DEVELOPMENT OF A METHOD FOR RECORDING ENERGY COSTS AND USES DURING THE CONSTRUCTION PROCESS

A Dissertation

by

ALTHEA GAYLE ARNOLD

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

May 2008

Major Subject: Architecture

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ABSTRACT

Development of a Method for Recording Energy Costs and Uses During the Construction Process.

(May 2008)

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Rising energy costs should be a concern to contractors, designers, and owners. It is difficult to make a quantity takeoff for energy usage because these costs are imbedded in the materials, equipment, or overhead costs. This research examines energy consumption during the construction process, sets forth methods for recording this energy consumption and establishes a program for the recording and analysis of this data.

An energy study of electricity, gasoline, and diesel consumption was made for the construction of three buildings to determine what data was available. After available data was evaluated, and the Energy Data Analysis program developed, three other construction sites were visited to determine how readily energy data can be recorded using the program.

Four construction energy phases were identified from this research. The four phases are: 1) site clearing and preparation, 2) building structure, 3) interior

finishes, and 4) commissioning. The main type of energy consumption during Phase 1 is diesel fuel for earth moving equipment. The energy uses for Phases 2 and 3 varied considerably among the projects studied and were difficult to quantify. However, the energy use during these phases was low compared to other phases and for many projects may not be economical to evaluate. During Phase 4, electrical energy demand was high due to Heating, Ventilation and Air Conditioning (HVAC) commissioning requirements and power up of all electrical power uses including lighting.

These few construction projects are not enough to make definitive conclusions about what percentage of the total project cost is spent on energy. This research found that construction energy costs vary during different phases of the building process and can be a significant part of that phase (as high as 5.7% of the cost). The Visual Basic program developed during this research will facilitate future energy studies on construction sites. When the program is applied to a project, it identifies and quantifies the energy use, and makes predictions as to which project tasks warrant further energy studies.

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CHAPTER I

INTRODUCTION

The construction of buildings is an energy intensive endeavor, yet contractors do not have a standardized method for determining how much of their outlays are for purchasing energy. The topic, energy use during construction, has not been studied in a research environment. There is a paucity of journal papers on this topic. Email correspondence with Paul Hesse of the National Energy Information Center confirms the lack of government research (Hesse 2006). DOE publishes energy use data on manufacturing but none on construction (DOE 2005). At the Stockholm 1981 International Road Federation World Meeting researchers forecasted that construction equipment innovations and advances will emphasize energy efficiency and productivity (Benson 1981). While there have been some advances in equipment, there has not been a study showing how their energy efficiency affects construction costs.

The costs of electricity, gasoline, and diesel increase as the cost of petroleum increases. This increase will affect the cost of construction directly in terms of construction energy use and indirectly the energy costs to manufacture and transport materials. This research develops a standardized method for collection and analysis of energy cost data during construction on a comparable project basis. The results of this study may be used in the future to identify sustainable construction methods in terms of efficient energy use.

This dissertation follows the style and format of *Journal of Construction Engineering and Management*.

CHAPTER II

PROBLEM STATEMENT AND OBJECTIVE

Problem Statement

The research proposes to identify and evaluate energy consumption during the construction process and to develop a standardized method for collecting energy cost and consumption data.

Objective

The objective of this study is to develop a guide that may be used by designers and contractors to evaluate their construction energy costs. This guide will include: 1) a computer program for recording construction energy related data, 2) functions in the program for analysis of that data detailing relative energy costs for different types of construction on a project comparable basis and 3) a guide for use of the program. This program may be used for the organization of energy cost data and a standardized energy analysis. It will aid designers and contractors in making sustainable decisions for their construction projects.

CHAPTER III

BACKGROUND (LITERATURE REVIEW)

Introduction

This study began as a study to determine how renewable energy can be utilized during building construction. The amount and types of renewable energy resources that can be utilized are dependent on the amount and types of energy used in construction. However, since construction energy usage has not been well documented uses and needs had to be researched before a methodology could be developed and proposed for standardizing the collection of construction energy data. This research has lead to procedures and information that may be valuable in future studies to determine the cost effectiveness of using renewable resources in construction and evaluating more energy efficient construction methods.

This chapter presents background information for energy trends in the United States, how this affects construction, and references for energy used in construction.

Energy Trends

In 1956, M. King Hubbert predicted that the United States oil production would reach its peak in the 1970's. This prediction came true. In his book Hubbert's Peak, Kenneth S. Deffeyes (2003) predicts that the world oil production will reach its peak between 2004 and 2008. Oil production has not increased since 1998 (Deffeyes 2005) and is expected to begin its decline in the next four years. The cost of energy today is at its highest level and is expected to continue to rise. The *Annual Energy Outlook 2005*, which forecasts the US and world wide oil demand states "the price of oil will be influenced by many factors about which there is considerable uncertainty (Energy Information Administration February 2005)." Hurricanes occurring in 2006 caused the cost of oil to fluctuate wildly. Previously, there were local price increases due to lost productivity from hurricane damage (Energy Information Administration/Energy Consumption Series Office of Energy Markets and End Use, eds. October 1995). However, the general trend will be an increase in the price of oil resulting in overall increases in energy costs.

Energy Affects Construction

The cost of energy affects the cost of construction. According to the *Economics Indicators January 2005* (Council of Economic Advisers, ed. 2005), the 2004 consumer prices of energy went up 16.6% over the 2003 prices. These increasing energy costs are mainly due to the uncertainty in the price of oil. Dependence on fossil fuels makes the cost of construction dependent on a volatile market. As the price of gas and diesel go up, so will construction costs.

On-site construction consumes energy in two ways: 1) the use of gasoline and diesel operated equipment, and 2) the use of from-the-grid electricity. In addition, construction equipment using gasoline and diesel in combustion engines increases air pollution. The EPA has adopted a tier program in which all off-road equipment, including construction equipment, will be required to meet new air quality standards by 2008 as dictated in their document *Reducing Air Pollution from Nonroad* Engines (United States Environmental Protection

Agency, Air and Radiation, ed. April 2003). From-the-grid electricity is produced in many ways depending on the local resources and existing power plants. Nationwide, 71% of the electricity is produced from fossil fuels (coal, petroleum, and natural gas), 19.2% through nuclear methods, 7.2% through hydro-power, and only 2.5% through other renewable energy methods (Biomass, Geothermal, solar, and wind)(US Government 2007). This means that the majority of the electrical energy consumed during construction is produced from non-renewable resources.

Extensive searches of construction related journals available through the Texas A&M University Library provided no articles on the cost of energy during construction. Measuring energy use during construction has even eluded the US government. The Energy Information Administration (EIA) classifies energy use into the following categories: residential, commercial, industrial, and transportation. Construction is included in the industrial category; however, energy use for on-road construction vehicles is included in the transportation category. In the article *Measuring Energy Efficiency in the United States Economy: A Beginning* (Energy Information Administration/Energy Consumption Series Office of Energy Markets and End Use, eds. October 1995), the EIA states “Data are insufficient to permit the development of robust energy-efficiency indicators for the non-manufacturing sector.” A foot note explains that non-manufacturing includes agriculture, mining, and construction. Although energy use during construction has not been well documented or researched, the government is aware of this need. In 1996, a symposium entitled *Federal*

Policies to Foster Innovation and Improvement in Constructed Facilities (National Academy of Sciences, Federal Facilities Council (FFC) Standing Committee on Research, ed.1996) was held with a goal to "foster innovations and improvements in constructed facilities." Some of the findings from this symposium are: a) Fragmentation in the construction industry has led to poor investment in R&D; b) As an owner of constructed facilities, the government should provide leadership in innovation technologies; c) Fixed price contracts do not provide incentives for innovation and performance based specifications should be employed; d) There is inadequate investment in R&D; and e) There needs to be a link between the construction industry and its environment.

Kristen Widen in her article "Innovation in the Construction Process" (2003) discusses the reasons for a lack of innovation in the construction process. The reasons center on the lack of communication and learning in the construction industry. This is evident in the lack of research on energy impacts on construction. However, energy related information can be pieced together from several sources.

Construction References

There are several books available on construction methods that have been utilized in this study. *Construction Planning, Equipment, and Methods* (Peurifoy and Schexnayder 2002) discusses how to determine fuel expense from company records or manufacturing data. *Construction Management Fundamentals* (Schexnayder and Mayo 2004) has a section on equipment operating costs which include fuel costs. *Construction Methods and*

Management (Nunnally 2004) discusses construction productivity and suggests methods for reducing construction costs, but like the other construction text books, it does not discuss other non-equipment energy costs during construction.

Sustainable Construction Green Building Design and Delivery (Kibert 2005) describes green building design and delivery systems focusing on green buildings, rather than green construction, although lifecycle material costs are discussed.

On the other hand, the energy used in occupied buildings is well documented and studied. The availability and cost of energy have long affected how buildings are designed and constructed. Organizations such as the U.S. Green Building Council (USGBC) and the Austin Green Building Program have arisen in order to address these issues. The goal of the USGBC is to "promote buildings that are environmentally responsible, profitable and healthy places to live and work" (USGBC 2006). Most of the emphasis by these types of organizations has been on making buildings more energy efficient, but with a lesser emphasis on the use ofrenewable energy resources. Construction professionals are mainly involved in green building projects through the Leadership in Energy and Environmental Design (LEED) certification program (Kibert 2005). LEED is a certification program administered by the Green Building Council. Its purpose is to promote the building of sustainable buildings. To do this, each building is evaluated in areas determined to have an effect on natural resources. While there are a few items specifically addressing the construction process, the majority of the LEED points are awarded to the building design and the selection of construction materials.

Building Information Modeling

Building Information Modeling (BIM) systems associate drawings, 3D/4D modeling, materials, scheduling, and design in one package to be used thought out the Design-Construction process. It is intended to be updated as the building design and construction advance and be delivered to the building owner as a documentation of the building that can continue to be updated and serve as a record of the building's history. The advantages of this system are fewer mistakes as information is transferred from architect to engineer to contractor. According to Kale (Kale et al. 2007), "BIM definitely plays a significant role in design clarification and communication." BIM does this by integrating graphic and non-graphic information in one resource, for each project, accessible to all professionals associated with the design and construction of a building. While no studies have been found that integrate energy consumption during construction with BIM, this information can be integrated with the individual construction elements within BIM. In the keynote address of the BIM Symposium at the University of Minnesota, the speaker stated that BIM applications have the ability to be connected to other applications through a user developed Application Programming Interface (API). (Khemlani 2006b)

CHAPTER IV

DELIMITATIONS

Within the constraints of this research, it was not possible to test this methodology through a typical two year construction process. However, the methodology was developed using a broad spectrum of data and tested on multiple projects with the scope limited to a few days of observation. The test scope was limited to diesel consumption in phase1 and electrical consumption in phases 2 and 3. Further refinement to tailor it to the contractor’s needs and style of construction can be performed at the contractor’s discretion.

For the development of the overall methodology, existing data was used. This data has limitations in that specific work tasks are not recorded with the existing energy use records. There are two distinct types of energy used during construction: petroleum and electrical energy. Gasoline and diesel are used to power trucks, earth moving equipment, and generators. Electrical power is used to power motors, lights, and power tools. Electricity used during construction was documented through electrical utility bills. However, electrical usage for each task during construction was inferred through knowledge of the tools used and duration on the job site. This method gave more detailed results since for large projects many tasks were performed at the same time or their time construction line overlapped. Gasoline and diesel usage was estimated from subcontract billing or from knowledge known about the specific type of equipment used. The methodology developed during this study examines each of these methods in more detail.

CHAPTER V

SIGNIFICANCE OF THIS STUDY

The term construction has two components: 1) the act of constructing a building and 2) the materials and methods used to construct a building. Energy efficient construction also has two components. It can refer to the materials and building methods that makes a building energy efficient during its use, or it can mean the use of energy efficient methods to reduce the cost of energy during construction. All of these components must be considered when studying the sustainability of a building.

Sustainable Construction Green Building Design and Delivery (Kilbert 2005) defines sustainable construction as “addresses the role of the built environment in contributing to the overarching vision of sustainability.” It goes onto say that the principles of sustainability include ecological design, life-cycle assessment, life-cycle costing, and high-performance building. The focus of sustainability in this study will be limited to the energy usage during construction and the effects thereof.

Costs of Construction Energy

The degree of a building’s sustainability can be perceived as a dependence on a volatile energy market. Fluctuating costs affect many aspects of building construction, from the price of materials to the price of diesel. Since different construction methods require different amounts of energy, the difference in energy costs may become a decisive factor in choosing a construction method. Just as importantly, the construction method and materials impact the embodied energy of the building. The embodied energy for some energy efficient buildings exceeds the lifetime building use energy as found in a study of modern European buildings (Casals 2006). Given these considerations, how does a contractor know which method consumes more energy, what is the potential cost of that energy, and how do changes in energy costs affect the cost of construction and the true sustainability of a building? The methodology developed in this research will provide a means of determining the most economic construction methods in terms of the cost of energy. No one building type will be economical for all markets. Building design and construction methods should be balanced as the cost of energy fluctuates.

Possible Benefits of This Study

Benefits can be classified in many different ways. Direct benefits to a project may be defined as cost or time savings. If energy costs are significant and ways of reducing these energy costs can be found then a project would warrant extensive energy monitoring based on the possibility of future cost saving alone. However, other considerations must be taken into account when energy is involved. Fossil fuels are becoming more costly to produce as they become less available. As a result, the costs of petroleum products are increasing. Air pollution due to the use of fossil fuels is another major concern. New energy sources must be evaluated for use in construction. However, before these energy sources can be deemed economical, the present energy uses in construction must be identified and quantified. And while there may not be an immediate cost benefit to this study, the far reaching effects of this study can be significant. Sustainable alternative energy sources must be identified in order for construction to be a viable industry in the future. This research develops a method for identifying and quantifying energy use in construction. Future research can use this method to intensively study construction energy use and this information can be used to evaluate sustainable alternatives for construction energy.

Another benefit would be the cumulative effect of smaller energy saving methods over many projects. One possible outcome of studying energy uses in construction is the identification of more efficient methods. If only one method were identified that could save energy, its effect on one project would be small. However, as the energy savings procedure was utilized by other projects the cumulative energy savings could be significant.

Methods for Tracking Energy Costs

A preliminary study found that there are no standard methods for tracking energy costs during construction. This thesis investigates and develops a method that a contractor can use to track energy costs. One obvious method of determining energy use during construction would be to record daily meter readings, and observe the jobsite every day, recording the quantity and duration of use for all tools and equipment that consume power. While this would give very accurate data, it is extremely time consuming and therefore very costly for contractors interested in the energy use of their projects. This type of data could only be gathered during construction and would not be available from past construction projects. A more efficient method for determining energy costs for previously constructed projects and projects under construction needed to be developed. In this study, an analysis was made of the types of documents available and a practical method for tracking on the job site energy use was developed. This research led to the development of the Energy Data Analysis program.

