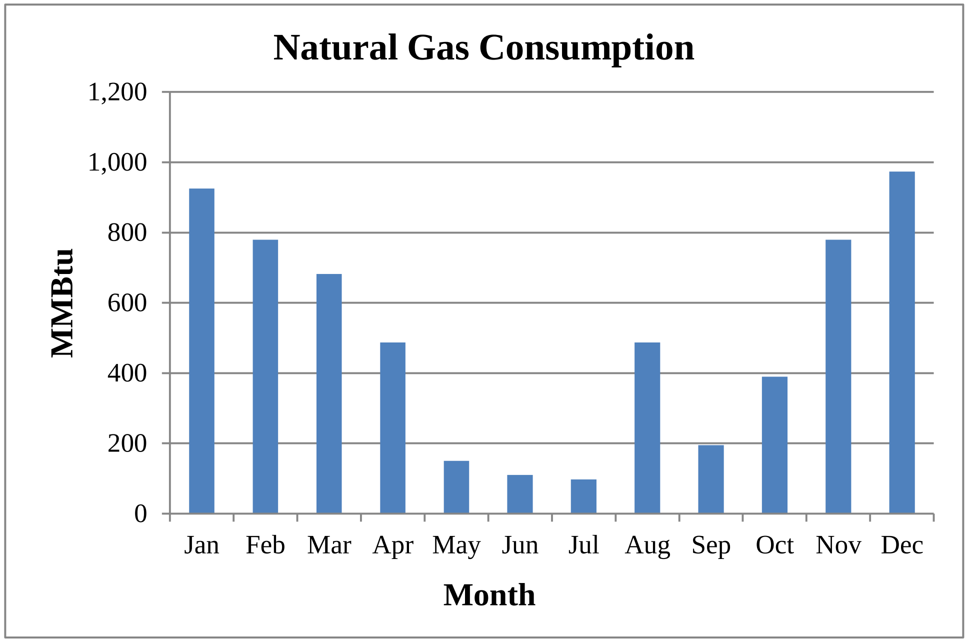

Figure IV-5 Annual Natural Gas Consumption

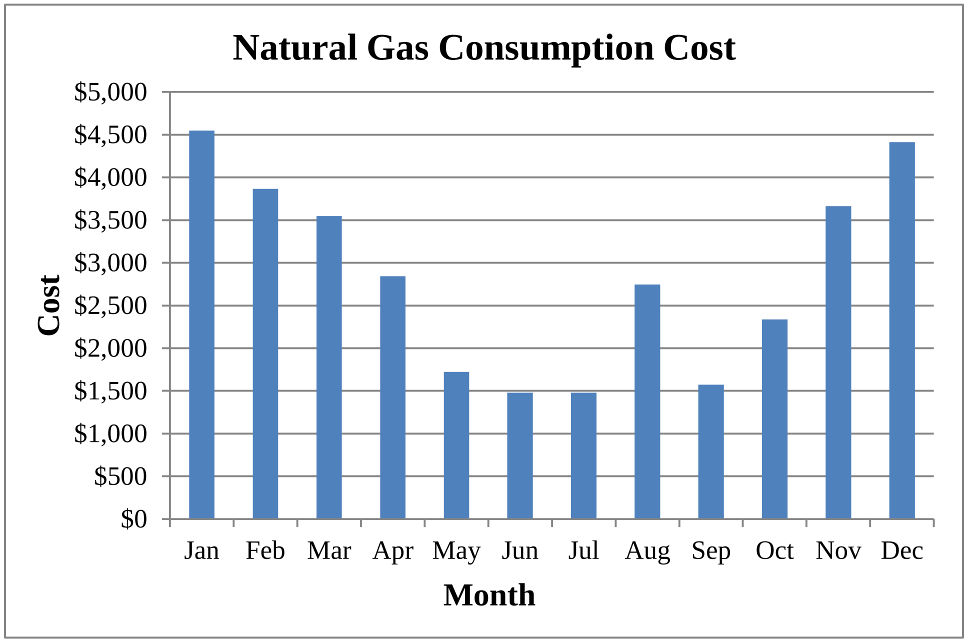

Figure IV-6 Annual Natural Gas Consumption Cost

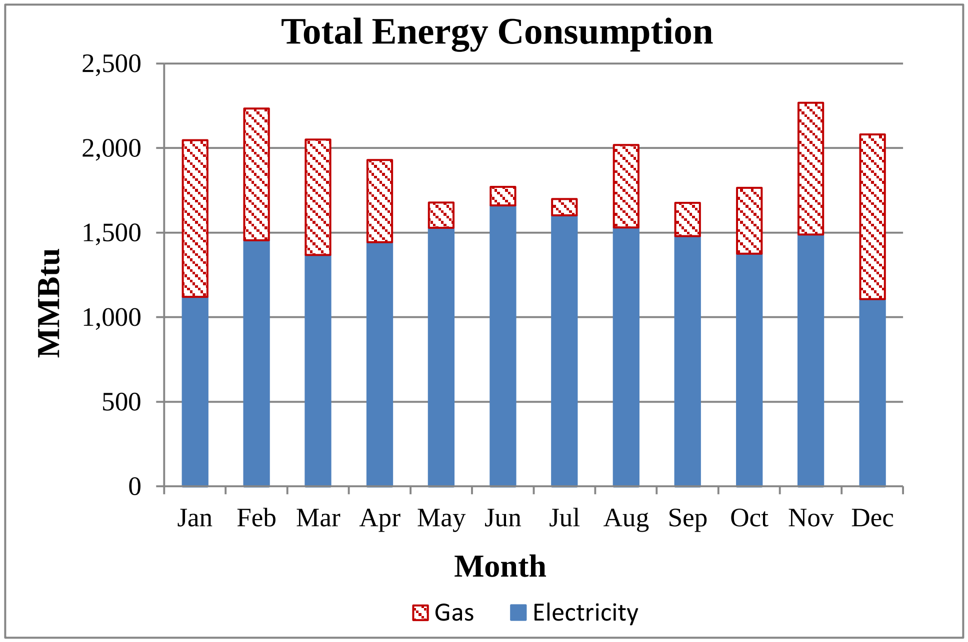

Figure IV-7 Annual Total Energy Consumption

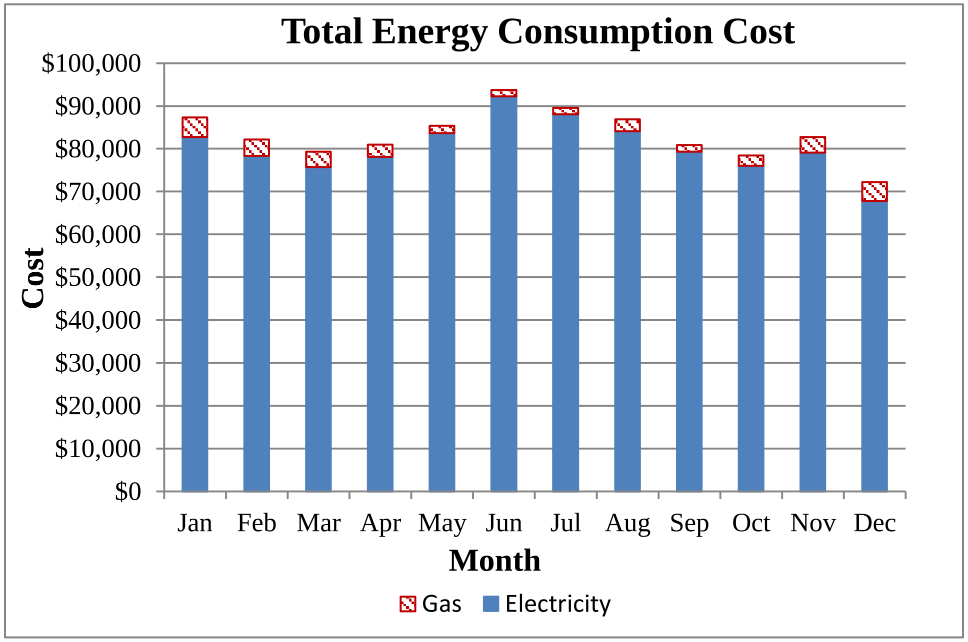

Figure IV-8 Annual Total Energy Consumption Cost

4.3 APPLICATION OF CONCEPTUAL FRAMEWORK

Step 1

The annual utility costs (ϵ) for the ACME Inc. totaled $1,000,000. This includes electricity and natural gas. The annual operating cost (ν) for the organization was $10,000,000, which brings the proportion of annual operating cost attributed to energy (γ) to 10%, using Equation 3.1.

Step 2

The completed energy management maturity grid seen in Table IV-4 below. This identifies the organization's energy management maturity is currently in its early stages with the majority of its self-assessment placing it in Stage I and II. Using the energy matrix, ACME Inc. estimated the facility currently has approximately 30% actual energy waste. Using Equation 3.3, this equates to an annually energy waste in dollars (μ) equal to ($1,000,000)(0.30) = $300,000.

Step 3

To set the initial budget for its EnMS, Equation 3.4 was used along with a budget multiplier, *X*, of 0.3 based on the historical data indicating SMMs participating in the IAC program typically implement 30% of the identified savings within one year of an energy assessment. This provides ACME Inc. with an initial EnMS budget of:

$$\text{Initial budget } (\beta_0) = (\$300{,}000)(0.30) = \$90{,}000$$

This is equal to approximately 1% of the overall operating budget for the organization and is deemed a reasonable amount by ACME Inc.'s management. This money is earmarked for the EnMS system use.

Table IV-4 ACME Inc. Completed EMMG

Energy Management Maturity Grid - Conceptual Example
Rating Tool

Measurement Categories	Stage I: Uncertainty	Stage II: Awakening	Stage III: Enlightenment	Stage IV: Wisdom	Stage V: Certainty
Management understanding and attitude	No comprehension of energy as a management tool. View energy as a cost of doing business.	Recognizing that energy management may be of value but not willing to provide money or time to make it all happen. X	Going through energy improvement program to learn more about energy management; becoming supportive and helpful.	Participating. Understanding principles of energy management reasoning. On-going energy conservation projects.	Integration. Consider energy management an essential part of company management system.
Energy management organization status	Energy management is hidden in maintenance or engineering departments; energy considered 'just the cost of doing business'. X	An energy management leader is appointed but main emphasis is still on getting the product out the door.	Energy-sustainability management group reports to top management, focus is on compliance.	Energy sustainability manager is an officer of company; effective performance indicators, reporting and improvement actions. Focus on compliance and improvements.	Energy sustainability manager leading efforts; Systems which are integrated across organization with financial and quality systems.
Improving energy intensity & solving energy related problems	Improvements are made based on patchwork basis with little concern for efficiency. React and fix current problems. X	Teams are set up to attack major improvements. Long-range solutions are not solicited.	Thought is given to energy efficiency when seeking solutions. Life cycle savings considered over first cost.	Energy efficiency is considered in initial design. All functions are open to suggestion and improvement.	Innovative energy efficient solutions implemented; energy intensity is a focus.
Amount of waste as % of utility bill	Estimated: unknown Actual: 50%	Estimated: 30% Actual 40%	Estimated: 20% Actual: 30% X	Estimated: 10% Actual: 20%	Estimated: 5-10% Actual: 5-10%
Energy management improvement actions	No organized activities. No understanding of such activities.	Trying obvious "motivational" short-range efforts. X	Implementation of first energy management step with thorough understanding and establishment of each step.	Implementation of ISO 50001	Energy improvement is a normal and continued activity.
Summation of company energy management posture	"We don't know why our energy costs are what they are."	"Is it absolutely necessary to consider energy consumption a given?" X	"Through management commitment and energy improvement -- we are reducing our consumption."	"Identifying energy improvement opportunities are a routine part of our operation."	"We know where our energy goes and why it goes there."

Step 4

ACME Inc. is beginning to work through energy management system steps, using eGuide level 1. The driver behind implementing an EnMS is ACME's upper management, and therefore they have upper management buy-in already. An energy team was created consisting of staff members from various departments across the organization (maintenance, engineering, management, production, etc.). One of the first steps taken by the energy team is to contact their local IAC for a "free" energy assessment to assist with the identification of conservation opportunities. This assessment identifies the following recommendations for ACME Inc.:

- Implement regular compressed air leak maintenance program
- Install more efficient lighting
- Utilize free cooling on chilled water system
- Replace chillers with new high efficiency units
- Replace production equipment with more efficient models
- Install programmable thermostats for night setback
- Install variable frequency drive on grinding system

Detailed descriptions for several of these recommendations can be found in Appendix D.

The IAC team helps provide ACME's energy team with training on how to improve their operation, introducing them to the DOE eGuide/50001 Ready Navigator, and alerts them to the Association of Energy Engineers (AEE) Certified Energy Manger (CEM) training and certificate program. ACME Inc. decides to send several of their team members to this training, funded through the initial EnMS budget.

After completing the training and initial assessment, the energy team begins to determine what initial improvements they would like to focus on. They first identify goals for their overall EnMS program, and set targets for how they would like to reduce their energy consumption over the next five years. These include:

EnMS five year goals:

1. Identify where energy is going in the production process
2. Set baselines for current use
3. Identify true cost of each product based on energy consumption
4. Train employees in energy conservation best practices
5. Utilize submetering in facility to determine energy intensity metrics
6. Maintain sustainable growth of the EnMS system

EnMS five year targets:

1. Reduce energy consumption by 10% facility-wide
2. Improve energy intensity of products by 2% per year
3. Reduce air leaks by 5% annually
4. Reduce chiller kW/ton from previous years baseline

Submetering Budget

In order to begin addressing their goals and targets for the EnMS system, ACME Inc. must develop useful energy intensity metrics and create consumption baselines. The IAC assessment utilized data loggers for short term metering, and the information produced by them proved valuable for identifying several energy saving opportunities. However, such a small 'snap shot' of what is occurring in the facility, and a backwards-looking view, is not as beneficial to the energy team as a real-time monitoring system. While management is slightly skeptical, the energy team argues that installing submetering equipment in several areas of its facility is the best way to achieve this, and show savings over time. The following steps demonstrate the process they take to identify where to initially meter and justify the expense such a system requires:

4.1. Conduct an energy balance for major equipment

The EnMS energy team developed the energy balance described in Table IV-5 using estimated energy consumption based on nameplate data and equipment operating characteristics:

Table IV-5 Energy Balance

System	Estimated Electricty Consumption (kWh)	% Annual Bill	Estimated Natural Gas Consumption (MMBtu)	% Annual Bill
Production Line A	700,000	14%	-	-
Production Line B	525,000	10%	-	-
Production Line C	400,000	8%	-	-
Production Line D	375,000	7%	-	-
Chiller	1,250,000	25%	-	-
Air Compressor	500,000	10%	-	-
Production Lighting	400,000	8%	-	-
Resin Dryer	250,000	5%	-	-
Grinder	200,000	4%	-	-
Rooftop HVAC Equipment	150,000	3%	5,752	95%
Office Area	250,000	5%	-	-
Misc. Other	31,427	1%	303	5%
Total	5,031,427	100%	6,055	100%

From this data, the Pareto diagram shown in Figure IV-9 was developed for the major electrical equipment:

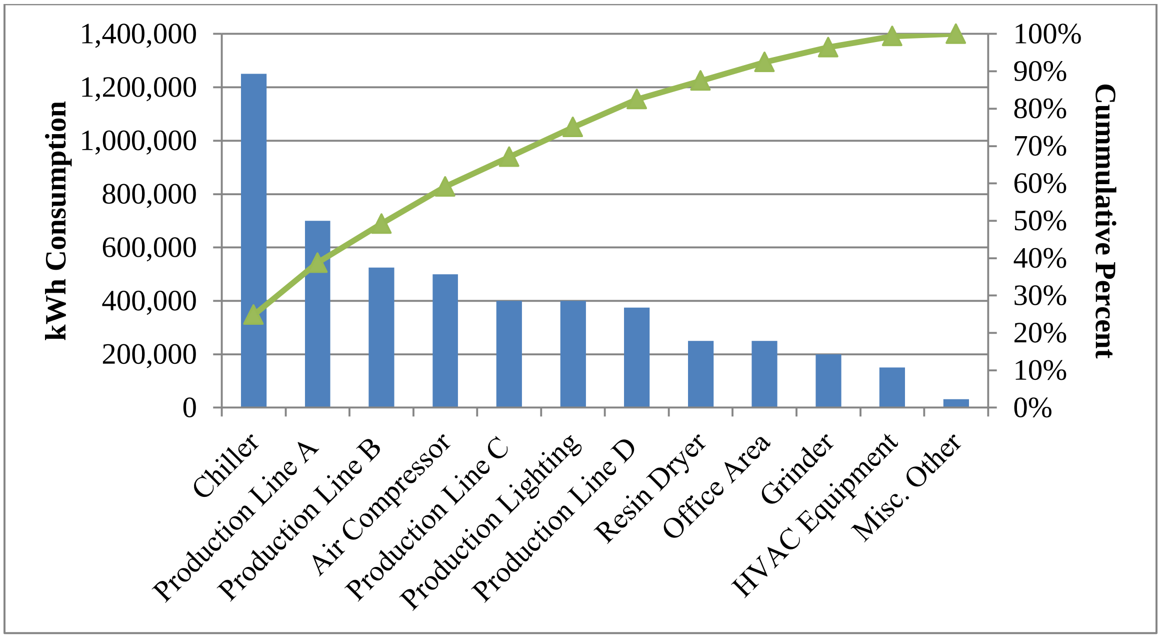

Figure IV-9 Pareto Diagram of Major Energy Using Equipment

Collectively the production lines account for a majority of the energy consumption, followed by the chilled water system, and air compressor system.

