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Evaluating Opportunities and Barriers to Improving the Energy Efficiency of Small Nebraska Wastewater Treatment Plants

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EVALUATING OPPORTUNITIES AND BARRIERS TO IMPROVING THE ENERGY EFFICIENCY OF SMALL NEBRASKA WASTEWATER TREATMENT PLANTS

By

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EVALUATING OPPORTUNITIES AND BARRIERS TO IMPROVING THE ENERGY EFFICIENCY OF SMALL NEBRASKA WASTEWATER TREATMENT PLANTS

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Wastewater treatment plants (WWTP)s account for about 0.8% of U.S. electricity use. Small WWTPs serving communities of populations less than 10,000 accounts for 95% of treatment plants in Nebraska. These plants are significantly less efficient compared to large systems and thus improving their energy efficiency (E2) is a growing focus in efforts to reduce greenhouse gas emissions associated with their operation. Energy use of plant unit operations was evaluated for several plants and included analysis of energy for space heating. Specific infrastructure and/or operational changes reported by operators following an E2 benchmarking project were evaluated by quantifying the change in annual billed energy use. Barriers to implementing E2 improvements were ranked by operators in a one-page survey. Supplemental observations from plant assessments occurring throughout the E2 benchmarking project and fifteen subsequent energy assessments were provided.

Aeration was identified as the largest energy use (66-73%) of total process energy use and space heating accounted for 4-34% of total plant energy use. Changes were reportedly being made at 19 plants (37% of respondents), with 12 plants reporting changes recommended in the previous benchmarking letters. Energy bills collected for 13 plants reporting changes had 9 plants showing energy reductions of 4-35% and an

approximate $39,000 of annual cost savings, with the largest reductions involving the use of VFDs. These plants showed an 8.5% average reduction in energy compared to a 1.2% reduction shown by 16 plants reporting to have not made changes.

Survey responses from 41 operators showed that financial related barriers and lack of time or other priorities are the largest barriers for small municipalities in making E2 improvements. Organizational issues also exist within small municipalities in which energy management is not prioritized and often is neglected. Plants reporting making changes had reported lack of staff of awareness as less of a relevant barrier compared to plants reporting to have not made changes. This may suggest that raising awareness about E2 can potentially lead to greater implementation of changes.

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LIST OF ABBREVIATIONS

AC	Automated DO Control
AU	Augur
AWIN	Assessing Wastewater Infrastructure Needs
BEP	Best Efficiency Point
CB	Corse Bubble Diffusers
CBOD	Carbonaceous Biochemical Oxygen Demand
CO	Constant Operation
CSR	Continuous Sequencing Reactor
CV	Coefficient of Variation
DO	Dissolved Oxygen
DOE	Department of Energy
EA	Extended Aeration
ECHO	Environmental Compliance History Online
EI	Energy Intensity
EIA	Energy Information Administration
EPA	Environmental Protection Agency
EPRI	Electric Power Research Institute
E2	Energy Efficiency
FB	Fine Bubble Diffusers
GR	Grinder
HDD	Heating Degree Days
ICV	Inlet Control Valve
IRB	Institutional Review Board

LCCA	Life Cycle Cost Analysis
LCA	Life Cycle Assessment
LNM	League of Nebraska Municipalities
MA	Mechanical Aerator
MGD	Million Gallons per Day
NDEQ	Nebraska Department of Environmental Quality
NeRWA	Nebraska Rural Water Association
NOAA	National Oceanic and Atmospheric Administration
NYSERDA	New York State Energy Research and Development Authority
OD	Oxidation Ditch
OP	Open Pipe
OTE	Oxygen Transfer Efficiency
OUR	Oxygen Uptake Rate
PDEP	Pennsylvania Department of Environment Protection
RAS	Return Activated Sludge
RBC	Rotating Biological Contactor
SBR	Sequencing Batch Reactor
SRT	Solids Retention Time
TF	Trickling Filter
UNL	University of Nebraska –Lincoln
VFD	Variable Frequency Drive
WAS	Waste Activated Sludge
WWTP	Wastewater Treatment Plant

Chapter 1: Introduction

1.1 Background

Energy management of wastewater treatment plants (WWTP)s has been a growing focus in the water sector to help minimize the operating cost and greenhouse gas emissions associated with their use (DOE, 2017). A report produced by the Electric Power Research Institute (EPRI) and Water Research Foundation estimated that about 30.2 terawatt hours or 0.8% of U.S. electricity use is for treatment of wastewater annually (EPRI, 2013). Electricity has been observed to account for 25% to 40% of a WWTPs annual operating budget (NYSERDA, 2008). Small community WWTPs serving populations of less than 10,000 make up 95% of all systems in the state of Nebraska. Since many small communities often have constrained financial and human resources, they face challenges in maintaining efficient wastewater treatment facilities (EPA, 2018).

Energy data management in which energy data are tracked, analyzed, and used to track energy-saving changes is a key element in effective energy management systems (DOE, 2017). Although there is a large body of information on energy efficiency (E2) changes at WWTPs, the literature generally refers to large treatment plants and no studies could be found that evaluate the impact of changes for exclusively small treatment systems. There are currently a few studies that include evaluation of unit process energy use at small plants and include actual measurements (Foladori et al., 2015; Young and Koopman, 1991).

In addition to the lack of information on opportunities to making changes at small plants, there are currently few studies that focus on evaluating the specific barriers to making energy efficiency changes at small WWTPs. The New York State Energy Research and Development Authority (NYSERDA, 2008) highlighted several issues facing wastewater treatment systems in efforts to improve energy efficiency. These barriers included constraints experienced by and/or the result of operators, public officials, design engineers, and regulators involved for the systems. The primary goal of WWTPs is to reduce pollution to protect public health. This leads to more conservative measures being used when making energy efficiency changes that could negatively impact process performance. This is even more common for smaller facilities that have smaller cost savings achievable with such changes (NYSERDA, 2008). The EPA (2010) had reported that the barriers to making E2 improvements at WWTPs are due to a lack of awareness or understanding the many benefits of investing in energy efficiency projects and the many programs that are available for financing E2 projects.

The study presented here adds to the growing body of knowledge on the energy use of processes within small WWTPs and presents quantified energy and cost savings observed from reported changes at several small communities. By surveying plant operators, the perceived relevancy of barriers to making E2 changes at plants was evaluated. The survey was supplemented with observations and discussions with operators throughout the course of the energy efficiency benchmarking project conducted in 2016 and the subsequent energy assessments of 15 plants.

1.2 Objectives

The specific objectives of this study were to:

1. Evaluate the energy usage and energy intensity of unit processes within several small Nebraska wastewater treatment plants.
2. Quantify the impact of reported infrastructure and/or operational changes made following the E2 benchmarking project conducted by Hanna et al. (2018).
3. Assess the impact of the past benchmarking project on the self-reported awareness to plant energy use by WWTP operators in Nebraska.
4. Identify the major barriers to implementing energy efficiency improvements at small Nebraska WWTPs, and to analyze any relations between barriers.

1.3 Thesis Organization

This thesis is organized into five chapters. A literature review is presented in Chapter 2 that provides an overview of energy management of wastewater treatment systems, energy use and benchmarking of their unit processes, specific E2 related opportunities, and barriers to making E2 changes. Chapter 3 details the methods used for data collection and analysis of data. Chapter 4 presents the results of the energy analysis and survey of operators. Chapter 5 provides a summary of the conclusions made from the study and proposes recommendations for future research. References and appendices included at the end provide supplemental information such as the survey materials, data collection forms, and data collected in the study.

Chapter 2: Literature Review

2.1 Introduction

To provide context to this study, an examination of available literature was performed. Topics included studies of energy use by treatment processes, energy management, energy efficiency considerations in design, and common energy efficiency improvements reported in the literature. Also, barriers to making energy efficiency improvements were reviewed in general literature and then barriers specifically reported for wastewater treatment plants were identified.

2.2 Energy Management of Small Wastewater Treatment Plants

Energy management of wastewater treatment plants (WWTP)s has been a growing focus in the water sector to help minimize the operating cost and greenhouse gas emissions associated with their use (DOE, 2017). A report produced by the Electric Power Research Institute (EPRI) and Water Research Foundation estimated that about 30.2 terawatt hours or 0.8% of U.S. electricity use is for treatment of wastewater annually (EPRI, 2013). Electricity has been observed to account for 25% to 40% of a WWTPs annual operating budget based on a study by the New York State Energy Research and Development Authority (NYSERDA, 2008). Energy data management in which energy data are tracked, analyzed, and used to evaluate energy-saving changes is a key element in effective energy management systems (DOE, 2017). Benchmarking is a component of this analysis that uses data to help quantify the energy efficiency of WWTPs for comparison against other plants and has been used in tracking efficiency within a plant over time.

Benchmarking the energy efficiency of treatment plants has generally been carried out using one of two different methods. The first method for benchmarking involves the use of regressed models that relate energy use or energy intensity to several plant characteristics (flowrate, percent design capacity, etc.). Examples of such models include the U.S. Environmental Protection Agency's (EPA) ENERGY STAR benchmarking model for medium to large plants (Energy Star, 2014) and the models developed by Hanna (2017) for benchmarking the electric intensity of small Nebraska facilities. The second and more simplistic approach involves the normalization of energy usage by a unit of capacity to evaluate the E2 and is more commonly reported in literature (EPRI, 2013; PDEP, 2011; NYSERDA, 2008; Foladori et al., 2015; Belloir et al., 2015; Mizuta and Shimada, 2010; Krampe, 2013) . Benchmarks based on flowrate (kWh/MG) or pollutant loadings removed (kWh/lb-BOD) are the most commonly used benchmarks for WWTPs, often noted as an energy intensity (E.I.) metrics. This terminology will be used subsequently throughout this study.

These benchmarking metrics have been applied to overall plants and are also being used in benchmarking unit processes within plants. Despite the extensive research on methods of benchmarking WWTPs and their processes, there is currently still debate on the most effective way to evaluate the E2 of wastewater treatment processes (DOE, 2017). It was highlighted by Foladori et al. (2015) that processes may have energy intensity metrics best represented by normalizing energy by flow, BOD, or other variables. Pumps, for example, will exhibit energy use that will vary more with the flow, whereas an aeration system equipped with automated DO controls may be more appropriately benchmarked with BOD.

2.3 Energy Use and Energy Efficiency of Small WWTP Processes

Evaluation of the energy use and E2 of unit processes within a plant is used to provide insight into where the most energy is used within plants, where the most savings may be achieved through making changes, and in quantifying the impact from making E2 related changes. Aeration has been widely reported across literature as the most energy-intensive process within treatment with pumping and solids management also being identified as large users (EPRI, 2013). Although not directly included in the treatment process train, space heating also been a notable energy user at WWTPs (EPA, 1978). The following section discusses energy used by wastewater treatment processes, benchmarking of their usage, and some factors that can impact their usage.

2.3.1 Unit Process Energy Use and Efficiency

In a review of the literature describing energy use and efficiency of unit processes at wastewater treatment plants, results are presented typically showing relative energy usage of processes or with the normalized metrics described in the prior section.

An EPA (1973) report estimated unit process energy use for commonly used processes in plant sizes of 1 to 100 MGD based on information taken from literature available from equipment manufacturers and some reports of EPA-sponsored research projects. The report showed that an economy of scale existed in terms of energy consumption by unit processes over varying flowrates. More detailed estimates of process energy use had been reported by EPRI (1996) which had used data from several EPA studies, process computations, and data from energy audits conducted by Metcalf & Eddy for New England plants. The EPRI study provided daily kilowatt-hour consumption of unit processes for plants of varying size from 1 MGD to 100 MGD. The data from this study had then been adapted by Tchobanoglous et al. (2014) by normalizing the daily energy use by average flowrates to create energy intensity metrics for processes. A follow-up report by EPRI (2013) had been prepared to update data being used and to include discussion of current energy management opportunities, practices, and technologies being used in the industry.

There are currently only a few studies that include evaluation of unit process energy use at small plants and even fewer that include actual measurements of that energy use. A study by Young and Koopman (1991) evaluated the energy use of five WWTPs with design flowrates ranging from 0.0066 m^3/s (0.15 MGD) to 0.197 m^3/s (4.5 MGD). Electrical measurements performed on 63 three-phase motors were used to estimated motor load, power factor, efficiency, and energy use of the motors. Most motors that consume more than 5 kW or more had been observed to operate within load ranges providing optimal efficiency. In contrast, smaller motors appeared to be oversized for many systems resulting in a poor power factor and thus poor efficiency (DOE, 2014). Figure 2.1 presents an example of the relative energy usage of one of the small WWTPs analyzed by Young and Koopman (1991).

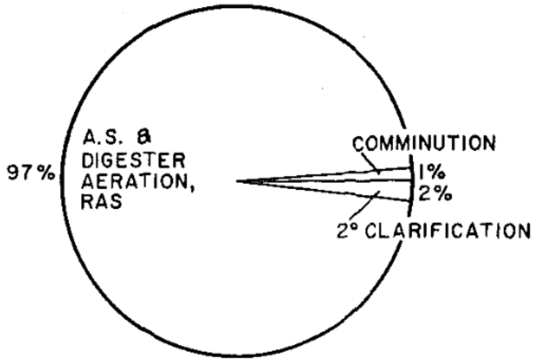


Figure 2.1: Relative Energy Use of Unit Processes at a Small Extended Aeration Plant (Young and Koopman, 1991)

Aeration had been reported as accounting for 54% to 97% of the total electricity usage. Another key observation from the study was the observation that many of the small treatment systems lack the capacity to adjust energy use in response to varying influent loads which largely may attribute to the plant's energy EI showing up as inversely related to plant inflow.

The most in-depth analysis of unit process energy use and benchmarking of unit processes for small plants had been conducted by Foladori et al. (2015) at five plants in north Italy that had average flowrates from 102 m^3/day (0.027 MGD) to 3,088 m^3/day (0.816 MGD). Some continuous electrical measurements conducted for two years and additional measurements made during single day campaigns were used to estimate energy usage of electromechanical units used for treatment and non-process related systems such as lighting, control panels, etc. A data quality check of the estimates was performed by comparing the collective sum of energy use estimated for equipment was compared with the plant's energy meter used for billing. The unit process energy use estimates of the study came within ±10% of the overall plant metered usage.

As a comparison, the derived hydraulic based energy intensity metrics of unit processes estimated by Tchobanoglous et al. (2014) based on the EPRI (1996) was compared to values reported by Foladori et al. (2015) for processes reported in both to compare the energy usage at large plants and small plants. These were the same processes also commonly investigated in the current research being presented here. Table 2.1 shown below summarizes the comparison of the estimated energy intensity of these unit processes. It can be observed that smaller facilities showed a generally higher energy intensity metric for the unit processes. Some processes had been noted by Foladori et al. (2015) to not be appropriately benchmarked with flowrate-based metrics and these are noted in the table with an asterisk mark.

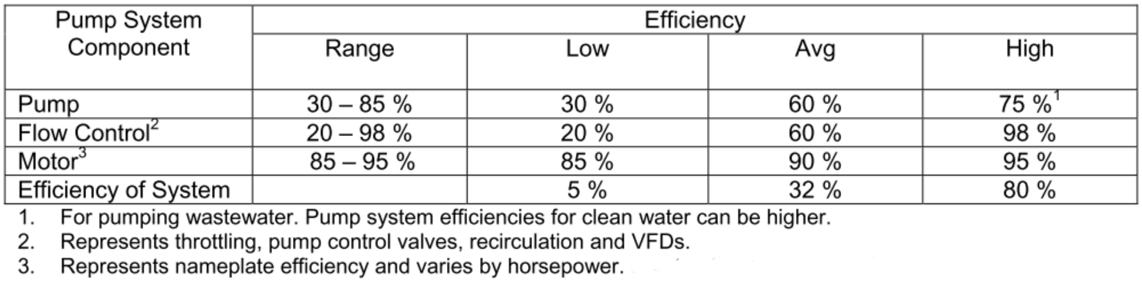
Table 2.1: Estimated Energy Intensity of Unit Processes by Prior Studies

Unit Process	**Electricity Intensity (kWh/m^3)**	
	Tchobanoglous et al. (2014)	**Foladori et al. (2015)**
Wastewater Pumping	0.032-0.045	0.032-0.076
Screens	0.0003-0.0005	0.004-0.017
Aerated Grit Removal	0.003-0.013	0.027
Secondary Clarifiers	0.003-0.004	0.010-0.014
Return Sludge Recirculation	0.008-0.013	0.030-0.226
Aeration with nitrification and denitrification*	Mixers and Aeration: 0.23	Mixers: 0.072-0.121 Aeration: 0.068-0.799
Aerobic Digestion*	0.13-0.32	0.009-0.530
*Flowrate-based metric was noted by Foladori et al. (2015) to not be appropriate for the process		

2.3.2 Factors Influencing Energy Efficiency

Many of the unit processes within a treatment plant are comprised of several components that collectively impact the efficiency. For example, pumping system efficiencies can vary significantly because of differences in efficiency from the pump, motor, and/or flow control. The overall efficiency of the system is the product of each component efficiency (DOE, 2006). Table 2.2 below shows an example of the component efficiencies of a pumping system as reported by the EPA (2010). The efficiency of the system can vary based on operations and maintenance of the system but can also vary based on the operating conditions relative the designed best efficiency point (BEP).