Building Information Modeling

The results of the Energy Data Analysis program are made available in a data base that associates the energy consumption data with the CSI Master Format. Autodesk's Revit platform is a 3-D building design program that has been developed to support Building Information Modeling (BIM). Building elements in Revit are also keynoted with the CSI Master Format. Therefore the platform is available to associate the energy cost information with the building elements in BIM by keynoting each with the CSI Master Format. (Khemlani 2006a) Therefore the data gathered as part of a future research project using the Energy Data Analysis program developed herein can be linked to Building Information Models in the design development stage to determine the effects of energy costs on the project. Different scenarios can be modeled in BIM to determine the most cost effective and most energy conservative designs.

CHAPTER VI

RESEARCH PHILOSOPHY

Quantitative research and qualitative research are complementary research methods. This research primarily used a qualitative methodology. Paul Leedy and Jeanne Ormrod describe, in *Practical Research* (2001), the purpose of qualitative research is to “describe and explain, to explore and interpret, and to build theory.” These purposes matched well with the goals of this research: first to describe and explain the energy uses during the complex construction process; secondly, to explore and interpret energy used so that they may be correlated with future construction projects; and thirdly, to build a methodology of how energy use during construction affects the cost of a project and how this information can be used to predict costs for future projects.

This research was approached from a holistic point of view rather than focused on a few variables. The variables of this study are the construction processes that consume energy. While many of these variables were known at the outset of the project, some of them were be discovered during the research. While these variables have quantitative parameters (kW/hr or Joules), they themselves are of a qualitative nature (lighting energy, welding energy, HVAC). Rather than a static design, the research process was of an emergent nature culminating in energy uses as they were defined by individual projects. However, the viewpoint of the researcher was one of detachment rather than the personal view associated with qualitative research. Research of a qualitative nature has lead to a quantitative methodology for defining, tracking, and accumulating cost data, thus providing the means for forecasting, cost comparison, and decision making in the future.

CHAPTER VII

PROCEDURE

Kristian Widen in *Innovation in the Construction Process* (2003) defines architectural innovation as how “Exiting knowledge, technical and other, is combined to form something new.” As discussed in the Problem Statement, this research was performed in three phases. However, each phase is not distinctive in terms of completion. The research was iterative between the phases, and items in earlier phases were often changed as the methodology for the later phases was developed.

Phase I – Procedure to Document, Describe, and Explain the Energy Uses during Construction

The purpose of Phase I was to document, describe, and explain the energy uses during construction. The existing energy use data was studied for three buildings constructed on the Texas A&M Campus. These buildings were selected because information about these buildings was available through the facilities management division at Texas A&M; they were recently completed or under construction at the time this study began; and they were all built by Vaughn construction. These buildings were the Brown Chemical Engineering Building, the General Services Building, and the State Chemist Building.

The Brown Chemical Engineering Building is located on the Texas A&M Main campus at the corner of University Drive and Spence Street. The General Services Building is located near the Texas A&M Veterinary School on the corner of Agronomy Road and F and B Road. The State Chemist Building is also located on Agronomy Road.

Utility bills for each project were obtained and correlated with major items of work. These results are described in Chapter VIII, Results. The owner's project files were studied not only to determine what data was available but also to determine what information had been omitted. The building parameters for each case studied were documented and this information led to the development of a parameters form that was incorporated in the data recording and evaluation program developed in Phase III.

The information obtained during Phase I were: project schedules of work from Vaughn Construction (the General Contractor for all three buildings), the electrical meter monthly consumption from the TAMU Physical Plant (the utility provider), and general building information from TAMU Facilities Management (Contract Administrator for the owner).

Phase II – Procedure to Determine the Organization to Facilitate Meaningful Data Collection

The second phase of this study explored and interpreted the building energy uses. The information gathered from Phase I was analyzed to determine the best organization to facilitate meaningful data collection and future evaluation. Since the purpose of this research was to develop the methodology for data collection and evaluation, it was impossible at this point to determine which construction categories had significant energy use. However, studying the project files led to a method for organizing the data collection and is discussed in Phase III.

Phase III – Procedure to Develop a Guide for Future Data Collection and Analysis

The third phase of this study developed a guide for future data collection and analysis. The synthesis of this information led to the development of a standardized method for recording and predicting energy use during construction on a project comparable basis. In addition, construction site visits were made to ascertain the effectiveness of selected proposed data collection procedures. A Rubric was used to organize the data collection and to provide a structure for data comparison. Rubrics are commonly used to evaluate student progress in subjects at public high schools (Mertler 2001); however, they also have been developed to evaluate other projects as well. Studying the rubric methodology led to a better system for evaluating energy use during construction using an Energy Data Analysis database computer application developed for this project using Microsoft Visual Basic. This computer application will henceforth be referred to as the Energy Data Analysis Program (EDA Program).

The EDA Program is designed to be all inclusive; therefore, all construction categories were considered, as defined in the CSI (Construction Specifications Institute) Master Format (Construction Specifications Institute 2005). The CSI Master Format groups “type of work” under major divisions using a four level numbering system. Level 1 represents the divisions which are then subdivided into sections for level 2, level 3, and sometimes level 4 categories. Construction professionals are familiar with this numbering system as it is widely used to organize specifications for construction contracts and to organize bid packages for line item construction costs in the building construction industry. It was used as a framework for the EDA Program.

For the development of the EDA Program, several different methods of electronic storage were investigated. The first was to write a macro in excel for data entry and subsequent data retrieval and manipulation. However, data retrieval and manipulation are cumbersome for the user. The second method considered was to write a visual basic program that automates Microsoft Excel for the recording and evaluation of the organized data collected in Phase II. However, the current version of Visual Basic (Visual Basic 2005 Express Edition) is not fully functional with Excel, but was developed to make use of SQL Server Express, a database program internal to Visual Basic. Thus, a Visual Basic database system was chosen as the best electronic storage method. The database function allowed for better manipulation of the data and sorting from any parameter.

Development of the EDA Program for evaluating energy use during construction led to the development of a two part guide: 1) a Visual Basic Program utilizing a database for electronic storage and evaluation of the data gathered, and 2) Instructions for the use of the Visual Basic Program.

CHAPTER VIII

RESULTS

Phase I – Results: Document, Describe, and Explain the Energy Uses during Construction

The purpose of Phase I was to document, describe, and explain the energy uses during construction in order to develop a methodology for recording and understanding this energy use. The following sections are part of the Phase I results.

Building Parameters

The first item researched was building construction parameters. To obtain meaningful results from the data analysis program, building parameters identified in this project should meet the following three conditions:

1) Items that are common in all building construction projects,
2) Their values have the potential to affect the energy use during construction, and
3) They are quantifiable.

Table 1. Potential Building Parameters for the Three Projects Studied shows a list of information readily gathered about the three buildings studied; the Jack E. Brown Chemical Engineering, the General Services Complex and the State Chemist Building. The next step was to determine which of these informational items should be parameters to the study of energy use during building construction.

Table 1. Potential Building Parameters for the Three Projects Studied

Building Parameters	Jack E. Brown Chemical Engineering	General Services Complex	State Chemist Building	Meets Condition:
Building Square Footage	205,000	200,000	20,000	Quantifying
Building Cost	$38,000,000	$21,000,000	$4,500,000	Quantifying
Cost per Square Foot	$185	$105	$225	Quantifying
Number of Stories	7	2 and 3	1	Quantifying
Construction Time (months)	26	17	13	Quantifying
Building Use	Research	Offices	Research	Descriptive
Type of Structure	Cast-in Place concrete	Tilt-up Wall & Steel	Tilt-up Wall & Steel	Descriptive
Special Features	Glass & Aluminum Curtain Wall, Chemical Laboratories	2-Story & 3-Story Sections	Chemical Laboratories	Descriptive

"Building Square Footage" and "Total Building Cost" meet all three of the building parameters requirements. All buildings have square footage and total construction costs, although the values vary widely among the three projects. The "Building Square Footage" ranges from 250,000 to 20,000 and "Total Building Cost" ranges from $38,000,000 to $4,500,000. These quantifiable values affect building costs and it is common practice to quote rough building estimates in terms of costs per square foot. "Cost per Square Foot" also meets all three of the parameters, however, it is comprised of the first two parameters and is therefore considered redundant.

“Number of Stories” and “Construction Time” are also quantifiable values that affect the cost of construction. The three projects range from one story to seven stories and the construction times ranges from 13 to 26 months.

The parameters “Building Use”, “Type of Structure, and “Special Features” are descriptive items that affect the cost of construction but are non-quantifiable. Even though all of these parameters affect construction energy use and should be recorded in the project database, only the quantifiable parameters are used in the analysis portions of this study.

Information from Contract Documents

The contract documents for the Jack E. Brown Chemical Engineering Building were studied to determine contract items that pertained directly to energy use during construction. A discussion of these items follows.

Temporary utilities: The contractor was responsible for the cost of all temporary utilities; this includes their installation, removal, and the cost of services. Per the contract, TAMU Physical Plant provided one service drop and one meter for that service drop, the contractor was required to provide all other materials and labor for the services. The contactor was also required to pay for any additional service drops and for a larger service if needed. There were four separate service drops and meters used for this project. The contractor was exempt from paying state and local sales taxes on utilities used for construction purposes given that this was a state project. Since TAMU was the service provider for the utility services, the rates for these services were fixed and part of the contract. However, if a contractor purchased utility services from a private provider, the costs would fluctuate according to the provider's contracts.

Temporary Heating and Ventilation: The contractor was required to provide temporary heating to the building not less than 7 days prior to the installation of drywall and was required to maintain the building temperature of at least 55°F. The contract also required the building temperature to be maintained at least 65°F for not less than 5 days prior to delivery of mill work and wood doors. The contractor was also required to provide ventilation to all areas to cure materials, control humidity, and prevent accumulations of dust, fumes, vapors and gas. Since millwork and drywall began in April and lasted through the summer, keeping minimum temperatures in the building would not require heating energy. However, for the College Station climate, humidity control can be more of a problem for construction occurring during spring and summer months, although it was not required for this project.

Security: The contractor was required to submit a security program and provide facilities to protect work, existing facilities, and owner's operations. These facilities included security lighting.

Field offices: The contractor was required to provide temporary field offices for their own purposes and separate offices for the Owner's Representative. Weather tight offices were required to have sufficient light, heating, air conditioning, and ventilation.

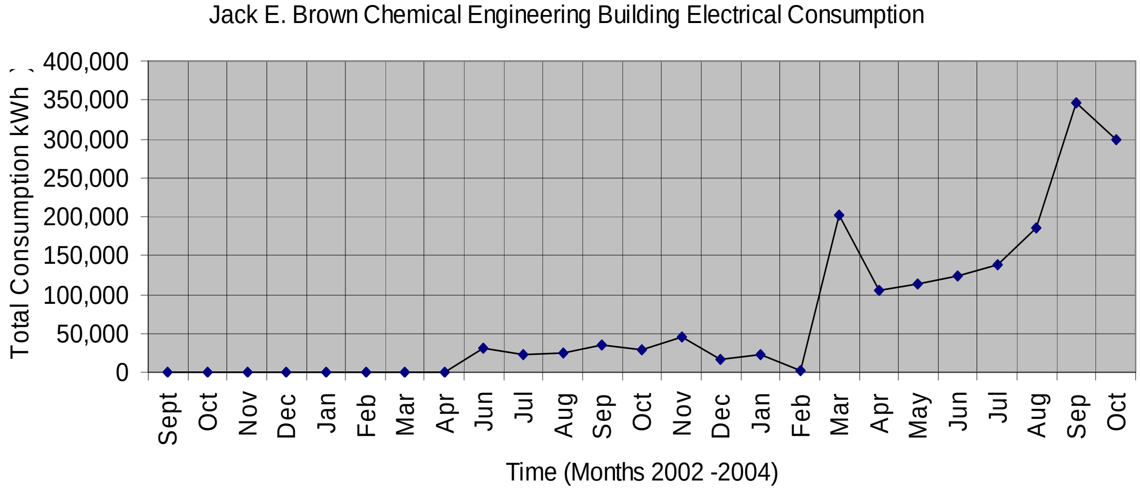
Electrical Energy Data

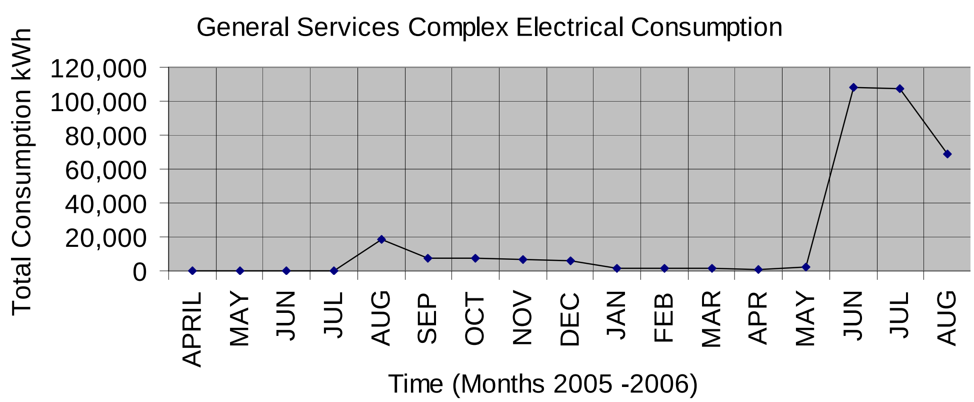
Utility companies maintained records of the amounts of electricity used for each project on a monthly basis. This information is public. Texas A&M University (TAMU) Physical Plant provides electricity to all projects on the College Station campus. The TAMU Physical Plant, who administers power distribution for these three projects, provided monthly cost and usage data for each of the service drops. Monthly electrical utility information was obtained for each building. Figure 1 shows their monthly utility consumption. It is important to note that while the timeline scale remains the same for each graph, the energy use scale is different.

Figure 1 also shows that at the beginning of the Chemical Engineering building project, the electrical energy consumption on site was low and appeared to be zero. The main use of electricity during this time was for service to the construction office trailers.

A sharp rise in the electrical consumption occurred in May when the building temporary power was installed for building lighting and air handling testing. Another sharp rise occurs near the completion of the building when the HVAC system was powered up to bring the building to a constant temperature during building commissioning and in preparation for building occupancy.

The electrical consumption for the Jack E. Brown Chemical Engineering building ranged from 44 kWh per month to 345,700 kWh per month.