4.2. Determine cost of operating major equipment/systems

Using the energy balance data and average $/kWh for the facility, the energy team was able to determine the estimated annual operating cost for each major system as seen in Table IV-6. For simplicity this estimate does not include kW cost or operating cost as a result of maintenance activities.

Table IV-6 Annual Operating Costs Attributed to Energy for Major Equipment*

System	Estimated Electricty Consumption (kWh)	Annual Operating Cost - kWh ($)
Chiller	1,250,000	$142,500
Production Line A	700,000	$79,800
Production Line B	525,000	$59,850
Air Compressors	500,000	$57,000
Production Line C	400,000	$45,600
Production Lighting	400,000	$45,600
Production Line D	375,000	$42,750
Resin Dryer	250,000	$28,500
Office Area	250,000	$28,500
Grinder	200,000	$22,800
HVAC Equipment	150,000	$17,100
Misc. Other	31,427	$3,583
Total	5,031,427	$573,583

*Note: This operating cost estimate does not include kW demand charges

4.3. Determine which pieces of equipment/systems that most impact the process

The team debated which of the major pieces of equipment were critical to their operation and decided on the four production line injection molding presses, the air compressor, and the chiller.

4.4. Determine a maximum justifiable budget for metering each system

The process critical equipment was assigned a budget multiplier of 15%, and the remaining systems assigned a multiplier of 10%.

Using Equation 3.12, the justifiable submetering budget for each system can be seen in Table IV-7. If ACME Inc. were to meter all of the major systems, this justifiable budget would amount to $78,000. While the initial budget for the EnMS is $90,000, the team does not want to spend all of this money on submetering. Therefore, they decide to focus on only the critical systems initially, giving them a justifiable budget for metering of $64,000. Based on the typical installation costs of metering equipment (see Appendix C), the team finds that the six critical electric systems will cost approximately $3,000 per point metered and includes the cost for the associated EIS software and data storage.

The associated software provided by the submetering manufacturer allows for the creation of several dashboards, indicating the current consumption of the end use, as well as the historical baseline for each system. ACME Inc. is also able to configure the software to trigger alerts based on deviations from the baselines it sets. Initially, the submetering data and software are not interfaced with the production data system.

Table IV-7 Max Electrical Submetering Budget by System

System	Estimated Electricty Consumption (kWh)	Annual Operating Cost - kWh ($)	Budget Multiplier	Budget ($)
Chiller	1,250,000	$142,500	15%	**$21,375**
Production Line A	700,000	$79,800	15%	**$11,970**
Production Line B	525,000	$59,850	15%	**$8,978**
Air Compressors	500,000	$57,000	15%	**$8,550**
Production Line C	400,000	$45,600	15%	**$6,840**
Production Lighting	400,000	$45,600	10%	$4,560
Production Line D	375,000	$42,750	15%	**$6,413**
Resin Dryer	250,000	$28,500	10%	$2,850
Office Area	250,000	$28,500	10%	$2,850
Grinder	200,000	$22,800	10%	$2,280
HVAC Equipment	150,000	$17,100	10%	$1,710
Misc. Other	31,427	$3,583	10%	$358
Total	5,031,427	$573,583		$78,733

Based on this information, the EnMS team decides to budget $18,000 on metering equipment for their six major electrical energy-consuming systems. This expense is less than the maximum reasonable budget identified in Table IV-7, and will be included in the cost of energy improvement projects performed on the related systems, allowing the ACME Inc. EnMS to build reliable baselines and gather performance data to help support future energy improvements. This equipment would have an expected useful life of ten years with an estimated $1,000 reoccurring cost for running the system ($200 per end point; calibration, software licenses, data storage, etc.).

Based on the IAC report, the energy team determines that in the initial year of the EnMS creation they will spend part of their budget on a compressed air leak maintenance program. This improvement was chosen based upon the high probability of savings, low technical skill requirement, and low financial risk. The team wants to start with a project they feel will show success and help gain further support from the ACME Inc. management.

Prior to implementing the compressed air leak maintenance program, the ACME Inc. team determines the expected savings generated by the project to determine if it is a good decision, working through Steps 5 and 6 for the project.

Estimated Savings from Improvement Project #1 – Implement Regular Air Leak Maintenance Program

DATA

- EnMS Project (i) 1
- Year of EnMS project implemented (m). 1
- Initial EnMS Budget (β_0) $90,000
- Initial EnMS expenses[5]. $6,000
- Annual operating cost attributed to energy (γ) 10%
- Proposed improvement estimated useful life[6]...... .... 5 years
- Current compressed air system operating expense …..… $57,000/year
- Current air system maintenance cost $1,000/year

Costs

- PL - Planning cost......... .... $100 (one time)
- M - Material cost.. ……... ……... .... $500/year
- I - Installation cost $1,020/year
- T - Training/technical cost.. …..… .... $100 (one time)
- O - Operating cost......... .... $0
- MV – Measurement & Verification cost[7].. …..… $3,000/year 1

Savings

- E - Energy savings[8].. …..… $14,439/year
- R - Utility rebate savings $0
- M - Maintenance savings.......... .... $0
- P - Production savings/Production increase.. ……... .... $0
- L - Labor savings $0
- IN - Intangible savings.. .... $0

Constraints

- For the expected EnMS revenue (δ) of the proposed project, i, when added to the projected EnMS year-end budget over the useful life, u, of the proposed project, must be greater than 0: $\sum_{j=1}^{u}(\delta_{ij}) + \sum_{j=1}^{u}(\beta_m) \geq 0$

  In other words, the proposed project cannot deplete the expected EnMS budget.

---

[5] Training costs for EnMS energy team
[6] The costs are based on new air leaks occurring every year, and the program continuing for 5 years
[7] Cost for submetering system to monitor compressed air use; $200 after year 1
[8] Based on energy team calculations – See Appendix D

Step 5

Total Net Savings for Year 1 ($S_{1,1}$)

$$= \ TS_{1,1} = \sum_{i=1}^{1}\sum_{j=1}^{5}\left[\left(E_{1,1} \ + MA_{1,1} + P_{1,1} + L_{1,1} + IN_{1,1}\right)\right] \qquad (3.5)$$

= [$14,439 + $0 + $0 + $0 + $0]
= $14,439/project year 1

$$= \ TC_{1,1} = \sum_{i=1}^{1}\sum_{j=1}^{5}\left[\left(PL_{1,1} + M_{1,1} + I_{1,1} - R_{1,1} + T_{1,1} + O_{1,1} + MV_{1,1} \ \right)\right] \qquad (3.6)$$

= [$100 + $500 + $1,020 + $100 + $0 + $3,000]
= $4,720/project year 1

$$= \ S_{1,1} = \sum_{i=j}^{1}\sum_{j=1}^{5}\left[\left(TS_{1,1}\ \right) - \left(TC_{1,1}\ \right)\right] \qquad (3.7)$$

= ($14,439) – ($4,720)
= $9,719/project year 1

Total Net Annual Savings Project Year 2

(A given air leak repair's useful life is assumed to be one year; after one year it is assumed the major air leaks are identified and fixed, with year two having half as many leaks as year one, and years three through five decreasing in savings exponentially.)

$$= \ TS_{1,2} = \sum_{i=1}^{1}\sum_{j=2}^{5}\left[\left(E_{1,2} \ + MA_{1,2} + P_{1,2} + L_{1,2} + IN_{1,2}\right)\right] \qquad (3.5)$$

= [$7,220 + $0 + $0 + $0 + $0]
= $7,220/project year 2

$$= \ TC_{1,2} = \sum_{i=1}^{1}\sum_{j=2}^{5}\left[\left(PL_{1,2} + M_{1,2} + I_{1,2} - R_{1,2} + T_{1,2} + O_{1,2} + MV_{1,2}\right)\right] \qquad (3.6)$$

= [$0 + $500 + $1,020 + $0 + $0 + $200]
= $1,720/project for year 2

$$= \ S_{1,2} = \sum_{i=j}^{1}\sum_{j=2}^{5}\left[\left(TS_{1,2}\right) - \left(TC_{1,2}\ \right)\right] \qquad (3.7)$$

= ($7,220) – ($1,720)
= $5,500/year 2

Savings for years one through five accounting for decayed savings are shown in table IV-8.

Table IV-8 Project #1 Total Savings and Cost Summary

Project Year *i*	Total Savings TS_{ij}	Total Cost TC_{ij}	Total Net Savings S_{ij}
1	14,439	4,720	9,719
2	7,220	1,720	5,500
3	5,911	1,720	4,191
4	5,348	1,720	3,628
5	4,839	1,720	3,119
	37,757	11,600	26,157

<u>Step 6</u>

The EnMS only claims revenue from the portion of the project attributed to energy savings and would only collect a percentage of the net savings after costs for the given year have been deducted at a rate in keeping with the breakdown of savings for the project. Below is the revenue that the EnMS would claim over the useful life of the program based on the energy team's projections.

Percentage of savings attributed to energy

For project 1, all of the savings identified are attributed to energy savings:

$= \left(\frac{E_{1,1}}{TS_{1,1}}\right)$

= (Energy savings) / (Total savings)

= ($14,439) / ($14,439) = 100% = 1.0

Costs that would be deducted from energy savings in year 1

$$D_{1,1} = \sum_{j=1}^{5}\left[\left((TC_{1,1})\left(\frac{E_{1,1}}{TS_{1,1}}\right)\right)\right] \tag{3.11}$$

= ($4,720)(1.0)

= $4,720/year

EnMS Revenue Share Year 1

$$= \ \delta_{1,1} = \sum_{i=1}^{g}\sum_{j=1}^{5}\left[(E_{1,1}) - (D_{1,1})\right](\gamma) \tag{3.10}$$

= **[**($14,439) – ($4,720)](0.10)

= ($9,719)(0.10)

= $972/project year 1

EnMS Revenue Share Years 2 – Year 5

$$= \delta_{1,2-5} = \sum_{i=1}^{g}\sum_{j=2}^{5}\left[\left(E_{1,2-5}\right) - \left(D_{1,2-5}\right)\right](\gamma) \tag{3.10}$$

Table IV-9 Project #1 EnMS Revenue Share

Project Year i	**Energy Savings** E_{ij}	**Proportional Cost** D_{ij}	**Net Energy Savings** E_{ij}-D_{ij}	**EnMS Revenue** $\delta_{ij} = (E_{ij}-D_{ij})(\gamma)$
1	14,439	4,720	9,719	972
2	7,220	1,720	5,500	550
3	5,911	1,720	4,191	419
4	5,348	1,720	3,628	363
5	4,839	1,720	3,119	312
	37,757	11,600	26,157	2,616

Total net savings generated for ACME Inc. over improvement project #1 useful life
= $26,157

Total EnMS revenue generated improvement project #1 useful life
= $2,616

Table IV-10 Project #1 'Regular Air Leak Maintenance Program' Savings Summary

Project (i): **#1** Air leaks **Useful Life:** 5 years **Begins EnMS Year:** 1

Year (j)	Project Savings						Project Costs								EnMS Impact			
	E_{ij}	MA_{ij}	P_{ij}	L_{ij}	IN_{ij}	TS_{ij}	PL_{ij}	M_{ij}	I_{ij}	R_{ij}	T_{ij}	O_{ij}	MV_{ij}	TC_{ij}	D_{ij}	S_{ij}	δ_{ij}	**Year** (m)
1	14,439	0	0	0	0	14,439	100	500	1,020	0	100	0	3,000	4,720	4,720	9,719	972	1
2	7,220	0	0	0	0	7,220	0	500	1,020	0	0	0	200	1,720	1,720	5,500	550	2
3	5,911	0	0	0	0	5,911	0	500	1,020	0	0	0	200	1,720	1,720	4,191	419	3
4	5,348	0	0	0	0	5,348	0	500	1,020	0	0	0	200	1,720	1,720	3,628	363	4
5	4,839	0	0	0	0	4,839	0	500	1,020	0	0	0	200	1,720	1,720	3,119	312	5
Total	37,757	0	0	0	0	37,757	100	2,500	5,100	0	100	0	3,800	11,600	11,600	26,157	2,616	

Based on the projections in Steps 5 and 6 above the constraints for the project are deemed to be met:

- For the expected EnMS revenue of the proposed project, i, when added to the projected EnMS year-end budget over the useful life, u, of the proposed project, must be greater than 0: $\sum_{j=1}^{u}(\delta_{ij}) + \sum_{j=1}^{u}(\beta_m) \geq 0 \rightarrow$ \$2,616 + \$84,000[9] = \$86,616

  Based on the projected savings the proposed project will not deplete the EnMS budget.

[9] β_1 = \$90,000 - \$6,000 = \$84,000

Table IV-11 Improvement Project #1 Financial Analysis

$D_{1,1}$	-4,720
$E_{1,1}$	14,439
$S_{1,2}$	5,500
$S_{1,3}$	4,191
$S_{1,4}$	3,628
$S_{1,5}$	3,119
IRR	249%
SPP	0.33

Based on the energy savings projections and financial analysis, the energy team decides to move ahead with project one. The actual savings achieved from this project and actual revenue paid into the EnMS budget would be determined each year using the M&V method chosen by the ACME Inc. team and budgeted for in the project's cost (using submetered data to set a baseline of compressed air use during non-production periods prior to the air leak maintenance system and comparing usage after implementation).

EnMS Year 1 Summary

During the initial year of ACME Inc.'s EnMS program, the energy team had an IAC program conduct an energy assessment, sent several of its team members to CEM training, and implemented a regular air leak maintenance program along with a submetering system on the facility's compressed air system. This improvement provided ACME Inc. with significant savings, as well as shared revenue with the EnMS. Below is a summary of the projected EnMS year-end revenue accounting for year one:

Summary

- Initial EnMS budget (β_0)........... .... $90,000
- Year β_0 expenses
  - CEM training....... .... $6,000
  - IAC Assessment.. .... No cost
- Year 1 EnMS budget (β_1)........... .... $84,000
- Project 1 .... Reduce Air Leaks
  - Useful life............ .... 5 years
  - Initial expense ($TC_{1,1}$) (year 1) $4,720
  - Annual expense ($TC_{1,2-5}$) (years 2-5) $1,720
  - Initial net savings ($S_{1,1}$) (year 1) $9,719
  - Annual net savings ($S_{1,2-5}$) (years 2-5)..... .... See table IV-12
  - Initial EnMS revenue ($\delta_{1,1}$) (year 1).......... .... $972
  - Annual EnMS revenue ($\delta_{1,2-5}$) (year 2-5). .... See table IV-12

Table IV-12 summarizes the projected EnMS revenue over five years for the expected savings generated by project one.