Table 2.2: Example of Component Efficiencies of Pumping Systems (EPA, 2010)



Pump System Component	Efficiency			
	Range	Low	Avg	High
Pump	30 – 85 %	30 %	60 %	75 %[1]
Flow Control[2]	20 – 98 %	20 %	60 %	98 %
Motor[3]	85 – 95 %	85 %	90 %	95 %
Efficiency of System		5 %	32 %	80 %

1. For pumping wastewater. Pump system efficiencies for clean water can be higher.
2. Represents throttling, pump control valves, recirculation and VFDs.
3. Represents nameplate efficiency and varies by horsepower.

Evaluation of an aeration system efficiency for both secondary aeration and aerobic digesters shows increasing complexity due to the inclusion of additional steps involved with the process. The components of a typical secondary aeration system are shown in Figure 2.2. There is an efficiency associated with each component of the system, but often parts are grouped together for ease of analysis.

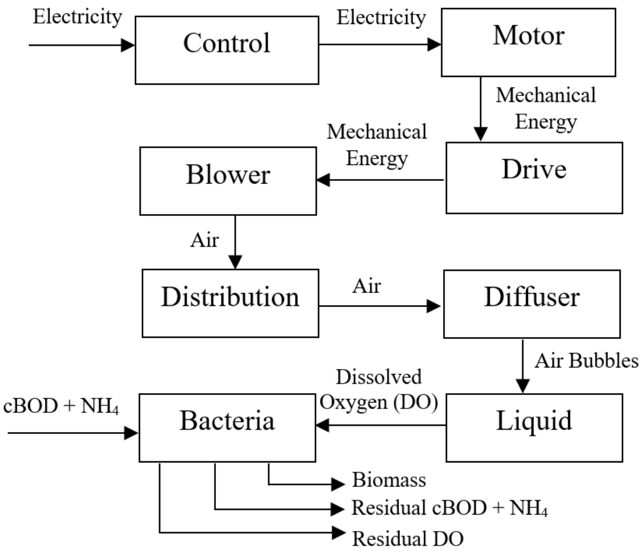
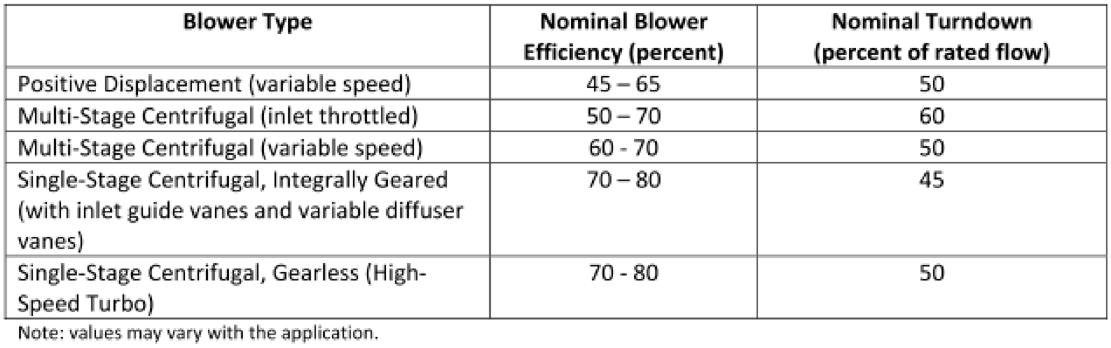


Figure 2.2: Components of a Wastewater Treatment Diffused Aeration System

Wire-to-air efficiency is used to describe the collective efficiency of the control, motor, transmission, and blower system (Mathson et al., 2016). This efficiency metric is commonly used in the design, benchmarking, and in process optimization of fan systems (DOE, 2016). In a review of the blower and control component of this system, efficiency can vary significantly among different types of fans and controls as highlighted in Table 2.3 which presents some typical blowers used in these processes (EPA, 2010).

Table 2.3: Common Efficiencies and Turndown Capacity of Blowers Used in Wastewater Treatment Plants (EPA, 2010)



Blower Type	Nominal Blower Efficiency (percent)	Nominal Turndown (percent of rated flow)
Positive Displacement (variable speed)	45 – 65	50
Multi-Stage Centrifugal (inlet throttled)	50 – 70	60
Multi-Stage Centrifugal (variable speed)	60 - 70	50
Single-Stage Centrifugal, Integrally Geared (with inlet guide vanes and variable diffuser vanes)	70 – 80	45
Single-Stage Centrifugal, Gearless (High-Speed Turbo)	70 - 80	50

Note: values may vary with the application.

Oxygen transfer efficiency (OTE) describes the amount of mass transfer of oxygen from the air to the liquid phase and is influenced by various operating and design conditions. For example, a nonporous diffuser may have efficiencies in the 9 to 13% range whereas a ceramic disc diffuser setup in a grid placement may exhibit a 25 to 35% OTE (Tchobanoglous et al., 2014). If the diffusers are placed in a basin with a lower depth, the oxygen bubbles will have a greater contact time with water leading to improved oxygen transfer. In contrast, an example of an operations influencing efficiency may be the regularity of cleaning in which diffusers that are cleaned less may provide fewer bubbles.

The biological oxygen uptake rate (OUR) of bacteria to oxidize contaminants can be influenced by factors such as the concentration, age, and type of bacteria. Research furthering this component the process has developed significantly with discoveries such as Annamox bacteria to help reduce aeration cost and use of biocatalyst and algae for treating nitrates (Tchobanoglous et al., 2014).

As with pumping systems, aeration system efficiency is significantly influenced by the type of system used and the current operating condition relative to the designed value.

Many plants have been built based on projected growth rates that were never realized and this resulted in aeration systems that were oversized that provided more air then needed and that are unable to operate at the BEP (Tchobanoglous et al., 2014).

The level of control employed in aeration systems at WWTPs can vary significantly. Many small plants in Nebraska operated aeration with no form of control or dissolved oxygen monitoring equipment (Hanna et al., 2018). Some systems may have aeration regulated based on manually measured dissolved oxygen concentrations in the basins with an operator then reducing aeration by throttling an inlet control valve to a blower or adjusting a VFD operating frequency. Other automated systems can employ a variety of control strategies that can adjust aeration and/or sludge recirculation rates based on variables such DO, Flowrate, time, SRT, Ammonia, OTE, and/or the respiratory OUR (EPA, 2010).

The large variety of components of the aeration system and variability among variables influencing them shows why there may be currently some difficulty in deriving a suitable benchmark metric for representing the energy efficiency of the system, especially in light of the current lack of quantity and quality of process data that would be needed (Chini and Stillwell, 2017). In general, it appears that there needs to be more work in delimitating how much the total system efficiency is impacted by design, operational, and environmental related factors.

2.4 Barriers to Energy Efficiency

In analyzing the barriers to energy efficiency improvements, general literature was consulted to identify common barriers reported across different sectors and particularly for the wastewater treatment industry. In general, much of the literature deals with the economic, behavioral, and organizational barriers to adoption of energy efficiency conservation measures. For the wastewater treatment industry, most literature provides discussion primarily pertaining to large treatment facilities, but there is still some discussion of barriers specifically for small systems.

2.4.1 Barriers to Energy Efficiency Reported Across Literature

A study by Sorrell et al. (2000) sought to investigate the nature and relative importance of specific theoretical barriers that are leading to an existence of an energy efficiency gap in which the cost-effective energy efficiency investments identified in energy models/estimates are not being adopted in practice. To provide a definition to this idea in the context of E2, Sorrell et al. reported a barrier as a mechanism that inhibits a decision or behavior that appears to be both energy efficient and economically efficient. The following section describes the 15 barriers investigated by Sorrell et al. (2000) and is followed with specific case studies of sectors where they were further explored. The specific listing of barriers used in the different studies is then summarized and compared at the end of the section. These barriers have been largely classified into three different perspectives: economic, behavioral, and organizational and are described on the next few pages.

The economic perspective, also referred to as neo-classical economics, relates to purely economic related based ideas in which barriers can be further sub-divided as either market failures or non-market failures.

Market failures are barriers that largely arise directly from the market that interacts with an organization. The four specific barriers described by Sorrell et al (2000) are described below.

- *Imperfect information* is an example where there is a lack of clear and useful information to an organization from the market.
- *Split incentives* are another type of market failure which arises from a party being unable to appropriate the benefits of a change which can occur when the party involved is not accountable for energy cost.
- *Adverse selection* is a market failure that arises because buyers often face difficulties in both obtaining information prior to a purchase and verifying performance after the purchase. As a result, buyers may purchase a good based on more clearly visible aspects such as the capital cost and thus not invest in the higher efficiency product.
- *Principal-agent relationships* in which the interests of one party (the principal) depend on the actions of another (the agent) and is commonly observed in hierarchy-based firms. The basis of this barrier is that the principal lacks detailed information about the activities and performance of the proposed projects by the agent and thus can result in principals requiring stringent investment criteria for projects.

Non-market failures in contrasts are related to economic barriers that exist largely independent of the influence of markets (Sorrell et al. 2000).

- *Heterogeneity* is a non-market failure that refers to the idea that although some technologies may be cost-effective on average, it may not be cost-effective in all cases leading to a lack of adoption.
- *Hidden costs* are another type that results from engineering-economic analysis failing to include additional costs and/or reductions in benefits that may result from making an E2 change.
- *Access to capital* is a third type of non-market barrier attributed to a company being unable to support projects due to a lack of available capital either from internal funds or borrowing from external sources.
- *Risk* is a non-market barrier that may relate to financial risks such as risks associated with longer paybacks with uncertainty in estimates made and may also be present in the form of technical risks such as process disruptions.

The second broad perspective of barriers described by Sorrell et al. (2000) was defined as behavioral and has been classified as a form of bounded rationality or a form of the human dimension which are described in the following points.

Bounded rationality had been described as a barrier that arises from actors not making optimizing decisions due to various constraints such as lack of time, attention, and/or ability to process information. The actors in some respects have been led to rely on imprecise routines and rules of thumb which can result in the lack of uptake of E2 practices, even when good information and incentives are provided.

The human dimension was a type of barrier reported by Sorrell et al (2000) that relates to perceptions of people and how the information is delivered and received. It had been broken into four different components and are discussed briefly below.

- The *form of information* can be a barrier and has been cited as being effective when the information is provided in the specific, personalized, vivid, simple, and timely way with respect to choices being made with the information.
- *Inertia* is another form which relates to agents resisting change because they are committed to what they are currently doing (e.g. favor preserving the status quo) and even may even act to downgrade contrary information. Making changes in practice to improve E2 often involves some uncertainty in the outcome and thus this barrier can exist from the actor's view of that uncertainty.
- *Credibility and trust* also are a form of the human dimension barrier which relates to how the actors view the reliability of the source's information on making E2 changes and whether they may act on that information provided.
- *Values* can be a potential barrier in which there may be a desire to proceed with making E2 changes based on how an actor's internal ideology aligns with the action of improving E2. If someone values the preservation of the environment, they may be more likely to act on E2 opportunities.

The last perspective reported by Sorrell et al. (2000) was based on organizational theory in which the barriers of power and culture are discussed.

- *Power* can be barriers within organizations when certain groups may hold the more formal authority to implement actions with the resources available. Since these groups may have different perspectives on key things such as where the resources are utilized, some actors may have more difficulty in making changes related to E2 as a result.
- *Culture* may be viewed as the collective values, norms, and routines of an organization that may or may not support E2 improvements.

Understanding the barriers that impede the uptake of cost-effective E2 changes is a crucial step in helping curb greenhouse gas emissions associated with energy use from all sectors. Sorrell et al. (2004) further investigated these barriers in a case study looking at why organizations impose such stringent investment criteria on E2 projects and why investments that meet these criteria, continue to be not implemented. Additionally, evaluation was made on the potential for organizational, contractual, and public policy measures to overcome them. The dependent variable of study was the ‘organizational performance in energy efficiency’ and was evaluated based on qualitative measures of energy consumption, responses to questionnaires, evidence from energy/environmental reports, energy audit reports, trends in energy efficiency, responses in interviews on energy management practices, investment opportunities, barriers to E2, and also included review of quantitative data on the extent of adoption of a number of E2 technologies that had been commonly reported in literature as available and cost-effective. This research had been carried out through 48 case studies involving organizations from the brewing, mechanical engineering, and higher education sectors in three different countries.

Investigation of these barriers by Sorrell et al. (2004) found hidden costs and access to capital to be the primary reason for not investing in E2. Some specific examples of hidden cost detailed in the study involved the overhead cost of energy management, cost of gathering information and identifying opportunities, etc. Access to capital involved specific instances of capital budgeting procedures within the organization and availability of capital to the organization. Secondary barriers identified included imperfect information as observed in instances when there is a lack of information on the organizational energy use and with split incentives where departments and/or designers may not be accountable for energy costs. The two barriers that were not found as relevant were risk and bounded rationality. Risk was associated with E2 technologies that may be subject to technical and economic investment risks for a company. Bounded rationality was based on constraints of time, attention, resources, and ability to process information leading to the use of imprecise routines and rules of thumb and was noted to neglect the small cost savings associated with E2 improvements. In addition to the evaluation of barriers, it had been highlighted that the coexistence of multiple barriers has a cumulative effect of inhibiting change. Even if some relevant barriers are addressed, others may need to be resolved before implementation can occur. Initiatives to encourage cost-effective investments must understand and address each aspect of the issue if they are to be successful. The research proposed by others included a focus on the determinants of success in energy management instead of reasons for failure. Another recommendation relevant to this study is the need for more work on the costs and benefits of previous energy efficiency programs and the efficacy of proposed policy options. In addition to these case studies carried out by Sorrell et al., several other studies have investigated these barriers in different sectors.

A study conducted by Thollander and Ottosson (2008) evaluated barriers to E2 specifically in the Swedish pulp and paper industry. The aim of the study was to identify if there was an existence of the E2 gap present in the industry and if so, what specific barriers may be inhibiting the implementation of cost-effective energy efficiency measures and what driving forces stressing implementation may be present. Barriers were classified as either market-related or as behavioral and organizational-related. The study had been carried out with the use of a questionnaire centering on barriers to and driving forces for energy efficiency. It also included questions on whether respondents thought there exist cost-effective energy efficiency measures at their mill. The study achieved a response rate of 40 from a sample of 59 mills (68%). All but one respondent in the study agreed that cost-effective E2 measures exist at their plant. The study found that technical risk disruptions and the cost of production disruptions/hassle/inconvenience were perceived as the largest and second largest barriers respectively to making energy E2 changes. Significant E2 improvements often require the stopping of the plants that have continuous operations which leads to a loss in production. Other notable barriers included technology not being appropriate for the plants, lack of time and other priorities, lack of access to capital, and slim organization.

In a study by Trianni et al. (2013), barriers to making E2 changes were investigated at the European foundry industry as case studies with the use of semi-structured interviews and questionnaires. There were 831 foundries that the survey was sent to with 125 foundries responding and 65 completing the survey completely (8% response rate). The sample was then broken up by size, types of alloys produced and based on having a prior energy audit. Barriers in the study were also evaluated with a Likert-type scale asking respondents to evaluate how relevant they perceive certain barriers to making E2 changes. In addition to evaluating the magnitude of barriers, correlations between barriers were investigated with use of the Pearson r correlation coefficient. The study pointed out there is a general lack of resources in terms of time and capital and the need to guarantee the continuity of business being in this sector. There were differences in perceived barriers observed between small and large enterprises which had been pointed out by previous studies as well. For small firms, there appeared to be a deficiency of special personal dedicated to researching E2 opportunities. Another interesting finding of the study was that plants that had received energy audits generally reported a higher perception of barriers being relevant which may have been due to an increase in awareness of the effective difficulties in undertaking an E2 change.

To help summarize the barriers evaluated in these studies, Table 2.4 lists the specific barriers listed in surveys used. The barriers are listed in the first column with the other columns indicating whether the barriers were used with exact wording, with similar wording, or not at all. Barriers that were found as the most relevant among studies are noted and listed first. The barriers found as least relevant are also indicated for each of the barriers in the studies and listed at the end of the table. Across these three studies, it can be observed that the largest barriers relate to non-market failures including cost and technical risks associated with production upsets, lack of access to capital, and lack of time or other priorities.

Table 2.4: Summary of Barriers to Energy Efficiency Investigated in Other Studies

Barrier Investigated in Study	**(Sorrell et al., 2000)**	**(Trianni et al., 2013)**	**(Thollander and Ottosson, 2008)**
Lack of capital	E, MR	S, MR	S, MR
Cost of production disruptions/hassle/inconvenience	E, MR	E, MR	E, MR
Lack of time/other priorities	E, MR	E, MR	E, MR
Technical risks	E, MR	S, MR	S, MR
Other priorities for capital investment	E, MR	E, MR	E
Cost of identifying opportunities, analyzing cost-effectiveness and tendering	E, MR	E	E
Low priority given to energy management	E, MR	E	S
Lack of budget funding	-	E, MR	E
Department/individuals not accountable for energy costs	E, MR	E	S, LR
Slim organization	-	E	E, MR
Technology inappropriate at this site	E	E	S, MR
Possible poor performance of equipment	E	E	E
Business/market uncertainty	E	-	-
Lack of information/poor quality information on energy efficiency opportunities	E	S	S
Difficulty/cost of obtaining information on the energy consumption of purchased equipment	E	E	E, LR
Lack of technical skills	E	E	E
Lack of staff awareness	E	E	E
Strict adherence to capital investment	E	-	-
Energy manager lacks influence	E	E	E
Lack of sub-metering	-	E	E
Long decision chains	-	E, LR	E
Uncertainty regarding company’s future	-	E	E, LR
Energy objectives not integrated into operating, maintenance or purchasing procedures	E	E	E, LR
Cost of staff replacement, retirement, retraining	E	E, LR	E, LR
Conflicts of interest within the company	E	E, LR	S, LR
E = Barrier used with exact wording, S = Barrier used with similar wording, “-“ = Barrier not used in study MR = Barrier found to be most relevant, LR = Barrier found as least relevant			

Another related study conducted by Kuppig (2015) investigated the business motivations of implementation of sustainability improvements at businesses previously assisted by the UNL Partners in Pollution Prevention (P3) program. Kupping had asked businesses to identify the specific reasons for not implementing specific recommendations which can be viewed as barriers. Kupping had also found similar barriers found as relevant in the prior study including:

- Not technically feasible
- Lack of capital (financing)
- Insufficient financial payback
- Other priorities for capital investments
- Risk of production disruption/inconvenience/slowdown
- Uncertainty/lack of confidence in technology (quality, cost, benefits)

Some additional barriers that were identified as relevant in implementing energy and waste reduction recommendations included the following points. Lack of staff awareness and limited in-plant expertise/capability show that there are some serious limitations for some companies in carrying out changes which highlights the potential value of technical assistance providers external to the company in helping over coming some of these barriers.