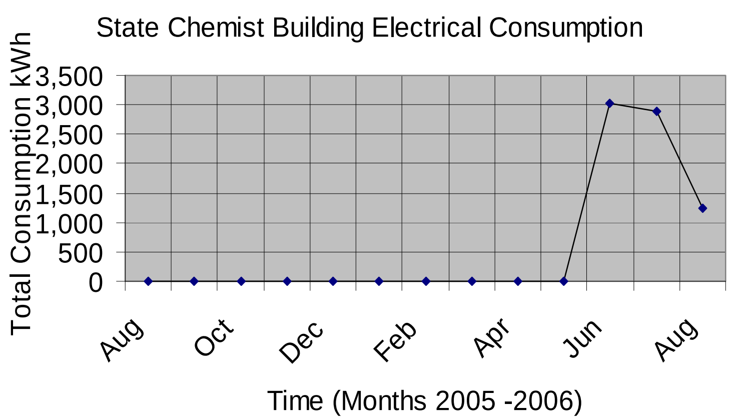


Figure 1. Comparisons of the Monthly Electrical Energy Consumption for Three Projects

Figure 1 also provides a graph of the Total Electrical Energy consumption on a time scale for the General Services Complex. Once again, it can be seen that in the beginning of the project electrical energy use from the construction trailers was low in comparison with the building energy use. The first spike in electrical use corresponded with the welding of the tilt up wall panels and turning on the security lighting. The second spike coincided with the building commissioning and preparation for building occupancy. For The General Services Complex it ranged from 33 kWh per month to 338,300 kWh per month.

The graph for the State Chemist Building presented in Figure 1 shows no electrical consumption until June. This site did not have construction trailers since it was located across the road from the General Services Complex and was built by the same contractor. Electrical power needed was provided by generators until temporary power was hooked up. Temporary power was not provided to the site until the building was ready for HVAC testing. The electrical consumption for the State Chemist building ranged from 0 kWh per month to 3,025 kWh per month.

Table 2 summarizes the average electrical consumption values broken down in terms of magnitude for these three projects and defines the general construction tasks corresponding to the time frame for each.

Table 2. Average Monthly Electrical Consumption as Defined by the Magnitude of the Values

Average Monthly Use (kWh) for:	Jack E. Brown Chemical Engineering	General Services Complex	State Chemist Building
Construction Trailers	130 kWh	53 kWh	------
Temporary Building Power	23,372 kWh	5,348 kWh	------
Building Commissioning	188,936 kWh	94,872 kWh	2,384 kWh
Total Project Electrical Usage	1,746,135 kWh	338,305 kWh	7,150 kWh

The average monthly trailer use for the Jack E. Brown Chemical Engineering building was 130 kWh; and 53 kWh for the General Services Complex. These values are low compared to the electrical consumption during building dry-in tasks and commissioning; 23,372 kWh and 188,936 kWh for the Jack E. Brown Chemical Engineering building; 5,348 kWh and 94,872 kWh for the General Services Complex; and 2,384 kWh for the State Chemist Building. Energy consumption for these three projects is broken down and discussed in detail later in this chapter.

Phases of Construction for Energy Studies

Breaking down each graph in Figure 1 according to the magnitude of the energy use and then comparing them to the construction tasks performed for that month, led to energy consumption trends. This information, combined with knowledge of construction, allowed the encapsulation of energy consumption into four phases of construction. The four construction phases for energy consumption identified are: 1) site clearing and preparation, 2) building structure, 3) interior finishes, and 4) commissioning.

For the purposes of energy study, the first construction phase, site clearing and preparation, begins at the beginning of the project and ends when major earth moving equipment is removed from the site. Energy consumption during this phase is mainly in the form of diesel used to power earth moving equipment. For some projects, this phase may be constructed under a separate contract.

The second construction phase, building structure, begins when construction trailers are installed or a temporary power is set up at the site and ends when a temporary power drop to the building is installed. Phase 2 includes foundation work and structural framing. There may be some overlap with phase 1 if construction trailers are installed early on the site or the project is performed in phases. An example would be large development projects such as strip malls or housing developments. There are several categories of energy use during this phase. One is to power the construction trailers. Another is to provide security and task lighting for the building as it is being constructed. Welding of structural members is another use of energy and is usually provided by a diesel operated welding machine, although some sites set a temporary utility pole to provide this power. Cranes to lift structural members are also a use of energy during this phase.

The third construction phase of energy use, interior finishes, begins with the installation and connection of a temporary power drop to the building and ends when permanent building power is connected to the utility service. A major consumption of electrical energy use during this phase is the mechanical controls testing and temperature and humidity control of the building during finishes and mill work. Flush-out of construction volatiles in the building may occur during phase 3 or 4. As discussed in the section "Information from Contract Documents**"** of this chapter, there are minimum temperature and humidity requirements that occur during this construction phase. This is important for properly curing finishes, woodwork, and flooring. Security and tasks lighting may now be provided by the permanent lighting fixtures of the building.

The fourth construction phase of energy use, commissioning, begins when permanent building power is connected by the utility provider and ends when the owner assumes responsibility for the cost of electricity usage, takes possession of the building, or when substantial completion is achieved. During this phase, the building mechanical systems are fully operational and commissioning of the building is performed.

Table 3 provides a summary of the construction energy phases described above.

Table 3. Summary of Construction Energy Phases

	Activities	Begins/ends	Energy Use	Comments
Phase 1	Site Clearing & prep	Beginning of the project Ends when Earthmoving equipment is removed	Mainly diesel for earth moving equipment and generators	Phase 1 may be under a separate contract Phase I & 2 may overlap
Phase 2	Foundation and building frame work, Rough out of mechanical, electrical, plumbing	Begins when construction trailers are installed on the site or when temporary power is established	Electrical power for construction trailers, security & task lighting, Diesel generators for welding, other tasks	Electrical Energy use is low and hard to allocate to individual tasks
Phase 3	Interior and exterior finishes work, mill work, install fixtures	Temporary power to building is connected	Electricity; mechanical controls testing, temperature & humidity control of the building	Temperature and humidity requirements are less than at occupancy levels
Phase 4	Commissioning, punch work, stabilize the humidity and temperature, flush out	Permanent power to building is installed, Ends when owner takes possession	Electricity; maintain temperature and Humidity at occupancy levels	Electrical Energy use is at it's highest during this phase

Construction Phases for the Jack E Brown Chemical Engineering Building

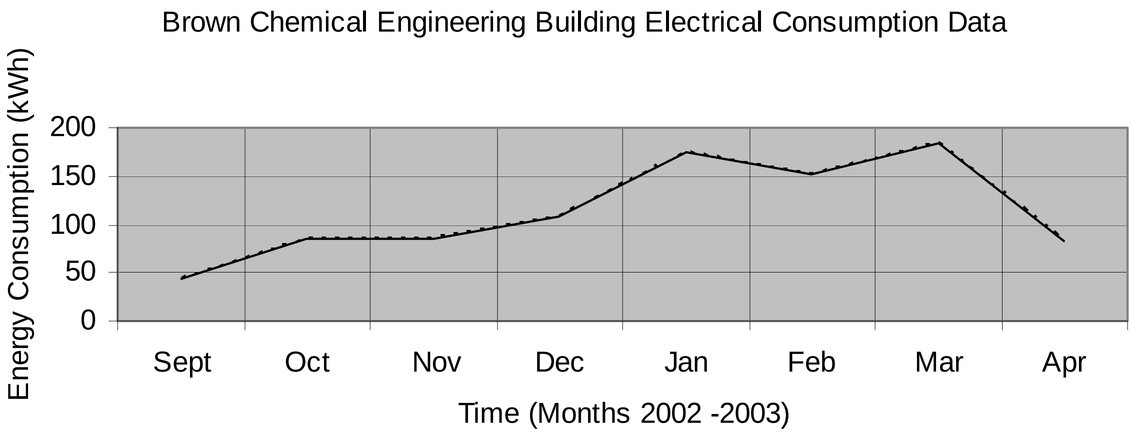
The electrical consumption graph for the Jack E. Brown Chemical Engineering Building shown in Figure 1 can be broken down according to the phases for energy consumption and correlated with the major tasks of work from the project schedule. In this paper the term correlation refers to Merriam

Webster's Dictionary (1988) meaning; a parallel relationship existing between phenomenon; not the statistical meaning referring to a correlation coefficient. The results of these correlations are discussed further in the following sections.

Construction Energy Phases 1 and 2

A separate contract was issued to install service utilities and upgrade existing infrastructure required for the building services. The construction energy phase 1 was encompassed in this separate contract. Therefore no site preparation was required at the beginning of the building project in order to install the construction trailers. The second phase began on the first day of the contract "notice to proceed".

Figure 2 shows the monthly utility consumption over the 8 months of the second phase and correlates it on the time line with major construction tasks obtained from the project schedule.



Layout & Temp Structures. **Temp Electrical**	Drill Piers & Perimeter Wall	Erect Tower Crane, Level 1 Pours	Level 2&3 Pours	Level 4-6 Pours, Structural Steel, MEP	Level 7 Pours	Roof Pours, Duct Work, Mason & Dry Wall	Finish Pours Set up Temp Material Hoist
Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr

Figure 2. Phase 2 Monthly Utility Consumption for the JEB Chemical Engineering Building

The construction tasks for phase two used little electrical energy; with construction trailers the main electrical energy consumer. Since the construction trailers were powered by a separate electrical meter, their consumption for the duration of the project was known. The Jack E. Brown Chemical Engineering Building had both a tower crane for building the structure and a materials hoist for bringing materials to all floors after the structure was complete.

Figure 3 shows the construction trailer consumption throughout the project. The electrical consumption followed a seasonal cycle with greater electrical use during the colder and hotter months. The average monthly electrical consumption for the trailers was 130 kWh. This value appeared to be low considering that four air-conditioned and heated trailers were connected to this meter.

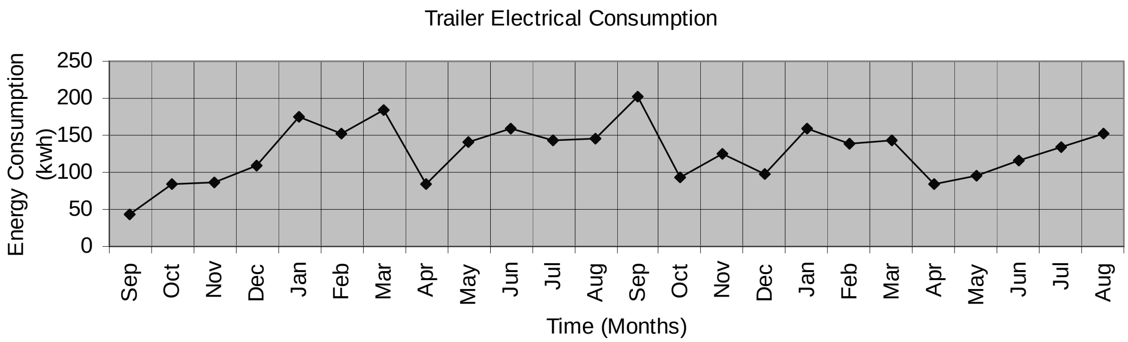


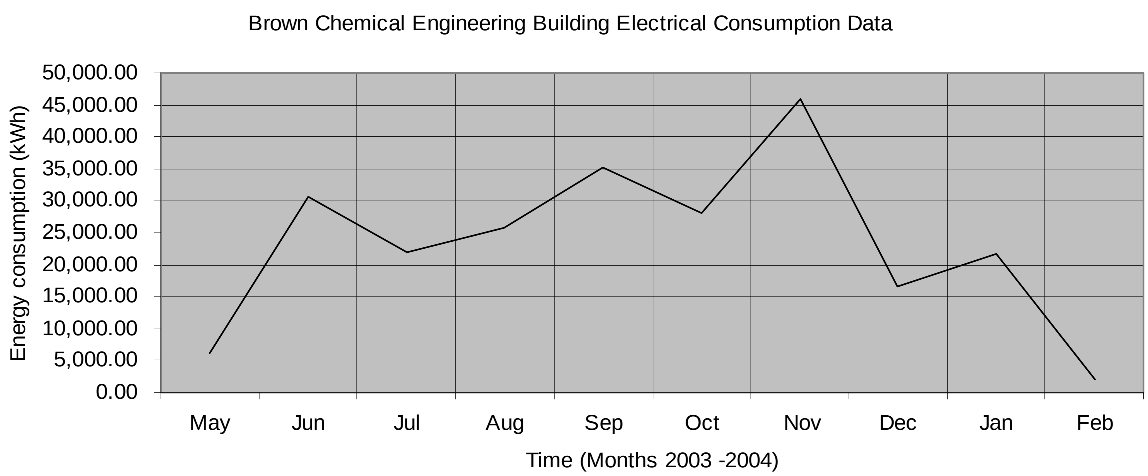
Figure 3. Construction Trailer Electrical Consumption for the JEB Chemical Engineering Building

The total cost of electricity for Phase two was $88. The total cost for the construction trailer electricity was $290 over the entire two year project. Electricity for this project was provided by Texas A&M University who set their own rates and the rates were fixed in the construction contract.

Construction Energy Phase 3

Phase three for this project was marked by the power up of the temporary building meters and continued for 10 months. Figure 3 presents the monthly utility consumption correlated with construction tasks for phase 3. The average monthly electrical consumption for this phase was 23,372 kWh. This included both the building electrical use and the trailer electrical consumption. It should be noted that the building consumption was two magnitudes higher than the trailer consumption and the vertical axis scales for

Figure 2 and Figure 4 reflected this magnitude difference. The average monthly cost for phase 3 was $2,220 and the total phase 3 electrical cost was $22,204.



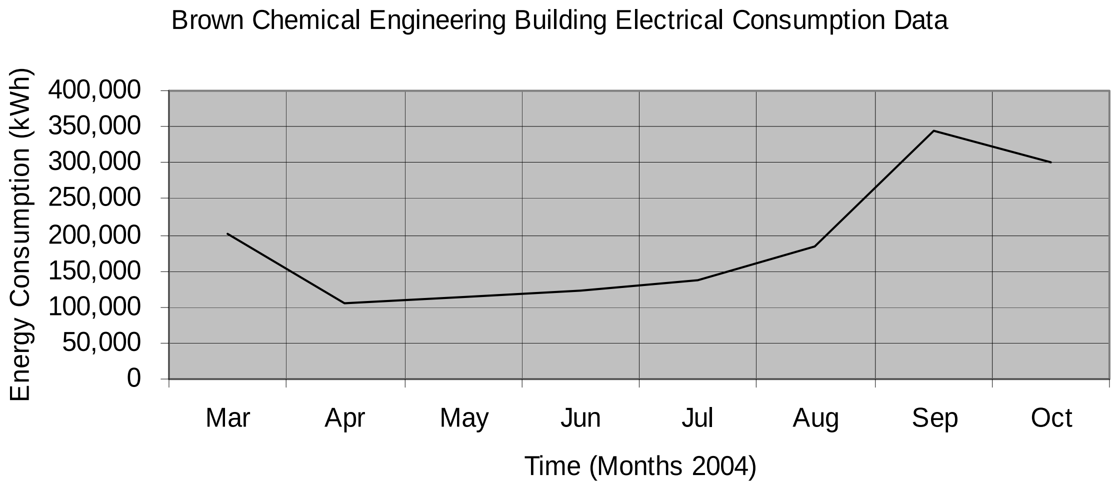
Metal Stairs, Curtain Walls, Piping	**Test Air Handle** for Leakage, Damp Proofing and Flashing	Install Elevators	Continuation of all Work & Matrix Steel	Remove Tower Crane, Install Drywall; Tape & Float	Stairs, Electrical, Lab Racks	Remove Material Hoist, Ceramic Tile	Case Work, Electrical Fixtures	Masonry, Remove Scaffold	**Mech Controls Testing,** Flooring & Millwork
May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb

Figure 4. Phase 3 Monthly Utility Consumption for the JEB Chemical Engineering Building

Construction Energy Phase 4

Phase 4 began with the switching from temporary building power to permanent service and ended when the owner took possession of the building. Phase 4 lasted for 8 months. Building commissioning began in September and the temperature and humidity were brought up to occupancy levels.