Table IV-12 EnMS Summary for Project #1 Expected Values

	Project (i) Year (j)				
	i = 1				
EnMS Year (m)	***j***	$S_{1,j}$	S_{ij}	β_m	$\beta_m - \beta_0$
0	-			90,000	-
1	1	972	972	84,972	-5,028
2	2	550	550	85,522	-4,478
3	3	419	419	85,941	-4,059
4	4	363	363	86,304	-3,696
5	5	312	312	86,616	-3,384
	Total	2,616	2,616		
	IRR	249%			
	SPP	0.33			

At the end of the EnMS year one, several of the organization's goals were achieved, ACME Inc. took the first steps towards identifying where their energy was going in the production process through their initial energy balance and submetering. Their initial submetering also assisted in the creation of baselines for the compressed air system. Several of their EnMS team members were also trained in energy conservation best practices, and the EnMS grew in a sustainable manner.

Step 7 – Iteration 1

As the first year improvements of the EnMS prove successful and begin to generate revenue for growing the EnMS, the ACME Inc. team is able to re-invest some of the savings in a way that will advance its energy management maturity level (ex. more advanced metering, further upgrades to equipment, projects with longer paybacks, ISO 50001 certification, etc.).

7.1 Based on Table IV-12 above, at the end of year one, the ACME EnMS has an expected revenue of $972 and an end of year balance equal to $84,972.

7.2 The ACME Inc. team decides to reinvest some of the savings generated by the EnMS into making improvements in its grinder system based on the IAC report recommendation. It currently operates continuously during operating hours, even when it is not actively grinding. The energy team identified that the installation of a variable frequency drive would help slow down its motor (when not actively grinding scrap plastic) and reduce its grinder system energy.

7.3 The costs and savings for this 'next step' are determined below in order for the ACME team to identify if this is an appropriate investment:

Estimated Savings from Improvement Project #2 – Install VFD on Grinding Equipment

DATA

- EnMS Project (*i*) 2
- Year of EnMS project implemented (*m*). 2
- EnMS Year 2 Budget (β_2) $84,972
- Annual operating cost attributed to energy (γ) 10%
- Proposed improvement estimated useful life .... 5 years
- Current grinder system operating expense …..… $22,800/year
- Current grinder system maintenance cost[10] $3,000/year

Costs

- PL - Planning cost .... $1,000 (one time)
- M - Material cost.. ……... ……... .... $8,000 (one time)
- I - Installation cost .... $1,000 (one time)
- T - Training/technical cost.. …..… .... $500 (one time)
- O - Operating cost $0
- MV – Measurement & Verification cost[11].. …..… $300/year

Savings

- E - Energy savings.. …..… $13,690/year
- R - Utility rebate savings $0
- MA - Maintenance savings $0
- P - Production savings/Production increase.. ……... .... $0
- L - Labor savings $0
- IN - Intangible savings.. .... $0

Constraints

- For the expected EnMS revenue of the proposed project, i, when added to the projected EnMS year-end budget over the useful life, u, of the proposed project, must be greater than 0: $\sum_{j=1}^{u}(\delta_{ij}) + \sum_{j=1}^{u}(\beta_m) \geq 0$

[10] Estimated based historic ACME Inc. costs

[11] Estimated cost to have VFD checked twice per year using spot measurements to ensure proper operation and ensure it is meeting energy savings predictions

Total Net Savings for Project Year 1 ($S_{2,1}$)

$$= TS_{2,1} = \sum_{i=1}^{2}\sum_{j=1}^{5}\left[\left(E_{2,1} + MA_{2,1} + P_{2,1} + L_{2,1} + IN_{2,1}\right)\right]$$

= [$13,690 + $0,000 + $0 + $0] = $13,690

$$= TC_{2,1} = \sum_{i=1}^{2}\sum_{j=1}^{5}\left[\left(PL_{2,1} + M_{2,1} + I_{2,1} - R_{2,1} + T_{2,1} + O_{2,1} + MV_{2,1}\right)\right]$$

= [$1,000 + $8,000 + $1,000 - $0 + $500 + $300] = $10,800

$$= S_{3,1} = \sum_{i=1}^{3}\sum_{j=1}^{8}\left[\left(TS_{3,1}\right) - \left(TC_{3,1}\right)\right]$$

= ($13,690) – ($10,800)

= $2,890/ project year one

Total Net Annual Savings Project Year 2 – Year 5

Because the savings generated by the VFDs would likely decrease over time due to mechanical wear on the motor, the exponential decay equation is used to identify the conservative energy savings over time, as shown in Table IV-13.

$$= TS_{2,2-5} = \sum_{i=1}^{2}\sum_{j=1}^{5}\left[\left(E_{2,2-5} + MA_{2,2-5} + P_{2,2-5} + L_{2,2-5} + IN_{2,2-5}\right)\right]$$

= See Table IV-13

$$= TC_{2,2-5} = \sum_{i=1}^{2}\sum_{j=1}^{5}\left[\left(PL_{2,2-5} + M_{2,2-5} + I_{2,2-5} - R_{2,2-5} + T_{2,2-5} + O_{2,2-5} + MV_{2,2-5}\right)\right]$$

= [$0 + $0 + $0 + $0 + $000 + $300] = $300

$$= S_{2,2-5} = \sum_{i=1}^{2}\sum_{j=1}^{5}\left[\left(TS_{2,2-5}\right) - \left(TC_{2,2-5}\right)\right]$$

= $22,944 total for years 2-5 based on Table IV-13

Table IV-13 Project #2 Savings Accounting for Exponential Decay

Project Year i	**Total Savings** TS_{ij}	**Total Cost** TC_{ij}	**Total Net Savings** S_{ij}
1	13,690	10,800	2,890
2	12,387	300	12,087
3	11,208	300	10,908
4	10,142	300	9,842
5	9,177	300	8,877
	56,604	12,000	44,604

Step 7.4

Percentage of savings attributed to energy

For project two, all of the savings identified are attributed to energy savings:

$= \left(\frac{E_{2,1}}{TS_{2,1}}\right)$

= (Energy savings) / (Total savings)

= ($13,690) / ($13,690) = 100% = 1.0

Costs that would be deducted from energy savings in year 1

$$D_{2,1} = \sum_{j=1}^{5}\left[\left(\left(TC_{2,1}\right)\left(\frac{E_{2,1}}{TS_{2,1}}\right)\right)\right] \qquad (3.11)$$

= ($13,690)(1.0)

= $13,690/project year 1

Step 7.5

The portion of the savings shared with the EnMS for project two would be determined as follows:

EnMS Revenue Share Project Year 1

$$= \ \delta_{2,1} = \sum_{i=1}^{g}\sum_{j=1}^{5}\left[\left(E_{2,1}\right) - \left(D_{2,1}\right)\right](\gamma)$$

= [($13,690) – ($10,800)](0.10)

= ($2,890)(0.10)

= $289/project year 1

EnMS Revenue Share Project Years 2 – Year 5

$$= \delta_{2,2-5} = \sum_{i=1}^{g}\sum_{j=1}^{5}\left[\left(E_{2,2-5}\right) - \left(D_{2,2-5}\right)\right](\gamma)$$

Values summarized in Table IV-14

Table IV-14 Project #2 EnMS Revenue Share

Project Year i	**Energy Savings** E_{ij}	**Proportional Cost** D_{ij}	**Net Energy Savings** $E_{ij}-D_{ij}$	**EnMS Revenue** $\delta_{ij} = (E_{ij}-D_{ij})(\gamma)$
1	13,690	10,800	2,890	289
2	12,387	300	12,087	1,209
3	11,208	300	10,908	1,091
4	10,142	300	9,842	984
5	9,177	300	8,877	888
	56,604	12,000	44,604	4,460

Total Net Savings over Useful Life

= $56,604

Total EnMS Revenue over Useful Life

= $4,460

Table IV-15 Project #2 'Install VFD on Grinder' Savings Summary

Project (i): #2 **Useful Life:** 5 years **Begins EnMS Year:** 2

Year (j)	Project Savings						Project Costs								EnMS Impact			**Year (m)**
	E_{ij}	MA_{ij}	P_{ij}	L_{ij}	IN_{ij}	TS_{ij}	PL_{ij}	M_{ij}	I_{ij}	R_{ij}	T_{ij}	O_{ij}	MV_{ij}	TC_{ij}	D_{ij}	S_{ij}	δ_{ij}	
1	13,690	0	0	0	0	13,690	1,000	8,000	1,000	0	500	0	300	10,800	10,800	2,890	289	1
2	12,387	0	0	0	0	12,387	0	0	0	0	0	0	300	300	300	12,087	1,209	2
3	11,208	0	0	0	0	11,208	0	0	0	0	0	0	300	300	300	10,908	1,091	3
4	10,142	0	0	0	0	10,142	0	0	0	0	0	0	300	300	300	9,842	984	4
5	9,177	0	0	0	0	9,177	0	0	0	0	0	0	300	300	300	8,877	888	5
Total	56,604	0	0	0	0	56,604	1,000	8,000	1,000	0	500	0	1,500	12,000	12,000	44,604	4,460	

<u>Step 7.6</u>

Based on the projections in Steps 7.4 and 7.5 above the constraints for the project are deemed to be met:

- For the expected EnMS revenue of the proposed project, i, when added to the projected EnMS year-end budget over the useful life, u, of the proposed project, must be greater than 0: $\sum_{j=1}^{u}(\delta_{ij}) + \sum_{j=1}^{u}(\beta_m) \geq 0$ → $4,604 + $86,616 = $91,076
  Based on the projected savings the proposed project will not deplete the EnMS budget.

Step 7.7

Table IV-16 Improvement Project #2 Financial Analysis

$\boldsymbol{D}_{2,1}$	-10,800
$\boldsymbol{E}_{2,1}$	13,690
$\boldsymbol{S}_{2,2}$	12,087
$\boldsymbol{S}_{2,3}$	10,908
$\boldsymbol{S}_{2,4}$	9,842
$\boldsymbol{S}_{2,5}$	8,877
IRR	114%
SPP	0.79

Based on these projections, the energy team decides to move ahead with project two. The actual savings achieved from this project and actual revenue paid into the EnMS budget would be determined each year using the M&V method chosen by the ACME Inc. team and budgeted for in the project's cost (regularly spot checking VFD performance).

EnMS Year 2 Summary

During the second year of ACME Inc.'s EnMS program, the energy team installed a VFD and control system on the grinder system and continued the air leak maintenance system and submetering on its compressed air system. Below is a summary of the projected EnMS year-end revenue accounting for year two:

Summary

- Initial EnMS budget (β_2)............ ....$84,972
- Project 2........... ....Install VFD on grinder
    - Useful life............ ....5 years
    - Initial expense ($TC_{2,1}$) (year 1)..... ....$10,800
    - Annual expense ($TC_{2,2-5}$) (years 2-5)...... ....$300
    - Initial net savings ($S_{2,1}$) (year 1) $13,690
    - Annual net savings ($S_{2,2-5}$) (years 2-5)..... ....See Table IV-17
    - Initial EnMS revenue ($\delta_{2,1}$) (year 1).......... ....$289
    - Annual EnMS revenue ($\delta_{2,2-5}$) (year 2-5). ....See Table IV-17

Table IV-17 summarizes the projected EnMS revenue over five years for the expected savings generated by projects one and two.

Table IV-17 EnMS Summary for Projects #1 and 2 Expected Values

	Project (*i*) Year (*j*)						
	i = 1		**i = 2**				
EnMS Year (*m*)	***j***	$S_{1,j}$	***j***	$S_{2,j}$	S_{ij}	β_m	$\beta_m - \beta_0$
0	-		-		0	90,000	-
1	1	972	-		972	84,972	-5,028
2	2	550	1	289	839	85,811	-4,189
3	3	419	2	1,209	1,628	87,439	-2,561
4	4	363	3	1,091	1,454	88,892	-1,108
5	5	312	4	984	1,296	90,188	188
6	-		5	888	888	91,076	1,076
	Total	2,616	Total	4,460	7,076		
	IRR	249%	IRR	114%			
	SPP	0.33	SPP	0.79			

At the end of the second EnMS year, the EnMS continued to grow in a sustainable manner, and after six years of operation the EnMS is projected to have surpassed its original earmarked value by $1,076.

Step 7 – Iteration 2

As the second year improvements of the EnMS prove successful and begin to generate revenue for growing the EnMS, the ACME Inc. team is able to re-invest some of the savings in a way that will further advance its energy management maturity level.

7.1 Based on Table IV-17 above, at the end of year two, the ACME EnMS has an expected revenue of $839, and an end of year balance equal to $85,811.

7.2 The ACME Inc. team decides to reinvest some of the savings generated by the EnMS into making improvements in its chilled water system, as identified by the IAC report. It currently does not take advantage of free cooling and has aging equipment. ACME decides to install high efficiency water-cooled chillers along with cooling towers and heat exchangers to take advantage of free cooling. Part of the improvement would include submetering the new chiller system.

7.3 The costs and savings for this ‘next step’ are determined below in order for the ACME team to identify if this is an appropriate investment:

Estimated Savings from Improvement Project #3 – Implement Free Cooling on Chilled Water System

DATA

- EnMS Project (i) 3
- Year of EnMS project implemented (m). 3
- EnMS Year 3 Budget (β_3) $85,811
- Annual operating cost attributed to energy (γ) 10%
- Proposed improvement estimated useful life[12] .... 5 years
- Current chiller system operating expense …..… $142,500/year
- Current chilled water system maintenance cost[13] $5,000/year

Costs

- PL - Planning cost......... .... $3,000 (one time)
- M - Material cost.. ……... ……... .... $100,000 (one time)
- I - Installation cost .... $30,000 (one time)
- T - Training/technical cost.. …..… .... $1,000 (one time)
- O - Operating cost......... .... $0
- MV – Measurement & Verification cost[14].. …..… $3,000/year 1

Savings

- E - Energy savings[15].. …..….... .... $77,813/year
- R - Utility rebate savings $0
- MA - Maintenance savings $0
- P - Production savings/Production increase.. ……... .... $0
- L - Labor savings $0
- IN - Intangible savings.. .... $0

Constraints

- For the expected EnMS revenue of the proposed project, i, when added to the projected EnMS year-end budget over the useful life, u, of the proposed project, must be greater than 0: $\sum_{j=1}^{u}(\delta_{ij}) + \sum_{j=1}^{u}(\beta_m) \geq 0$

[12] The useful life would be closer to 20 years, however 5 years is used in this example for simplicity
[13] Estimated based historic ACME Inc. costs
[14] Cost for submetering initially, with $200 per year reoccurring cost.
[15] From example IAC report Appendix D

Total Net Savings for Project Year 1 ($S_{3,1}$)

$$= TS_{3,1} = \sum_{i=1}^{3}\sum_{j=1}^{5}\left[\left(E_{3,1} + MA_{3,1} + P_{3,1} + L_{3,1} + IN_{3,1}\right)\right]$$

= [$77,813 + $0,000 + $0 + $0] = $77,813

$$= TC_{3,1} = \sum_{i=1}^{3}\sum_{j=1}^{5}\left[\left(PL_{3,1} + M_{3,1} + I_{3,1} - R_{3,1} + T_{3,1} + O_{3,1} + MV_{3,1}\right)\right]$$

= [$3,000 + $100,000 + $30,000 - $0 + $1,000 +$0 + $3,000] = $137,000

$$= S_{3,1} = \sum_{i=1}^{3}\sum_{j=1}^{5}\left[\left(TS_{3,1}\right) - \left(TC_{3,1}\right)\right]$$

= ($77,813) – ($137,000)

= -$59,187/ project year one, indicating that the project will not generate any net savings for the EnMS during the first year. Without the EnMS budget, this type of project would often be difficult to justify in a typical SMM.