- Lack of perceived environmental/risk reduction benefits
- Limited in-plant expertise/capability
- Lack of staff awareness/willingness to change
- Customer specifications

- Insufficient information regarding recommendation
- Difficulty in coordinating between units within company

A broad analysis of barriers to environmental innovation was conducted in Spain utilizing data from the Community Innovation Survey (CIS) which included 6,553 firms from 44 industries (Souto and Rodriguez, 2015). The study evaluated how the relevancy of barriers are different among firms that are pursuing environmental innovation relative to firms that are not. The Wilcoxon-Mann-Whitney test was used to compare the two groups. The most important barriers identified among firms were: lack of funds, high innovation costs, lack of external funding sources, and uncertain demand for innovative goods and services. It was found that several barriers had greater relevancy to firms pursuing innovation compared to plants that were not. Barriers related to this study are shown below along with the percentage of plants not pursuing innovation compared to the ones that are in addition to the resulting p-value of the Wilcoxon-Mann-Whitney test.

- Lack of funds (81% versus 92% of firms, $p < 0.001$)
- Lack of external funding source (77% versus 89% of firms, $p < 0.001$)
- High innovation cost (80% versus 89% of firms, $p < 0.001$)
- Lack of qualified staff (68% versus 84% of plants, $p < 0.001$)
- Lack of information on technology (68% versus 84% of plants, $p < 0.001$)
- Lack of information on markets (67% versus 84% of plants, $p < 0.001$)

2.4.2 Barriers Related to Small Wastewater Treatment Systems

In a review of the literature on barriers to E2 at specifically wastewater treatment plants, there were only a few reports and studies discussing this and no studies were identified focusing only on small plants. Despite not being backed with empirical data, a report on energy conservation measures by the EPA (2010) had stated that the real barriers to making E2 improvements at WWTPs are due to a lack of awareness or understanding of the many benefits of investing in energy efficiency projects and the many programs that are available for financing E2 projects. In terms of making changes, WWTPs face a large mixture of barriers that have also been observed in other sectors.

A study by Kerri (1993) had developed a self-instruction training program for operators of small plants due to the significant barriers they have in maintaining effective operation. In general, these same barriers would impede E2 improvements from being made. Operators of small plants frequently live in remote areas where operator training is not always readily available. Secondly, their jobs are very complex requiring a broad knowledge and skill set to run their plants effectively and thus the availability of quality operator training presents a real barrier for operators in improving E2. In a statewide assessment of the wastewater sector, the New York State Energy Research and Development Authority (NYSERDA, 2008) also highlighted the issue of operational expertise in niche areas of plant operations for plants including energy management.

Another critical barrier facing small plants in achieving improved energy efficiency is the availability of quality process data. Chini and Stillwell (2017) had investigated what kind of energy and water flowrate data was collected in large utilities within all 50 states and with populations larger than 100,000. They found that there were variable degrees of data being collected at plants on both energy and flowrate data (e.g. data collected on a daily, monthly, or annual basis). In addition to this, they identified some constraints in gathering the data such as the need for non-disclosure agreements to release information and time/cost by municipalities to gather the data. In theory, these observations of data quantity issues and barriers to gathering data would be more prevalent in small communities where resources are far scarcer.

Data on the pollutant loadings to the plants and effluent characteristics (e.g. CBOD and NH_3) are even more infrequently measured which limits effective evaluation of plant performance. For example, influent CBOD is only measured annually and effluent is typically only measured monthly in Nebraska which likely does not provide a very representative sample (Hanna, 2017). In addition to the lower frequency of sampling, it has been pointed out that small communities can also exhibit more extreme flow and concentration fluctuations which further compounds the issue of obtaining quality data (Boller, 1997). As noted in Section 2.2 and 2.3, the data are needed for benchmarking and evaluation when carrying out energy management. Secondly, feedback data to the operator on how certain process control changes are impacting water quality is essential to minimizing energy use while maintaining compliance with state and federal regulations. Since the primary goal of WWTPs is to reduce pollution to protect public health, there is a tendency to be more conservative when making energy efficiency changes that could negatively impact process performance and this is even more common with smaller facilities that have smaller cost savings achievable with such changes (NYSERDA, 2008).

From an organizational perspective, there is the issue that operating personnel do not see the utility bills and thus have no responsibility for reducing energy usage. (NYSERDA, 2008). Additionally, it had been reported that a lack of understanding by political officials of the technical and economic aspects of implementing E2 and unwillingness to invest in improvement that will fail to result in savings within their term serving in office. There also has been resistance from regulators and consultants to making any change that may reduce the “public safety buffer” and this results in the design and use of oversized equipment which can be inefficient (NYSERDA, 2008). Secondly, it was stated that the regulators are generally more conservative and thus are less willing to accept new technologies that may be more efficient in addition to revising design standards that may reflect the use of these newer technologies.

As noted in previous studies, financial barriers are commonly a barrier in all sectors and this was also emphasized to be relevant for wastewater treatment facilities (NYSERDA, 2008). The lack of ability to get short-term funding for projects without creating volatility in user rates was noted as a barrier. Since WWTPs are just a component of a municipality’s budget, there may be a tendency for savings achieved by improvements to be returned to the general budget and thus they may not be reinvested in the plant which may discourage making the changes in the first place. A final economic barrier observed and that which may be very relevant to Nebraska is the low cost of electricity resulting in high paybacks on investment that make projects either unappealing or impractical.

2.5 E2 Opportunities at Small Wastewater Treatment Facilities

Improving the energy efficiency of a wastewater treatment system can be carried out in various ways and generally these changes can be classified into three different types (EPA, 2013). The first type of change involves replacing an existing piece of equipment with a higher efficiency alternative such as premium efficiency motor or more efficient belt drive. The second type of change involves improving operation of existing infrastructure to reduce energy use such optimizing use of the aeration system. The third type of change would involve some form of change to the facility buildings such as improving insulation or replacing heating. It should be emphasized that the energy reduction potentials and paybacks reported in literature are primarily based on analysis of large plants and the actual potential for cost-effective modifications will be largely dependent on the size of the system, time of active operation, current system design, current system efficiency, and energy costs (EPRI 2013; Public Commission of Wisconsin, 2016).

2.5.1 Pumping Systems

To reduce the energy use of pumping systems, operational or infrastructure changes can be made to pumping systems (EPA, 2010). Flow can be regulated by throttling valves or by adjusting the speed of the system with a VFD to reduce energy. In contrast to operational changes, engineers can resize these systems to better fit the design conditions to the operating conditions to operate closer to the BEP improving efficiency. A pump may be installed to pump under more than one condition and may be less efficient compared to systems with pumps with discrete functions. An example of this would be a pump used for moving Return Activated Sludge (RAS) and Waste Activated Sludge (WAS) with each process having a different hydraulic head to overcome. In this case, the use of a separate pump or use of a VFD may help improve the efficiency of the system.

Additionally, higher efficiency pumps are available that can pump water at a lower power demand relative to less efficient ones. Several plants have been able to reduce pumping energy with optimization of pumping systems having a reported energy saving potential of 15-30 percentage of the unit process energy use and typical paybacks of 0.25-3 years (Public Service Commission of Wisconsin, 2016). Long-term pump testing and maintenance programs can be a useful management practice to ensure pumps are operating efficiently. It has been recommended to test the efficiency of these systems about every two to three years. Life-Cycle Cost estimates should be made when evaluating major pumping system improvements (Lawrence Berkeley National Laboratory, 2006).

2.5.2 Aeration Systems

As outlined in Section 2.3, aeration systems have various components that impact the efficiency of the system and often account for the largest energy use in plants. As with pumping systems, savings can be realized by installing more efficient equipment, improving system design, or improving the operation of existing infrastructure. These measures can be applied to both diffused aeration systems or mechanical aerator systems (EPA, 2010).

As noted previously, oversized systems have occurred due to design population growth projections not being realized and thus resizing of blower systems can improve efficiency. As with pumping systems, use of blowers for discrete purposes can also help improve efficiency. The type of diffusers present in the aeration basin can be changed to improve the aeration supply being provided with respect to treatment goals (Eckenfelder and Grau, 1998). Use of intermittent aeration is also a method of reducing energy use associated with aerations systems. In terms of operational changes, air supply can be regulated with speed control devices or direct control devices including adjustment of inlet air dampers, inlet vanes, or outlet dampers (Liptak, 2006). Adjustment of outlet dampers will not result in direct energy savings and thus, use of the other methods is recommended. VFDs are commonly used for varying a fan speed and can offer significant savings. Some motors are also designed to operate at variable speeds and can be used to regulate air supply. With the use of any of these methods, care needs to be taken to ensure that the minimum dissolved oxygen concentrations are maintained in the basins and that adequate aeration is provided for mixing.

In a review of aeration control, Åmand et al. (2013) had presented case studies of various automated aeration control schemes used to optimize process performance by achieving specific effluent water characteristic goals while minimizing energy usage. It can be seen from this literature that there is a heavy emphasis being put into process control optimization of secondary aeration systems and that there is a wide range of saving potential depending on the desired treatment goals. Optimization of aeration systems has been reported to yield 30-70% unit process energy savings with paybacks possible in the 3-7 year range (Public Service Commission of Wisconsin, 2016).

Dissolved oxygen control was reported to have savings potentials in the 20-50% range with a simple payback of around 2-3 years. It should be emphasized, that these reported figures are mostly representative of larger plants and actual potential savings are dependent on several factors noted previously.

2.5.3 Solids Management

Since aerobic digestion is the primary form of stabilization in small plants and involves largely the same components as the secondary aeration system, many of the same conservation measures can be employed to reduce aeration associated with stabilization of waste sludge. Use of automated DO control has been reported to cut digester energy requirements by 20 to 50 percent (Public Service Commission of Wisconsin, 2016). An additional energy conservation measure for these systems is reducing the overall digestion time by meeting the vector attraction criteria using the specific oxygen uptake rate (SOUR). This test can be used to evaluate if the sludge has been aerated for long enough to stabilize the sludge, so it can be disposed of. If sludge is held for a longer time, additional oxygen and energy will need to be supplied to ensure adequate mixing and will ultimately make the process less energy efficient. Foladori et al. (2015) had also noted that the use of discrete blowers and air supply lines to an aerobic digester basins can allow for greater ease to adjust aeration.

2.5.4 Building Lighting and Heating

Improvements in building performance is an area of work that extends well beyond wastewater treatment plants and has been heavily covered by ENERGY STAR®

(2014), a U.S. EPA program aimed at helping reduce global warming through improving energy efficiency.

A study conducted by the EPA (1978) had analyzed the energy usage associated with construction, electrical energy, chemical use, sludge hauling, digester heating, and space heating for plants with design flowrates of 1 MGD to 100 MGD. The report also estimated that 5-10% of the operating energy usage was for heating and that 80% could be recovered from the use of energy wheels. Improvements to lighting operation have been reported to have energy saving potential of 15 to 90 percent. Other recommendations related to building improvements include: maintaining ventilation devices, installing VFDs on-air control devices, and installing higher efficiency lighting and HVAC systems in general (Public Service Commission of Wisconsin, 2016).

2.6 Integration of E2 Design Standards for Wastewater Treatment Plants

Since cost-effective energy efficient retrofits may not always be feasible at small wastewater treatment plants, examination of design guidelines was an equally important area to review. In a review of state design guidelines nationwide for WWTPs, Cantewell et al. (2010) had pointed to the clear lack of consideration of E2 in design standards in almost all states with only 3 of 35 states that responded to the study noting that they include E2 considerations. Furthermore, the current guidelines recommended for design are based on meeting maximum loads over 20-year periods which can lead to over-sized and inefficient systems, especially if the population growth projections used for the original designs are not actualized, which has been observed with many small Nebraska communities. Cantewell et al. had provided some example guidelines that could be included in the design guidelines created by wastewater treatment organizations.

A review of the most recent version of the *Recommended Standards for Wastewater Facilities*, commonly referred to as the “Ten State Standards”, and used by engineers in Nebraska for design showed that some considerations for E2 had been recommended by the study of Cantewell et al. were now included (Great Lakes-Upper Mississippi River Board of State and Provincial Public Health and Environmental Managers, 2014). It was recommended that careful consideration should be given in the design of aeration systems to maximize oxygen utilization per unit of power input and that systems should be designed to match diurnal organic load variation. Use of multiple smaller blowers and providing a design that allows aeration systems the capacity to vary air supply was also being recommended. A specific recommendation that had been provided by Cantewell et al., but not included was an analysis of the energy savings attributed to each individual process components (e.g., drive, motor, and method of control) in addition to a cost analysis of the system integrated as a whole. Additionally, the recommendation of using a Life Cycle Cost Analysis (LCCA) to evaluate the energy savings attributable to incrementally scalable system design and the inclusion of a sensitivity analysis that considers how energy supply cost volatility may affect the LCCA was not observed in the current design standards. Consideration of these additional factors could aid design engineers in providing a more comprehensive analysis that could be used to help communicate the cost-effectiveness of some E2 designs to towns.

Chapter 3: Methods

3.1 Introduction

In performing this study, data had been collected and analyzed from surveys of plant operators, utility bills and water characteristic data of plants, and from energy audits performed at several plants. The process involved preparation of data collection materials and then data collection by undergraduate and graduate engineering students. Upon completion of this process, the analysis was performed by first organizing the data, visualization of the data, and applying statistics to help answer research questions. Discussion and conclusions were provided based on results obtained from analysis of the data. The following sections detail the specific steps taken to conduct, 1.) a survey of operators that was used to evaluate impacts from the past E2 benchmarking project and in evaluating perceived barriers to making E2 changes and 2.) the analysis of unit process energy consumption at several plants in addition to methods used in conducting energy audits of the plants.

3.2 Benchmarking and Follow-up Survey

3.2.1 Benchmarking

The basis of this study was following up on the past energy benchmarking project conducted in the state (Hanna, 2017). Prior to the development of the models in the study, energy intensity metrics based on flow were generated for the plants and presented in an infographic in a letter that was provided to town operators and administration to communicate the initial findings. Additional information on potential energy conservation measures observed during the site visit was included in the letter. The

Nebraska Energy Office had provided a cover letter that included a solicitation of energy audits and 1% loans that were available for communities to help analyze and fund projects. An example letter provided to towns is presented in Appendix A.

3.2.2 Follow-up Survey

The first intent of the survey was to gauge the perceived impact of the site-visit and follow-up benchmarking letter on the operator's perception of awareness of energy use at their plant. Secondly, it was to investigate if any operational or infrastructural changes had been made in the past year. Table 3.1 on the next page summarizes the questions used for this part of the survey. The first question was used for screening of operators who did not recall the project or that may have not been involved with the project. It was assumed that an operator that does not recall the site visit by the student or the follow-up benchmarking letter would be unable to provide a representative sample. The following ideas were described as having awareness of energy efficiency to ensure a consistent understanding of the terminology being used and were based on a review of literature pertaining to energy management (EPA, 2010):

- Understanding how much energy is being used at your plant, where it is being used, and how it compares to other plants;
- Knowing if there are potential E2 opportunities possible at your plant; and
- Knowing where the E2 opportunities exist in the plant.

Table 3.1: Summary of Questions for Identifying E2 Improvements Made at Plants

Do you recall meeting with a student last summer for an energy efficiency benchmarking project? ☐ Yes ☐ No ☐ Uncertain
On a scale of 1 to 5*, how much did this interaction improve your awareness of your plant's energy use? *(1 = Awareness not increased at all, 3= Somewhat improved my awareness, 5 = Strongly improved my awareness)
Have you changed any operational strategies in the past year that may have resulted in improved energy efficiency? (1= No changes made, 3= Minor changes made, 5= Significant changes made) If changes were made, please indicate what changes were made: _________________________
Do you remember receiving the letter regarding energy efficiency benchmarking of your facility? ☐Yes ☐No ☐ Uncertain
On a scale of 1 to 5, did the information showing your plant's energy intensity metric and specific observations from the visit help improve your awareness of your plant's energy use? (1 = Awareness not increased at all, 3= Somewhat improved my awareness, 5 = Strongly improved my awareness)
Have any changes been made at the plant in terms of infrastructure because of the letter? (1= No changes made, 3= Minor changes made, 5= Significant changes made): If changes were made, please indicate what changes were made: ____

The second portion of the survey asked operators how relevant specific barriers are to making energy efficiency changes at their plant. Table 3.2 on the next page summarizes the questions used and related literature from which the questions were derived. The first question was used to help identify the potential existence of an energy efficiency gap as had been done in a study by Thollander and Ottosson (2008). Despite being an imperfect method of measuring the idea of an E2 gap, it can still provide some general insight into how operators are perceiving the potential for change within their plant. The specific Likert-type scale labels used in the study were based on the ones used by Trianni et al. (2013). Similar Likert-type scales were also observed in other studies and this allowed for a simpler comparison of results to literature (Thollander and Ottosson, 2008; Sorrell et al., 2000). The studies referenced for development of the survey had the commonality of presenting a list of specific barriers related to making energy efficiency improvements and asking the participants to evaluate the relevance or importance of the barrier on a Likert-type scale. Some of the listed barriers used in this study were not used verbatim from the other studies due to being structured for public municipalities and not industrial clients. Some of the barriers also were recommended to be included based on discussions with wastewater treatment plant operator trainers from the Nebraska Rural Water Association (NeRWA) and the League of Nebraska Municipalities (LNM).