Figure 5 presents the monthly utility consumption correlated with construction tasks for phase 4. The average monthly electrical consumption for this phase was 188,936 kWh. This includes both the building electrical use and the trailer electrical consumption. It should be noted that the building consumption for phase 4 was almost one magnitude higher than the phase 3 consumption and the vertical axis scales for Figure 4 and Figure 5 reflect this magnitude difference. The average monthly cost for phase 4 was $14,043 and the total phase 4 electrical cost was $112,344.



Fire Proofing, Hang Entry Doors	Millwork, Plumbing Fixtures, Terrazzo	Drywall, Electrical, Fixtures, Terrazzo	Drywall, Electrical, Fixtures, Terrazzo	Roof, Sprinkler Punch Work, P-lam Doors & Hdwr	Removed Trailers	Punch Work, Landscaping	**Owner Move In**
Mar	Apr	May	Jun	Jul	Aug	Sep	Oct

Figure 5. Phase 4 Monthly Utility Consumption for the JEB Chemical Engineering Building

In summary, Phase 4 for the Jack E Brown Chemical Engineering Building consumed the most electrical energy with an average monthly cost of \$14,043 and a total cost of \$112,344. The total electrical cost for this project was \$134,636. This is 0.35% of the total project cost. While this may appear to be almost insignificant when compared with the total cost, a reduction in these costs could significantly increase profit.

Construction Energy Phases for General Services Complex

Phase 1 for the General Services Complex occurred over less than two months. The first task was to prepare a site for the construction trailers and a gravel parking lot for employee vehicles and initial staging of materials. Construction trailers were installed during the first month and temporary power connected. There was some overlap of phases 1 and 2. The General Services Complex utilized a track crane to hoist up steel framing.

Figure 6 shows the electrical consumption during phases 1 and 2. The main consumer of electrical power is the construction trailers. The average monthly use was 53 kWh. This number also seems low considering that six trailers were powered through this meter. The total cost of electricity for phases 1 and 2 was $22.

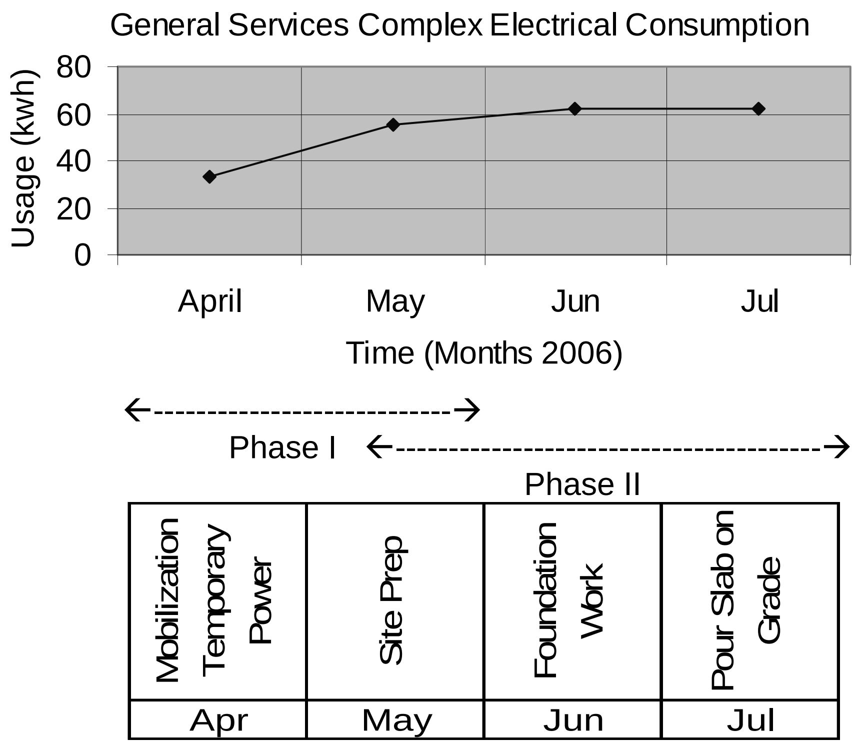
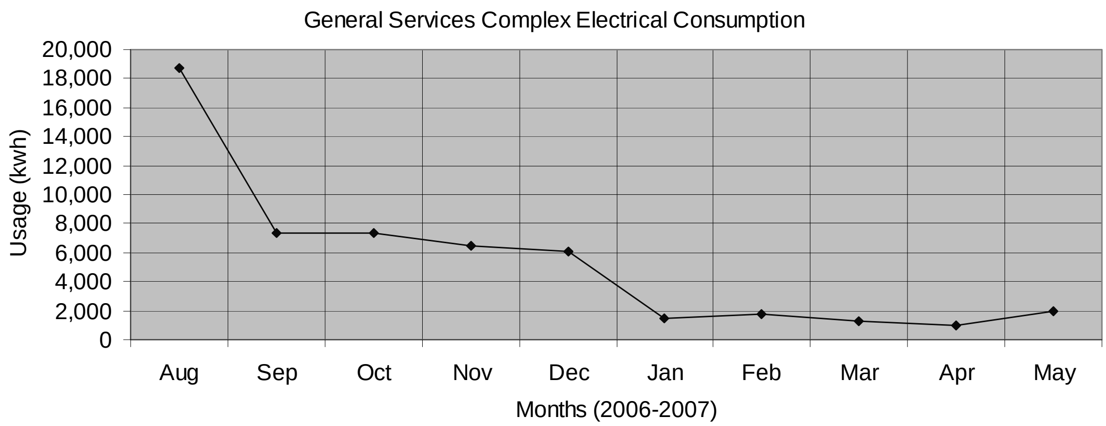


Figure 6. Phase 1 and 2 Monthly Utility Consumption for the General Services Complex

Temporary power to the building was established in August marking the beginning of phase 3.

Figure 7 shows the electrical consumption for the 8 months of phase 3 along with the major construction tasks performed. A spike of electrical usage occurred in August when the tilt-up walls were installed. Framing has a higher electrical usage than the interior finishing. This is a reverse of the pattern from the Brown Chemical Engineering Building mainly due to the type of building structure. The Brown Chemical Engineering Building was mainly a cast-in-place concrete structure while the General Services Complex was tilt-up walls with structural steel framing. The average electrical consumption for phase 3 was 5,348 kWh. The average monthly cost for phase 3 was $547 and the total cost of electricity for phase 3 was $5,468.

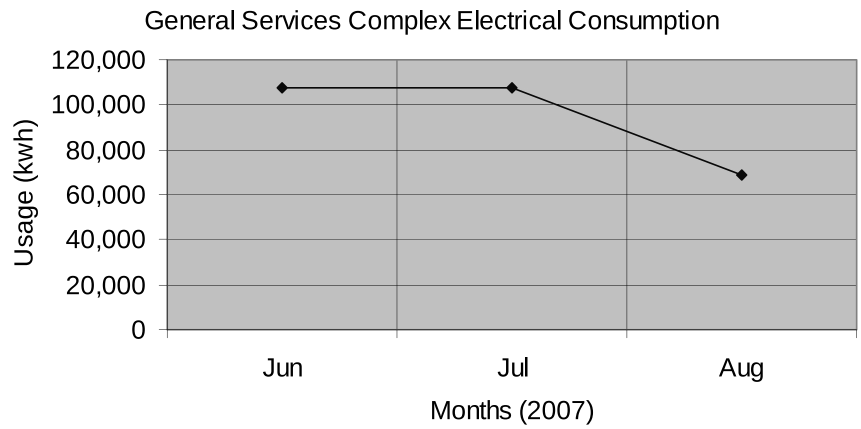


Tiltup Wall Panels Security lighting	Structural Steel	Second & Third Floor Deck	Mechanical Equipment	Finish out Shell	Interior Finishes	Tape & Float	Ceilings	Mill Work	Flooring Finish Area 1
Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May

Figure 7. Phase 3 Monthly Utility Consumption for the General Services Complex

Phase 4 began in June with the turn on of the buildings permanent power and continued for three months as shown in

Figure 8. The average electrical consumption for phase 4 was 94,872 kWh. The average monthly cost for phase 4 was $10,056 and the total phase 4 electrical cost was $30,169.



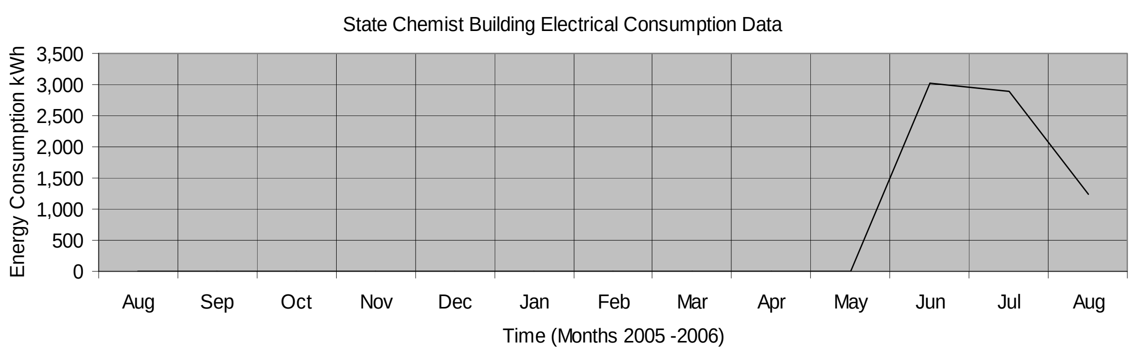
Finish Area 2 Commissioning HVAC	Finish Area 3	Finish Area 4 Substantial Completion
Jun	Jul	Aug

Figure 8. Phase 4 Monthly Utility Consumption for the General Services Complex

In summary phase 4 for General Services Complex consumed the most electrical energy with an average monthly cost of $10,056 and a total cost of $30,169. The total electrical cost for this project was $35,659. This is 0.17% of the total project cost.

Construction Energy Phases for State Chemist Laboratory

Figure 9 gives the electrical consumption for the State Chemist Building correlated with the major tasks of construction. Note there was no electrical consumption until June. As discussed earlier, the General Services Complex construction offices were utilized for this site, therefore there was no trailer electrical consumption. Temporary power was not provided to the site until the building was ready for HVAC testing in May. Notice that the mechanical, electrical, and plumbing (MEP) tasks began in March, but the electrical was not provided until May.



Mobilization	Earth Work	Site Utilities	Foundations	Slab on Grade	Tilt Wall Panels Structural Steel	Roof Exterior Wall	MEP Equipment	Interior Finishes	Ceiling & Ceramic Tile	Fixtures Millwork	Flooring	Final Completion
Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug

Figure 9. Construction Electrical Energy for State Chemist Laboratory

Costs of Electrical Energy

Construction costs are of primary concern to contractors, designers, and building owners. The cost of energy is also much easier to comprehend than Kilowatt-hours used.

Table 4 gives the average monthly cost of electricity for each phase and the total electrical cost for the building projects. Table 5 presents the total electricity cost during each of the project phases, the total cost for the building projects, and the percentage of the building construction costs that relates to electricity costs during construction.

Table 4. Monthly Electricity Cost during Project Phases of These Projects

Average Monthly Cost ($) for:	Jack E. Brown Chemical Engineering	General Services Complex	State Chemist Building
Construction Trailers	$11	$6	------
Temporary Building Power	$2,678	$547	------
Building Commissioning	$14,043	$10,056	$253
Total Project Electrical Cost	$134,636	$35,659	$758

Table 5. Total Electricity Costs during Project Phases of These Projects

Total Costs ($) for:	Jack E. Brown Chemical Engineering	General Services Complex	State Chemist Building
Construction Trailers	$88	$22	------
Temporary Building Power	$22,204	$5,468	------
Building Commissioning	$112,344	$30,169	$758
Total Project Electrical Cost	$134,636	$35,659	$758
Percentage of total Project cost	0.35%	0.17%	0.02%

While these percentages may seem small, the total electrical utility costs are comparable with many items of work. Table 6 lists the scheduled values for a few items of work from an approved invoice for the JEB Chemical Engineering Building. The total project electrical cost is listed as the first item. This is not an exhaustive list, but it is provided to help the reader understand the magnitude of this utility cost.

Table 6. Work Items Comparable to the Electrical Utility Cost for JEB Chemical Engineering Building

Work Item Description	Cost
Total Project Electrical Power Cost	$134,636
Tower crane (materials only)	$140,011
Safety precautions (m&l)*	$88,555
Drill Piers (m&l)*	$129,209
Drilled Piers Reinforcing (m&l)*	$55,827
Drill Piers Concrete (m&l)*	$135,850
Columns for all 7 levels (m&l)*	$113,360
Millwork (total project (m&l)*)	$198,273
Wood & steel doors & frames (m&l)*	$99,730
Average drywall per floor (m&l)*	$158,340
Terrazzo (m&l)*	$177,200
Carpet (m&l)*	$153,167
Above floor sanitary plumbing (m&l)*	$132,300
Domestic water plumbing (m&l)*	$186,600
*(material & labor)	

Electrical Building Usage and Building Parameters

An evaluation of the data presented in Table 4 and Table 5 appears to lead to inconclusive results when one only looks at the dollar values. Electrical usage for each phase of the project and for the different projects studied varied considerably across the projects. For this reason the use of building parameters is important. Dividing the values in the previous tables by the quantitative building parameters may normalize the results for the size and cost of the building.

The first parameter is the square footage of building area. This value is often used to give a rough estimate of building construction cost since contractors know how much it costs to build similar types of buildings. Table 7 gives the average monthly use divided by the floor area.

Table 7. Average Monthly Electrical Use per Building Floor Area

Average Monthly Use per floor area (kWh/sf) for:	Jack E. Brown Chemical Engineering	General Services Complex	State Chemist Building
Construction Trailers	0.0006	0.0003	------
Temporary Building Power	0.1140	0.0267	------
Building Commissioning	0.9216	0.4744	0.1192
Total Project Electrical Usage	8.5177	1.6915	0.3575

Table 8 gives the total usage for each phase divided by the floor area. Since these buildings are not similar in complexity, structure, or building size the costs per floor area cannot be expected to be the same.

Table 8. Total Electrical Use per Building Floor Area

Total Use per floor area (kWh/sf) for:	Jack E. Brown Chemical Engineering	General Services Complex	State Chemist Building
Construction Trailers	0.0045	0.0011	------
Temporary Building Power	1.1401	0.2674	------
Building Commissioning	7.3731	1.4231	0.3575
Total Project Electrical Usage	8.5177	1.6915	0.3575

Table 9 and Table 10 compare the monthly average and total costs of electricity with the total building costs. Once again the normalized values are not comparable across the projects. Building construction is a complex project and therefore, energy use cannot be defined by simple variables such as cost and floor area. A more complex analysis needs to be made to gain meaningful results.