An alternate method would be to consider the marginal cost of the improvement, under the assumption that ACME Inc. would replace the chillers regardless, and the energy team would argue for high efficiency chillers instead of standard efficiency chillers, reducing the material cost.

Total Net Annual Savings Project Year 2 – Year 5

Because the savings generated by the chillers would likely decrease over time, the exponential decay equation is used to identify the energy and maintenance savings over time, as shown in Table IV-19.

$= TS_{3,2-5} = \sum_{i=1}^{3}\sum_{j=1}^{5}\left[\left(E_{3,2-5} + MA_{3,2-5} + P_{3,2-5} + L_{3,2-5} + IN_{3,2-5}\right)\right]$ = See Table IV-18

$$= TC_{3,2-5} = \sum_{i=1}^{3}\sum_{j=1}^{5}\left[\left(PL_{3,2-5} + M_{3,2-5} + I_{3,2-8} - R_{3,2-5} + T_{3,2-5} + O_{3,2-5} + MV_{3,2-5}\right)\right]$$

= [$0 + $0 + $0 + $0 + $000 + $200] = $200

$$= S_{3,2-5} = \sum_{i=1}^{3}\sum_{j=1}^{5}\left[\left(TS_{3,2-5}\right) - \left(TC_{3,2-5}\right)\right]$$

= $54,205 total for years 2-5 based on Table IV-18

Table IV-18 Project #3 Savings Accounting for Exponential Decay

Project Year i	**Total Savings** TS_{ij}	**Total Cost** TC_{ij}	**Total Net Savings** S_{ij}
1	77,813	137,000	-59,187
2	70,408	200	70,208
3	63,708	200	63,508
4	57,645	200	57,445
5	52,160	200	51,960
	321,734	137,800	183,934

Step 7.4

Percentage of savings attributed to energy
For project three, all of the savings identified are attributed to energy savings:
$= \left(\frac{E_{3,1}}{TS_{3,1}}\right)$
= (Energy savings) / (Total savings)
= ($77,813) / ($77,813) = 100% = 1.0

Costs that would be deducted from energy savings in year 1

$$D_{3,1} = \sum_{j=1}^{5}\left[\left((TC_{3,1})\left(\frac{E_{3,1}}{TS_{3,1}}\right)\right)\right] \quad (3.11)$$

= ($137,000)(1.0)
= $137,000/project year 1

Step 7.5

The portion of the savings shared with the EnMS for project three would be determined as follows:

EnMS Revenue Share Project Year 1

$$= \delta_{3,1} = \sum_{i=1}^{g}\sum_{j=1}^{5}\left[(E_{3,1}) - (D_{3,1})\right](\gamma)$$

= **[**($77,813) – ($137,000)](0.10)

= (-$59,187)(0.10)

= -$5,919/project year 1

EnMS Revenue Share Project Years 2 – Year 5

$$= \delta_{3,2-5} = \sum_{i=1}^{g} \sum_{j=1}^{5} [(E_{3,2-5}) - (D_{3,2-5})] (\gamma)$$

Values summarized in Table IV-19

Table IV-19 Project #3 EnMS Revenue Share

Project Year i	**Energy Savings** E_{ij}	**Proportional Cost** D_{ij}	**Net Energy Savings** E_{ij}-D_{ij}	**EnMS Revenue** $\delta_{ij} = (E_{ij} - D_{ij})(\gamma)$
1	77,813	137,000	-59,187	-5,919
2	70,408	200	70,208	7,021
3	63,708	200	63,508	6,351
4	57,645	200	57,445	5,745
5	52,160	200	51,960	5,196
	321,734	137,800	183,934	18,393

Total Net Savings over Useful Life

= $321,734

Total EnMS Revenue over Useful Life

= $18,393

Table IV-20 Project #3 'Implement Free Cooling' Savings Summary

Project (i): **Useful Life:** **Begins EnMS Year:** 3

Year (j)	Project Savings						Project Costs								EnMS Impact			
	E_{ij}	MA_{ij}	P_{ij}	L_{ij}	IN_{ij}	TS_{ij}	PL_{ij}	M_{ij}	I_{ij}	R_{ij}	T_{ij}	O_{ij}	MV_{ij}	TC_{ij}	D_{ij}	S_{ij}	δ_{ij}	**Year (m)**
1	77,813	0	0	0	0	77,813	3,000	100,000	30,000	0	1,000	0	3,000	137,000	137,000	-59,187	-5,919	1
2	70,408	0	0	0	0	70,408	0	0	0	0	0	0	200	200	200	70,208	7,021	2
3	63,708	0	0	0	0	63,708	0	0	0	0	0	0	200	200	200	63,508	6,351	3
4	57,645	0	0	0	0	57,645	0	0	0	0	0	0	200	200	200	57,445	5,745	4
5	52,160	0	0	0	0	52,160	0	0	0	0	0	0	200	200	200	51,960	5,196	5
Total	321,734	0	0	0	0	321,734	3,000	100,000	30,000	0	1,000	0	3,800	137,800	137,800	183,934	18,393	

Step 7.6

Based on the projections in Steps 7.4 and 7.5 above the two constraints for the project are deemed to be met:

- For the expected EnMS revenue of the proposed project, i, when added to the projected EnMS year-end budget over the useful life, u, of the proposed project, must be greater than 0: $\sum_{j=1}^{u}(\delta_{ij}) + \sum_{j=1}^{u}(\beta_m) \geq 0$ → $18,393 + $91,076 = $109,470

  Based on the projected savings the proposed project will not deplete the EnMS budget.

<u>Step 7.7</u>

Table IV-21 Improvement Project #3 Financial Analysis

$D_{3,1}$	-137,000
$E_{3,1}$	77,813
$S_{3,2}$	70,208
$S_{3,3}$	63,508
$S_{3,4}$	57,445
$S_{3,5}$	51,960
IRR	41%
SPP	1.76

Based on these projections, the energy team decides to move ahead with project three. The actual savings achieved from this project and actual revenue paid into the EnMS budget would be determined each year using the M&V method chosen by the ACME Inc. team (use of submetering data to determine baselines for old vs. new system and adjusting for weather, production levels, etc.).

EnMS Year 3 Summary

During the third year of ACME Inc.'s EnMS program, the energy team installed a new chilled water system and cooling towers to allow for free cooling. Along with this, a submetering system was installed to monitor and verify the associated savings. Below is a summary of the projected EnMS year-end revenue accounting for year three:

Summary

- Initial EnMS budget (β_2)........... ....$85,811
- Project 3........... ....Free cooling
    - Useful life........... ....5 years
    - Initial expense ($TC_{3,1}$) (year 1)..... ....$137,000
    - Annual expense ($TC_{3,2-5}$) (years 2-10).... ....$200
    - Initial net savings ($S_{3,1}$) (year 1) .. ..$-59,187
    - Annual net savings ($S_{3,2-5}$) (years 2-5)..... ....See table IV-22
    - Initial EnMS revenue ($\delta_{3,1}$) (year 1).......... ....$-5,919
    - Annual EnMS revenue ($\delta_{1,2-5}$) (year 2-5). ....See table IV-22

Table IV-18 summarizes the projected EnMS revenue over seven years for the expected savings generated by projects one, two, and three.

Table IV-22 EnMS Summary for Projects #1-3 Expected Values

	Project (i) Year (j)								
	i = 1		**i = 2**		**i = 3**				
EnMS Year (m)	***j***	$S_{1,j}$	***j***	$S_{2,j}$	***j***	$S_{3,j}$	S_{ij}	β_m	$\beta_m - \beta_0$
0	-		-		-		0	90,000	-
1	1	972	-		-		972	84,972	-5,028
2	2	550	1	289	-		839	85,811	-4,189
3	3	419	2	1,209	1	-5,919	-4,291	81,520	-8,480
4	4	363	3	1,091	2	7,021	8,474	89,994	-6
5	5	312	4	984	3	6,351	7,647	97,641	7,641
6	-		5	888	4	5,745	6,632	104,274	14,274
7	-		-		5	5,196	5,196	109,470	19,470
	Total	2,616	Total	4,460	Total	18,393	25,470		
	IRR	114%	IRR	41%	IRR	41%			
	SPP	0.79	SPP	1.76	SPP	1.76			

At the end of the third EnMS year, the EnMS continued to grow in a sustainable manner and after seven years of operation the EnMS is now projected to have surpassed its original earmarked value by $19,470.

<u>Step 7 – Iteration 3</u>

7.1 Based on Table IV-22 above, at the end of EnMS year three, the ACME EnMS has an expected revenue of -$4,291, and an end of year balance equal to $81,520.

7.2 At the beginning of EnMS year four, ACME's energy team identifies the next step for their EnMS system is to further reduce the energy intensity of Product Line C and D to their target. Through the IAC report, the team identified that its injection molding equipment are not as efficient as they could be (see Appendix D, AR 1.4). There has been talk regarding completely replacing the injection molding press with a new line, similar to the recently replaced equipment within the plant. This improvement is largely being considered as a result of the increased production and decreased quality problems; however a 'side' benefit would be improved energy intensity. As a result, the EnMS team adds their support to the improvement.

7.3 Determine costs and savings for the proposed next step:

Estimated Savings from Improvement Project #4 – Install more efficient production equipment

DATA

- EnMS Project (i) 4
- Year of EnMS project implemented (m). 4
- EnMS Year 4 Budget (β_4) $81,520
- Annual operating cost attributed to energy (γ) 10%
- Proposed improvement estimated useful life[16] .... 5 years
- Current system operating expense .... …..… $88,350/year
- Current system maintenance cost........... .... $10,000/year

Costs

- PL - Planning cost......... .... $5,000 (one time)
- M - Material cost.. ……... ……... .... $3,200,000 (one time)
- I - Installation cost .... $800,000 (one time)
- T - Training/technical cost.. …..… .... $8,000 (one time)
- O - Operating cost......... .... $0
- MV – Measurement & Verification cost[17].. …..… $12,000/year 1

Savings

- E - Energy savings.. …..… $49,697/year
- R- Utility rebate savings $0
- M - Maintenance savings........... .... $5,000 /year
- P - Production savings/Production increase.. ……... .... $500,000 /year
- L - Labor savings[18]........ .... $10,000 /year
- I - Intangible savings[19] .. .. $5,000 /year

Constraints

- For the expected EnMS revenue of the proposed project, i, when added to the projected EnMS year-end budget over the useful life, u, of the proposed project, must be greater than 0: $\sum_{j=1}^{u}(\delta_{ij}) + \sum_{j=1}^{u}(\beta_m) \geq 0$

[16] The costs are based on new air leaks occurring every year, and the program continuing for ten years
[17] Initial cost for submetering system ($3,000 per product line) followed by $200/year per line for calibration
[18] New system increased production capacity reduces the need for overtime
[19] New system is also safer and less likely to have loss time accidents, etc.

Total Net Savings for Project Year 1 ($S_{4,1}$)

$$= TS_{4,1} = \sum_{i=1}^{4}\sum_{j=1}^{5}\left[\left(E_{4,1} + MA_{4,1} + P_{4,1} + L_{4,1} + IN_{4,1}\right)\right] \quad (3.5)$$

= [$49,697 + $5,000 + $500,000 + $10,000 + $5,000]
= $569,697/project year 1

$$= TC_{4,1} = \sum_{i=1}^{4}\sum_{j=1}^{5}\left[\left(PL_{4,1} + M_{4,1} + I_{4,1} - R_{4,1} + T_{4,1} + O_{4,1} + MV_{4,1}\right)\right] \quad (3.6)$$

= [$5,000 + $3,200,000 + $800,000 -$0 + $8,000 + $0 + $12,000]
= $4,025,000/project year 1

$$= S_{4,1} = \sum_{i=1}^{4}\sum_{j=1}^{5}\left[\left(TS_{4,1}\right) - \left(TC_{4,1}\right)\right] \quad (3.7)$$

= ($569,697) – ($4,025,000)
= -$3,445,303/project year 1

Total Net Annual Savings Project Years 2 – Year 5

The savings decay equation (3.9) is used to estimate savings generated by the new equipment for years two through five. The calculations for year two are shown below, and Table IV-23 summarizes the savings for the remaining years based on the exponential decay formula.

$$= TS_{4,2} = \sum_{i=1}^{4}\sum_{j=2}^{5}\left[\left(E_{4,2} + MA_{4,2} + P_{4,2} + L_{4,2} + IN_{4,2}\right)\right] \quad (3.5)$$

$= E_i(j) = ae^{kj}$ (3.9)
$= E_1(1) = (\$569,697)e^{-(0.1)(1)}$
= $515,483, this would equal the 'decayed' savings in year two of the improvement.

$$= TC_{4,2} = \sum_{i=1}^{4}\sum_{j=2}^{5}\left[\left(PL_{4,2} + M_{4,2} + I_{4,2} - R_{4,2} + T_{4,2} + O_{4,2} + MV_{4,2}\right)\right] \quad (3.6)$$

= [$0 + $0 + $0 -$0 + $0 + $0 + $800]

= $800/year for project year 2

$$= S_{4,2} = \sum_{i=1}^{4}\sum_{j=2}^{5}\left[\left(TS_{4,2}\right) - \left(TC_{4,2}\right)\right] \quad (3.7)$$

= ($515,483) – ($800)
= $514,683/project year 2

Table IV-23 Estimated Annual Savings from Improvement #4

Project Year i	**Total Savings** TS_{ij}	**Total Cost** TC_{ij}	**Total Net Savings** S_{ij}
1	569,697	4,025,000	-3,455,303
2	515,483	800	514,683
3	466,428	800	465,628
4	422,042	800	421,242
5	381,879	800	381,079
	2,355,530	4,028,200	-1,672,670

Note: It is important to point out that a shortened time horizon of five years is used here for simplicity; a piece of process equipment would typically have a useful life of at least 30 years, providing more time for the savings to accumulate.

Step 7.4

Percentage of savings attributed to energy

For project four, only a portion of the savings identified are attributed to energy savings:

$= \left(\frac{E_{41}}{TS_{4,1}}\right)$

= (Energy savings) / (Total savings)

= ($49,697) / ($569,697) = 8.72% = 0.087

Costs that would be deducted from energy savings in year 1

$$D_{4,1} = \sum_{j=1}^{5}\left[\left((TC_{4,1})\left(\frac{E_{4,1}}{TS_{4,1}}\right)\right)\right] \tag{3.11}$$

= ($4,025,000)(0.087)

= $350,332/project year 1

Step 7.5

The portion of the savings shared with the EnMS for project three would be determined as follows:

EnMS Revenue Share Project Year 1

$$= \delta_{4,1} = \sum_{i=1}^{g}\sum_{j=1}^{5}[(E_{4,1}) - (D_{4,1})]\,(\gamma)$$

= **[**(\$49,697) – [(\$350,332)](0.10)

= (-\$300,635)(0.10)

= -\$30,064/project year 1

EnMS Revenue Share Years 2 – Year 5

$$= \delta_{4,2-5} = \sum_{i=1}^{g}\sum_{j=1}^{5}[(E_{4,2-5}) - (D_{4,2-5})]\,(\gamma)$$

Values summarized in Table IV-24:

Table IV-24 Improvement Project #4 Savings Summary

Project Year i	**Energy Savings** E_{ij}	**Proportional Cost** D_{ij}	**Net Energy Savings** E_{ij}-D_{ij}	**EnMS Revenue** $\delta_{ij} = (E_{ij}-D_{ij})(\gamma)$
1	49,697	351,117	-301,420	-30,142
2	44,968	70	44,898	4,490
3	40,688	70	40,619	4,062
4	36,816	70	36,747	3,675
5	33,313	70	33,243	3,324
	205,483	351,396	-145,914	-14,591

Total Net Savings over Useful Life

= \$2,355,530

Total EnMS Revenue over Useful Life

= -\$14,491

Note: As mentioned earlier, due to the large initial expense and the shortened time horizon for this example, the savings do not have time to accumulate and show a positive return.