Table 3.2: Summary of questions about barriers to energy efficiency changes

Specific Questions
Question 1: Do you think that there are cost-effective energy efficiency opportunities at your plant?[1] ☐Yes ☐No ☐ Uncertain
Question 2: On a scale of 1 to 5*, please indicate how relevant each of the following barriers are to implementation of energy efficiency related infrastructure improvements and/or operational changes at your wastewater plant. (examples of improvements may include: motor/pump/blower replacements, VFD installation, dissolved oxygen controls, new air diffusers, building climate control/light improvements, etc.) *(1= Not Relevant), (2= Slightly Relevant), (3= Relevant), (4= Very Relevant), (5= Absolutely Relevant) _______: Access to capital [1,2,3] _______: Other priorities for capital investments[1,3] _______: Perceived lack of payback on investment (Risk of return on investment) _______: Cost of identifying opportunities/analyzing cost effectiveness and tendering[1,3] _______: Lack of support from city council/ utility board ________: Lack of staff to coordinate/ implement changes _______: Would require additional operator training _______: Staff not accountable for energy costs[1,3] _______: Technical risks such as risk of process disruptions [1,2,3] _______: Lack of electrical sub-metering [1,2] ________: Poor information quality regarding energy efficiency opportunities[1, 2, 3] ________: Lack of time or other priorities [1,2,3] _______: Lack of staff awareness[1,2,3] _______: Preference to keep things the way they are
[1]Barrier evaluated in study by Thollander & Ottosson (2008) [2]Barrier evaluated in the study by Trianni et al. (2013) [3]Barrier evaluated in the study by Sorrell et al. (2004)

Since the study involved perceptions of human subjects, the project had been reviewed and approved by the NU Institutional Review Board (IRB). A participant informed consent form was also created for the project and a copy is provided in Appendix A. Additional documentation required by the IRB included sources of funding for the project, approval documentation from supporting agencies involved, and supplemental information involved with the project which is provided in Appendix A.

3.2.3 Survey Administration

The survey was provided to wastewater treatment plant operators by two different methods. The first method of surveying was conducted by attending in-class operator training sessions hosted by the Nebraska Rural Waster Association (NeRWA) and in-class training sessions held by the League of Nebraska Municipalities (LNM). This involved an approximate 1-hour training session relating to energy efficiency at wastewater treatment plants prior to surveying the operators. The presentation involved a definition of the terms used in the survey. A copy of the powerpoint used in this training session is provided in Appendix A. The second method used to survey operators was through a mailing followed by phone calls to the operators. The survey sent by mail also included a cover letter describing the intent of the research and a participant consent form. These documents can be found in Appendix A. Mailings were sent with a pre-paid return envelope to reduce the burden on the operator. Mailings were sent out at the end of October of 2017 with follow-up phone calls conducted in early-mid November of 2017. The phone call was provided to ensure that the operators had received the survey, to help clarify any of the terminology used, and to answer any questions the operator may have had regarding the survey. Contact information for the mailing and phone calls came from data previously collected by the Partners in Pollution Prevention (P3) Program when conducting the energy efficiency benchmarking project in 2016. These originally had been provided by the LNM or were extracted from online sources including Nebraska Department of Environmental Quality's (NDEQ) inspection reports, permit applications, and/or discharge monitoring reports.

Communities that responded to the survey were then contacted to obtain additional electricity and gas usage bills to evaluate changes in energy use at the plants. Additional water quantity and quality characteristics were extracted from Environmental Compliance History Online (ECHO) database and the NDEQ online database for use in evaluating the change in the energy efficiency of the plants.

3.2.4 Population and Response Rate

The population of this study was composed of small mechanical wastewater treatment plants defined as towns with populations of less than 10,000 or average flowrates less than 1.5 MGD. There were 109 plants meeting this criterion in Nebraska. A summary of the sampling within the study and responses to the question about making changes are presented on the next page in Figure 3.1, with the size of each box being proportional to the number of plants in the indicated category. Data for benchmarking these plants had been collected on 95 of these plants of which 89 had been visited to confirm data collected for the study. Plants exhibiting data quality issues were removed from this set before being benchmarked and having a letter mailed to the community. The sample of this study was only of plants that had participated in the past energy efficiency benchmarking project conducted in the state and that did not show data quality issues (Hanna, 2017). Using this criterion, the final sample size was narrowed down to 83 plants. An initial surveying carried out at 5 operator training sessions throughout the state only yielded responses from 5 communities (6% response rate). The surveys were then mailed out to the 78 remaining communities with follow-up calls resulted in a larger response of 46 communities yielding a total response rate of 51 communities (61%).

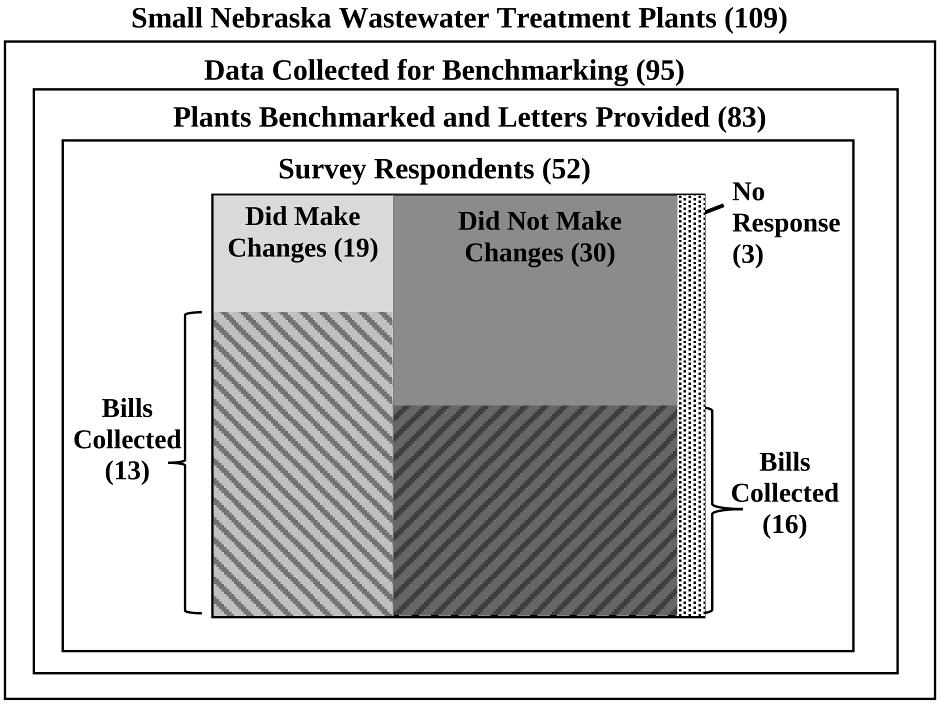


Figure 3.1: Breakdown of the Population Sample and Responses for the Benchmarking Project and Follow-up Survey

There were 3 survey respondents that did not fully complete the first portion of the survey due to not recalling the project and 41 responses were made to the barriers section of the survey with 18 of the operators of that group reporting making changes and 21 reporting not making changes.

3.2.5 Data Analysis

The questions of the survey relating to awareness received almost a uniform response noting that process of benchmarking through the site visit and letter somewhat increased their awareness to E2. Since there was not a large enough variation among responses, no statistical analysis was performed for this data.

Respondents that noted making changes and reporting the specific changes made were compared against plants that did not report making changes. To evaluate the impact of changes made on the plant's actual energy usage a baseline performance was first established as recommended by the U.S. Environmental Protection Agency (2010) and also Wisconsin Focus on Energy (2016) in carrying out an energy management plan for wastewater treatment systems. The annual energy usage of 2016, 2015, and 2014 was averaged and compared against 2017 to account for year-to-year variation in energy consumption that had been observed across plants in the previous years. Reports from the benchmarking project were consulted to ensure that there were no anomalies occurring with energy usage of the plants sampled. This estimate is described by the following equation, where $\%\Delta E$ is the percent change in energy usage, E_{2017} is the annual energy usage of the plant in 2017, and $E_{Avg,2014-2016}$ is the average annual energy usage of 2014 through 2016. The same analysis was also applied in evaluating the percent reduction in flowrate and energy intensity of the treatment facility.

$$\%\Delta E = (E_{2017} - E_{Avg,2014-2016})/E_{2017} * 100\%$$

The mean values of changes in percent energy use of these two groups were compared using a one-sided t-test and Wilcoxon signed-rank test. The mean values of perceived barriers were also compared across both groups using the same methods. The two different statistical analysis were used due to reported contradictions and uncertainties reported in literature on which tests may be appropriate for analyzing means of small samples involving particularly non-normal distributions and ordinal data (Meek et al., 2007). The statistical technique has been reported to be more robust for use when analyzing dependent variables that are ordinal compared to parametric alternatives (Mann and Whitney, 1947; Wilcoxon, 1945). The first hypothesis tested was that the plants reporting making changes would a have smaller mean a percent reduction in energy usage compared to plants not reporting making changes. In evaluating the means of perceived barriers of the two groups, the hypothesis was that plants not making changes would perceive barriers as less relevant than plants reporting making changes.

The barriers ranked by participants in this study were averaged among all plants then were ranked in terms of the largest perceived barriers to least. This approach of evaluating the largest perceived barriers was used in studies by Thollander & Ottosson (2008) and Trianni et al. (2013). The Pearson r correlation coefficient and Kendall tau correlation coefficient were used in evaluating if any of the perceived barriers were correlated with each other. The same analysis had been performed by Trianni et al. (2013) utilizing the Pearson r correlation coefficient to analyze correlations among barriers and had shown several barriers that appeared to be slightly correlated. The Kendall tau coefficient was used because it does not rely on the assumption of the data being normally distributed which did not hold with data being analyzed in this study. The Pearson r correlation coefficient was also used for comparison to literature.

3.3 Energy Assessments and Unit Process Energy Assessment

3.3.1 Plant Selection and General Assessment Methodology

Energy assessments were carried out on 15 previously benchmarked wastewater treatment plants. To select plants for assessment, the overall set of benchmarked plants were categorized based on their observed energy intensity, Assessing Wastewater Infrastructure Needs (AWIN) score (NDEQ, 2014), and perceived interest for an audit. The facilities were then solicited by phone for participation in the assessments. The 15 plants that had agreed to participate were then divided up into three groups to have undergraduate engineering interns lead five assessments each. The assessments were carried out with the supervision of UNL faculty, graduate students, and a staffed energy engineer.

The assessment began with obtaining electricity and gas utility bills from the town to be analyzed. Plant water characteristic data and weather data were also collected and analyzed in conjunction with the utility bills. Following this, the lead student had visited the plant to collect plant-specific information and confirm data already collected. Key information included equipment nameplate data, equipment operation information (operating times of equipment, pumping rates, etc.), and other information pertaining to the infrastructure and operations of the plant. Data collected from the 2016 benchmarking project was also confirmed during the site visits. The specific data collection forms used for the assessments are provided in Appendix D. The goal following the first visit was to use the collected data to perform an initial quantification of the unit process power and energy usage to identify the most energy-intensive processes. Data quality validation was performed by comparing the estimated energy usage of equipment against the plant’s overall utility bills. The first visit was used to also prepare a list of specific energy conservation measures to be further investigated. The specific recommendations identified were then discussed with the consultants of each plant to confirm the applicability of changes and to gather more information on what could be done. Specific recommendations were also discussed with the local state regulatory agency to avoid plant compliance issues resulting from changes. Once data from the first visit had been analyzed, a second visit was carried out to collect recommendation specific information, to conduct electrical sub-metering of equipment, and to collect any data that had not been gathered during the initial visit. Some additional visits had been made to certain plants requiring additional data collection. A detailed report of the findings of the energy audits was prepared and shared with each community. Each report included a description of the current system's process energy use and specific recommendations on how to improve their energy efficiency including projected savings and implementation cost.

Electrical metering and further analysis of energy use were conducted at 8 of the original 15 plants and are described in the following section. Selection of the plants for metering was based on size, process complexity, operator availability, and was used to help better quantify the energy use of processes and in energy reduction estimates for recommended changes. Table 3.3 on the next page presents some process information on the plants. Each plant is listed in a column with process information being listed in the rows. This includes the design flowrate and current hydraulic loading, plant energy use, plant energy intensity, and information on the type and control methods of treatment equipment.

Table 3.3: Process Information of Sub-metered WWTPs

Process Information		**Plant A**	**Plant B**	**Plant C**	**Plant D**	**Plant E**	**Plant F**	**Plant G**	**Plant H**
Design Flowrate (MGD)		0.33	0.220	0.365	0.270	0.12	0.168	0.560	0.350
Average Flowrate (MGD)		0.197	0.127	0.254	0.107	0.058	0.070	0.260	0.164
Percent Design Flowrate (%)		60%	58%	70%	40%	48%	42%	46%	47%
Energy Use (MWh/yr)		250	429	535	331	143	115	670	804
Energy Intensity (MWh/MG)		3.6	9.3	5.8	8.1	6.1	5.15	8.33	12
Headworks Pumping[1]		FL	CO	-	-	FL	FL	VFD	FL
Preliminary Treatment[2]		GR	GR	GR, AGR	GR, VGR	GR	GR	GR, AU	GR, AU
Secondary Treatment	Process Type[3]	EA	EA	CSR	SBR	OD	OD	SBR	SBR
	Type of Control[4]	NC	ICV	TC	AC	NC	NC	AC	VFD, AC
	Aerator Type[5]	FB	CB	FB	FB	MA	MA	FB	CB
Aerobic Digestion	Type of Control[4]	NC	ICV	TC	TC	NC	NC	TC	VFD, AC
	Aerator Type[5]	FB	CB	FB	FB	OP	OP	FB	CB

[1] **Pump Control:** FL = Pressure Floats, CO = Constant Operation, VFD = Variable Frequency Drive

[2] **Preliminary Treatment:** GR = Grinder, AGR = Aerated Grit Removal, VGR = Vortex Grit Removal, AU = Auger

[3] **Secondary Process Type:** EA = Extended Aeration, CSR = Continuous Sequencing Reactor, OD = Oxidation Ditch, SBR = Sequencing Batch Reactor

[4] **Type of Aeration Control:** NC = No Control, TC = Timer Control, AC = Automated DO Control, ICV = Inlet Control Valve Throttling Control

[5] **Aerator Type:** FB = Fine Bubble Diffusers, CB = Corse Bubble Diffusers, MA = Mechanical Aerator, OP = Open Pipe

3.3.2 Electrical Measurements

Electrical sub-metering was carried out on about every major mechanical unit for the select plants for a total of 59 measurements. A certified electrician made current and voltage measurements on each phase of each unit. Current measurements were made with use of HOBO UX120-006M analog data logger and CTV amp split-core AC current sensors (ONSET, 2018). Voltage measurements were carried out using the FLUKE® 115 True RMS Multimeter (FLUKE®, 2018). The motor load was estimated with a method documented by the Department of Energy Advanced Manufacturing Office (DOE, 2014). Some continuous measurements of true power was made with use of a TED Pro 1200 electric meter (TED®, 2018) and/or current were also conducted when possible. This data was used in conjunction with motor nameplate data to estimate the motor load. The estimate was made by the following expression:

$$Motor\ Load = \left(\frac{I_{Measured}}{I_{Nameplate}}\right) x \left(\frac{V_{Measured}}{V_{Nameplate}}\right)$$

where $I_{Measured}$ is the averaged 3-phase measured current, $I_{Nameplate}$ is the nameplate full-load current, $V_{Measured}$ is the averaged measured 3-phase voltage, and $V_{Nameplate}$ is the nameplate full-load voltage. This method assumes that the operating power factor of the motor is equivalent to the nameplate full-load power factor which may be a reasonable estimate for motors above 50% load in which the power factor has been reported to be relatively close to the full load power factor (DOE, 2014). It had been shown by Young and Koopman (1991) that many of the smaller motors at a plant may be oversized and over loaded resulting in a lower power factor, thus the estimated energy use made on underloaded motors may be low. However, these smaller motors typically only account for a small portion of the collective energy use and thus may not influence comparisons of the total energy estimates to the bills too much. The electrical power of equipment was estimated with the following expression:

$$P_{Electrical} = \left(P_{Nameplate}\right)x(Motor\ Load)x(\frac{0.7457kW}{HP})/(\eta_{Motor})$$

where $P_{Electrical}$ is the electrical power drawn by the motor, $P_{Nameplate}$ is the nameplate mechanical horsepower provided by motor, and η_{Motor} is the efficiency of the motor in converting the electrical energy to mechanical energy. The estimated electrical power was then multiplied by estimated or documented operating times of equipment to determine their net energy consumption over a time interval. This was represented by the following expression:

$$E_{Electrical} = (P_{Electrical})x(t_{operation})$$

where $E_{Electrical}$ is the electricity consumption of a unit over a certain timeframe, and $t_{operation}$ is the operating time of the unit over a given time interval. Some units such as heaters have highly variable and unknown operating times due to being under automatic control. Because of this and lack of sufficient electrical sub-metering equipment, energy usage for heating was estimated based on an analysis of the utility bills in conjunction with weather data when possible and is discussed in the following section. Electrical measurements were not possible on some of the smaller units at a few plants and nameplate values were used instead.