Table 9. Average Monthly Electrical Power Cost per $Million Construction Costs ($/$)

Average Monthly Cost per $million Construction Cost ($/$) for:	Jack E. Brown Chemical Engineering	General Services Complex	State Chemist Building
Construction Trailers	0.29	0.26	------
Temporary Building Power	70	26	------
Building Commissioning	370	479	56
Total Project Electrical Cost	3543	1698	168

Table 10. Total Electrical Power Costs per $Million Construction Cost ($/$)

Total Costs per $million Construction Cost ($/$) for:	Jack E. Brown Chemical Engineering	General Services Complex	State Chemist Building
Construction Trailers	2.31	1.05	------
Temporary Building Power	584	260	------
Building Commissioning	2,956	1,437	168
Total Project Electrical Cost	3,543	1,698	168

The electrical consumptions for individual construction tasks cannot be determined from the data as collected on these projects. Therefore a more informative method of analyzing electrical use would be provided by recording and studying the daily consumption from jobsite service drops. Daily records of the electrical use from the onsite meters could be correlated with the daily tasks. However, the decision to record this data must be made during pre-construction project planning and would most likely become a part of cost control data collection. This information could be gathered on the jobsite and entered into the program developed in Phase III for further analysis.

Other Energy Types

There were no records of gasoline and diesel fuel usage on the three construction projects studied. These costs were incorporated into the equipment use costs. Contractors and subcontractors typically provide fuel storage tanks on site or bring a fuel tank on the back of a pickup truck for dispensing to the equipment on site. The fuel use could be determined on the jobsite by fueling up each piece of equipment at the end of each day and recording the amount of fuel dispensed on a daily basis. Another project was studied to obtain information about diesel fuel consumption. This is discussed further in Chapter IX, Site Visits to Take Data Measurements.

Phase II – Results: Determine the Organization to Facilitate Meaningful Data Collection

The information gathered from Phase I was analyzed to determine the best organization to facilitate meaningful data collection and meaningful results. Information collected for the energy study came in two forms. The first was numerical data providing the amount of electricity, gasoline, and diesel used in the project. The second was the descriptive information for the task that the energy was used. These tasks also occurred over a period of time. The time frame was relevant because the longer a task takes; the more costly the task is in terms of energy use. The time frame of a task can be determined from the project schedule or from daily inspection of the job site.

Tasks could be organized by time frame as defined in the project schedule. However, since the project schedule is not the same for all projects, a more universal organization of task, such as the CSI Master Format (Fisk and Reynolds 2005) will lead to more standardized results. Using this format, the program developed here will meet the parameters identified to record, organize, and analysis energy data. The program will organize construction tasks by CSI format, allowing for daily entries of multiple tasks and correlate this with the daily energy use of electricity, gasoline, and diesel fuels. This quantification of energy use can then be grouped according to a time line, energy tasks, or fuel type. The CSI Format is also used by most contractors for cost, materials, and schedule control.

In a future project, data from many building sites can then be gathered and factored according to building parameters to give a project comparable basis for evaluation.

Phase III – Results: Develop a Guide for Future Data Collection and Analysis

The data accumulated in Phase II were used as a basis for the Phase III development of a two part data collection and analysis guide: 1) a Visual Basic

Program utilizing a database for electronic storage and evaluation of the data gathered, and 2) instructions for using the Visual Basic Program. The compiled EDA Program accompanies this dissertation and is available for downloading. The instructions, titled “Users Guide to the Energy Data Analysis Program” are presented in Appendix B. This program allows for the recording of energy data during a construction project. This data is organized by CSI Division Levels as discussed in the procedure for Phase III. Chapter X, Methodology for Data Collection and Recording with Respect to the Data Analysis Program, discusses these results in detail.

CHAPTER IX

SITE VISITS TO TAKE DATA MEASUREMENTS AND TEST DATA ANALYSIS PROGRAM

In order to test the comprehensiveness and flexibility of the methodology for collecting and recording data developed in the EDA Program; three sites were visited and energy data recorded. These sites are: 1) Project A, a new strip mall development of a 250 acre site, 2) Project B, an addition to a church, and 3) Project C, a retail store in a strip shopping center. The following is a detailed description of the information obtained and how this information should be formatted for entry into the EDA Program.

Project A: Retail Development

Project A is the new development of a 250 acre site for retail development. The developer is also the general contractor. The finished project includes roadways, parking lots, and nine commercial building areas. The total building footprint area is 383,942 square feet. This project began construction in June 2007 and is expected to be completed by August 2008. On the days that the project was observed, the existing vegetation has been removed and earth work had commenced.

The general contractor’s construction trailer was delivered and set up on July 11. It was powered by a diesel generator until July 25 at which time the electrical service drop was heated up. A photograph of the construction trailer being powered by the generator is presented in Figure 10. Note the service drop has been installed and is ready to be heated up pending city inspection.

Figure 10. Photograph of the Construction Trailer, Service Drop and Generator

The generator was refueled every day and consumed an average of 20 gallons of fuel per day. This is a total of 280 gallons of diesel at $2.35 per gallon giving a total cost of $658 for diesel over the two weeks electrical service was not available. It should be noted that over the following five months, diesel costs have increased to $3.38 per gallon. This is a good example of how volatile energy costs can be and how important accurate estimates can be to profitability. Table 11 shows the trailer generator data to be entered into the Energy Data Analysis Program. This data was entered into the program and successfully saved.

Table 11. Data Entry for Trailer Generator: Project A

Level 1	Level 2	Level 3	Level 4	CSI Division Title	Work Description	Begin Date	End Date	Hours	Gallons of Diesel	Price per Gal Diesel
01	52	13	0	Field Offices and Sheds	Generator for construction trailer	7/11/07	7/25/07	112	280	2.35

The subcontract for the utilities and earth work portion of this project is for $2.5 million. This is a major earth moving project that incorporates heavy earth moving equipment predominately manufactured by Caterpillar. Table 12. Equipment Diesel Use, lists the equipment, the gallons per hour of diesel consumed by each piece of equipment, and the approximate hours of equipment usage for two days of observation.

Table 12. Equipment Diesel Use

Quantity	Description	Gal/hr	Hours in use 7/23/07	Hours in use 7/24/07
1	Cat V10 Dozer	15	8	8
1	Cat D6 Dozer	8	8	8
2	Cat D8 Dozer	10	8	8
4	Cat 631 Scrapers	10	4	4
3	Cat 623 Scrapers	10	5	5
1	Cat 825 Compactor	12	8	8
1	Disk tractor	8	8	8
1	Water Truck	8	0	0
1	1200 gal Fuel Truck	5	4	4
2	Lube trucks	5	4	4

The large amount of equipment is serviced daily using two lube trucks and a 1200 gallon fuel tank truck also listed in the table. The lube trucks arrive on the site at 6am to service the equipment before the workers begin at 7am. Figure 11 shows the fuel truck and one of the lube trucks. Figure 12 shows the lube truck servicing the equipment at the beginning of the work day.

Figure 11. Lube and Fuel Trucks


Figure 12. Equipment being Serviced on the Job Site

As shown in Table 12. Equipment Diesel Use, the dozers are in continual use. The scrapers however are not. A scraper requires a dozer to push it. According to the contractor the scrapers are more prone to breakdowns and are a less expensive piece of equipment than a dozer, so more scrapers than can be used at one time are kept on the site. The disk tracker is in constant use disking up tree roots. Because of recent rains the water truck has not been needed. Totaling the products of the equipment quantity times the numbers of hours used times the quantity of gallons per hour gives 874 gallons of diesel fuel consumed per day for each of the two days observation. The current cost of off-road diesel is $2.35 per gallon. The price of diesel for construction use is less than the price of diesel at a gasoline station because fuel used in equipment operated solely on private land has a different tax base than fuel consumed by vehicles using public roads. The energy information could be entered into the Data Analysis program in two different ways. Table 13. Data Entry for Earthwork, shows these two different entries. The CSI division levels and title are "31 14 00 Earth Stripping and Stockpiling." The description of work is a summary of Table 12. Since the equipment use was the same for both days, the information can be entered in one row as shown on the first data line or with two row entries as shown on the last two data lines. The begin and end dates are the two days that data was collected for the one row entry method, and are the same date respectively for the two row data entry method since the data is for one day only. The "Hours" are the work hours per day performed; a total of 16 hours for both days or 8 hours each day. The "Gallons of Diesel" entry is the total for both days in the one row method or the total for each day in the two row method. The "Price per Diesel" of $2.35 is the same for all rows and is entered without the "$" sign.

Table 13. Data Entry for Earthwork Performed at Project A

Level 1	Level 2	Level 3	Level 4	CSI Division Title	Work Description	Begin Date	End Date	Hours	Gallons of Diesel	Price per Gal Diesel
31	14	00	00	Earth Stripping and Stockpiling	4 dozers, 7 scrapers, compactor, disk tractor, 3 lube and fuel trucks	7/23/2007	7/24/2007	16	1748	2.35
or										
31	14	00	00	Earth Stripping and Stockpiling	4 dozers, 7 scrapers, compactor, disk tractor, 3 lube and fuel trucks	7/23/2007	7/23/2007	8	874	2.35
31	14	00	00	Earth Stripping and Stockpiling	4 dozers, 7 scrapers, compactor, disk tractor, 3 lube and fuel trucks	7/24/2007	7/24/2007	8	874	2.35

Table 13 shows the diesel consumption data to be entered into the Energy Data Analysis Program. This data was entered into the program and successfully saved. The program automatically computed the total cost of diesel. For these entries it was $2,543.90 a day.

This data is not completely accurate in that it assumes that the equipment is consuming diesel fuel at a constant rate during operation. A more accurate method of determining the diesel use would be to fill the fuel truck at the end of the work day and record the actual fuel used for that day. For this project the fuel truck is filled as needed which may be approximately twice every 3 days; more or less depending on the equipment used and hours of operation. It is estimated that this level of diesel consumption will occur for approximately 70 days. This gives an estimated cost of diesel of $140,000 or 5.7% of the total cost of the construction subcontract. This warrants a more detailed study of diesel use in Phase 1.

Project B: Church Addition

The 24,000 square foot church addition consists of a sanctuary, offices, restrooms, and eight class rooms. At the time of the site visit the steel structure was complete and the roof installed. No exterior work was being performed because of rain. The inside work consisted of installation of HVAC ductwork, electrical conduit, window frames and sheetrock. The sanctuary ceiling slopes to a height of 16' and the workers were using battery powered scissor lifts to reach the ceiling. Six scissor lifts were on the job site and four were in continuous use. The scissor lifts were plugged in at night to recharge their batteries. Eight - 60 watt incandescent bulbs provided temporary lighting to the work areas in the smaller rooms. Daylight through large window openings in the sanctuary provided adequate lighting to this work area. Various saws and electric screw guns were being used.

Electrical power to the construction site was tapped off of the existing service to the existing building. There was no separate meter and the owner (church) was paying the electrical bill for the construction. A new service will be installed for the new building and when the new service is completed the contractor will pay the utility bill until the building is turned over to the owner. The building service will be connected to the utility service provider when all electrical panels inside the building have been completed and inspected. At the time of the site visit no electrical panels had been installed. Figure 13 is a photograph of the service tap as seen through the metal wall framing of the building under construction. Two service lines extend from the grey service box. One of the service lines is located in the conduit that goes overhead to service the construction trailer; the other travels down from the box then underground to a panel inside the building under construction. Figure 14 shows the service panel inside the building under construction with 8 ground fault interrupter outlets and the extension cords that provide the electricity to the various construction tasks.

Figure 13. Electrical Service to the Construction Trailer and the Building under Construction for Project B

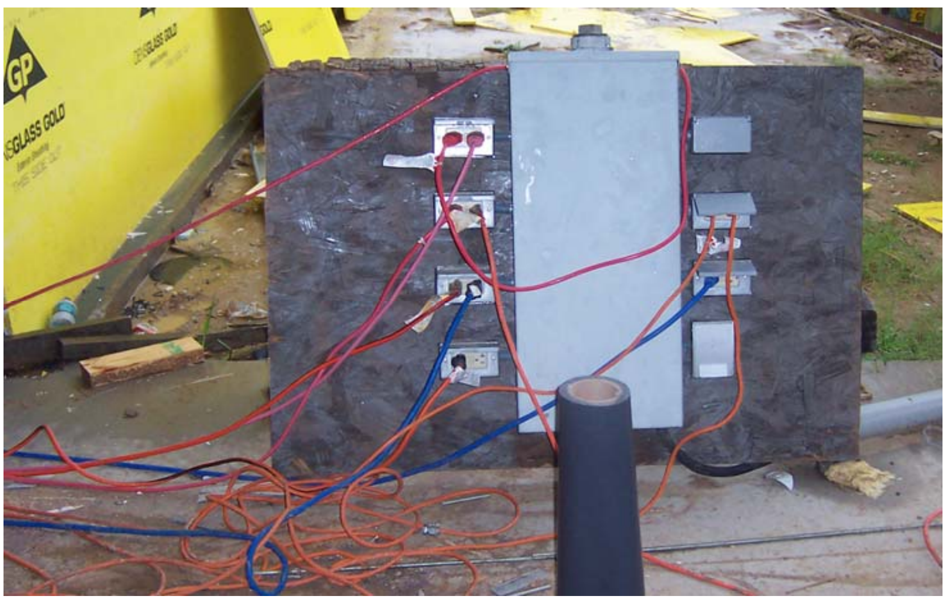


Figure 14. Photograph Showing Service Outlets for Project B Constuction Tasks

In this configuration, electrical energy consumption cannot be measured. Church utility bills will show the church use as well as the construction use since they are both measured with the same meter. To obtain meaningful information, two electrical meters should be installed; one in the service line to the trailer to determine the electrical energy consumed by the construction trailer; the other in the service line to the construction area. This will separate the trailer usage from the building construction usage, but not divide the building construction usage into individual work tasks. In order to determine the usage of individual work tasks a plug-in meter can be placed between the ground fault interrupter on the service panel and the extension cord. The electrical use for each construction task can be determined by tracking the extension cord that services it and recording the daily usage.

Project C: Construction of a Retail Store in a Strip Shopping Mall

The third site studied was the construction of a retail store in a strip shopping mall. At this site, buildings are built as they are leased so that construction takes place next to a new business. All the buildings in this shopping strip share adjoining walls. The buildings are tilt up concrete with 18 gauge metal studs as interior wall dividers.

One meter provided power to the construction trailer and a separate meter provided electricity to the retail store and adjacent buildings under construction. The meter is located outside the buildings on a transformer box. Electricity is brought through an underground conduit to the building service panels located in the second floor building equipment room. A flexible electrical cable delivers the electrical power to a construction service panel on the first floor of the building. Figure 15 is a photograph of the permanent service panels installed in a second story area at the back of the store to service the completed store. A heavy duty electrical cable exits the center panel to service the construction panel on the first floor. In Figure 15 this flexible conduit can be seen exiting the bottom of the service panel, coiling on the floor, and then exiting through the wall.