Table IV-25 Project #4 ‘Install More Efficient Production Equipment’ Savings Summary

Project (i): **Useful Life:** **Begins EnMS Year:** 4

Year (j)	Project Savings						Project Costs								EnMS Impact			
	E_{ij}	MA_{ij}	P_{ij}	L_{ij}	IN_{ij}	TS_{ij}	PL_{ij}	M_{ij}	I_{ij}	R_{ij}	T_{ij}	O_{ij}	MV_{ij}	TC_{ij}	D_{ij}	S_{ij}	δ_{ij}	Year (m)
1	49,697	5,000	500,000	10,000	5,000	569,697	5,000	3,200,000	800,000	0	8,000	0	12,000	4,025,000	351,117	-301,420	-30,142	1
2	44,968	4,524	452,419	9,048	4,524	515,483	0	0	0	0	0	0	800	800	70	44,898	4,490	2
3	40,688	4,094	409,365	8,187	4,094	466,428	0	0	0	0	0	0	800	800	70	40,619	4,062	3
4	36,816	3,704	370,409	7,408	3,704	422,042	0	0	0	0	0	0	800	800	70	36,747	3,675	4
5	33,313	3,352	335,160	6,703	3,352	381,879	0	0	0	0	0	0	800	800	70	33,243	3,324	5
Total	205,483	20,674	2,067,353	41,347	20,674	2,355,530	5,000	3,200,000	800,000	0	8,000	0	15,200	4,028,200	351,396	-145,914	-14,591	

Step 7.6

Based on the projections in Steps 7.4 and 7.5 above the constraints for the project are deemed to be met:

- For the expected EnMS revenue of the proposed project, i, when added to the projected EnMS year-end budget over the useful life, u, of the proposed project, must be greater than 0: $\sum_{j=1}^{u}(\delta_{ij}) + \sum_{j=1}^{u}(\beta_m) \geq 0 \rightarrow$ -\$14,591+ \$109,470 = \$87,002

  Based on the projected savings the proposed project will not deplete the EnMS budget.

Step 7.7

Table IV-26 Improvement Project #4 Financial Analysis

$D_{4,1}$	-351,117
$E_{4,1}$	49,697
$S_{4,2}$	44,898
$S_{4,3}$	40,619
$S_{4,4}$	36,747
$S_{4,5}$	33,243
IRR	-16%
SPP	7.07

Note: This IRR value is based on energy savings alone; considering production increases and maintenance savings the IRR would be positive and above the company MARR.

While the project shows a poor IRR when considering only energy savings based on the five-year time horizon, the energy team takes into consideration the longer useful life of the equipment. Based on these projections, the energy team decides to move ahead with project four. The actual savings achieved from this project and actual revenue paid into the EnMS budget would be determined each year using the M&V method chosen by the ACME Inc. team (using submetered data to set a baseline and track consumption over time, as well as manually determine energy intensity at set intervals).

EnMS Year 4 Summary

During the fourth year of ACME Inc.'s EnMS program, the energy team argued for the installation of new production equipment that would improve the energy intensity of the products, as well as increase production capacity among other benefits. Along with this, a submetering system was installed to monitor and verify the associated savings. Below is a summary of the projected EnMS year-end revenue accounting for year four:

Summary

- Initial EnMS budget (β_2).. $81,520
- Project 4... New production equip.
  - Useful life.. 5 years
  - Initial expense ($TC_{4,1}$) (year 1).. $4,025,000
  - Annual expense ($TC_{4,2-5}$) (years 2-5)................................ $800
  - Initial net savings ($S_{4,1}$) (year 1)..................................... -$3,455,303
  - Annual net savings ($S_{4,2-5}$) (years 2-5)............................ See table IV-27
  - Initial EnMS revenue ($\delta_{4,1}$) (year 1)................................ -$30,142
  - Annual EnMS revenue ($\delta_{4,2-5}$) (year 2-5)........................ See table IV-27

Table IV-27 below summarizes the projected EnMS revenue over seven years for the expected savings generated by projects one, two, three, and four.

Table IV-27 EnMS Summary for Projects #1-4 Expected Values

	Project (i) Year (j)										
	i = 1		i = 2		i = 3		i = 4				
EnMS Year (m)	j	$S_{1,j}$	j	$S_{2,j}$	j	$S_{3,j}$	j	$S_{4,j}$	S_{ij}	β_m	$\beta_m - \beta_0$
0	-		-		-		-		0	90,000	-
1	1	972	-		-		-		972	84,972	-5,028
2	2	550	1	289	-		-		839	85,811	-4,189
3	3	419	2	1,209	1	-5,919	-		-4,291	81,520	-8,480
4	4	363	3	1,091	2	7,021	1	-30,142	-21,668	59,852	-30,148
5	5	312	4	984	3	6,351	2	4,490	12,137	71,989	-18,011
6	-		5	888	4	5,745	3	4,062	10,694	82,683	-7,317
7	-		-		5	5,196	4	3,675	8,871	91,554	1,554
8	-		-		-		5	3,324	3,324	94,878	4,878
	Total	2,616	Total	4,460	Total	18,393	Total	-14,591	10,878		
	IRR	249%	IRR	114%	IRR	41%	IRR	-16%			
	SPP	33%	SPP	79%	SPP	176%	SPP	7.07			

While project four does not have as quick of a return as projects one through three, at the end of the fourth EnMS year, the EnMS continued to grow in a sustainable manner. After eight years of operation the EnMS is now projected to have surpassed its original earmarked value by $4,878. While this is a decrease in the previous projection from the end of year three, the constraints are met and the EnMS fund is helping promote projects that might otherwise not be implemented.

Over the course of the EnMSs life, the energy team would update the expected savings values with the actual measured and verified values based on the actual reported data. The decisions made by the EnMS energy team allowed it to work towards addressing the targets and goals set by the team and sustainable improve its energy management over time. Possible next steps for this example moving past EnMS year four would be working towards installing an MIS type system that would allow the real-time energy consumption data for the product lines (made possible in project four) to interface with production data in real-time, resulting in a real-time calculation of energy intensity.

This process would continue through time as ACME’s EnMS continued to grow and adapt to the organization’s needs.

4.4 CHAPTER CONCLUSION

These four improvement project examples carried across several years illustrate how the methodology presented in this dissertation might be applied to multiple scenarios in an SMM facility to help justify energy improvement projects that advance an organization’s energy management system in a sustainable manner. The examples presented demonstrate how some improvements implemented by the energy management team might not have been considered without the existence of the EnMS. The examples also illustrated how a portion of the savings generated by the projects selected by the energy team are shared with the EnMS budget and used to further the systems maturity.

CHAPTER V

CONCLUSION

The model presented in this research, as described in Chapter III and demonstrated/validated in Chapter IV, has helped the author better understand energy management systems and small and medium sized manufacturing organizations. A discussion of the possible implications of the model is presented below.

The connection between the quality movement of the 1970s and 1980s and the current energy management movement was made. This dissertation drew from the successes and realizations from this past, parallel movement in order to chart its direction. First, four absolutes of energy management were presented. These absolutes were created based on the author's experience in the IAC program and observations made in the literature. Next, an energy management hierarchy is presented, describing the stages in which an organizations energy management system matures over time.

An Energy Management Maturity Grid, modeled after Crosby's Quality Management Maturity Grid is also presented, is developed on the basis of the energy management hierarchy. This grid provides a way for management and plant personnel to assess the current state of their 'energy management system'. The most powerful aspect of the grid is its ability to communicate an estimate of what a facility's current system is costing them in terms of wasted energy. This waste is a result of inefficiencies and poor energy management.

There is an obvious need in the literature for improving energy efficiency in SMM facilities, however, an ‘energy efficiency gap’ persists. A gap in the existing programs and literature on the subject of energy management in manufacturing is that such programs do not exist in a vacuum; they are competing with other, often more critical (from management’s view point) activities. Therefore, it is crucial that energy management systems and programs are sustainable and pay for themselves.

This dissertation has addressed this issue by presenting a methodology for SMM organizations. This methodology shows how an organization can set an initial energy management system budget based on its current estimated waste. Based on the energy savings generated by the system, the methodology argues a portion of the savings should be shared with the energy management system, ensuring its funding in a sustainable manner that does not detract from ‘core’ business focuses. As the EnMS identifies more savings, the system would grow; as the identified savings declined, the grown of the system would also decline accordingly.

Implications of this research include the ability to better justify energy improvement programs, supporting an increased use of formal energy management systems in SMM facilities, such as those assisted by the IAC program. This might include a broader addition of energy efficiency technology/equipment as a result of organizations’ continued improvements.

Additional implications of this research might be the increased interest in ISO 50001 certifications in North America. Many of the benefits of the standard can be achieved through the use of resources such as the DOE eGuide or 50001 Ready Navigator without a formal certification process. However, if an organization is able to see the benefits and can financially justify a system similar to ISO 50001 (ex. eGuide Level 1), it is logical that more organizations will continue their improvement process and increase the maturity of their EnMS to possibly pursue ISO 50001 certification over time.

In order for SMM organizations to reduce their energy waste to a minimum and reach a mature level of energy management, they must integrate their existing management systems with that of their energy usage. There is currently a disconnect between the management of other major resources. By combining the management of energy with that of personnel, production, raw materials, etc., an organization will be able to better justify improvements. This will allow for additional insights to be gained such as the energy intensity of individual product lines over time, the true cost of producing individual products (using ABC), behavioral trends impacting energy consumption, and allow for energy to be viewed as it impacts an organization's processes and products, instead of simply an overhead expense.

CHAPTER VI

RECOMMENDATIONS FOR FURTHER RESEARCH

In the process of writing this dissertation several potential areas for future research on the topic of energy management systems, submetering, and energy information systems became apparent. These recommendations for future research are presented below.

In Chapter IV of this dissertation, a validation of the methodology is presented using a conceptual example. The data used is based on actual SMM facilities and provides a reasonable example of how the presented method could be used within an organization to justify the implementation of a formal energy management system. This validation shows the methodology has merit and will be useful for SMM facilities. The next step for future research would likely involve a case study involving the presented model and taking a facility through the entire process. This would not only further validate the model, but given a successful outcome, would likely prompt more organizations to implement EnMS within their own organizations.

Similarly, an additional area for further research identified by this dissertation is the need for the literature to document field experiences with the design, development, and implementation of energy management systems in SMMs, in addition to the need for more data collection involving both submetering and EIS at SMMs in order to provide additional data and perspective. While these technologies offer many benefits, facilities are often hesitant to be an ‘early adopter’.

Sponsored research documenting the benefits provided by such technologies in SMM environments would be very useful towards encouraging the technology's use in industry.

As energy management systems within SMMs mature and begin to utilize more information technology such as submeters and energy information systems, these systems will need to be further integrated with an organization's existing management systems. As discussed earlier, this will allow for energy to move from an overhead cost to one that can be better managed and better influence decisions within an organization. This might also be a component of smart manufacturing initiatives.

The broader issue of the lack of ISO 50001 adoption in North America also warrants further research. This dissertation attempts to address this in part by proving a means to justify such a systems undertaking. The U.S. DOE is also addressing this in part with their eGuide and ISO 50001 Ready Navigator programs. However, more research on specific barriers to ISO 50001 and energy management system adoption in general at SMMs in North America may be beneficial to furthering the adoption of such systems.

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APPENDIX A

ACRONYM GLOSSARY

ABC	– Activity Based Costing
ANSI	– American National Standards Institute
ASHRAE	– American Society of Heating, Refrigerating and Air-Conditioning Engineers
BAS	– Building Automation System
BRECSU	– Buildings Research Energy Conservation Support Unit
CEM	– Certified Energy Manager
CMM	– Capability Maturity Model
CT	– Current Transducer
DOE	– Department of Energy
DOE	– Department of Energy
DPBP	– Discounted Payback Period
ECM	– Energy Conservation Measure
EI	– Energy Intensity
EIA	– Energy Information Agency
EIS	– Energy Information System
EMMG	– Energy Management Maturity Grid
EnMS	– Energy Management System
EnPIs	– Energy Performance Indicators
ESCO	– Energy Service Company
EVO	– Energy Valuation Organization
FASB	– Financial Accounting Standards Board
FEMP	– Federal Energy Management Program
HVAC	– Heating Ventilation and Air Conditioning
IAC	– Industrial Assessment Center
IPMVP	– International Performance Measurement and Verification Protocol
IRR	– Internal Rate of Return
IRS	– Internal Revenue Service
ISO	– International Standards Organization
KPIs	- Key Performance Indicators
LBNL	– Laurence Berkley National Laboratory
LCC	– Life Cycle Costing
M&V	– Measurement and Verification
MARR	– Minimum Acceptable Rate of Return
MMBtu	– Million British Thermal Units
MSE	– Management System Energy
NAICS	– North American Industry Classification
NEEA	– Northwest Energy Efficiency Alliance
NEMVP	– North American Measurement and Verification Protocol
NPV	– Net Present Value
OPEC	– Organization of the Petroleum Exporting Countries
PDCA	– Plan-Do-Check-Act
QMMG	– Quality Management Maturity Grid
SIC	– Standard Industry Classification
SMM	– Small and Medium Sized Manufacturing
SPP	– Simple Payback Period
TVOM	– Time Value of Money

APPENDIX B

VARIABLE GLOSSARY

ϵ = Annual energy cost

ν = Annual operating cost

$\gamma = \frac{\epsilon}{\nu}$ = Proportion of annual operating cost attributed to energy

$\mu = (\epsilon)(\%\, Wasted\ from\ EMMG)$ = Amount of annual energy purchased which is wasted

$\beta m = \sum_{m=1}^{n}[(\delta_m) + (\beta_{m-1})]$ = EnMS Budget, where *m* is the current year of the of the energy management systems existence ranging from 1 to n, δ_m is the revenue generated in a given year, and β_{m-1} is the year-end balance from the previous year.

$\beta_0 = (\mu)(X)$ = Initial EnMS budget

X = budget multiplier

$TS_{ij} = \sum_{i=1}^{g}\sum_{j=1}^{u}\left[\left(E_{ij} + MA_{ij} + P_{ij} + L_{ij} + IN_{ij}\right)\right]$ = Total savings for the project where there total number of projects range from *i*= 1 to *g*, and each project has a useful life u ranging from *j*=1 to *u*.

E_{ij} = Energy savings, MA_{ij} = Maintenance savings, P_{ij} = Production savings, L_{ij} = Labor savings, IN_{ij} = Intangible savings

$TC_{ij} = \sum_{i=1}^{g}\sum_{j=1}^{u}\left[\left(PL_{ij} + M_{ij} + I_{ij} - R_{ij} + T_{ij} + O_{ij} + MV_{ij}\right)\right]$ = Total savings for the project where there total number of projects range from *i*= 1 to *g*, and each project has a useful life u ranging from *j*=1 to *u*.

PL_{ij} = Planning cost, M_{ij} = Material cost, I_{ij} = Installation cost, R_{ij} = Utility rebate savings, T_{ij} = Training/technical cost, O_{ij} = Operating cost, MV_{ij} = Measurement & Verification cost.

$S_{ij} = \sum_{i=1}^{g}\sum_{j=1}^{u}\left[\left(TS_{ij}\right) - \left(TC_{ij}\right)\right]$ = Total net annual improvement project savings where there total number of projects range from *i*= 1 to *g*, and each project has a useful life u ranging from *j*=1 to *u*.