3.3.3 Utility Bill Analysis and Data Validation

Two to four years of electricity bills of the plants were analyzed in conjunction with the estimated unit process energy usage as a check of the quality of the estimates. Comparisons were made only for the summer months when the electrical measurements had been taken and due to a lack of capability to monitor heating energy use. The outside temperature may fall below the building's typical setpoint, but this does not guarantee that heating is being utilized. The usage also may be too small to detect within the noise of the plant energy use data. Because of this, the non-heating months were defined as any month that had a Heating Degree Day (HDD) of 400 ˚F-days or less. This threshold was set based on observed natural gas usage amounts and respective HDD values from other utility bills (see Appendix F).

The first step of the analysis was to normalize the reported monthly energy usage by the number of days within the billing cycle to estimate the daily energy usage (kWh/day). This removed variable energy usage observed in the bills that would result from a longer or shorter reading period. Influent pumping energy usage estimates were made by first estimating a specific energy consumption value of the influent pump (kWh/MG) and then multiplying this by the cumulative flow for a given month. UV disinfection was estimated based on the nameplate operating power and operating time required during the recreation period (May 1st – September 30th). The estimated energy usage of the remaining equipment was assumed constant unless otherwise observed to vary based on variable operating times or operating levels well documented by plant staff. The power consumed by these units was estimated based on measurements from the 1-day visit and were described in the previous section of the report. The sum of estimated energy usage of equipment was compared to the average value of billed summer monthly energy usage. The relative variability of month-to-month billed energy usage was measured with the coefficient of variation (CV). This provided additional insight into the energy usage variation of the processes which could be expected to be fairly low for some small plants due to a lack of automation and control.

For some of the plants, estimates of the energy usage from heating was estimated by analysis of the utility bills in conjunction with equipment energy use estimates. The estimated energy usage of the influent pumping, UV disinfection, and aeration in some cases was subtracted from the utility bills monthly usage to remove the energy use variability from these processes. The HDD was determined by gathering average daily temperatures from the National Oceanic and Atmospheric Administration (NOAA). The energy use data was then correlated with HDD to evaluate if there was an apparent trend. Although this approach is very generalized, it has been performed in analyzing and projecting heating energy consumption in residential buildings (Quayle and Diaz, 1979). If a correlation was obtained between these two variables, then the increase in energy usage with respect to HDD was subtracted from the baseline energy usage from the summertime months. In this study, a threshold R^2-value of 0.6 was used for this analysis due to other processes contributing to high variability in the energy use.

3.3.3 Unit Process Benchmarks

Process benchmarks were estimated for both treatment equipment and the estimated plant heating. This involved the normalization of the energy usage by a variable that would be expected to be related to the energy usage. Equipment used for treatment were normalized by the average summertime monthly flowrate for comparison to literature. This same analysis was carried out by Foladori et al. (2015) for small wastewater treatment facilities and also as reported by Tchobanoglous et al. (2014) based on data from the EPRI (1996) report for large plants. Plant building heating energy use was normalized by building floor area for benchmarking as done in studies by the Energy Information Agency (EIA, 2012). Floor area for buildings was estimated from google maps (Google, 2018) utilizing the distance measurement tool and the specific spaces that were space heated with either gas or electricity were determined during sites visits.

Chapter 4: Results and Discussion

4.1 Introduction

To help further the understanding of what opportunities exist in making energy efficiency improvements at small wastewater treatment plants in Nebraska, a follow-up assessment of a past benchmarking project was performed and had identified and quantified the impacts of specific changes being made at eleven plants. To add to this discussion, an evaluation of the unit process energy usage of four facilities was also performed. This included the development of hydraulic-based energy intensity metrics for the processes. Estimated energy use for space heating buildings utilizing an analysis of utility bills and equipment for eight of the plants found that heating can be a significant part of small plants energy use. Energy intensity benchmarks based on floor area were also created for plants, which were supplemented with observations from site visits to explain variability in the metrics.

To further understand the barriers to making such changes, a survey carried out to help evaluate the perceived relevancy of barriers by operators and to help understand how these barriers were correlated and vary among plants making changes and plants not making changes. To provide supportive information, specific observations from various energy audits and discussions with operators are provided. As noted previously in the methods section, small plants are defined has been defined as plants treating wastewater of community populations of 10,000 or less and facilities treating an average flowrate of 1.5 MGD.

4.2 Unit Process Energy Use and Benchmarks

The following sections discuss the energy use estimates and benchmarks of processes used within some Nebraska wastewater treatment plants. Energy use per day of processes at four plants was estimated and compared to summertime billed energy use normalized by days in a given billing cycle. The relative energy use of processes is shown for 4 plants and estimated energy intensities of processes based on flowrate are provided. Estimates for energy used for heating and benchmarks based on floor area are also presented for 8 plants.

4.2.1 Estimated Process Energy Use

Evaluation of the energy usage of unit processes and comparison of the estimates to the billed usage had been successfully carried out on four of the nine plants where electrical measurements were collected. After further analysis, four plants were omitted due to various issues relating to data quality issues with either the unit process data and/or billed usage. The estimated sum of the daily equipment energy usage in comparison to the normalized monthly energy usage is shown on the next page in Table 4.1. The first column lists the 4 plants that were analyzed in this study and the number of months used in the analysis. The second column summarizes the normalized daily energy usage determined from the bill, the energy use estimated for equipment, and the percent difference between the two values. The final column lists the coefficient of variation (CV) determined for both the bills and equipment estimates based on the average and standard deviation values.

Table 4.1: Comparison of Unit Process Energy Use Estimates to Billed Usage

Plant (# of months of summer electric usage available)		**Average Summer Electricity Usage (kWh/day)**	**CV of Summer Billed Energy Usage**
Plant A[1] (10)	Bill	716	**2%**
	Equipment Estimate	736	
	Percent Difference	**3%**	
Plant B (13)	Bill	1,082	**6%**
	Equipment Estimate	1,151	
	Percent Difference	**6%**	
Plant C (23)	Bill	1,452	**14%**
	Equipment Estimate	1,346	
	Percent Difference	**-7%**	
Plant D (10)	Bill	893	**9%**
	Equipment Estimate	910	
	Percent Difference	**2%**	

[1] Variation in monthly equipment energy use was accounted for at Plant A

Estimates based on this study's methods yielded results within 2 to 7% of the billed usage. The summertime monthly energy usage is relatively constant for these plants exhibiting a CV of 2 to 14% in billed usage. This result may be unique to many small treatment facilities due to the general lack of variation in process energy use, specifically relating to control of aeration processes. Some of the process energy variations such as with pumping and UV disinfection can be accounted for and subtracted from bills to observe clearer baselines of energy use for smaller plants. Despite the percent differences observed, these estimates may still yield some error in certain variables, particularly when estimating the power usage of equipment. Smaller unit processes may be oversized resulting in a low power factor that would not have been accounted for with methods used in this study.

The relative energy usage of unit processes at the four plants is shown below in Figure 4.1. In all the plants analyzed, aeration accounted for a majority of the total process energy use ranging from 66 to 80 percent which is largely consistent with what has been reported in the literature for both small and large plants (EPRI, 2013; Young and Koopman, 1991). Plant B had utilized a single blower for the supply of air to both the aerobic digester, secondary aeration, and for sludge wasting, and thus the energy use of this was divided among two aeration basins based on the volume of wastewater they aerated. Within this usage, aerobic digestion accounted for a significant portion of the energy usage but had exhibited a smaller portion of the usage in plants C and D relative to plant A. This largely can be attributed to the use of timer systems on aeration system which can allow for better regulation of air and minimization of energy usage. An additional observation is that UV disinfection appeared to account for a significant portion of the energy usage for most of the plants but may not be entirely representative due measurements being unavailable on this unit process and thus reported values are based on data pulled from nameplates or design specifications. In contrast to what has been observed with many large plants, pumping accounted for a relatively small portion of the process energy usage ranging from 2 to 7 percent. Additionally, lighting was found to be practically negligible at plants A and B but still was a relevant user for plants C and D. Mixing was also found to be a large user of energy for plant D, which can be viewed as a component of the secondary aeration process and aerobic digestion.

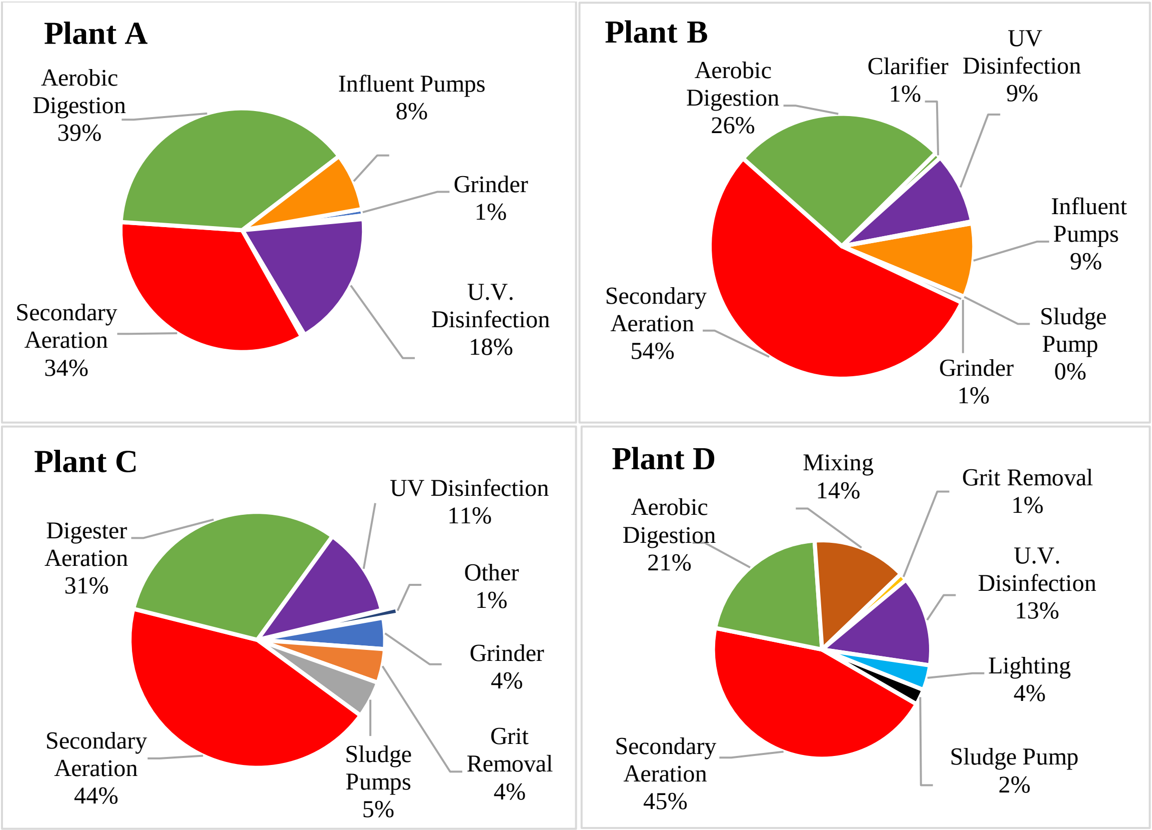


Figure 4.1: Summary of the Relative Energy Usage of Unit Processes

As noted by Foladori et al. (2015), determination of absolute benchmarking metrics for unit processes can help aid in our understanding of energy use at wastewater treatment facilities. In Table 4.2, the energy intensity of processes based on flow is shown for the four plants noted previously. The unit processes for which benchmarks were created are shown in the first column with the estimated values for each plant being shown in the columns to follow.

Table 4.2: Calculated Energy Intensity Metrics of Unit Processes

Unit Process	Process Energy Intensity (kWh/m^3)			
	Plant A	Plant B[1]	Plant C	Plant D[2]
Influent Pumping	0.075	0.189	NA[3]	NA[3]
Comminutor	0.008	0.016	0.034	0.125
Grit Removal	NA[3]	NA[3]	0.037	0.019
Clarifier	0.005	0.016	0.004	NA[3]
Secondary Aeration	0.339	1.140	0.526	1.065
Aerobic Digestion	0.382	0.550	0.269	0.374
Sludge Pumps	0.001	~0	0.044	0.048
U.V. Disinfection	0.178	0.181	0.231	0.240
Lighting	0.004	0.005	0.039	0.067

[1] Aeration energy usage for Plant B was divided among secondary aeration and aerobic digestion based on the relative basin volumes

[2] Plant D also utilized mixing with a benchmark of 0.228 kWh/m^3 for the process

[3] NA: Not Applicable

Values shown here appear to be similar in value as reported by Foladori et al. (2015) and higher than what had been reported for large plants by Tchobanoglous et al. (2014). Plant B exhibited a very high secondary aeration metric relative to the other plants and values reported by the previous studies. This may be largely due to the use of a single blower for both secondary aeration, the aerobic digester, and was sludge pumping with minimal control of the system. This plant had also shown high dissolved oxygen levels throughout the plant (6 to 8-mg/L) further supporting the observation of the high metric. In contrast, Plant A utilized a modular design where multiple small blowers were used, and dissolved oxygen levels were observed to be lower in the 2 to 3-mg/L range. As observed with the relative usage, the metrics show how use of timers on the aerobic digestion system can help reduce energy use. In comparing the collective aeration metrics to the overall plant energy intensity that can be seen in Table 3.3, it appears that plants that had exhibited a higher aeration metric also had a higher plant energy intensity which would be expected given that the process accounts for a majority of the overall energy usage.

Benchmarking UV disinfection with flow-based normalized energy metrics also showed some interesting results. As observed with the relative usage, UV shows a relatively high metric and showed a fair amount of variation among plants. Many of these systems were sized for design conditions that were not realized and have a lack of ability to adjust output power with respect to the flowrate they are treating. Although not investigated in this study due to the limited sample size, the magnitude of these metrics may be highly dependent on the percent design capacity that the plant is operating at.

Analysis of the pumping energy efficiency with these normalized metrics is likely a good indicator due to the function of them being directly related to flowrate. Comparison of the two influent pumping metrics showed a large difference in energy intensity. The influent pumps for both plants A and B had to pump over an approximate 15-foot head, but the key difference among the two was that Plant A had influent pumps that were controlled by floats that would only engage when water in the well had reached a certain level. In contrast, Plant B had magnetically-coupled influent pumps that ran constantly leading to a much higher observed metric.

4.2.2 Plant Space Heating Estimates and Benchmarks

Energy usage for space heating buildings was one component not investigated by Young and Koopman (1991) and was only briefly mentioned by Foladori et al. (2015) in studies of small WWTP energy use thus was an area of focus for this study. Due to most heating systems being automated and a lack of sufficient electrical metering capacity, heating estimates were made through a coupled analysis of monthly utility bills and equipment energy. This involved subtracting variable process energy that was well-documented use from the bills and then plotting the adjusted plant energy use against heating degree days (HDD). For plants that exhibited some degree of correlation in these variables ($R^2 > 0.60$), the energy usage during heating months was subtracted from the averaged value of the non-heated months. For comparison within the group and to literature, the estimated heating energy usage was normalized by the heated floor area of buildings.

Table 4.3 below lists the results of this analysis. The first column lists the plants by letter and the second column indicates the type(s) of energy used for heating. The third column shows the R^2-value for the linear regression of the monthly adjusted energy usage against the plant's heating degree days (HDD). The number of months used for the analysis is shown in fourth column and the climate-controlled floor area of the plant is shown in the fifth column. The resulting estimated heating energy usage, the percentage of the total plant annual energy use this accounts for, and the building heating energy benchmarks are shown in the sixth, seventh, and eighth columns respectively.