Figure 15. Electrical Panel Installation for Project C

Meter readings were taken twice a day and are shown in Table 14. Readings were taken for the electrical usage for the building construction power and for the construction trailer. Table 14 also gives the daily electrical consumption for each meter and a brief description of the work in progress. Readings were not taken at the same time every day because access to the meters was often blocked by construction equipment and work in progress.

Table 14. Three Day Electrical Consumption for Project C

Date	Time	Building kWh Reading	kWh Used	Trailer kWh Reading	kWh Used	Day of Week	Work description
7/27/07	9:48 am	5	-----	4755	-----	Friday	Paint Ceiling, install electrical panels, install restroom fixtures
7/27/07	7:30 pm	6	1	4767	12	Friday	No work at night, electrical lifts recharged
7/28/07	10:50 am	7	1	4780	13	Saturday	No work, electrical lifts remained plugged in
7/28/07	8:00 pm	8	1	4792	12	Saturday	No work at night
7/29/07	10:00 am	10	2	4804	12	Sunday	Hang aluminum door frames and Aluminum Awning frames
7/29/07	7:00 pm	11	1	4816	12	Sunday	No work at night, electrical lifts recharged
7/30/07	7:00 am	12	1	4828	12	Monday	Fascia Brick work, continue electrical, continue installing restroom fixtures
7/30/07	8:00 pm	13	1	4843	15	Monday	No work at night, electrical lifts recharged

Figure 16 shows a photograph of the front of the construction service panel located on the first floor. The electrical cable supplying power runs across the floor and into the left side of the panel. Yellow extension cords exit the top of the panel to provide temporary lighting in the smaller rooms along the back of the building. Other extension cords run along the floor to provide electricity to other construction operations.

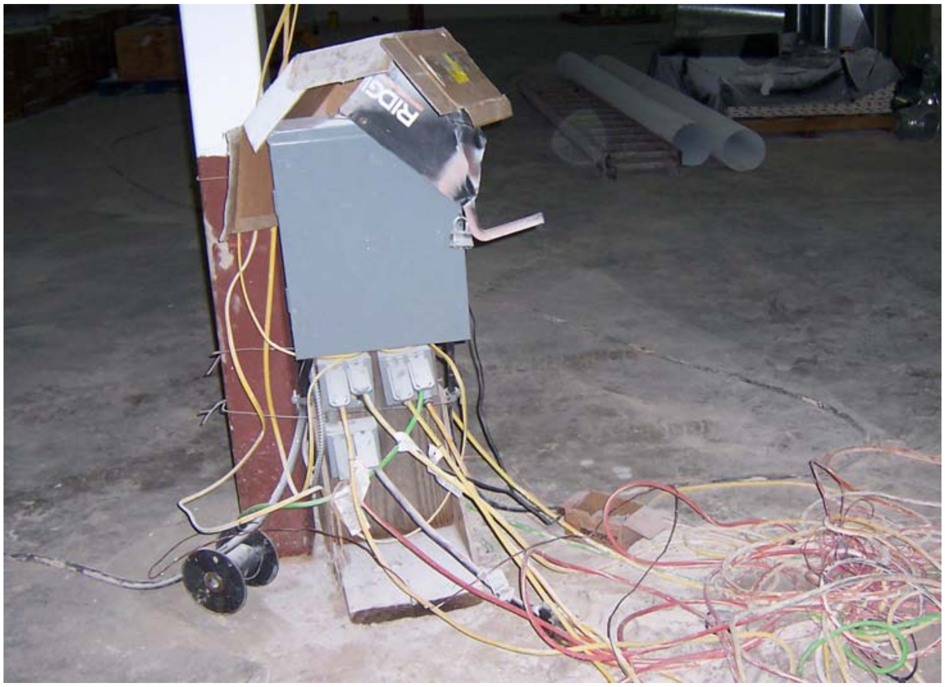


Figure 16. Construction Service Panel

At the time of the first site visit, the interior walls were being taped and floated. The exposed joist ceiling was being spray painted, the HVAC duct work was being installed and the restroom fixtures were being installed. The store has 16 foot ceilings that are reached using scissor lifts. Ten scissor lifts were being used in this building while two more were being used in the adjacent buildings. These scissor lifts are electric powered and are plugged into the construction service panel at night to recharge. Figure 17 shows the scissor lifts battery being recharged during the night.

Figure 17. Charging Scissor Lift Batteries Overnight

Another nightly use of electricity is security lighting. The light provided for the daily work tasks remained on during the night. There are two types of lighting provided. Eight metal halide lights are connected to the permanent lighting wiring in the ceiling of the main room. In the smaller rooms six- 60 watt incandescent lights provide temporary lighting.

As shown in Table 14, meter readings were obtained twice a day to obtain the difference between active construction consumption during the day and passive lighting and scissor lift charging at night. The meter readings show an average of one kWh per twelve hour period. This is inconsistent with the expected electrical consumption. Six-60 watt bulbs lit for 12 hours should require 4.32 kWh of power. Metal halide lights used in construction consume 1000 watts of power. Over a 12 hour period the eight metal halide lights should have consumed 96 kWh of power. The total power consumption for security lighting over a 12 hour period should be approximately 100 kWh. Therefore it can be concluded that this meter was not functioning properly.

Data Entry Example

For the purpose of providing a data entry example estimated values will be used. Three separate tasks were performed on 7/27/07: Painting, Electrical Cabinets and Enclosures, and Commercial Plumbing Fixtures. It is impossible to know exactly how much of the daily electrical consumption should be allocated to each task since they were not measured separately. Therefore assumptions should be made knowing the methods used to perform each task and the time taken to perform each task. The daily use can then be divided proportionally among the daily tasks. For example if the meter reading value of 1 kWh per work day were correct this value might be divided among the three tasks as follows: 0.25kWh for plumbing, 0.25 kWh for electrical and 0.5 for painting. Painting is assumed to take a larger percentage since paint sprayers use more energy than electric hand tools. Table 15 shows how this information would be entered into the Visual Basic database.

Table 15. Method One Data Entry for Daily Electrical Consumption for Project C

Level 1	Level 2	Level 3	Level 4	CSI Division Title	Work Description	Begin Date	End Date	Hours	kWh of Electricity	Price per kWh
Method 1										
09	91	00	00	Painting	Paint Ceiling	7/27/07	7/27/07	8	0.5	.09
26	27	16	00	Electrical Cabinets and Enclosures	install electrical panels	7/27/07	7/27/07	8	0.25	.09
22	42	00	00	Commercial Plumbing Fixtures	install restroom fixtures	7/27/07	7/27/07	8	0.25	.09

Another method of estimating electrical consumption would be to record the hours each tool was used and compute the electrical consumption from energy information about that specific tool. The installation of both the plumbing fixtures and the electrical panels required the use of electric hand tools. A typical 6 amp drill using standard 120V service will consume 0.72 kW of electricity. Assuming that the drill is actually running 30% of the time over an eight hour work day gives the daily consumption to be 1.7 kWh of electricity. Assuming three similar hand tools were used for the electrical installation and the plumbing fixtures installation, the power consumed for the day observed would be 5 kWh for each task. This information is entered into Table 16, method 2.

Table 16. Method Two Data Entry for Daily Electrical Consumption for Project C

Level 1	Level 2	Level 3	Level 4	CSI Division Title	Work Description	Begin Date	End Date	Hours	kWh of Electricity	Price per kWh
Method 2										
09	91	00	00	Painting	Paint Ceiling Compressor & scissor lifts	7/27/07	7/27/07	8	385	0.09
26	27	16	00	Electrical Cabinets and Enclosures	install electrical panels 3-electric drills	7/27/07	7/27/07	8	5	0.09
22	42	00	00	Commercial Plumbing Fixtures	install restroom fixtures 3-electric drills	7/27/07	7/27/07	8	5	0.09
26	55	53	00	Security Lighting	Eight metal halide lights & Six-60 watt bulbs	7/27/07	7/31/07	64	535	0.09
26	56	23	00	Area Lighting (task)	Eight metal halide lights & Six-60 watt bulbs	7/27/07	7/31/07	32	268	0.09

Painting required the use of paint sprayers which used air compressors and battery powered scissor lifts to lift the painters up to the ceiling. A typical air compressor using 450 amps with the standard 120V service will consume 54 kW of electricity. Air compressors run continuously during painting. Assuming 30 minutes each for setup and cleanup, the estimated daily consumption for seven hours of work gives the daily consumption to be 378 kWh of electricity. The scissor lifts have four – 6V 225Amp batteries with a 25 amp battery charger. It is estimated that the batteries can be fully charged in two hours. This results in 6 kWh electrical consumption per day to fully charge the batteries. The total electrical consumption for painting on the day observed is computed as 384 kWh and is entered into Table 16, method 2.

Task and security lighting are also energy uses that are not listed as work tasks. The computed task and security lighting consumption computer earlier was 100.32 kWh for a 12 hour period. Since task and security lighting are provided by the same lights, task lighting can be computed as that portion of lighting provided over an eight hour work day (66.88 kWh) and the remaining 16 hours of lighting (133.76 kWh) would be allocated as security lighting. Since these values are expected to be the same for each of the four days observed, they may each be entered into Table 16, method 2 as one item resulting in 535 kWh for security lighting and 268 kWh for task lighting. Task lighting is provided for 8 hours a day for four days therefore “32” is entered into the hour column. Security lighting remained on for 16 hours a day for the four days observed requiring “64” to be entered into the hour column.

Table 15 and 16 show the two methods to enter the electrical consumption data into the Data Analysis Program. This data was entered into the program and successfully saved. Both methods resulted in the same total values for total power consumed and for total price.

One small construction trailer was located on site and was powered by its own service drop. This trailer accommodated the needs for the construction management personnel for the remaining buildings. Referring back to Table 14 for the construction trailer electrical usage; the total electrical consumption by the trailer for the four days recorded was 88 kWh. It is significant to note that the electrical consumption during the day was the same for most days and was also equal to the electrical consumption for most nights. The construction trailer lighting and air conditioning system were left on 24 hours a day regardless of occupancy which accounts for the consistency of these numbers. Table 17 shows the data entries for the electrical consumption for the Project C construction trailer. This data was entered into the EDA Program and successfully saved.

Table 17. Project C Construction Trailer Data Entry

Level 1	Level 2	Level 3	Level 4	CSI Division Title	Work Description	Begin Date	End Date	Hours	kWh of Electricity	Price per kWh
01	52	13	00	Field Offices and Sheds	One 16' Construction Trailer	7/27/07	7/31/07	96	88	0.09

CHAPTER X

METHODOLOGY FOR DATA COLLECTION AND RECORDING WITH RESPECT TO THE DATA ANALYSIS PROGRAM

Phase III developed a Visual Basic program for information collection, storage and analysis. Careful planning must be put into collation of this data in order for the results to be meaningful. The Visual Basic program places building construction energy into four categories: Electrical, Gasoline, Diesel, and Other. In order for the energy information to be accurate and meaningful, data for each of these energy types should be collected and entered into the program on a daily basis. As seen in the Project A study presented in Chapter IX, Site Visits to Take Data Measurements; data collected daily for the same work tasks may be entered together so long as the data has the same daily values. Each energy usage should be classified according to the CIS Master Format 2005 Edition ((CSI) 2004) along with a meaningful description. Daily project tasks can be obtained through personal observation, from the site construction manager, or from the owner's inspector (if there is one). This data may also be documented on the project schedule or the inspector's logs; however, personal observation is the most accurate method of data collection, as contractors schedules change as a result of weather conditions, materials availability, and unforeseen events. As daily energy consumption occurs it should be collected according to its energy type as outlined below.

Electricity

Electrical energy consumed may be determined by the use of electrical meters or by recording technical information about the electrical tools used on the job and how long they are used per tasks. Predicted electrical consumption may be computed from this data. The use of electrical meters is less time consuming, but may give energy consumptions for combined tasks depending on how many meters are used and where they are located. Hand held meters may also be used to determine power use for specific equipment.

A project may have one or more meters to deliver the electricity to different parts of the site. Additional electrical meters may be added as building construction progresses. Before data collection begins all electrical meters should be checked to determine it they are recording electrical power correctly. Service lines from each meter should be followed to determine what areas of the project are being serviced. Additional meters may be installed to determine power consumption for specific work tasks.

Electrical meters should be read every morning prior to the beginning of work. The previous days reading can be subtracted from the currents days reading to give the total electricity use for the previous day. Tasks using electricity should be recorded on the daily log. Table 18 provides an example of a two part form for recording meter readings and associated tasks. The first area is for recording construction trailer meter data. The “Trailer Size / Unusual Conditions” only need to be recorded once, unless the conditions change. The second area is for recording construction task meter data. Specific tasks that consume electrical power and the tools used should be accurately recorded in the associated columns. Data from this form can then be entered into the Visual Basic Database as described in Chapter IX, Site Visits to Take Data Measurements.

Table 18. Data Entry Form for Recording Electrical Meter Information

<table>
<tr><th colspan="6">Electrical Energy Data Collection Form
Meter Reading Data</th></tr>
<tr><td colspan="6">Project Name:</td></tr>
<tr><td colspan="6">Construction Trailer Electrical Consumption</td></tr>
<tr><td>Date</td><td>Meter Reading</td><td>Computed kWh</td><td>Cost per kWh</td><td colspan="2">Trailer Size/
Unusual Conditions</td></tr>
<tr><td></td><td></td><td>------</td><td></td><td colspan="2"></td></tr>
<tr><td></td><td></td><td></td><td></td><td colspan="2"></td></tr>
<tr><td></td><td></td><td></td><td></td><td colspan="2"></td></tr>
<tr><td></td><td></td><td></td><td></td><td colspan="2"></td></tr>
<tr><td colspan="6">Construction Tasks Electrical Consumption</td></tr>
<tr><td>Date</td><td>Meter Reading</td><td>Computed kWh</td><td>Cost per kWh</td><td>Tasks Performed</td><td>Equipment Used</td></tr>
<tr><td></td><td></td><td>-------</td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td></tr>
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</table>

When allocating electrical data to the project tasks it is important to determine which tasks use electricity and only allocate the energy data to those tasks. For instance, at the beginning of the project the construction office trailers may be set up and provided with an electrical service drop. The main work tasks will be earth moving and site preparation. Earth moving equipment will not use electricity from a service drop and therefore will not have an electrical energy component. Unless another electrical use is witnessed, all the electricity will be allocated to the construction office trailers (CSI division 01 52 13 00 Field Offices and Sheds) during this time period. An informative description for this task will be “General office use, lights, computers, and coffee maker.” In addition the trailer size may be entered. If more than one trailer is connected to the same service drop this too should be noted.

Security lighting can be a major use of electricity during construction. Security lighting should have its own meter and its energy use should be recorded daily. The description for energy lighting should include the number and types of lights used and the purpose of the lighting. The discussion of Project C in Chapter IX, Site Visits to Take Data Measurements, provides an example of recording and analysis of security and tasks lighting.