$D_{ij} = \sum_{j=1}^{u}\left[\left(\left(TC_{ij}\right)\left(\frac{E_{ij}}{TS_{ij}}\right)\right)\right]$ = Proportion of costs subtracted from energy savings for project *i* in year *j*.

$\delta_m = \sum_{i=1}^{g}\sum_{j=1}^{u}\left[\left(E_{ij}\right) - \left(D_{ij}\right)\right](\gamma)$ = Total net annual revenue paid to the EnMS from project savings where there total number of projects range from *i*= 1 to *g*, and each project has a useful life *u* ranging from *j*=1 to *u*, and the EnMS has a life *m* ranging from 0 to *n*.

APPENDIX C

SAMPLE/EXAMPLE SUBMETERING COSTS (2017)

Manufactuer System	Onset HOBO RX3000	Honeywell/E-mon Class 5000 Smart Meter	Schneider Electric Power Logic	GE EPM 4500	Eze Sys Eze io
System Price Estimate*	$4,500	$8,500	-	-	$4,000
Data Transfer**	Ethernet/Wi Fi/Cellular	Ethernet/Telephone modem	Ethernet	PLC or Modbus	Ethernet/Wifi/Cellular
Amp Monitoring	Yes	Yes	Yes	Yes	Yes
kWh Monitoring	Yes	Yes	Yes	Yes	Yes
kW Monitoring	Yes	Yes	Yes	Yes	Yes
PF Monitoring	Yes	Yes	Yes	Yes	Yes
Voltage Monitoring	Yes	Yes	Yes	Yes	Yes
Natural Gas monitoring	Yes	Yes	Yes	No	Yes
Export to Excel	Yes	Yes (.CSV)	-	-	Yes
Data Access	HOBOlink web servers	E-mon or third party software	Power Logic Software	GE or third party software	Cloud based
Annual Data Plan Fee	$0 to $150***	No	-	No	$84-$300****
Other meters avalible	Air velocity, compressed air flow, pressure CO2, humidity, temperature, VOC, water flow	Water (hot and cold), steam, Btus, compressed air	Water, compressed air, steam	-	This system sells the controller and data hosting service, and can connect to a sensor of any type

*Price for monitoring one end point for electricity and natural gas, as well as software. Cost breakdown provided for each system below.

**Varies based on the data plan. Free plan = 1 min interval vs $150 plan = 1 second interval.

**Varies based on the data plan. The least expensive plan is $7/month, with the most expensive plan $25/month

APPENDIX D

EXAMPLE IAC ASSESSMENT RECOMMENDATIONS FOR ACME INC.

(Recommendations for demonstration purposes only – these recommended actions are based on field operations but are not taken from actual IAC clients or report)

AR #1.1 IMPLEMENT COMPRESSED REGULAR AIR LEAK MANAGEMENT PROGRAM

BACKGROUND

This facility has two 100-hp Gardner Denver Model EBP rotary screw air compressors. Only one compressor is operated at a time, with the other acting as a back-up. Compressed air is supplied to the plant at approximately 125 psig; it is used in the injection molding presses to drive pneumatic parts as well as in other process equipment.

During the site audit, the plant personnel and the audit team observed several audible leaks at different locations around the plant. Air leaks increase the compressor's "online" hours of operation by creating exaggerated air requirements and also cause a pressure drop in the air lines.

Two data loggers were deployed, one on each of the compressors, and the collected data over a 5 day period. The facility normally shuts down the air compressors on the weekends, but left them on to allow our data loggers a chance to collect data when there was no load on the system. The data logger on the back-up compressor confirmed that it did not operate during this period. The data for the main compressor is shown in Figure 1.1.1. These logs indicate that during the period observed, the existing compressor was able to adequately meet its demand was not operating near its peak load.

The data loggers recorded the amperage of the main compressor. This data, along with the voltage and assumed power factor were used to calculate the compressors kW demand[20]. Finally, the calculated kW demand was used along with the manufacturers published kW/cfm data to determine the cfm output of the compressor during the time logged[21].

Analysis of the data shows that the main 100 hp compressor was producing an average of 113 CFM when the plant was closed on over the weekend, and the back-up compressor was not used. This average airflow leads to the conclusion that the plant leak rate is conservatively 113 cfm.

[20]Voltage = 460V, phase = 3, power factor was assumed to be 0.8.
[21] Based on the compressor data sheet, an air-cooled Gardner Denver ST 100 hp, EBP operating at 125 hp consumes 19.9 kW/100 cfm.

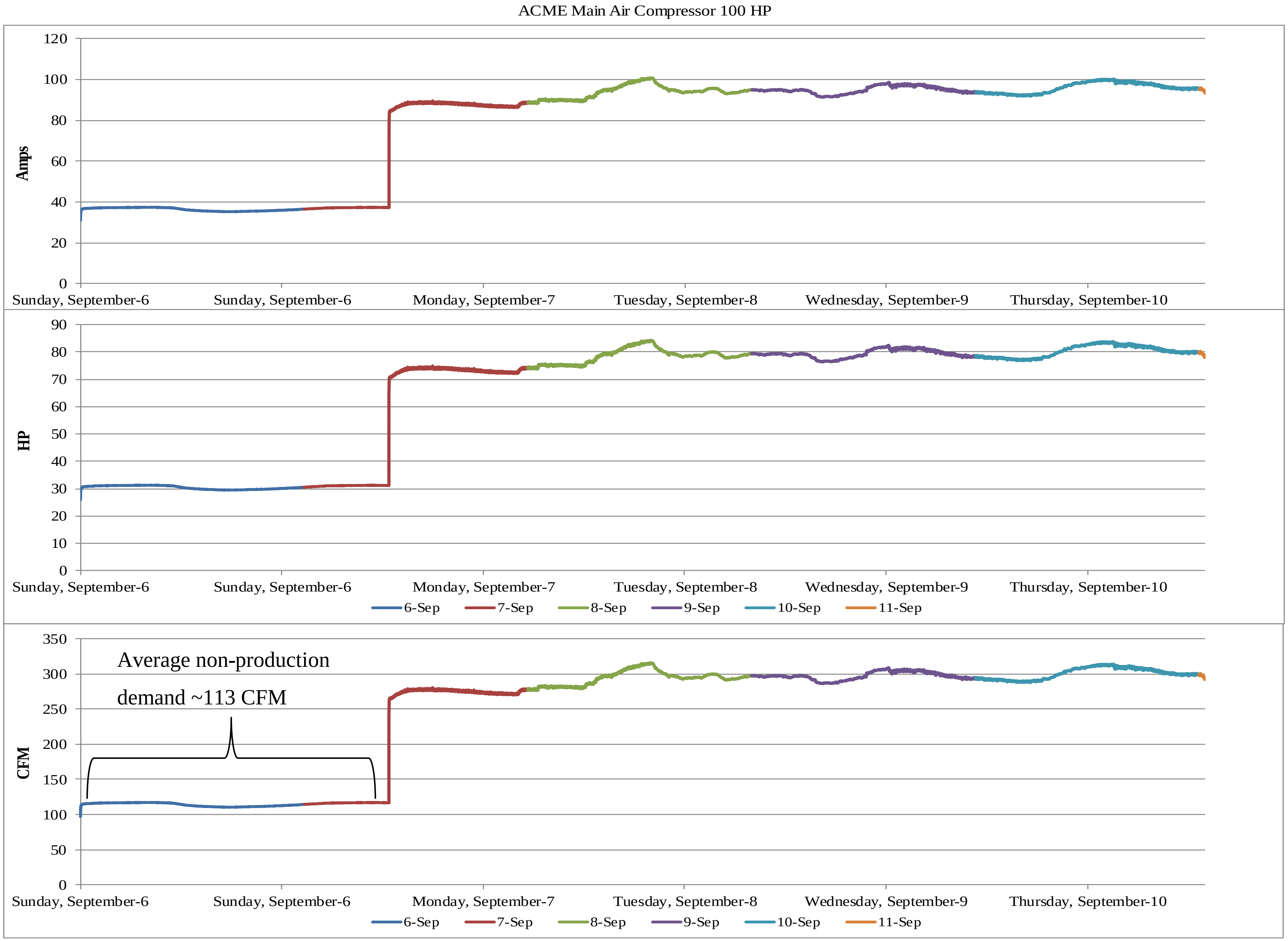

Figure 1.1.1 – Compressed Air System Data Logger Plot

RECOMMENDED ACTION

We recommend you conduct an air leak detection and maintenance survey on a monthly basis. It will help you to identify the air leaks more frequently and correct them as soon as possible. This initiative will help you save energy on a regular basis. Implementing an air leak survey on a regular basis can help the facility to save about 90% of the energy associated with air leaks. For a typical industrial facility, 5-10% of total system flow associated with air leaks is reasonable. We have estimated a reduction of the leakage rate from 113 cfm to 11 cfm, which corresponds to approximately a 90% reduction in the current leaks. Actual savings could be higher depending upon the success of the program. Ultrasonic leak detectors will help to locate the air leaks by filtering out the background noises. However, the air leak survey can be performed without an air leak detector, during the weekends, when the air leaks are clearly audible in the absence of heavy equipment operation.

SUMMARY

- Annual energy savings...122,660 kWh
- Total utility cost savings..$14,439/yr
- Implementation cost...$1,520
- Simple payback period..0.1 years

DATA

- Average cost of energy..$0.114/kWh
- Operating hours..6,240 hours/yr
- Labor cost...$20/hr
- 100-hp compressor specific power at full load[22]..........................0.199 kW/cfm

CALCULATIONS

Energy savings from leak reduction – 100hp compressor
= (Compressor specific efficiency)(Proposed leak reduction)(Operating hours)
= (0.199 kW/cfm)(113 cfm – 11 cfm)(6,240 hours/year)
= 126,660 kWh/yr

Reasonableness check = 2.5% of total consumption (5,031,427 kWh/yr), 20% of estimated air compressor consumption (500,000 kWh/year)

Annual cost savings
= (Proposed annual energy savings)(Average cost of energy)
= (126,660 kWh/yr)($0.114/kWh)
= $14,439/year

Implementation cost – fix leaks
= (Proposed leak reduction)(Maintenance cost)(Conversion factor) + (Cost of supplies)(Number of leaks)
= (102 cfm)($20/hr)(0.5 hr/cfm fixed) + ($25/leak)(20 leaks/year)
= $1,520/year

[22] Gardner Denver EBP 100hp@125psi

Simple payback
= (Implementation cost)/(Annual cost savings)
= ($1,520)/($14,439)
= 0.1 years

AR #1.2 INSTALL WATER COOLED CHILLERS AND COOLING TOWER TO IMPLEMENT FREE COOLING DURING THE WINTER SEASON

BACKGROUND

The facility currently uses four 45-ton air-cooled chillers to regulate the temperature of the production process, with one chiller serving each product line. These chillers are used to help cool down the injection molding equipment by supplying thermolators with chilled water. The thermolators allow for an exact temperature to be maintained based upon the requirements of the individual process. These chillers operate throughout the year, supplying water to the process at approximately 45°F and returning it to the chiller at approximately 70°F. Currently, these chillers are not connected with any cooling towers.

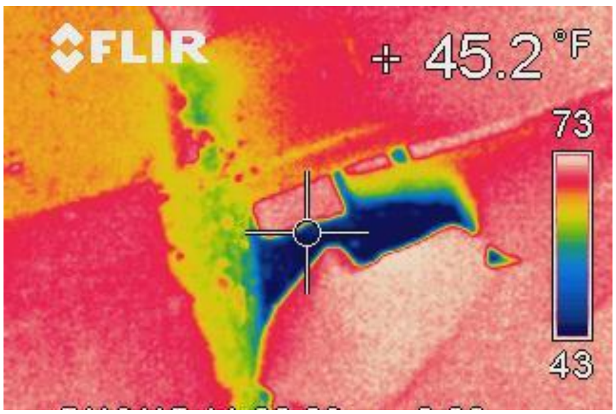

Figure 1.2.1 – Chilled Water Supply

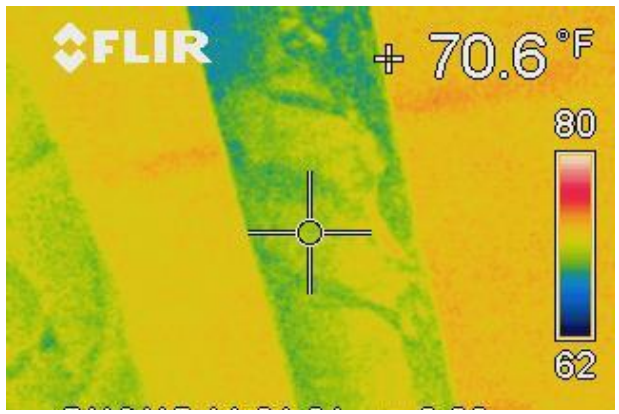

Figure 1.2.2 – Chilled Water Return

An identical 45-ton chiller services product line A and product line B, and an identical 45-ton chiller serves product line C, and product line D. The chillers serving product line C and D are old and not capable of being shut off and restarted with confidence, even though the facility does not currently operate on most weekends, and this line is used infrequently.

Data logger plots of the chiller serving product line A and product line C can be seen in Figures 1.2.3 and 1.2.4. From this data it can be seen that the facility is not using both chillers to their full capacity all of the time.