Table 4.3: Summary of Heating Estimates for Metered Plants

Plant	**Type of Energy**	**R^2-Value (Energy vs. HDD)**	**Months of Data[2]**	**Heated Floor Area[3] (ft^2)**	**Estimated Heating Usage (kWh/yr)**	**% Plant Energy Usage**	**Building Heating Intensity kWh/ ($yr\text{-}ft^2$)**
A	Electric	0.70	26	1,830	8,915	4%	5
B	Electric	0.61	25	2,975	25,773	6%	9
C	Electric	0.78	48	2,810	87,271	15%	31
D	Gas[1]	0.99	17	3,160	58,043	16%	18
E	Electric	0.85	35	670	26,714	19%	40
F	Electric	0.82	35	938	13,933	12%	15
G	Gas[1]	0.90	42	6,830	30,230	6%	4
H	Electric	0.77	31	2,000	54,503	7%	27
	Gas[1]	0.90	27	3,100	220,190	27%	71

[1] Gas was reported to be used exclusively for space heating

[2] Data are based on monthly billed usage with process energy use variability removed

[3] Floor area is based on measurements taken with Google Maps (2018)

It was observed that the energy usage for heating can vary significantly among small plants ranging from 4-34% of the total energy use. Plants utilizing natural gas for heating exhibited strong correlations (>0.9) of their gas use and HDD which was expected due to the gas being used explicitly for space heating. It was also observed that plants with electric heating that showed a higher percentage of plant energy use for heating also exhibited higher R^2-values when correlated with HDD. If a plant utilizes a larger portion of energy for heating, then the effect of heating is more likely to be detected since it will stand out further from the noise of other process energy use within a plant. This observation could have also been partly influenced by the variable number of data points in each set as well. The plants heated by gas presents a clear view of what fraction of a plants total energy use can be attributed to heating due to all heating energy use being measured. The gas heated plants show very similar results to those estimated for plants using electricity and showed a wide range

The estimated normalized building heating energy intensities are similar to the values reported in the most recent Commercial Building Energy Consumption Survey (CBECS) conducted by the Energy Information Administration (EIA) in 2012 which had shown a median building electric space heating energy intensity of 10.8-kWh/ft^2 with a 25th and 75th percentile intensity of 5.6-kWh/ft^2 and 21.3-kWh/ft^2 respectively (EIA, 2012). The plants that exhibited very high energy intensities relative to the values reported in the literature showed heating accounting for a large portion of the plant's total energy usage. This may partially explain why climate-controlled floor area was found as a statistically significant variable in benchmarking these small plants (Hanna et al., 2018).

Observations of the building envelopes during site visits support the observed values seen here. Plant A and Plant G had well-insulated buildings with no apparent air gaps. In contrasts, Building E had poorer insulation on some of the buildings and a heater had been found running during the summer in the lower level of a lift station. Common observations among plants with higher heating intensity metrics included: poor insulation of building envelopes, broken windows in some buildings, use of single-pane windows, thermostats being kept at excessively high temperatures. Plant H utilized both electric and gas for heating buildings and exhibited an unusually high building heating intensity. Review of assessment documents and pictures of the plant did not reveal any factors that may have contributed to this observation and thus could not be rejected from the data set. Gas had been noted to be exclusively used for heating and the specific buildings heated by gas and electric were also clearly noted. Potential sources of error may have come from the meter used to read the gas usage or in the process of billing.

It had been noted during many plant visits that the aeration blowers give off significant heat to an extent that heaters within the building do not turn on to run. Based on this observation, the size of room relative to the heat given off by a blower would impact the observed heating demand of a plant. This also means that energy loss from inefficient blower systems is not all wasted and is being used to offset energy use that would be utilized in space heating during the winter time. This observed transfer of waste process energy may be important to consider when carrying out an analysis of overall plant efficiency and unit process efficiencies.

In summary of these results, heating can be a significant energy use at many small WWTPs. In some cases, heating that is not regulated with the use of programmable thermostats and/or buildings that are poorly insulated can result in plants with very high observed building heating energy intensities. Considering this, energy and cost savings could be realized through relatively low-cost investments in improved controls and insulation.

4.3 Observed Infrastructure and Operational Improvements

In this section, the specific energy efficiency-related changes as reported by operators that had responded to the survey are discussed. The impacts of these reported changes were quantified based on follow-up collection and analysis of energy bills and water characteristic data for the plants as discussed in Section 3.2.5. This included utilizing an evaluation of percent change of these variables before and after the changes were made. Furthermore, the plants reporting that they had not made changes had the same analysis performed and the mean change in energy usage of the two groups was compared against each other.

4.3.1 Impact of Changes Being Made at Plants

The reported E2 related changes made by facilities were a mixture of operational and infrastructure changes, which are like those reported in the literature. These changes were observed across different process types and at plants with design flowrates ranging from 0.10 to 1.01-MGD. These changes resulted in a measurable reduction in energy usage at nine of the thirteen plants. There were two plants that had been removed as outliers and are discussed in more detail below. There were 12 plants that had reported making specific changes recommended in the 2016 E2 benchmarking letter provided to municipalities. Table 4.4 on the next page summarizes eleven plants that reported making specific E2 related changes and that had additional utility bills collected to evaluate the impact of improvements. The table lists plants in column one by number to maintain the confidentiality of the plant operator with the plant type also being included. Design flowrate is provided in column two for reference in discussion. The specific changes made shown in column three are listed exactly as the operator had reported them. The observed percent change in energy use, change in flowrate, and change in energy intensity are provided in columns four to six. The estimated cost savings based on the reduction of energy usage and the plant’s actual unit energy cost are also shown.

Table 4.4: Summary of the Observed Impacts of Plants Making Specific E2 Changes

Plant (Type[1])	Design Flow (MGD)	Specific Changes Made	% Change of 2017 value from the average of 2016, 2015, 2014			Estimated Annual Cost Savings[2]
			Energy	Flowrate	Energy Intensity	
1 (OD)	0.255	Regulating dissolved oxygen level with VFD's	-35%	-5%	-32%	$9,100
2 (TF)	1.01	VFDs, LED lights[3], heater replacement[3], pump replacements	-23%	11%	-30%	$11,400
3 (EA)	0.140	VFD installed on Blower[3]	-18%	-14%	-5%	$4,600
4 (SBR)	0.149	UV timer system installed, Motors replaced	-13%	10%	-21%	$3,000
5 (TF)	0.39	VFDs on pumps, turning off lights[3]	-9%	33%	-31%	$3,400
6 (EA)	0.504	Improved blower operation[3], Installed LED lighting[3]	-9%	-9%	1%	$2,300
7 (OD)	0.250	New Influent and Sludge Pumps	-6%	1%	-7%	$530
8 (OD)	1.8	Motor replacement[3] and Installed LED lighting[3]	-4%	-4%	0%	$3,400
9 (A. Mod.)	0.635	Properly programmed the DO controls[3]	-4%	-13%	11%	$1,600
10 (EA)	0.600	New Effluent Pumps w/ VFDs[3]	2%	-11%	15%	-
11 (SBR)	0.270	Timers on aeration, Lights off [3]	8%	1%	7%	-
Net cost savings of plants with observed reductions in energy use						**$39,300**

[1] Process types: TF= Trickling Filter, OD= Oxidation Ditch, EA= Extended Aeration, SBR= Sequencing Batch Reactor, AS= Activated Sludge, A. Mod= Aero Mod

[2] Annual Cost Savings are based on the observed reduction in billed energy and the plant's estimated unit energy cost ($/kWh)

[3] Recommended Change in 2016 Benchmarking Letter

The plants exhibiting the most significant energy use reduction had installed a VFD on a blower or pump or had improved operation of the VFD. There were 9 plants that showed reductions in energy usage ranging from 4-35%. The most significant change observed was with Plant #1 that had improved process control of their automation for aeration that was already present at the facility. This observation highlights not only the impact of automation at a facility but the importance of operators in utilizing the infrastructure to optimize the E2 of their plants. Plant #2 also showed a significant reduction in energy usage while receiving increased flowrates to the facility. Increases in flowrates may be more influential on the energy usage due to having a trickling filter system that includes a greater portion of the energy being utilized in pumping. Since this plant also implemented several different ECMs, the impact of the changes were greater and likely more detectable from the noise of the system. Plant #5 was also a trickling filter system that exhibited a 9% reduction in energy usage while receiving a 33% increase in flowrate. Between these two plants, installation of VFDs on pumps in trickling filter plants specifically can result in significant energy savings.

The four plants showing increases in energy use ranged from 2-8% except for one that showed a 19% increase in energy use. This plant had noted only repairing air leaks and operates with no control of the aeration system, thus the reported change alone, in theory, would not result in improved energy efficiency. This change may have increased the back pressure on the fan resulting in a higher load on the motor by creating a higher resistance to flow in the distribution system. A follow-up phone call with the facility’s operator had revealed that the plant had also experienced one of their basins freezing which is thought to have also increased the load on the motor resulting in a higher energy use. This was supported by a large increase in winter energy usage seen in the electricity bills. In a discussion with the operator from another plant, it was reported that their basins had also experienced some freezing which could have led to an increase in energy usage. Plant # 11 had exhibited high year to year variability in energy usage among the years prior to 2017. This variation appeared to make observing a small measurable change difficult with the methods used in this study. The changes in energy intensities among plants making changes showed similar results as those observed with changes in energy use in an exception for some plants experiencing large changes in flow. Plants that exhibited a high percent change in flowrate (>10%) may make use of these metrics for evaluating E2 changes within a small plant over time not appropriate. This may be especially relevant if the unit processes within the plant do not adjust energy use significantly with respect to flow.

4.3.2 Comparison of Plants Making Changes and Not Making Changes

A statistical analysis had been carried out to confirm that plants that had made changes (related to energy use) were observing a significantly different reduction in energy usage relative to plants not making changes. The same methods for analysis for estimating the percent change in energy usage used in the prior section were also used in this case. A t-test and Wilcoxon signed-rank test were used to evaluate whether plants that had made changes had observed a greater percent reduction in energy usage relative to plants that had not made changes.

Comparison of the mean change in energy usage of groups making and not making changes and are summarized in Table 4.5. The first column lists the two groups with the mean percent change in energy usage for the two groups being shown in column two. The sample size for each group is shown in the third column and the results of the two statistical analysis methods are summarized in the bottom row of the table. There was a measurable difference in individual plants, but there is some uncertainty in whether there is a significant difference when reviewing the collective groups. A t-test resulted in a statistically significant difference between the two groups, but the data was only somewhat normally distributed (thus uncertainty as to the validity of the t-test). In contrast, use of the Wilcoxon signed-rank test yielded a notable difference (p-value <0.1) between these two groups and may me be a more representative measure of the difference.

Table 4.5: Comparison of the Percent Change in Energy Usage of Plants Making and Not Making E2 Related Changes

Group	**Mean of % Change in Energy Usage**	**Sample Size**
Plants that reported making E2 changes	-8.5%	13
Plants that reported not making E2 changes	-1.2%	16
Statistical Analysis Comparing Groups	**t-test:** **p-value = 0.045**	**Wilcoxon signed-rank test:** **p-value = 0.100**

An observation from this dataset was that plants not making E2 changes still exhibited an average percent reduction in energy usage. In a review of the individual plant changes, it appears that this result may be partly due to one plant that exhibited a 17% reduction in energy usage that had not reported making changes in result skewing the result. Despite this, removal of the plant as an outlier could not be justified. The baseline energy use of these plants may be varying due to several other factors such as variability in weather conditions, variable loadings to the facility, and/or adjustments made by operators that were documented in the survey.

4.4 Awareness and Perceived Barriers to Energy Efficiency at Small Plants

Survey responses and results of analysis of the data presented in this section. The perceived impact of the E2 benchmarking project conducted in 2016 on operator awareness of energy efficiency is presented first. The reported relevancy of specific barriers to implementing E2 changes as reported by operators is also shown and correlations among barriers follow. The perceived barriers of plants reporting making changes and those that did not report changes are compared to investigate any significant differences among the groups.

4.4.1 Operator Awareness to Energy Efficiency

The first step in carrying out energy management is understanding where the plant is in terms of energy use and whether energy efficiency opportunities exist, thus one objective of this study was to evaluate how the site visit by a student to the plant and the follow-up E2 benchmarking letter that was sent 6 months after the visit had impacted operator’s perceived awareness to energy efficiency. Operators were also asked in the survey whether they thought cost-effective opportunities exist at their treatment plant which was used to help evaluate if there may be an “energy efficiency gap” present at small WWTPs.

Survey responses by most operators noted that the student interaction in visiting the plant and the follow-up benchmarking letter provided to towns had increased their awareness to energy use at their plant to some degree. The responses to these questions are summarized on the next page in Figure 4.2 with the Likert-type scale response being shown on the x-axis and the frequency of response being shown on the y-axis. One of the key factors likely contributing to this result was the discussion of the plant energy bills with operators of whom a majority had never seen their plant energy bills due to them being handled by the town clerk. During site visits, students would often ask about any unusual trends observed in the bills and/or apparent inefficient aspects of the plant operation (such as heated building with a broken window or old equipment that is not under control) that in effect would require operators to think more critically about their plant energy usage. Furthermore, operators were also asked during the site visit by students whether they thought there were any energy efficiency-related improvements that could be implement at their plants and often they were able to think of specific areas within their plant that could be improved in terms of E2. The follow-up benchmarking letter had provided feedback to plants in a specific, personalized, and simple way that showed how their plant’s energy use compared to plants of similar type. This was paired with specific recommendations for reducing energy use that were identified from the site visit and also likely contributed to this result.

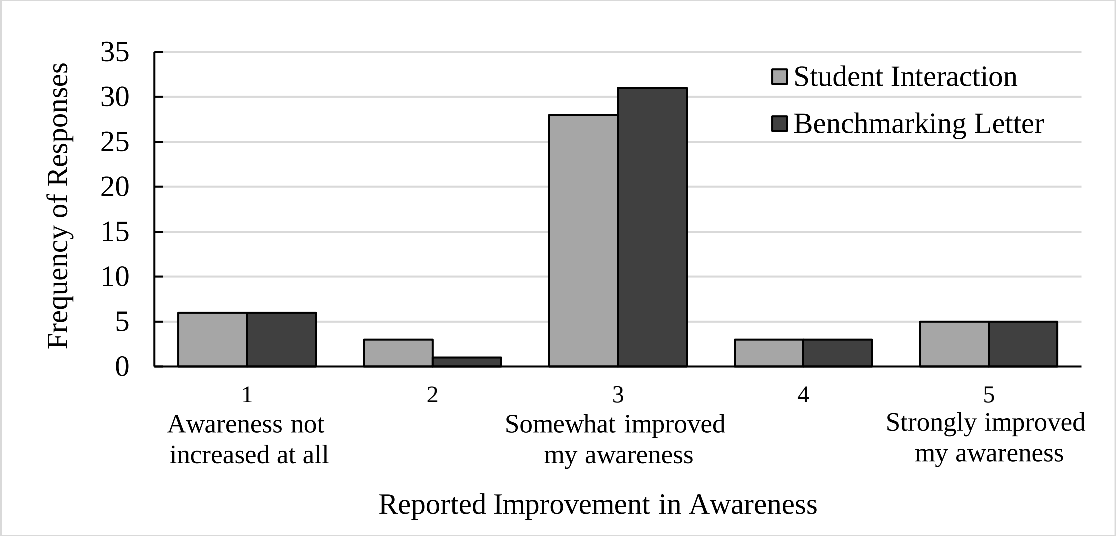


Figure 4.2: Reported Improvement in Awareness to Energy Use due to the Student Interaction and the Follow-up Benchmarking Letter

An assessment of whether operators thought that cost-effective energy efficiency opportunities existed at their plant, a less uniform response was observed as shown in Figure 4.3 on the next page. Although 75% stated that “Yes” they believe cost-effective changes exist, 17% did not think opportunities exist and 8% were uncertain. This result is quite different from almost unanimous agreeance on cost-effective opportunities exiting in pulp and paper-mills observed by Thollander & Ottosson (2008). In some cases, the energy efficiency improvements that could be undertaken may not yield a cost-effective result either due to the high initial cost of changes and/or low savings realized.

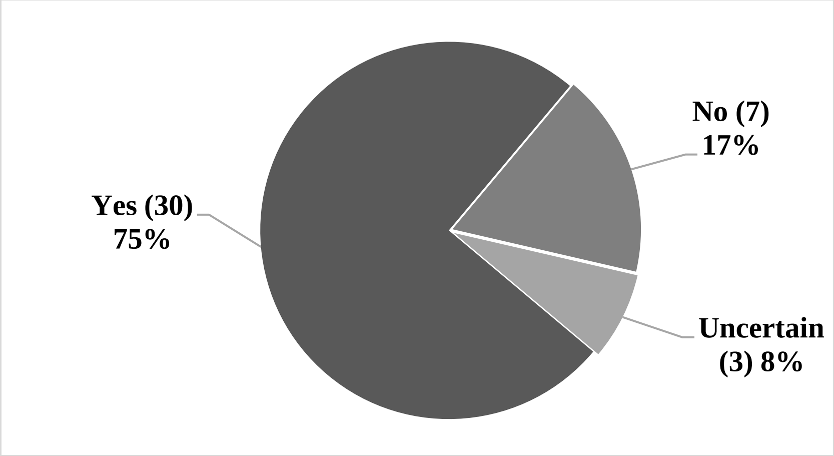


Figure 4.3: Operators Response of Whether They Think Cost-Effective Changes Exist at Their Plant

The uncertainty of a few of the operators observed here also highlights that there may be the barrier of imperfect information where insufficient information is being supplied to some public municipalities on what changes can be made and to what extent they may impact E2 of their plants. Despite some difference in opinions, most operators do believe that there are cost-effective changes possible which is supportive of the idea that an energy efficiency gap exists specifically for small wastewater treatment plants here in Nebraska. This may indicate that there are barriers beyond economic-based ones that are inhibiting the uptake of energy efficiency improvements.

4.4.2 Perceived Barriers to Making Energy Efficiency Changes

Understanding the multitude of barriers that inhibit the uptake of energy efficiency improvements at small plants is critical if they are to be overcome and changes are to be made. To evaluate these potential barriers, the operators were asked on the survey to evaluate how relevant they perceived specific barriers to making E2 changes on a Likert-type scale. The average value of the barriers was evaluated for all the plants and an investigation of whether any of the barriers were correlated was performed. An additional analysis investigated whether plants making changes versus not making changes had perceived the relevancy of certain barriers differently.