Choosing to record only meter data, or a more detailed analysis of tool power consumption would depend on the level of accuracy required and the cost of the job. Recording meter data and task information can be performed quickly. Information can be made more useful by planning meter locations and services. Computing energy consumption by recording tools and time used is more labor intensive and would only be practical for projects were there were specific energy concerns.

Gasoline and Diesel

The majority of construction equipment uses diesel fuel. There are two methods for dispensing diesel fuel into construction equipment. The first method is an onsite fuel storage tank. Equipment is driven to the storage tank and refueled as needed. The storage tank is filled periodically. The second method is to bring a fuel tanker truck to the site and fill the equipment directly. For larger projects diesel fuel is delivered to the site daily and records of the delivered quantities are kept in the contractor's office.

Two methods for determining diesel usage are to record the quantities of diesel brought to the site or to estimate the amount of diesel used by specific pieces of equipment multiplied by the number of hours the equipment is used. The study of Project A in Chapter IX, Site Visits to Take Data Measurements, utilized the second method of determining diesel fuel use. However, the first method is less time consuming and results in meaningful data when the number of different types of equipment is minimized.

Gasoline is mainly used by landscaping contractors and is brought to the site in five gallon cans or by 10 or 20 gallon tanks mounted on the back of pickup trucks or trailers. Gasoline receipts for the project would give the amount of fuel and date purchased. Table 19 represents a form for recording diesel and gasoline use. Diesel and Gasoline should be recorded separately. The information from this form can be easily entered in the Visual Basic database.

Table 19. Form for Recording Diesel and Gasoline Use

Data Collection Form Gasoline & Diesel Consumption					
Project Name:					
Diesel Consumption					
Begin Date	End Date	Gallons of Fuel Used	Cost per Gallon	Tasks Performed	Equipment Used
Gasoline Consumption					
Begin Date	End Date	Gallons of Fuel Used	Cost per Gallon	Tasks Performed	Equipment Used

Other Energy Sources

Other energy sources would be energy from renewable resources such as solar panels or the use of bio diesel fuels. They could also be gases from acetylene cutting torches or gas welding. Since these energy sources are small and varied the data entry into the Visual Basic database is slightly different than that for gasoline, diesel, and electricity. The difference occurs in how the energy data is recorded. Total cost is recorded instead of quantities and prices. A text entry column is provided to record quantities and prices along with their units since units will be different for the different types of “other energy sources.” Table 20 represents a form for recording energy consumption from other energy sources. The information from this form can be easily entered in the Energy Data Analysis Program.

Table 20. Form for Recording Energy from Other Sources

Data Collection Form Other Energy Sources					
Project Name:					
Begin Date	End Date	Amount of Energy Used	Total Cost of Energy	Tasks Performed	Equipment Used

Overview for Using the Visual Basic Program

This section provides a general overview for use of the EDA Program. For more detailed information refer to the Appendix B. The program is installed and run similar to any Microsoft Office based program. The name of the program is “Energy Data Analysis.” When the program is first started the computer screen will appear as that in Figure 18. In general, the green areas are for data entry, the yellow boxes are action boxes that perform a task, the red boxes are for building parameters, and the blue boxes give total energy quantities and/or costs.

Legend:
green areas: data entry
yellow boxes: action boxes perform a task
red boxes: building parameters
and the blue boxes: total energy quantities and/or costs

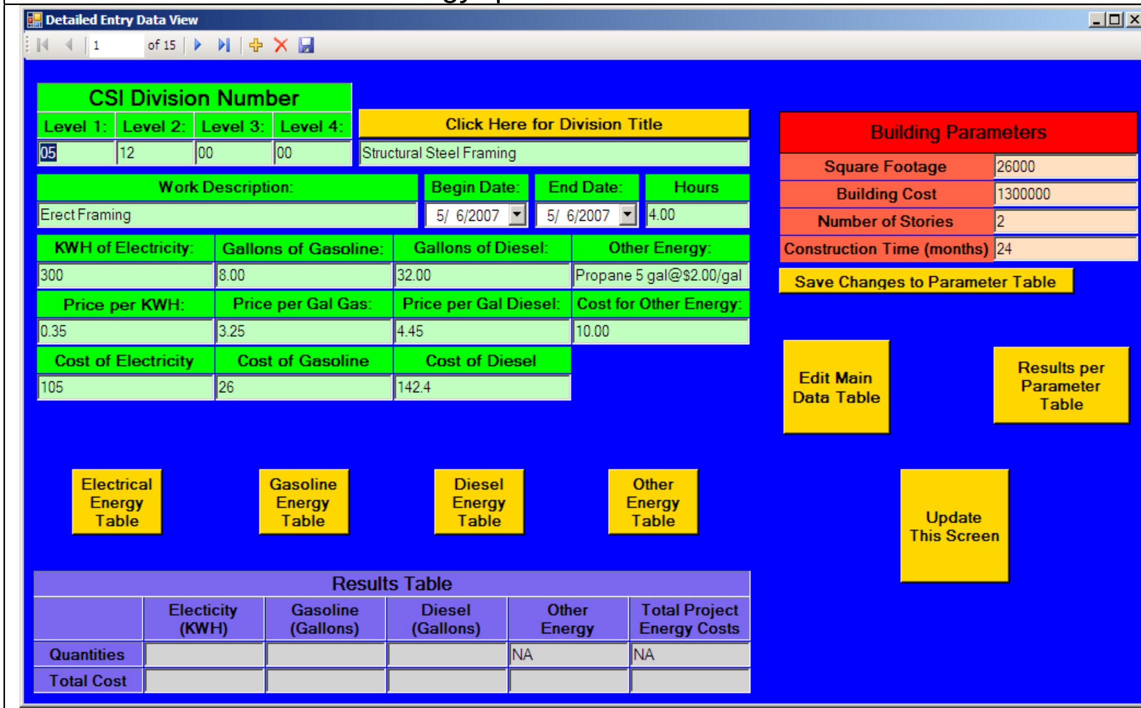

Figure 18. Energy Data Analysis Program Opening Window

An example database of fifteen data entries is opened when the program first opens. The data entry 1 is displayed in the green boxes and is so noted in the menu bar. The first eight data entries (numbered 1 through 8) contain fictitious data and were used to aid in the development of the program. The remaining seven entries (numbered 9 through 15) are the actual data gathered in the field as described earlier in this chapter. These data were used to test the functionality of the completed program. Data entries numbered 2 through 15 may be viewed by clicking on the right and left arrows in the menu bar. New entries may be added by clicking the yellow plus sign in the menu bar or deleted by clicking the red x. The save icon should be selected after each new entry or updating of existing information.

The yellow bar labeled “Click here for Division Title” will find the CSI title for the associated division numbers and insert it in the associated green bar.

The red area is for the building parameters. This information only needs to be entered once and is directly entered into the associated pink data entry boxes. Clicking on the yellow “Save Parameter Data” button will save any changes made to the parameter data.

The yellow “Edit Main Data Table” box will open a new window with a spread sheet type format as shown in Figure 19. More data may be viewed by scrolling the screen to the right using the scroll bar located at the bottom of the screen. More entries may be viewed by scrolling down using the scroll bar on the right. Data may be directly edited in this table and items may be added or deleted by highlighting the row; then to add click the yellow plus sign icon or to delete press the red x icon found on the grey menu bar. Save by choosing the save icon in the grey menu bar and close the window by choosing the x box in the upper right hand corner.

Data Entry Table

1 of 15

Level 1	Level 2	Level 3	Level 4	CSI Division Title	Work Description	Begin Date	End Date	Hours
05	12	00	00	Structural Steel Framing	Erect Framing	5/6/2007 7:00 AM	5/6/2007 5:00 PM	4.00
09	66	00	00	Terrazzo Flooring	Polish floor	7/6/2007 7:00 AM	7/7/2007 5:00 PM	16.00
31	13	13	00	Earth Stripping and Stockpiling	Use 2 front Loaders and 1 dump truck	4/6/2007 7:00 AM	4/6/2007 5:00 PM	8.00
02	41	16	00	Structure Demolition	Jack hammer, Generator	3/1/2007 7:00 AM	3/4/2007 5:00 PM	32.00
31	60	13	00	Concrete Piles	Diesel Pile Driver	5/13/2007 7:00 AM	5/14/2007 5:00 PM	16.00
31	22	13	00	Rough Grading	Dozer	4/15/2007 7:00 AM	4/16/2007 5:00 PM	16.00
08	14	00	00	Wood Doors	Install 10 wood doors	7/7/2007 7:00 AM	7/8/2007 3:00 PM	14.00

Figure 19. Main Data Table View

The yellow box labeled "Update This Screen" located on the main screen as shown in Figure 18, will update the main screen green boxes using information changed in the main data table and will also calculate the totals in the blue boxes. "Update This Screen" should be performed when ever data has been changed to insure that the calculated values have been updated. Figure 20 shows the updated Results Table.

Results Table					
	Electicity (KWH)	Gasoline (Gallons)	Diesel (Gallons)	Other Energy	Total Project Energy Costs
Quantities	1985	113.00	2640.00	NA	NA
Total Cost	257.65	336	11116.2	110.00	11819.85

Figure 20. Undated Results Table

Once again on the main screen as shown in Figure 18, choosing the yellow boxes labeled “Electrical Energy Table”, “Gasoline Energy Table”, “Diesel Energy Table”, or “Other Energy Table” will bring up a summary table of all the items showing the respective energy uses. Figure 21 shows an example of this window for the Diesel Energy Table. Notice only the seven items that use diesel fuel are listed and only the diesel fuel information is shown.

Diesel Energy Table

Level 1	Level 2	Level 3	Level 4	CSI Division Title	Work Description	Gallons of Diesel	Price per Gal Diesel
01	00	00	00	Test all Fields	test all energy fields	100.00	50.00
01	52	13	00	Field Offices and She...	Generator for Constru...	280.00	2.35
05	12	00	00	Structural Steel Frami...	Erect Framing	32.00	4.45
31	13	13	00	Earth Stripping and St...	Use 2 front Loaders a...	160.00	2.35
31	14	00	00	Earth Stripping and St...	4 dozers, 7 scrapers, ...	1748.00	2.35
31	22	13	00	Rough Grading	Dozer	160.00	2.75
31	60	13	00	Concrete Piles	Diesel Pile Driver	160.00	2.45

Figure 21. Diesel Energy Data Table

Choosing the yellow “Results per Parameter Table” box from the main screen, Figure 18, will open the window shown in Figure 22. Building Parameter Ratios This window shows the same energy totals and the cost totals as seen in the main window. It also shows these values as ratios to the building parameters and the average energy and energy costs per months of construction. The values in this example are extremely small because of the small example size. For a large building project there could be over a thousand item entries and the computed ratios would be larger.

Building Parameter Results

Results Table					
	Electicity (KWH)	Gasoline (Gallons)	Diesel (Gallons)	Other Energy	Total Project Energy Costs
Quantities	1985	113.00	2640.00	NA	NA
Total Cost	257.65	336	11116.2	110.00	11819.85

Energy Cost per Building Parameter Table					
	Electicity	Gasoline	Diesel	Other Energy	Total Project Energy Costs
Energy Cost per Square Foot	0.0099	0.0129	0.4275	0.0042	0.4546
Energy Cost per Building Cost	0.0002	0.0003	0.0086	0.0001	0.0091
Energy Cost per Floor	128.82	168	5558.1	55.00	5909.92
Average Energy Cost per Month	10.74	14	463.18	4.58	492.49

Energy per Building Parameter Table			
	Electicity (KWH)	Gasoline (Gallons)	Diesel (Gallons)
Energy per Square Foot	0.0763	0.0043	0.1015
Energy per Building Cost	0.0015	0.0001	0.002
Energy per Floor	992.5	56.50	1320.00
Average Energy per Month	82.71	4.71	110

Figure 22. Building Parameter Ratios

CHAPTER XI

CONCLUSIONS

The purpose of this study was to identify and evaluate energy consumption during the construction process and to develop a standardized method for collecting and recording energy cost and consumption data. This was accomplished using an iterative three part process: 1) the study of the construction process, 2) development of energy collection methods, and 3) development of a Visual Basic program to record and analyze energy data.

The Study of the Construction Process

The collection of energy costs and consumption data was performed by studying several construction projects. This information led to the development of four phases of construction energy consumption. These phases are identified as:

1) Site clearing and preparation

2) Building structure

3) Interior finishes

4) Commissioning

For phase 1, site clearing and preparation, the major energy usage was diesel fuel consumed by earth moving equipment. A limited test of the EDA Program was performed using Project A excavating equipment diesel fuel data. Using the EDA Program, the cost of Diesel fuel is estimated at 5.7% of the site preparation subcontract price. It should be noted that over the following five months, diesel costs have increased to $3.38 per gallon. This is a good example of how volatile energy costs can be and how important accurate estimates can be to profitability.

Energy consumptions for phase 2, building structure, were low and difficult to identify. The main energy consumers for this phase were the cranes for lifting structural materials and welding for structural members.

Interior finishes, phase three, had moderate electrical energy costs from mechanical HVAC testing, security and task lighting and power tools.

Phase 4, commissioning, had substantial electricity costs due to bringing the building temperature and humidity up to occupancy standards. The phase 4 value of $112,344 for the JEB Chemical Engineering Building was 83.4% of the total electrical utility costs and is comparable to many line items of work listed in the project invoice. Shortening the time for phase 4 of this project would have lead to reduced energy costs for the contractor thus increasing profit.

In addition to the construction tasks associated with the four phases, security lighting is an energy consumption that must also be considered. The type of lights used, duration of lighting, and the number of lights all affect the energy consumption of a project.

Development of Energy Collection Methods

This study found that construction energy data was not readily available and existing energy data was often incomplete or inaccurate. It was also difficult to associate energy consumption with construction tasks. Data collection methods were developed for recording diesel and electricity usage and determining their associated construction tasks. Gasoline and renewable energy sources were briefly discussed. The collection methods developed included the use of multiple intermediate meters to determine specific electrical energy consumption related to specific construction tasks and recording daily diesel fuel consumptions. Standardized forms for recording these energy uses were developed.

Development of a Visual Basic Program to Record and Analyze Energy Data

Information obtained from the development of the collection methods was used to develop a Visual Basic Program titled Energy Data Analysis (EDA). This program is used to organize and analyze the energy cost and consumption data. The program was developed using a Visual Basic program which utilizes an internal database for the collection of energy data along with subroutines that calculated energy consumption values and costs for each energy type. Energy use during construction is categorized using the CSI Masterformat Divisions which is widely used by the industry to categorize other aspects of construction.

Benefits of This Study

This study has developed a method for recording and analysis of energy consumption during construction. Future collection of data and analysis of this data will lead to the identification of areas of construction where energy savings can be realized. The direct benefit of energy savings result in a cost savings on future projects. Two areas identified in this study where future studies are warranted for direct energy savings are the costs of diesel fuel during earth moving operations and electricity costs during commissioning of the building prior to occupancy.