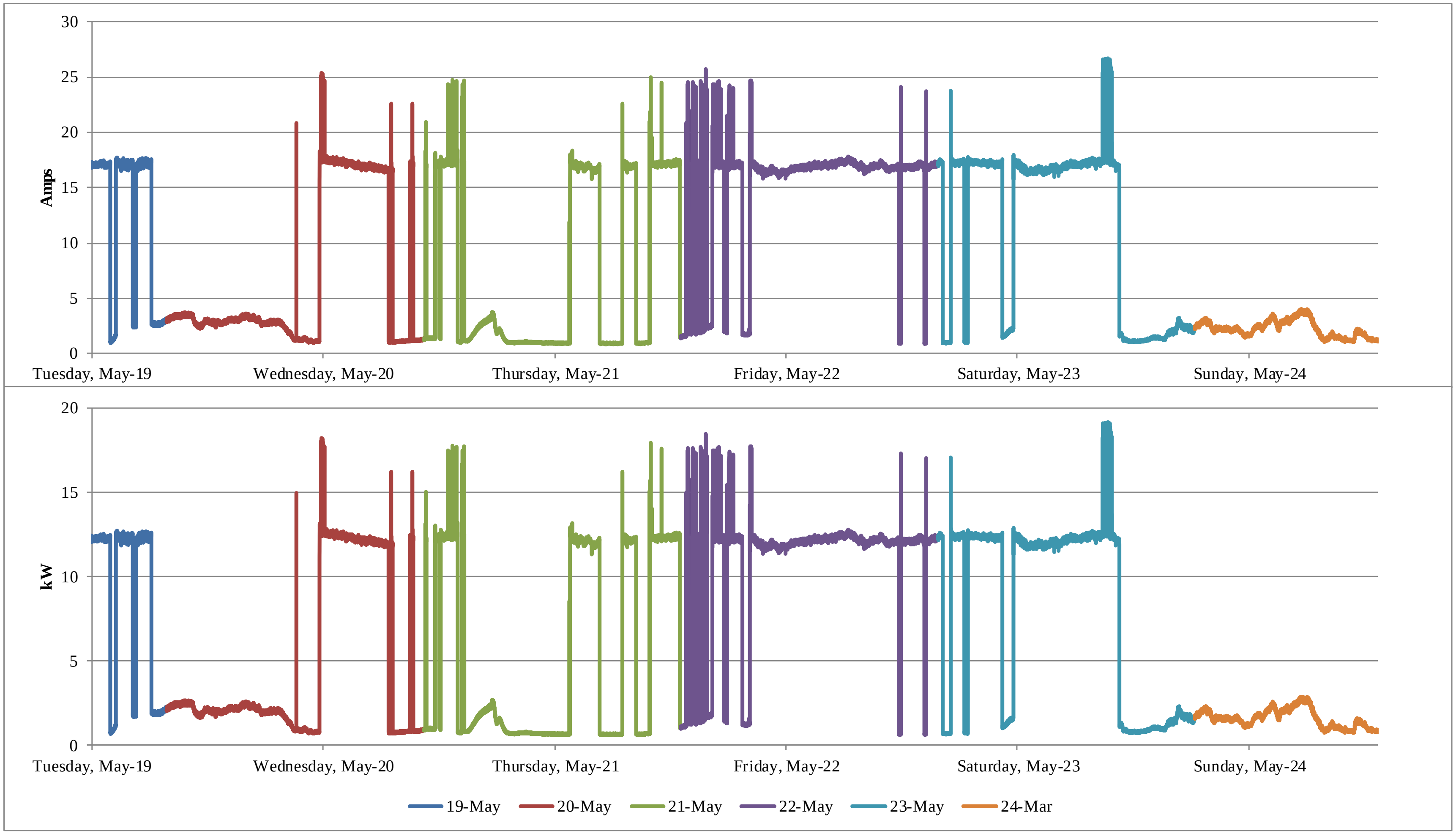

Figure 1.2.3 – Product Line A Chiller Data Log

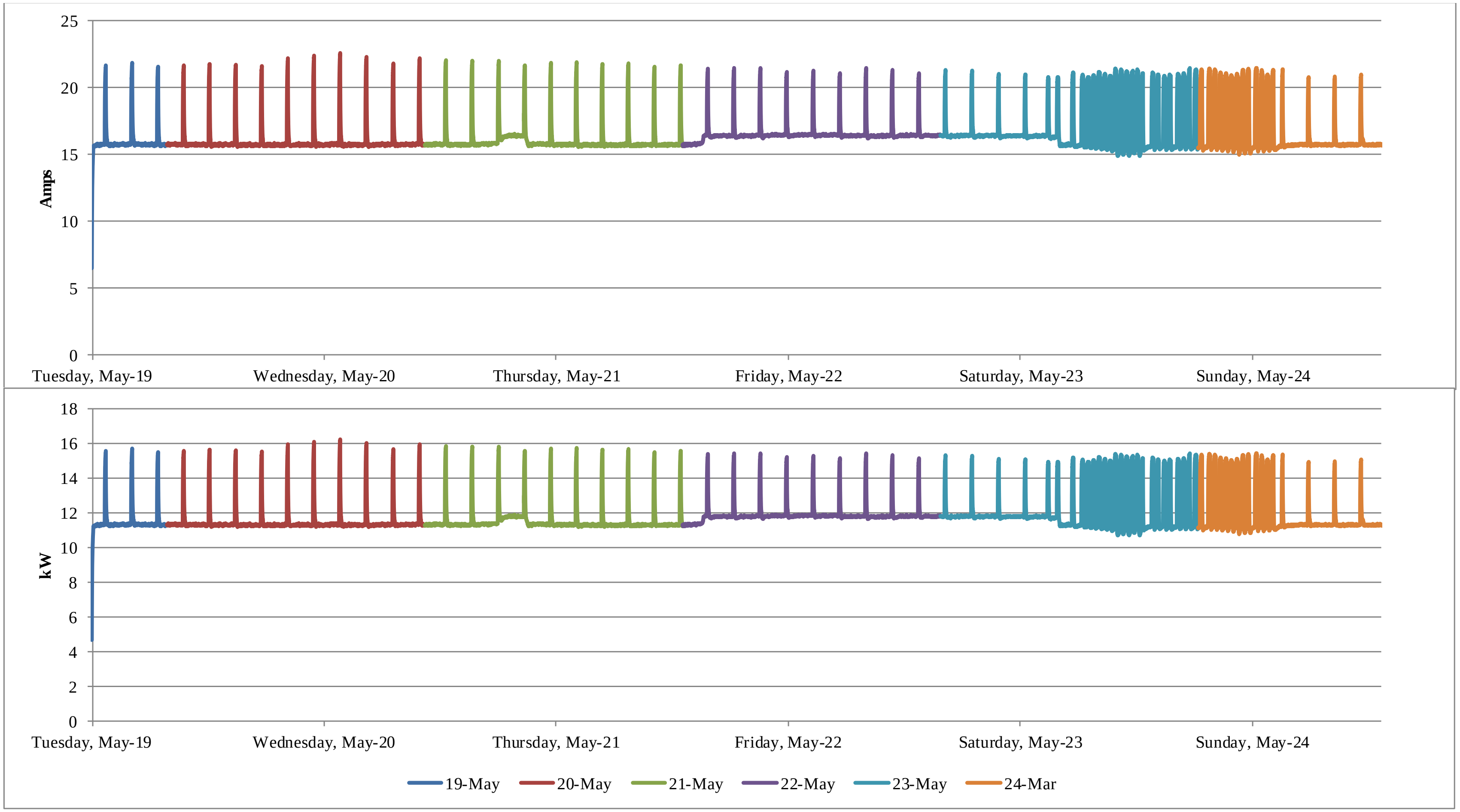

Figure 1.2.4 – Product Line C Chiller Data Log

RECOMMENDED ACTION

We recommend replacing the four existing air-cooled chillers with two water-cooled chillers and a cooling tower coupled with heat exchangers to facilitate indirect "free cooling" during the fall, winter, and early spring months. Water-cooled chillers offer greater efficiencies than air-cooled chillers. Figure 1.2.5 shows how the heat exchanger is simultaneously connected with the process cooling water loop and the cooling tower water loop.

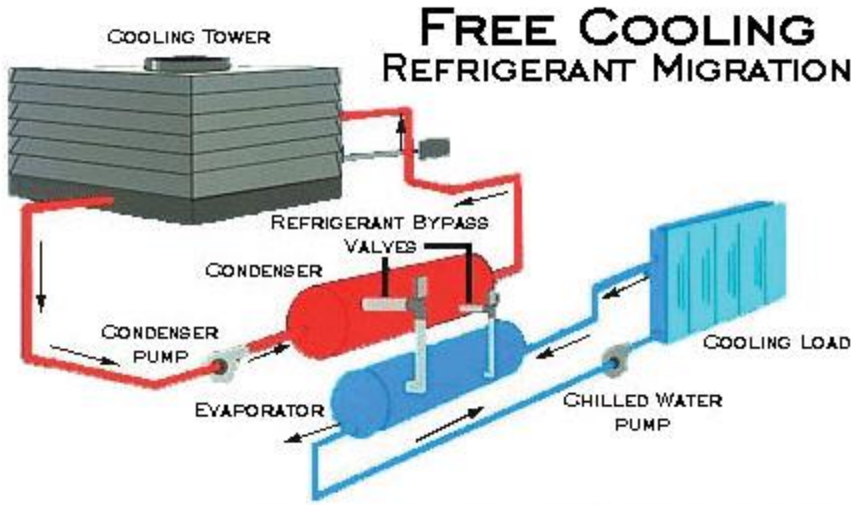

Figure 1.2.5: Example water cooled chiller with cooling tower[23]

Because the existing chillers are not used to their full capacity, especially the product line B chiller based on our data logs, we recommend replacing the four existing 45-ton air-cooled units with two 50-ton water-cooled chillers.

Savings from implementing this recommendation result from replacing four existing chillers with two high efficiency water cooled chillers, as well as reducing the operating hours of the chiller by using a cooling tower and heat exchangers to take advantage of 'free cooling'.

There are times when chillers can be turned off, and the outdoor conditions can be utilized for process cooling with the help of a heat exchanger coupled with cooling tower. This method is known as "free cooling". Free cooling can be used to save energy whenever the outside wet-bulb temperature drops below the required chilled water set-point. An efficient way of implementing free cooling is by the use of the heat exchangers as mentioned above. This method is known as indirect cooling.

In indirect cooling, incoming plant water will enter the heat exchanger instead of entering the evaporator. Instead of passing through the condenser loop, the cold water will pass through the heat exchanger. There will be a heat transfer between the two water loops. We save energy from this method because the condenser will be completely shut off during the winter season when conditions are favorable. The heat exchanger will be installed in a parallel loop which will be isolated from the main circuit with the help of reducers, non-return valves (NRV), and isolation valves.

[23]http://c03.apogee.net/contentplayer/templates/ces/images/c00119.jpg

An alternative method of achieving free cooling is the direct cooling method. In the direct cooling method, no heat exchanger is used. Water will directly enter the cooling tower. The water will get cold with the help of the cooling tower and then again return back to the loop. The reason why direct cooling is less favorable is because of the inter-mixing of plant water with the cooling loop water, causing it to become dirty.

SUMMARY

- Total dollar savings....... .... $77,813
- Annual energy savings.. .... 675,274 kWh
- Annual demand savings .... 83 kW
- Implementation cost...... .... $101,400
- Payback period .... 1.3 years

DATA
Existing System

- Capacity of the two Carrier chillers........ .... 90 tons
- EER of Carrier chiller...s........... .... 10.1[24]
- Capacity of the two Tri Service chillers.. .... 30 tons
- EER of Tri Service chillers........ .... 8.5[25]
- Total chiller tonnage..... .... 180 Tons
- Current power rating of existing pumps[26]........... .... 50 hp
- Cost of electricity.......... .... $0.114/kWh
- Cost of kw demand....... .... $10.00/kW

Proposed System

- Total tonnage of proposed chillers.......... .... 100 tons
- EER of proposed chiller[27].......... .... 15.9
- Wet side economizer hours........ .... 2,164 hrs/yr[28]
- Nominal flow for 50 Tons cooling tower .... 148 gpm
- Cost of 50 Ton cooling tower.... .... $6,000
- Installation cost .... 40% equipment cost

CALCULATIONS

Chiller Replacement Calculations
kW demand of existing units

= [(Tonnage of chiller) (Load factor) (12/ EER)](Quantity) + [(Tonnage of chiller) (Load factor) (12/ EER)](Quantity)
= [(45 tons)(0.7)(12/10.1)](2) + [(45 tons)(0.6)(12/8.5)]
= (75 kW) + (76 kW)
= 151 Kw

---

[24] Based on manufacture specifications
[25] Based on assessment team estimation
[26] It is assumed the existing water pumps will be able to be used for the proposed system.
[27] Based on manufacture data
[28] Hours for Tulsa, OK obtained from the book "Engineering Weather Data" by Michael J. Kjelgaard, McGraw-Hill Professional 2001.

kW demand proposed unit
= [(Tonnage of chiller) (Load factor) (12/ EER)](Quantity)
= (50 tons)(0.9)(12/15.9)](2)
= 68 kW

Demand savings
= (kW demand of existing system) – (kW demand of proposed system)
= (151 kW) – (68 kW)
= 83 kW

Electricity consumption of existing units
= (kW demand of exiting chillers)(Operating hours)
= (151 kW)(6,240 hr/year)
= 942,782 kWh/year

Electricity consumption of proposed units
= (kW demand of proposed chillers)(Operating hours)
= (68 kW)(6,240 hr/year)
= 423,849 kWh

Energy savings
= (Energy consumption of existing system) – (Energy consumption of proposed system)
= (942,782 kWh) – (423,849 kWh)
= 518,932 kWh

Annual dollar savings
= (Total kWh savings) + (kW savings[29])
= (518,932 kWh) ($0.114/kWh) + (83 kW)($10.00/kW)
= $59,158 + $832
= $59,990/year

Implementation cost – Installing new chiller
= (Cost of the new system) + (Cost of extra piping) + (Increased maintenance cost[30])
= (100 tons) ($500/ton) + $10,000 + (0.1*100 tons* $500/ton)
= $50,000 + $10,000 + $5,000
= $65,000

Free Cooling Calculations
Annual kWh savings
= (Total chiller capacity)(Chiller efficiency - 12/ Existing EER[31]) (Wet side economizer hours available)
= (100 Tons/Unit) (12/15.9) (2,164 hrs/yr)
= 163,321 kWh/yr

---

[29] Because the facility is billed on a ratchet clause, it is assumed this savings would occur during their peak demand time. Dollar savings will not take into account the effect of reducing the peak demand month, even though it would ultimately reduce the billed demand in later months.
[30] Assumed 10% of system cost.
[31] Assuming chiller replacement and new EER value

kWh required to operate cooling tower fan
= (Fan horsepower)(Conversion factor)(Operating hours)
= (1.5 hp)(0.7456 kW/hp)(6,240 hr/year)
= 6,979 kWh

Annual dollar savings
= [(kWh savings) – (kWh needed to operate fan)] (Cost of electricity)
= [(163,321kWh/yr) – (6,979 kWh/yr)] ($0.114/kWh)
= (156,342 kWh/yr) ($0.114/kWh)
= $17,823

Cost of cooling tower[32]
= [(Cost of 50 Ton cooling tower) + (Installation Cost)](Quantity)
= [($10,000) + ((0.4) ($10,000)](2)
= $28,000

Cost of heat exchanger
= [(Cost of heat exchanger) + (Installation Cost)](Quantity)
= ($3,000) + [(0.4) ($3,000)](2)
= $8,400

Free-Cooling implementation cost
= (Cost of cooling towers) + (Cost of heat exchanger)
= ($28,000) + ($8,400)
= $36,400

Total annual energy savings
= (kWh savings from free cooling) + (kWh savings from replacing chiller)
= (156,342 kWh/yr) + (518,932 kWh kWh)
= 675,274 kWh

Total annual dollar savings
= (Total annual energy savings)(Electricity cost) + (Total annual demand savings)(Demand cost)
= (675,274 kWh)($0.114/kWh) + (83 kW)($10.00/kW)
= $76,981/yr + $832/yr
= $77,813/yr

Total implementation cost
= (Cost to implement free cooling) + (Cost to replace chillers)
= ($36,400) + ($65,000)
= $90,200

Simple payback period
= (Implementation cost without rebates) / (Dollar savings)
= ($101,400) / ($77,813/yr)
= 1.3 years

[32] A cooling tower installation will be required to install a water-cooled chiller.

Utility Incentives
Your utility offers rebates for energy efficiency projects; the program details are as follows:

> The Friendly Utility Company's High Performance Business Program offers prescriptive incentives, which pays a flat dollar rate per unit installed or a custom incentive for measures not available on a prescriptive list. The custom incentive pays **$0.06 per kilowatt-hour** and **$175 per kilowatt** for both energy and demand savings. Incentives can be paid to either the customer or the contractor doing the work. Custom projects are capped at 50% of the project cost and 75% of the incremental costs for new construction projects. **A project is not eligible if the payback period is 1.5 years or less without the incentive**.

Custom incentive
= (Total kWh savings)($0.06/kWh) + (Total kW savings)($175/kW)
= (675,274 kWh)($0.06/kWh) + (83 kW)($175/kW)
= $40,516 + $14,522
= $55,070

Note: This is greater than 50% of our estimated project cost, therefore the available incentives are taken to be 50% of the project cost, or $45,100.

Note 1: Payback without utility incentives is currently 1.3 years based on our cost estimates, and is therefore not eligible. This may change in the future with rising energy prices.

AR #1.3 INSTALL VFD AND CONTROLS ON GRINDER

BACKGROUND

During the injection molding process parts that do not pass quality control standards as well as excess plastic generated by the mold are able to be re-ground and mixed with virgin material. A majority of waste generated is able to be re-used. This is accomplished through the use of a 50 hp grinder. Rejected parts from all four product lines are thrown onto a central conveyor system connected to the grinder. A forklift driver collects the reground material for reuse. The grinder is currently running at full speed all day, even when it is not actively grinding. Based on interviews with plant personnel, the grinder is actively grinding roughly 60% of the day, but currently runs approximately 19 hours per day, being turned off for breaks and between shifts.