4.4.2.1 Relevancy of Barriers to Making E2 Changes

An analysis of survey responses showed the existence of a wide range of perceived constraints for small WWTPs in making E2 improvements. The average perceived relevancy of each barrier for the 41 plant operators that responded to this part of the survey is presented in Figure 4.4. The x-axis shows the Likert-type scale response used and the specific barriers used in the study are listed on the y-axis. Financial related barriers specifically related to the availability of capital, other uses for it, and perceived payback on investment was observed as most relevant among operators. This finding had also been observed by Sorrell et al. (2000), Trianni et al. (2013), and Rohdin et al. (2007) across different sectors and countries. In many cases, a small municipality has likely already borrowed funds to help finance the water and wastewater systems and may be reluctant to borrow additional funds if the changes are not required and if they may only save a limited amount of the operating cost.

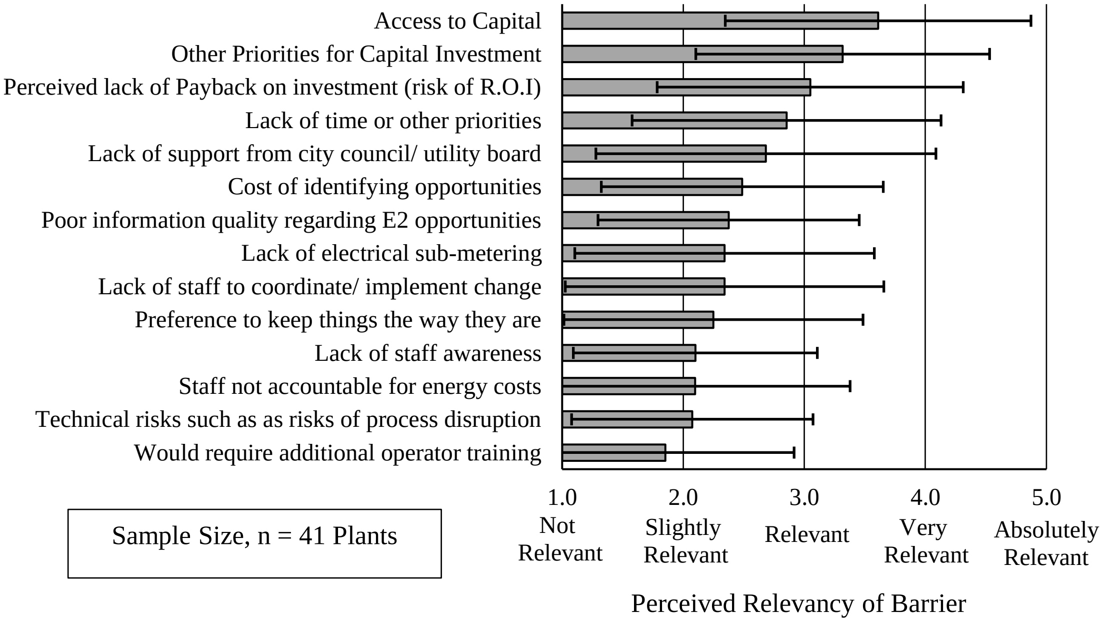


Figure 4.4: Reported Relevancy of Barriers Perceived by Operators in Making E2 Changes

Adverse selection appears to be a relevant barrier arising in this case based on the rating of perception of payback, cost of identifying opportunities, and lack of information quality regarding E2 opportunities as barriers (e.g. they may have difficulties in evaluating the performance of an improvement beforehand and afterward to guarantee a good payback and thus may make decisions based on more tangible items such as capital cost). This may be due to the complexity of evaluating the impact of changes beforehand due to the degree of technical analysis required to evaluate such changes. There can be significant uncertainty in variables that may impact the savings such as future wastewater loadings and performance of equipment and thus there is be a fair amount of economic risk associated with making these changes. This may lead municipalities to base their decision making on more clearly visible factors such as capital cost. The perceived lack of payback on investment may be partially viewed as a barrier because of the hidden cost associated with implementing the change such as the cost of additional operator time required to implement the change.

Heterogeneity (e.g. the idea that some technologies may be cost-effective on average but may not be cost-effective in all cases leading to a lack of adoption) could also be a factor at play here and may be partially expressed by the perceived relevancy of payback and cost of identifying opportunities. The cost-effective E2 related changes that are commonly reported in the literature are usually based at large wastewater treatment plants and may not be cost-effective for small treatment systems. An example of this is the installation of automated dissolved oxygen control systems or installation of VFDs. This kind of change may not be cost-effective for many small communities due to the small energy savings achieved relative to the high implementation cost. Furthermore, improved process control of aeration systems at small plants may not provide adequate energy savings to offset the increased labor cost associated with the change. Given the perceived constraint of this barrier, more detailed assessment needs to be made on the true cost and paybacks of these changes made at small plants. Evaluation of this in reference to what communities perceive as acceptable paybacks would help answer the question surrounding the existence of an energy efficiency gap.

The lack of time or other priorities was also reported as a fairly relevant barrier for small plant operators in making changes which had been reported as one of the largest constraints in the other studies (Sorrell et al. 2000; Thollander and Ottosson 2008; Trianni et al. 2013). In discussions with most operators of these small plants, operators are also tasked with many other duties within their town including maintaining the water systems, parks and recreation spaces, streets, and other responsibilities that limit their time to work at the plant and thus much of their time spent there is spent on basic maintenance and lab tests with little time for process optimization. Implementation of both infrastructure and/or operational improvements at a wastewater plant requires a significant amount of time that operators simply do not have. To add to this, the cost associated with the additional labor to implement improvements may outweigh the energy savings achieved by making the change which can be difficult to quantify in advance. Considering these barriers, improvements that may offer other benefits beyond energy savings such as reducing operators workload may help in justification of changes. Indirect or intangible benefits such as these had been suggested by Kuppig (2015) to be impactful on the implementation of changes being made.

Another interesting finding was the lack of support from city council/ utility board being perceived as a barrier for many plants which had been reported by NYSERDA (2008) as a barrier due to the lack of understanding by political officials of the technical and economic aspects of implementing E2 and unwillingness to invest in improvement that will fail to result in savings within their term serving in office. Effective communication of the benefits of changes being made to town councils must be done to overcome this barrier which may be assisted by a third party such as a technical assistance provider.

The barrier of technical risks such as process disruptions was perceived as less relevant compared to other barriers. This finding contrasts significantly from other studies in the manufacturing sector. Thollander and Ottosson (2008) identified this as the most important barrier in the pulp- and paper industry and as the second most relevant barrier in the study by Rohdin et al. (2007) foundry industry. These barriers are expected to be more relevant for the manufacturing sector due to the profit losses that will be associated with disruptions, whereas a small municipal wastewater treatment plant may expect less severe consequences from such disruptions. If a plant’s process is disrupted and they fall out of compliance, they generally will not be immediately fined for such occurrences and profits from their service will be largely unaffected.

4.4.2.2 Correlations Among Perceived Barriers

Barriers were also correlated with each other using the Pearson R correlation coefficient to investigate if there may be any interconnections among certain barriers. The correlation coefficient can range from -1 to +1, where numbers that are close to +1 represents barriers share a similar level of relevancy among individual respondents. Correlation values closer to -1 would mean that if a barrier is perceived as relevant then the other barrier is not perceived as relevant. A similar analysis conducted by Trianni et al. (2013) in analyzing foundries in Europe had set thresholds of slight relevance with a Pearson correlation coefficient (ρ) of 0.6 utilizing a sample of 65 respondents (8% the population). The threshold had been raised to 0.7 when analyzing the medium enterprise subset of the study population comprised of 34 respondents (4% of the total population). Using this study as a basis, a threshold of 0.5 was assumed as being slightly correlated and a value of 0.6 as somewhat correlated since a 50% response was achieved. It should be emphasized that observations from this analysis are only suggestive of relations between barriers and that additional observations from interactions with the municipalities are required to support any conclusions drawn from the data. Table 4.6 shows the Pearson r correlation coefficient for barriers that were identified to be somewhat correlated (ρ >0.5). Specific barriers are listed on the rows and columns and the correlation of two barriers are listed where they intersect on the table.

Table 4.6: Pearson r Correlation Coefficient (ρ) Between Different Barriers

Barriers	**Other Priorities for Capital Investment**	**Poor information quality regarding E2 opportunities**	**Technical risks**	**Staff not accountable for energy costs**	**Would require additional operator training**
Access to Capital	**0.67**	0.12	0.24	0.24	0.03
Lack of staff to coordinate/ implement change	0.15	**0.53**	0.29	**0.54**	**0.57**
Would require additional operator training	-0.14	0.35	0.47	**0.60**	-*
Staff not accountable for energy costs	0.24	**0.54**	**0.51**	-*	-*

-*: Correlation between the two barriers is already evaluated and shown in the table
Note: Values that are noted in bold exhibited slight correlations at a minimum (ρ > 0.5)

The highest level of correlation observed was between “Access to capital” and “Other Priorities for Capital Investment”. This observation was expected due to that a community with limited access to capital may invest funds in areas deemed more important relative to energy conservation. A similar correlation was also observed by Trianni et al. (2013) where a correlation of 0.60 was found between “Lack of budget funding” and “Access to capital” and was found to be 0.78 when looking at the subset of medium enterprises. In this case, the observation may indicate that a lack of “Access to

Capital" may limit what can be used for projects throughout the municipality leading to the higher perceived barrier of "Other Priorities for Capital Investments."

There also appeared to be a slight correlation between the barriers of "Lack of staff to coordinate/implement change", "Would require additional training", "Staff not accountable for energy costs", "Poor information quality regarding E2 opportunities", and "Technical risks". Many of the small plants investigated in the study had a relatively small staff consisting of 1-2 operators that would also be responsible for attending to various other tasks for the municipality such as maintaining the drinking water system and maintenance of public spaces. Most of the operators also hold primarily a level 2 operator license with no formal energy management training which may limit their ability to identify and implement E2 improvements. Furthermore, most of the operators are also not responsible for energy costs, as billing is typically handled by the town clerk with no review of energy patterns.

These barriers appear to suggest that there may be organizational issues of small municipalities where there is not a culture set up to consider and work towards improving energy efficiency. Given this, operators are largely not accountable for the energy costs from which they may be also less likely to work towards obtaining additional training on how to optimize their plant performance. With inadequate training or knowledge on improving E2 of their plant, operators may be less likely to make a change that may negatively impact their process performance and/or look for information regarding E2 opportunities. Trianni et al. (2013) had found a correlation between low priority given to energy management and lack of staff awareness in a sub-group of their study. When energy management is not considered as an important consideration by top management or a town board, then attention towards E2 practice, often expressed as awareness also becomes a relevant barrier to making changes.

4.4.2.3 Comparison of Barriers Between Plants Making and Not Making Changes

The sample of operators surveyed in this study was expected to be non-homogeneous given the variability of different types of plants, sizes, and organizational culture within towns. Due to this, further analysis was done to break the group into a sub-sample. In this study, the respondents were divided into groups that were reporting making changes and those that had not made changes. The average reported barriers of the two groups were compared assuming that plants that had made changes would generally perceive barriers as less relevant compared to the group that had not made changes. Figure 4.5 on the next page summarizes this comparison in a spider plot with the scale representing the relevancy of each barrier (i.e. a barrier is perceived as more relevant as you move further out on the plot). The average value of each barrier for the two groups is shown with the solid line representing the plants that did not make changes and the dotted line representing the plants that did make changes.

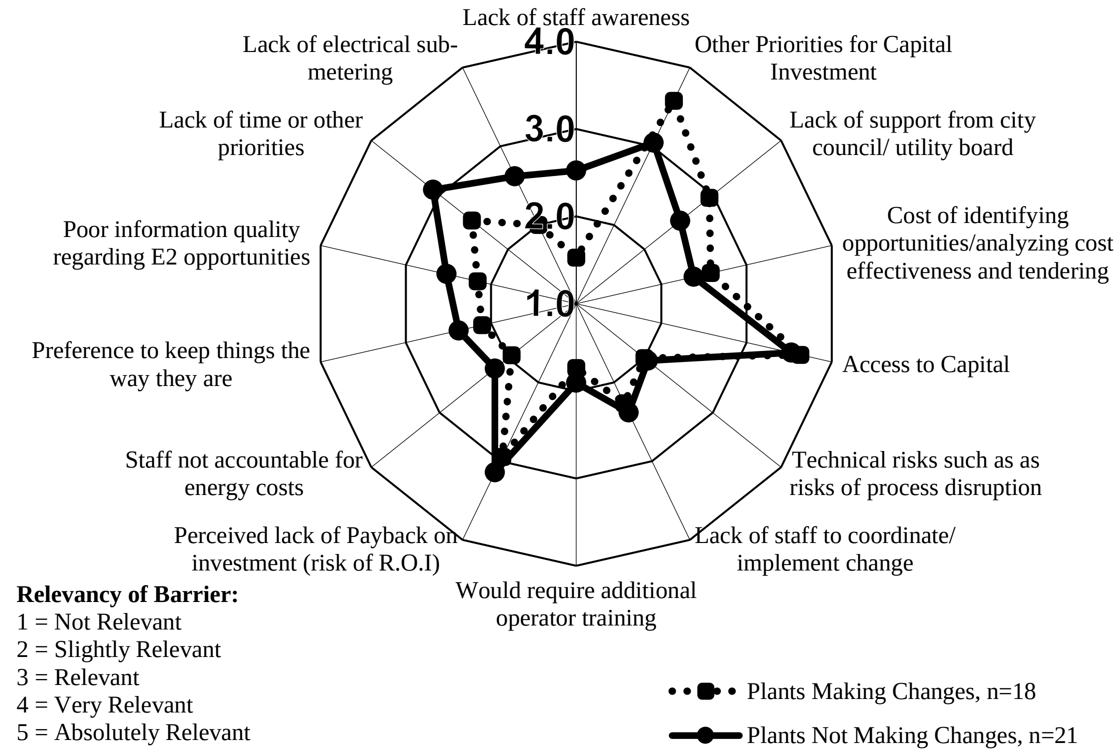


Figure 4.5: Comparison of Perceived Relevancy of Barriers for Plants Making and Not Making Changes

In comparing these groups, it can be observed that many barriers are perceived with a similar level of relevancy, but there is a divergence observed for a handful of barriers as hypothesized. There was a notable difference in the barrier of “Lack of time or other priorities” and “Lack of electrical sub-metering” which showed p-values of 0.067 and 0.078 respectively when an applying a Wilcoxon signed-rank test to compare the two groups. This finding may be suggestive that a lack of time by staff and lack of knowledge on how much energy is being used by unit processes often may be major barriers to the implementation of E2 changes. “Lack of staff awareness” was found to be significantly different between the two groups (p-value = 0.001) which is suggestive that staff awareness may be a larger factor in whether a change may actually be made which is expected since being aware of the plants energy use and understanding the benefits of making changes would be the initial driving force for moving to action. The energy conservation report by the EPA (2010) had clearly stated this, noting the real barriers to making E2 improvements at WWTPs are due to a lack of awareness or understanding the many benefits of investing in energy efficiency projects and the many programs that are available for financing E2 projects. This finding helps add to this claim with some degree of empirical evidence to suggest that awareness can really be a barrier to making changes.

In contrast to the initial hypothesis, there were a few barriers that were perceived as more relevant on average for plants that had made changes versus those that had not. “Other priorities for capital investment” was found to be notably different between the two groups (p-value = 0.068), which may be indicative that certain barriers may start to become more relevant in making further changes. If a plant has made E2 changes already, other priorities for the capital investment may become a more relevant barrier impeding further improvements from being made. Despite the median value of the barrier of “Lack of support from city council/ utility board” appeared somewhat different among the two groups, there was a high variability in responses from the two groups and thus was not found significantly or notably different (p-value = 0.23).

In addition to data presented in this section, operators had also provided some additional comments related to barriers to energy efficiency improvements at the end of the survey that added further support to results observed here. Operators have highlighted issues surrounding operator training, access to capital for improvements, issues with time and low priority for E2 changes, and issues related to understanding by decision makers. The most relevant notes that were found related to barriers are listed below verbatim.

- “Time and Money, the big things that would really make a difference cost a lot. The small things we will try to work in when we have time but they are not a high priority.”
- “The biggest obstacle facing the city is lack of funding for all of the improvements needed at an aging facility”
- “Lack of knowledge and understanding the way the system is set up”
- “People who make the decisions have no knowledge, understanding, or desire to learn about operations.”
- “Worthwhile program - continue efforts needed - further operator education in these areas via training at the conference!”
- “Getting people to buy into the idea in smaller communities can be difficult”

4.5 Observations from E2 Benchmarking and Energy Audits

To add further context and supporting evidence to the observations of the prior sections, a general discussion of observations made during the benchmarking project and energy audits conducted at small wastewater treatment plants in Nebraska are provided in this section. The discussion covers miscellaneous factors that have been observed to influence energy usage at plants and some observed opportunities and barriers related to infrastructure and operations.

4.5.1 Miscellaneous Factors Influencing Plant Energy Usage

Throughout the course of several energy audits and the benchmarking project, various miscellaneous factors were identified that impact energy efficiency at wastewater treatment plants. A more common observed occurrence was freezing of the various basins that retain water. Wintertime freezing of aerobic digesters that utilized intermittent aeration was reported by several operators, which would have resulted in an increase power draw of motors due to the creation of a greater back pressure on the blower system. Freezing in a clarifier had also been reported by a plant that had led them to install a heater unit above the scum trough to prevent wear on the system and ultimately led to an increase in energy use.