Another benefit would be the cumulative effect of smaller energy saving methods over many projects. As more energy efficient equipment and construction methods are identified and used on many projects, the cumulative energy savings could be significant.

Even thought the time and amount of money required to perform energy use studies may not prove to be cost effective on a specific single project, wasteful energy practices can be identified and this information may provide a cost benefit and be environmentally beneficial in the long term.

The Future of This Study

In beginning of this study the author's original intent was to investigate the possibility of using alternative energy resources during the construction process. However, the lack of knowledge about energy use during construction led to the need to develop a method to obtain data on energy use during construction. It is hoped that future studies will continue to gather data on construction projects and that this information will allow onr to evaluate the use of alternative energy in construction.

The EDA Program lends itself to integration with Building Information Modeling (BIM). The program is used to store data in a data base and using the CSI Masterformat. This same format is used to identify materials in BIM programs. Correlation of this information would allow one to predict energy use during the design phase of a project.

The results of this study will facilitate future studies to evaluate energy use during the construction of projects. It is hoped that this will lead to more sustainable construction methods.

REFERENCES

Benson, J. J. (1981). "A Forecast of Construction Equipment Innovations and Advances as They May Relate to Roads of the Future." 9th International Road Federation. World Meeting, Stockholm, 103-111.

Casals, X. G. (2006). "Analysis of Building Energy Regulation and Certification in Europe: Their Role, Limitations and Differences." Energy and Buildings, 38(5), 381-392.

Construction Specifications Institute (2004). MasterFormat™ 2004 Edition, The Construction Specifications Institute, Alexandria, VA.

Construction Specifications Institute. (2005). CSI Manual of Practice. The Project Resource Manual: CSI Manual of Practice / The Construction Specifications Institute, McGraw-Hill, New York.

Council of Economic Advisers, ed., (2005). "Economic Indicators January 2005." United States Government Printing Office, Washington, DC.

Deffeyes, K. S. (2003). Hubbert's Peak : The Impending World Oil Shortage, Princeton University Press, Princeton, NJ; Oxford.

Deffeyes, K. S. (2005). Beyond Oil : The View from Hubbert's Peak, Hill and Wang, New York.

Department of Energy. (2005). "Energy Outlook 2005, Market Trends - Energy Demand." Web site: http://www.eia.doe.gov/oiaf/aeo/demand.html

Energy Information Administration (February 2005). "Annual Energy Outlook 2005 with Projections to 2025." DOE/EIA-0383(2005).

Energy Information Administration/Energy Consumption Series Office of Energy Markets and End Use, eds., (October 1995). "Measuring Energy Efficiency in the United States' Economy: A Beginning." U.S. Department of Energy, Washington, DC.

Fisk, E. R., and Reynolds, W. D. (2005). Construction Project Administration, Pearson Prentice Hall, Columbus, OH.

Hesse, P. (2006). "Construction Energy Research." A. Arnold, ed., National Energy Information Center (NEIC), Washington, DC, Email correspondence.

Kale, A., Meyers, B., Evans, R., and Kang, J. (2007). "Empirical Application of Building Information Modeling to Academic Building Construction." Associated Schools of Construction Region 5, Dallas, TX, 26-30.

Khemlani, L. (2006a). "Autodesk Revit Building 9." AECbytes Product Review, Web Site: http://www.aecbytes.com/review/2006/RevitBuilding9.html

Khemlani, L. (2006b). AECbytes "Building the Future" Article. "BIM Symposium at the University of Minnesota." Web Site: http://www.aecbytes.com/buildingthefuture/2006/BIM_Symposium.html

Kibert, C. J. (2005). Sustainable Construction Green Building Design and Delivery, John Wiley & Sons, Inc, Hoboken, NJ.

Leedy, P. D. and Ormrod, J. E. (2001). Practical Research: Planning and Design,7th ed., Merrill-Prentice Hall, Upper Saddle River, NJ.

Merriam-Webster. (1988). Webster's Ninth New Collegiate Dictonary, Merriam-Webster Inc., Springfield, IL.

Mertler, C. A. (2001). "Designing Scoring Rubrics for Your Classroom." Practical Assessment, Research & Evaluation, 7(25), Web site: http://pareonline.net/getvn.asp?v=7&n=25.

National Academy of Sciences, Federal Facilities Council (FFC) Standing Committee on Research, ed., (1996). "Federal Policies to Foster Innovation and Improvement in Constructed Facilities: Summary of a Symposium ."

Nunnally, S. W. (2004). Construction Methods and Management, Pearson Prentice Hall, Upper Saddle River, NJ.

Peurifoy, R. L., and Schexnayder, C. J. (2002). Construction Planning, Equipment, and Methods McGraw-Hill, Boston, MA.

Schexnayder, C., and Mayo, R. (2004). Construction Management Fundamentals, McGraw-Hill, New York.

United States Environmental Protection Agency, Air and Radiation, ed. (April 2003). "Reducing Air Pollution from Nonroad Engines." Web site: http://www.epa.gov/otaq/cleaner-nonroad/f03011.pdf

US Green Building Council, (2006). "USBC Core Purpose. U S Green Building Council, ed., Copyright © 2006 U.S. Green Building Council, Web site: http://www.usgbc.org/DisplayPage.aspx?CategoryID=1.

US Government. (2007). "Monthly Energy Review January 2007." Energy Information Administration, ed., US Government, Web site: http://www.eia.doe.gov/emeu/mer/pdf/pages/sec7.pdf

Widén, K. (2003). "Innovation in the Construction Process." Competitive Building. Swedish Foundation for Strategic Research, Web site: http://www.competitivebuilding.org/artman/publish/article_38.shtml

APPENDIX A

THE ENERGY DATA ANALYSIS PROGRAM ATTACHMENTS

An executable Visual Basic program titled Energy Data Analysis accompanies this dissertation as a zip file available for down loading. Also contained in the zip file is a Microsoft excel file that contains a list of the 2005 CSI Masterformat headings that are utilized by the EDA program.

APPENDIX B

USER'S GUIDE FOR THE ENERGY DATA ANALYSIS PROGRAM

INTRODUCTION

The EDA Program is a windows based program written in Visual Basic 2005 Express. Its purpose is to record and analyze energy use data during a construction project.

The functions used in this program work similar to other windows based applications and are straight forward. However, it is important to read through this guide to gain a quick understanding of how to install and use this program.

File Handling

This program makes use of an embedded data base file to store and retrieve data. It also accesses the CIS Division data stored on the excel file named *CSI Divisions.xls*. This file is located on the installation CD and must be stored in a known location. The application will ask for this file's location during data entry.

Installing the Program

To install this program:

1. Copy all files and folders to the hard drive.
2. Open the file folder and locate the setup.exe file.
3. Double click on the setup.exe file.
4. Since this program is not a Microsoft sanctioned program a warning from the computer security program may appear. Select

install. (This program does not contain viruses and may be uninstalled following the uninstall procedures from the owner's computer manual.)

5. The program will install and then run.

Beginning the Program

After have installing the program, run it by clicking "Start"; "All Programs" similar to starting any other Windows Application. The name of the program is "Energy Data Analysis" and it will most likely be the last program on the programs list.

Saving Project Data

It is recommended that the data be saved after changes have been made to each record. To save data click on the save icon on the menu bar. There is no undo command so if a record is mistakenly deleted or changes made to the wrong record, you can "quit" the program, restart it, and the data will be reverted back to the point of the last save.

To Exit the Program

To exit this application, click the X-box on the upper right corner of the screen. First make sure that data has been saved by clicking the save icon in the menu bar at the top of the window.

DATA ENTRY

There are two methods of data entry available. The first method appears in the window when the program starts and is referred to as the "Detailed Entry Boxes" method. The second method makes use of a table format that is accessed by clicking the gold "Data Table" button and is referred to as the "Data

Table" method. Both methods are discussed below along with the advantages and disadvantages of each. Note that a record refers to all the data typed into one row of the "Data Table" or all the information displayed in the green boxes on one page of the "Detailed Entry Boxes" main window.

Each method has its own window and both windows may be open at the same time. However, they will not update automatically. In other words, if changes are made and saved to the data in the "Detailed Entry Boxes" view mode, these changes will not show in the data table view until the "Data Table" is closed and reopened. To show the changes made and saved in the Data Table view, click the gold "Update This Table" button in the Detailed Entry Boxes view.

Menu Bar

Both methods have a menu bar across the top that works the same way. The menu bar is used to navigate, add, delete, and save the data records. The right and left arrows are used to scroll through the records. A record may also be accessed by typing in its ID number in the window of the menu bar. A new record may be added by clicking on the "+" in the menu bar. Clicking on the save icon will add the record to the database or save changes to an existing record. The red "x" will delete the current record. If a record is deleted its Entry ID number will not be used again. The Entry ID numbers are attached to the records and remain the same for the records regardless of how the records are sorted.

Detailed Entry Boxes

The program opens a window showing the detailed entry boxes with the menu bar at the top to navigate, add, delete, and save the data records. The first record of data from the database is automatically entered into the detailed entry boxes. To enter a new record click on the "+" in the menu bar. This will blank all cells and create a new record for data entry. After entering data in these boxes, click on the save icon in the menu bar to add the data to the database. To edit existing records, display their values by choosing their ID number in the menu bar or scrolling through the records using the right and left arrows, then change their values in the text boxes. Be sure to save the changes by clicking on the save icon in the menu bar after editing each record. Clicking the save Icon will save all changes made to any records, not just the record showing. Changes may be made to several records and then saved all at one time. However, it is recommended that data be saved often or at the completion of each record.

The gold "Update This Table" button will update the records shown in this window if changes were made and will be saved in the "Data Table" window. It does not save changes made back to the data base. You must click the save icon in the grey menu bar to save changes to the data base.

Entering CSI Data

All detailed project information is stored by CSI categories which allows one to determine where energy costs are more significant. Begin data entry by entering the CSI Division Number for each level. Each level entry must be a two digit number. If more that two digits or if characters that are not numbers are entered, an error message will appear when save is selected. If an error message appears, click continue, then correct the number. Also, empty boxes are not allowed for the CSI Levels.

Once the division levels have been entered correctly, click the gold “Click Here for Division Title” button and the program will retrieve the division name and place this information in the division name box. If the division number is not valid an error message will occur. Type the correct number or the division title may be typed directly into the box.

The first time the “Click Here for Division Title” button is clicked, an open file dialog box will appear asking for the location of the “CSI Divisions” file. This file was included on the program disk and should have been copied with the program files. Locate the file and click open.

This program uses all four division levels for locating division titles. Level 4 is considered optional by CSI. Not all descriptions have a Level 4 designation, however some do. If there is no Level 4 designation, enter “00” in that field. When the number 00 occurs in the Level 4 box, the program will only look at the first three levels and select the title corresponding to the first match listed for the three levels. If a number other than 0 is entered in the Level 4 division box the program will attempt to match all four levels. If there is no match for all four levels a message box will open and ask for the CSI Division description. The CSI Divisions file may be opened in excel to view the levels and their descriptions.

The description may also be entered directly into the light green box under the gold button.

Entering Work Description

The “Work Description” text box is the light green box below the dark green label and may be used for any comments about this line item. Up to 100 characters may entered in this box.

Entering Date Information

The beginning date and ending date boxes will bring up a Month Calendar control. Click on the year to change the year. Click the right or left arrows to change the month and click on the day to select the date. Press enter to close the calendar and submit the date selected.

Entering Energy Data

Data may be entered into any or all of these fields or they may be left blank. If the “KWH of Electricity”, the “Gallons of Gasoline” or the “Gallons of Diesel” fields are left blank the program will automatically insert a 0 into these fields. This tells the program that these values will not be used in the calculations.

Enter the number of kilowatt-hours of electricity used in the light green text box below “KWH of Electricity” and enter the price per kilowatt-hour below that. These values must be numeric.

Enter the number of gallons of gasoline used in the light green text box below “Gallons of Gasoline” and enter the price per gallon below that. These values must be numeric.

Enter the number of gallons of diesel used in the light green text box below “Gallons of Diesel” and enter the price per gallon below that. These values must be numeric.

The “Other Energy” box accepts characters so that descriptions, quantities, or units may be entered. Enter the total cost of the other energy in the “Cost of Other Energy” box. This value must be numeric and will be used to calculate that total costs of “Other Energy.”

Data Table Entry Method

An advantage of the Data Table entry method is that many entries can be seen at one time. The arrows in the menu bar may be used to scroll through them. A disadvantage is that the name of the CSI Division can not be located from this view. However, after the division levels have be entered and the record saved, this function can be accessed in the Detailed Entry Boxes window. To do this, close the Data Table window, locate the record in the Detailed Entry Boxes window and click on the “Click Here for Division Title” button and the program will enter the division title into the record. Be sure to save the changes.

The data table may be accessed by clicking the gold “Edit Main Data Table” button. This will bring up a new window with each record of data listed in a table format. Data in the table may be changed by simply clicking on it. However, the database will not be updated until the save icon on the menu bar has been clicked. The table may be closed by clicking the X-box in the upper right hand corner. However, if the table is closed before saving, the data will be lost.

To add a new entry, choose the "+" icon on the menu bar. The new entry row will appear at the bottom of the table. Enter the data into the boxes by clicking on them or tabbing to the next box.

Data formatting follows the same requirements as the detailed entry boxes discussed above. However, there is no option to have the program enter the correct title for the CSI Divisions as discussed above, and the date entries will not call the Month Calendar control. Dates must be entered in the mm/dd/yyyy format.

VIEWING DATA SUMMARY TABLES

The data summary tables list only the CSI Division Information and the data for one type of energy. They may be viewed by clicking the gold buttons labeled "Electrical Energy Table," "Gasoline Energy Table," Diesel Energy Table," and "Other Energy Table" at the bottom of the page. Each button calls the respective table. The tables may be opened in any order and left open. The tables may be moved around on the screen by dragging the title bar as in any windows application. Data may not be edited in the Data Summary Tables. If the table is larger than the window, scroll bars will appear. If changes are made to the data base in the detailed boxes view or the data table view, they will not be reflected in an open summary table. To view the changes, close the summary table by clicking on the X-box and reopen it by clicking its gold button.

Total Energy and Total Cost

The total quantity and the total cost of each of the energy types are provided in the blue "Results Table" at the bottom of the main window. These will update when the gold “Update This Table” button is clicked. The total quantity is the total of the quantity column for each energy type. The total cost is computed my multiplying the quantity times the price per quantity for each record and them summing these values. The total cost of other energy is computed by summing the column “Cost of Other Energy.”

BUILDING PARAMETERS

Enter the building parameter data into the red “Building Parameters” table in the main window. All values must be numeric. The “Number of Stories” value must be an integer. This data is only entered once. However, changes may be made to it at any time.

Results per Parameter Table

Be sure that values have been entered into the red “Building Parameters” table before this window is opened or an error box will appear.

The “Results per Parameter Table” may be accessed by clicking the gold “Results per Parameter Table” button just under the red parameter table in the main window. This will open a new window.

If changes are made to the data base while this window is open, they will not be reflected here. Close the window and then reopen it to see the changes.

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