RECOMMENDED ACTION

We recommend the facility install a variable frequency speed drive (VFD, also referred as variable speed drive -VSD- or adjustable speed drive), and controls on the grinder. This would allow the motor to be slowed down when not actively grinding. By using a VFD, the speed of the motor is changed by varying the voltage and frequency of the electricity supplied which is based on the system load requirements. Usually a VSD is directly coupled to the electric motor to control the speed according to demand of the system. A possible control system or trigger for the VFD could include a laser on the conveyor belt to ramp up the motor's operation just prior to the parts entering the grinder.

Note: An alternative would be to turn the grinder off when not grinding, but due to grinding need throughout the day, this possibility was rejected due to start/stop/start/stop associated with the 50 hp motors current configuration.

SUMMARY

- Annual dollar savings $13,690
- Energy savings .... 120,080 kWh
- Implementation cost $9,000
- Payback period .... 0.7 years

DATA

- Electricity charge $0.114/kWh
- Annual operating hours for grinder[33] .... 4,940 hrs/yr
- 50 hp motor full load kW draw .... 40 kW
- 50 hp motor name plate efficiency 95%
- Current motor load 100%
- VFD loss at full load 10%
- Number of VFDs required 1
- 50 HP VFD Cost[34] $5,000
- Labor cost $20/hr

[33] Grinder operates 19 hr/day, 5 days per week
[34] Based on vendor estimate

CALCULATIONS

Full load kW demand of 50-hp motor
= (FL Amps)(Voltage)(Sqrt(phase))(Power factor)/(Conversion factor)
= (65 amps)(460 volts)(Sqrt(3))(0.77)/(1,000 W/kW)
= 40 kW

Energy consumption of one 50-hp motor without VFD
= (Full load kW)(100% Load)(1/% Motor Efficiency)(Operating Hours)
= (40 kW)(100% Load)(1/95% Efficiency)(4,940 hr/year)
= 208,000 kWh/year

Sample calculation for one 50-hp motor at 90% Speed
= [(% hours at 90 % speed)(Operating hours)[((Full load kW)(% Speed)^3))]
= (50%)(4,940 hr/year)[((40 kW)(90%^3)]
= (957 hr/year)(2.04 kW)
= 72,025 kWh @ 90% Speed

Table 1.3.1 Single 50-hp motor energy consumption with VFD

ENERGY CONSUMPTION WITH VFD											
% Speed	**10%**	**20%**	**30%**	**40%**	**50%**	**60%**	**70%**	**80%**	**90%**	**100%**	**Total**
% Hrs @ % Speed	30%	2%	2%	2%	2%	2%	2%	4%	50%	4%	**100%**
Hrs at % Speed	1482	99	99	99	99	99	99	198	2470	198	4,940
kW at % Speed	0.04	0.32	1	3	5	9	14	20	29	44	-
kWh at % Speed	59	32	107	253	494	854	1,356	4,047	72,025	8,694	87,920
Operating Cost	$6.76	$3.60	$12.16	$28.83	$56.32	$97.31	$154.53	$461.34	$8,210.87	$991.16	$10,023

Energy savings – One 50-hp motor
= [(Energy consumption without VFD) – (Energy consumption with VFD)]
= (208,000 kWh/year – 87,920 kWh/yr)
= 120,080 kWh/year

Total dollar savings
= (Total energy savings)(Energy cost)
= (120,080 kWh/year)($0.114/kWh)
= $13,690/year

Implementation cost
= [(50-hp VFD cost) + (Estimated control system cost) + (Estimated installation time)(Labor cost)
= [($5,000/VFD) + ($3,000) + (50 hours)($20/hr)
= ($5,000) + ($3,000) + ($1,000)
= $9,000

Simple payback
= (Implementation cost)/(Total savings)
= ($9,000)/($13,690/yr)
= 0.7 years

AR #1.4 REPLACE PRODUCTION EQUIPMENT WITH MORE EFFICIENT MODELS

BACKGROUND

The facility is currently producing approximately 335 tons of product per year (670,300 pounds) from a combination of eight new type machines and eight older type machines. During the assessment plant personnel mentioned that within the last several years they had upgraded some of their injection molding equipment from old hydraulic type systems to newer servo motor type systems. These upgrades were done on the premise of energy improvement; however the plant had not yet been able to verify that energy savings occurred as a result of the upgrades.

Table 1.4.1 – Current Production Capacities of Existing Equipment

	kWh/year	# Machines	% Capacity	Pounds/Year	Max Production
Line A	700,000	4	1.00	300,000	300,000
Line B	525,000	4	0.75	225,000	300,000
Line C	400,000	4	1.00	75,000	75,000
Line D	375,000	4	0.94	70,313	75,000
	2,000,000	16		670,313	750,000

Our team placed data loggers on the following pieces of production equipment over a period of five days:

1. Data Logger #1 – Machine #1 Product line A; Example of newer equipment (~2005)
2. Data Logger #2 – Machine #1 Product line C; Example of older equipment (70s-80s)

The logged amperage along with the name plant voltage, phase, and assumed power factor were used to calculate kW demand and kWh consumption.

Production data for the above equipment was also provided by the plant in 12-hour increments. This data was combined with the energy consumption data to determine the energy intensity of each machine logged. The average energy intensity (kWh/piece) for the equipment was:

1. Product line A – 2.31 kWh/piece
2. Product line C – 5.31 kWh/piece

It appears that the product line A equipment (newer servo type equipment) is significantly more efficient than product line C, the older type of equipment.

The energy intensity plots are provided on the following pages.

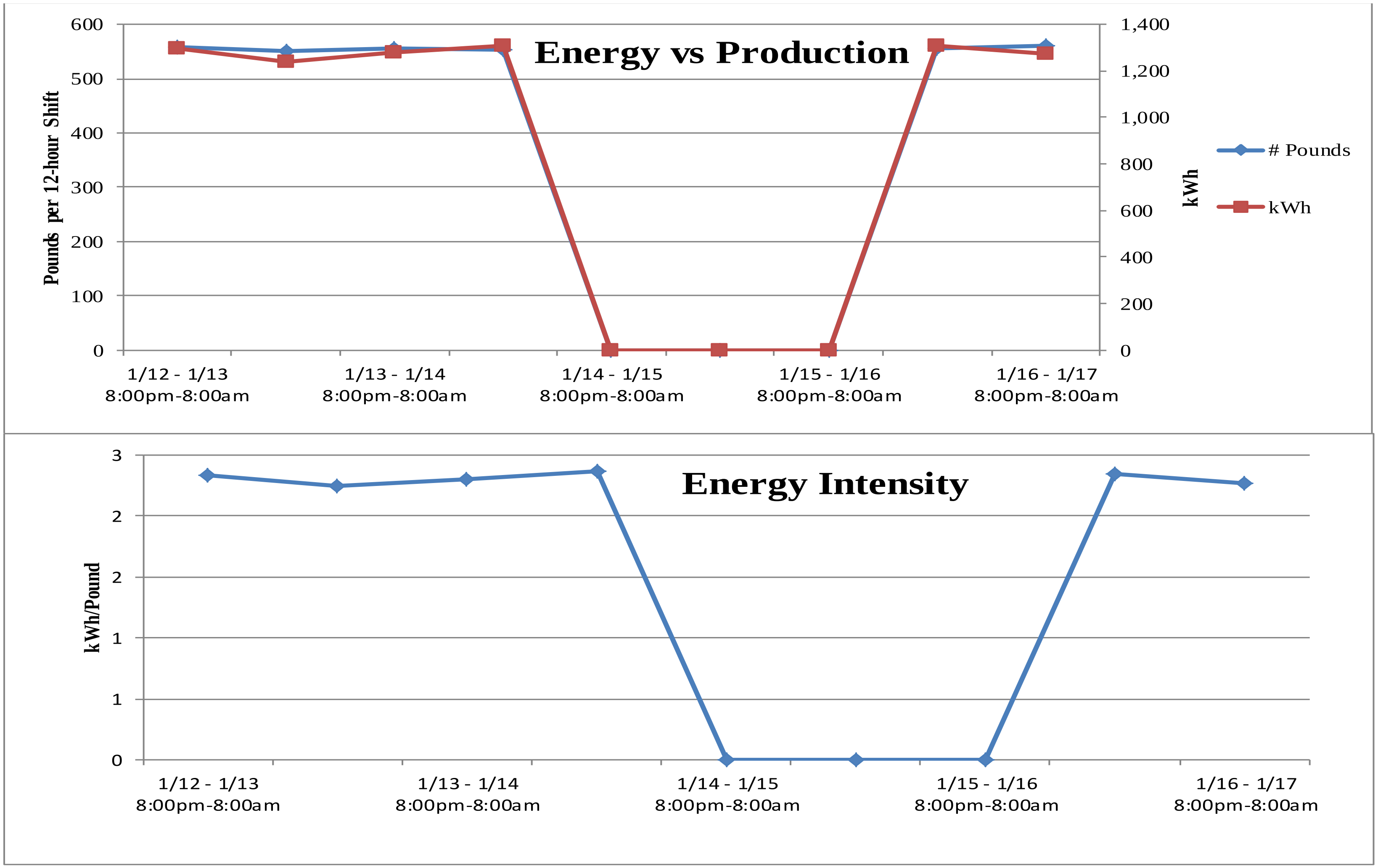

Figure 1.4.1 – Production Line A Machine #1 Estimated Energy Intensity

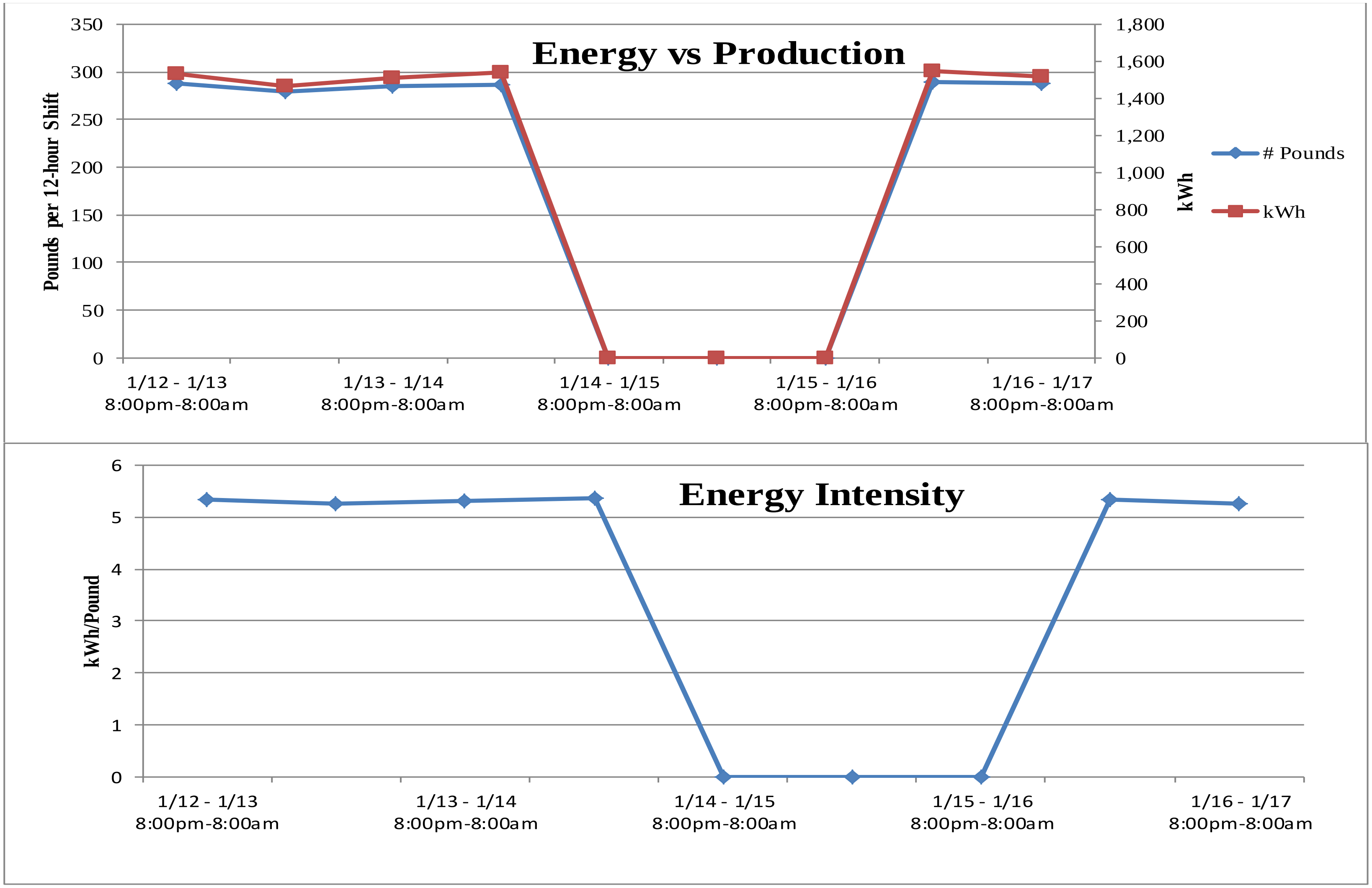

Figure 1.4.2 – Production Line C Machine #1 Estimated Energy Intensity

RECOMMENDATION

When the facility's current older type production equipment is ready to be replaced we recommend that it be replaced with the more energy efficient type equipment, similar to that used in product lines A and B.

We assume that the data logging results of product line A are representative of the new type of equipment which would be installed in the plant, and that the equipment logged on product line C is representative of the old type of equipment which would be replaced.

While the comparisons in this recommendation do not account for increased production capacity, and use the existing production levels, a new machine would capable of producing 3 times more than the existing type machines, and has an installed cost of $500,000.

SUMMARY

- Annual dollar savings $49,697
- Annual energy savings.. .... 1,830,360 kWh
- Annual demand savings .... 34,342 kW-mo/yr
- Implementation cost...... .... $4,000,000
- Payback period .... 805 years

DATA

- Number of existing old injection molding machines[35] 8
- Total number of pounds produced by old machines......... .... 145,313 pounds/yr
- Energy intensity of existing old machine .... 5.31 kWh/pound

- Number of machines to be replaced........ 8
- Total number of pounds produced by new machines .... 525,000 tons
- Energy intensity of new machine........... .... 2.31 kWh/piece
- Cost of electricity.......... .... $0.114/kWh

CALCULATIONS

Energy consumption of existing old type machines
= (Pounds produced by proposed machines) (Energy intensity)
= (145,313 pounds)(5.31 kWh/pound)
= 771,609 kWh/year

Energy consumption of proposed new type machines
= (Pounds produced by existing machines) (Energy intensity)
= (145,313 pounds)(2.31 kWh/pound)
= 335,672 kWh/year

Annual energy savings
= (Energy consumption existing machines) – (Energy consumption proposed machines)
= (771,609 kWh/year) – (335,672 kWh/year)
= 435,938 kWh/year

---

[35] Four per product line

Annual dollar savings
= (Annual energy savings) (Electricity consumption cost)
= (435,938 kWh/year) ($0.114/kWh)
= $49,697/year

Implementation cost
= (Number of PMP machines to be installed)(Cost per machine[36])
= (8)($500,000/machine)
= $4,000,000

Simple payback period
= (Implementation cost) / (Annual dollar savings)
= ($4,000,000) / ($49,697/year)
= 805 years

Note: This does not account for any increased production capability, improvements in reliability, or reduction in maintenance costs.

[36] Based on information from plant personnel from previous installation of similar machines. Roughly $400,000 for equipment and $100,000 for installation.

VITA

Patrick Kennedy Smith

Candidate for the Degree of

Doctor of Philosophy

Thesis: SUSTAINABLE ENERGY MANAGEMENT SYSTEM FRAMEWORK FOR SMALL AND MEDIUM SIZED MANUFACTURING FACILITIES

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Lead Student – Industrial Assessment Center	May 2014 - Present
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