Tumbleweeds had been reported to cause process issues within two plants that were assisted and that lacked appropriate fencing. In one case the tumbleweed would get tangled in the mechanical mixer of an oxidation ditch and would exert a high resistive load on the motor causing it to “draw more juice”, as the operator had put it. Tumbleweeds had also been reported to clog up clarifier units and would require extensive labor to remove. Another miscellaneous influence observed was from snails that would build up in fixed film systems. One plant operator had reported that the snail build-up would cause biomass to get scraped off a Rotating Biological Contactor (RBC) unit. This would negatively impact process performance and as a result, the operators had moved to aerate the basin to suspend the snails significantly increasing their energy use.

The influence of industrial users was also observed to influence the energy use of several small plants. Severe underloading of plants had been observed for towns that had large industry leave or industry that had significantly reduced their wastewater loads being discharged. In some cases, shock loads from industrial plants had been observed that led significantly to increased process energy demand and usage (e.g. ethanol from an ethanol plant or high strength wastewater from food processing).

4.5.2 Infrastructure and Operational-related Barriers to E2

In an analysis of the infrastructure of small wastewater treatment systems, there were several factors that likely impacted the energy efficiency of the plants. The largest factor that may be inhibiting energy efficiency and causing significant variation in observed values among plants is the capacity to regulate dissolved oxygen in both secondary treatment and in sludge management. For many older plants, there is no method to regulate the air supply (i.e. no air intake control valve, no VFD, and/or no timer). Additionally, many of the smaller systems would utilize a single air supply line and sometimes a single blower to provide oxygen to both the secondary aeration basin and the aerobic digester. Since these processes have oxygen requirements that will vary at different rates, there would be greater difficulty in regulating the air supply for the processes. Many of the plants had very aged equipment and basins with some components being up to 60-years old.

From an operational standpoint, many of the plants lacked dissolved oxygen (DO) monitoring equipment to evaluate where the DO levels are at. Many of the plants also outsource their water quality testing which severely hampers the ability to carry out effective process control due to the time delay in getting information back on the process from the time a change is made. Because of the limitation of process feedback data, many operators have expressed reluctance in making any type of process changes such as adjusting aeration that may negatively impact water quality, even with DO measurements being taken. This was specifically reported for the discharge of ammonia which has seen increasingly more stringent discharge limits in the recent years. This had been proposed as a reasoning why effluent ammonia concentration was found as statistically related to plant energy intensity in models developed by Hanna et al. (2018).

As reported by operators in the survey portion related to barriers, operators of these small communities often lack time to carry out changes due to many other responsibilities they carry for the town. This was supported by data observed from the energy audits conducted. Operators from the 15 plants that underwent the audits had reported spending on average 3 to 4-hours per day at their plant and ranging from as little as 30-minutes per day to a full 8-hour day.

Additional comments that had been pulled from site visit narratives during the original benchmarking project are provided below verbatim to help provide additional evidence of the many barriers reported by operators in these small communities. Again, there are numerous citing’s of issues surrounding effective operator training and care surrounding E2. Issues surrounding the aged infrastructure and a lack of access to capital to help finance changes were commonly reported by many operators. All names were removed to maintain the confidentiality of the operators.

- “-Name- stated that the town makes too much money to qualify for loans or grants and even more so due to being in the floodplain”
- “The facility was said to be originally built in 1938 and said to have had many “Band-Aids” “

- "The operator had to refabricate broken components himself, as the old technology (1960's) has phased out. He has tried contacting multiple engineering firms for the parts, but most companies do not manufacture them readily without an exorbitant cost."
- "He expressed that the previous water and wastewater director had been working for the city for a very long time and did not care much about the facility or look into many energy efficient opportunities."
- "-Name- has been the operator for the facility for the last year and stated that the old operator left for a new position without providing much training or guidance in operating the plant. -Name- shared that the operator training was not very useful in educating him on how to actually run the plant. He said that some hands-on training would have been helpful."
- "He also expressed that he would like to clean the diffusers, but because of the age of the plant, he is afraid he may damage the system if he attempted to remove the diffusers for cleaning"
- "-Name- had stated that the facility used to have DO control systems in place, prior to him being there, to optimize the process. The system had broken and he stated that the town did not have funding to redo the system."
- "-Name- was the operator when a full assessment of the facility had been done by the P3 Program in 2010, but said the plant did not implement almost any of the recommendations because of upfront capital cost"

4.6 Implications and Recommendations for Sector

The results of this study are relevant to the wastewater sector in the United States. Based on a synthesis of the results, a list of recommendations is provided subsequently to help improve the E2 for small municipal plants, large municipal plants, state agencies, technical assistance providers, and design engineers.

4.6.1 Recommendations for Small Municipalities

To help small municipal wastewater treatment systems address the challenges the face in becoming more energy efficient, six recommendations are provided based on the results of this study. These recommendations are listed below.

- Most operators in Nebraska have never viewed the energy bills associated with their treatment plant. Review of the energy bills can be an effective way to identify issues that may be occurring within the plant. It is recommended that the community clerk shares a copy of the energy bills with the operator for review. A best practice observed at one plant was daily documentation of the plant energy use. This requires a relatively small amount of time to be invested and has allowed the municipality to catch any issues occurring with equipment within the plant such as pumps getting clogged.
- The initial cost (e.g., construction and design) of small WWTPs can be quite significant, however, the long-term operating cost is also important and can be influenced by design decisions. Oversizing of plant processes can lead to greater energy use over time. It is recommended that small municipalities invest in plant infrastructure that can vary operating power in response to varying flowrates and varying organic loads. Use of modular design setups with the capacity to add

incremental blowers for future air supply could significantly help in minimizing energy use. Investing in higher quality building materials and programmable thermostats also can help reduce energy use. Since these facilities are going to be in continuous operation for a very long timeframe, investing upfront in energy efficiency infrastructure is very practical.

- For many plants in Nebraska, operators had limited time at the plant to take care of basic operations and maintenance. Due to this, there was typically no time to invest in improved process control and energy management. It is recommended that municipalities provide more staff time for operating and maintaining these plants.
- Some small WWTPs did not have an O&M manual that could be found by the operator during the energy assessments. It is recommended that the town ensure that this document is available and reviewed by the operator to ensure the plant is receiving proper maintenance.
- Some communities did not have an annual budget provided to their water and wastewater systems. It is recommended to have some annual budget provided for regular maintenance and improvements to help maintain up-keep of infrastructure. Energy savings associated with improvements should be recycled back into the process for improved maintenance and upgrades. This may help incentivize operators to pay more attention to operational decisions that could energy and money. It is also recommended that municipalities structure their billing for these services to ensure that funds are available for future improvements and upgrades.

Industrial users, in particular, should have their rates carefully structured to account for their impact on the plant influent loading.

- Some plants had operations external to the WWTP connected to the same electricity meter as the plant. This makes a review and benchmarking of the plant’s energy use difficult. Based on this, it is recommended that the treatment plants be placed on a discrete meter. Providing discrete meters for the plant's buildings and operating equipment may also be useful in analyzing energy use.

4.6.2 Recommendations for State Agencies

To help small wastewater plants become more energy efficient, the below four recommendations are provided for state agencies engaged with these treatment systems.

- Some operators have indicated that the current operator in-class training sessions provided is insufficient for running their specific plant. It is recommended that on-site training is provided for some small WWTP operators and that this training involve enhancing the training on E2, and consider (sometimes low) quantity of time operators will spend at the plant. These training should be structured to be interactive and specific to the plants where the operators work. Communicating best practices and perhaps providing a checklist for operators to use at their could help in the education.
- In addition to incorporating E2 in operator training, these concepts could also be incorporated into the certification exams to help improve retention of the information. Operators could be asked to evaluate how they might improve the

efficiency of certain parts of the plant, such as the building climate control and/or their aeration processes.

- Many of the small WWTPs were found to be over-sized due to population growth projections not being realized. More incremental addition of treatment capacity could help reduce inefficiencies caused by this issue. Most plants indicated the availability of funding as one of the largest barriers to making changes. It is recommended that financing such as loans and grants be structured to allow for more frequent access to funds for incremental additions to minimize the inefficiency resulting from this over-sizing.
- A large financial-related constraint observed in making E2 improvements at small plants is the cost associated with obtaining a PE (Professional Engineer) seal on the construction documents. These are required anytime there is a significant and permanent process change such as changing the size of a motor or pump. In some cases, it had been found that the engineering fees could be greater than the cost of the new equipment which greatly limits the economical viability of such a change. In some assessments, it had been found to be the main factor for lack of implementation of an automated system at a small plant. Finding a way to mitigate or offset this could significantly help improve the chances of implementing E2 improvements at small plants.

4.6.3 Recommendations for Technical Assistance Providers

There are four recommendations for technical assistance providers (e.g. Rural Water Circuit Riders, E2 Assessors) that assist small community WWTPs and are listed below.

- Benchmarking of small WWTPs should be carried out initially to identify plants that are the least efficient for more detailed assessments. In this initial benchmarking, a site visit should be performed to review the infrastructure, operations, and used to identify potential E2 changes. Documentation should be made of the existing capacity of aeration systems to be controled. Assessments should be avoided at plants that lack the capacity for adjusting aeration since improving E2 of these plants may be best achieved in improved design when upgrading or downsizing the plant. Review of the plant staffing time should also be considered when selecting a plant for assessments.
- A more in-depth data collection related to the energy efficiency of the infrastructure could likely help in performing assessments. Measuring the actual efficiency of the motors and equipment could help evaluate whether replacing equipment could realize reasonable paybacks. This may include using a dynamometer, flowmeters, and true power meters to help evaluate unit efficiencies and should have measurements carried out during summer, winter, and fall/spring time to account for seasonal variations. An online respirometer could also be useful to evaluate the OUR and OTE of the system.

- Many plants had been identified that had very poor building envelopes and/or operation of thermostats. Analysis of these items should be considered and should be evaluated through measurements carried out during the winter time.
- Analysis of utility bills should be carried out carefully and compared with plant equipment energy estimates to check the quality of process estimates. In many cases, more accurate billed energy use information could be obtained by working directly with the power provider of municipalities. A utility waiver can be a useful tool in getting approval to obtain this data from their power providers. In several cases, issues related to billing had been identified that mislead investigations of plant energy use. Meter numbers, rate structures, and meter multipliers should be reviewed to ensure the correct information is being provided and that utilities are being billed correctly.

4.6.4 Recommendations for Design Engineers

In many cases, the E2 of small WWTPs appears to be highly influenced by the original design. Since retrofits of small plants may not have favorable paybacks, greater consideration of E2 in the initial design may be the best way to improve these systems. There are four recommendations related to the design of these systems are shown below.

- There were a few communities identified that utilized a single large blower for supplying air to multiple processes and the energy intensity metric estimated for this type of design suggests that it is very inefficient. Modular designs using multiple small blowers should be used for the supply of air in aeration systems.

- Aerobic digestion air process requirements will vary at different rates compared to secondary treatment. Use of discrete air supply lines for these two processes and simple automation such as timers are recommended to help better match process requirements to air being supplied.
- Efforts should also be made to incorporate energy efficiency into building design. Programmable thermostats are highly advised. Many buildings may have very low occupational time and often operators are very busy leading to a neglect of climate control devices. Use of high resistance insulation is also recommended to help reduce heat loss of these buildings.
- Installation of flowmeters on the outlet lines of aeration systems could be useful for municipalities and technical assistance providers in evaluating the wire-to-air efficiency of these systems. This could be used to evaluate how the efficiency of the motor/blower system varies over the course of time.

4.6.5 Recommendations for Larger Wastewater Treatment Plants

This study had focused on the analysis of small WWTPs, however, there are several recommendations that can be extrapolated to large systems. Some of this information is also based on four assessments carried out with the Nebraska Industrial Assessment Center (NIAC) at larger plants in Nebraska. These recommendations are summarized below.

- Due to the low cost of energy in Nebraska, energy efficiency may also not be prioritized by larger municipalities and often neglected. There are likely opportunities in helping educate large wastewater utilities on where energy is used throughout their facilities. For many large wastewater plants in Nebraska, there is often a more sophisticated billing structure than that applied to small plants; often the large plant staff does not understand the rate structure and the implications of the rate structure on their electric charges. Opportunities likely exist in helping utilities understand how their energy is billed and specifically with respect to addressing large peak demands.

- It had been noted that many small WWTP operators may be reluctant to make changes that may negatively impact effluent water quality. It is expected, that many large utilities also may over-aerate their wastewater as a safety factor to ensure they stay within compliance. Many large plants can perform in-house testing of their wastewater and may do so on a daily or weekly interval. In this case, large plants may have more capacity to make changes without the risk of falling out of compliance with regulations.
- In a review of barriers to making E2 changes, it was found that small communities may be significantly constrained by a lack of time or other priorities to make E2 changes. When compared to large plants, it may be expected that these specific barriers may be less relevant and other barriers may emerge as more relevant. Other priorities for capital investment and lack of support from the city council may emerge as more relevant barriers for large plants. This may be partially due to the higher cost associated with making changes at large plants relative to smaller ones. In contrast perceived lack of payback on investment and poor information on E2 opportunities may be less relevant barriers for larger plants.

4.7 Summary

The overall results of the survey of operators conducted and analysis of energy use within some small wastewater treatment plants bring about several conclusions. Many small WWTPs may exhibit a relatively constant normalized monthly billed energy use during summer months due to a lack of control of secondary aeration processes (CV of 2% to 14%). Analysis of unit process energy use within some small plants showed that aeration processes accounted for the largest energy use ranging from 66% to 80% of the total usage. Modular designs of utilizing multiple smaller blowers and use of intermittent aeration appear to contribute efficiency of the design based on aeration intensity metrics.

Space heating of buildings was also determined as a large energy user for some plants, accounting for 4% to 35% of the total plant energy use for plants utilizing electricity for heating and benchmarking the building heating energy intensity resulted in values ranging from 4 to 70-kWh/(yr-ft^2) and an average value 24-kWh/(yr-ft^2). The benchmark values were supported by observations during site-visits of building envelopes, equipment used for heating, and operations of thermostat controls and likely explains why climate control floor area was found as a statistically significant variable in benchmarking the energy intensity of these small WWTPs (Hanna et al., 2018).

Most respondents (>80%) had reported that the student interaction and past E2 benchmarking letter from 2016 had at least somewhat improved their awareness to energy use at their plant. Infrastructure and operational E2 related changes were reported being made at 19 plants (37% of respondents) and twelve of the plants had reported changes specifically recommended in the previous benchmarking letters. Energy bills were collected for thirteen of the plants and nine showed an observed reduction in energy usage resulting in an approximate $39,000 of annual energy savings. The 13 plants reporting making changes showed an average 8.5% reduction in energy usage compared to a 1.2% reduction observed among a group of 16 plants reporting to have not made changes.

A majority (75%) of operators thought that cost-effective E2 related changes do exist at their plant. Survey responses to the barriers portion of the survey revealed that a large variety of barriers exist for small WWTPs in implementing E2 changes. Financial related barriers related to availability, a delegation of the funds, and risk of return on investment appeared as the most relevant. Lack of staff and/or time by staff to implement changes was also observed as a large barrier for these small communities. There also appears to be potentially some presence of adverse selection due to difficulties in evaluating the actual saving potential of some changes in advance. Since very few studies have been carried out evaluating the true economic viability of E2 related changes at specifically small WWTPs, towns may be less likely to invest in these changes and are more likely to base their decision making based on the upfront cost of changes.

Some of these barriers were also found to be slightly correlated with the most notable being the barriers of “Access to Capital” and “Other Priorities for Capital Investment” showed with a Pearson R correlation coefficient of 0.67. There also appears to be some organizational barriers present in small municipalities that limits the priority of energy management such as a lack of review of energy consumption data.

Chapter 5: Conclusions and Recommendations

5.1 Conclusions

A follow-up survey of operators who had participated in the past E2 WWTP benchmarking project was used to evaluate the impact of the project on their perception of energy use at their plant, to identify whether they thought cost-effective changes existed, to evaluate if any recent E2 related changes had been recently implemented, and to determine how relevant they perceive specific barriers are to the implementation of E2 changes. Collection of additional energy usage and water characteristics data was used to help quantify the impact of reported E2 changes. Analysis of unit processes energy use and building space heating within some small WWTPs was also carried out to help provide further context for the study. The following points are key conclusions based on this study.

- Energy use among unit processes within small WWTPs is largely used by aeration processes (66-80%) of which can have varying energy intensities which appear to be largely attributed by the original design configuration and current loading conditions to the facility. Modular blower design setups and timer systems on aerobic digesters appeared to contribute to more energy efficient aeration systems based on the observed energy intensities of these processes.
- Space heating was a significant energy use at small WWTPs accounting for an estimated 4 to 35% of the plant’s total energy use. Building heating intensity benchmarks for space heating showed relatively high values ranging from 5 to 71-kWh/(yr-ft^2) and an average value of 24-kWh/(yr-ft^2). This observation was likely

due to many of the buildings being built several decades ago when energy efficiency building standards were less stringent and with minimal to no upgrades being done since construction. This finding also likely explains why climate control floor area was found as a statistically significant variable in benchmarking the energy intensity of these small WWTPs (Hanna et al., 2018).

- Most respondents (>80%) had reported that the student interaction and past E2 benchmarking letter from 2016 had at least somewhat improved their awareness of energy use at their plant. Infrastructure and operational E2 related changes were reported being made at 19 plants (37% of respondents) and twelve of the plants had reported changes specifically recommended in the previous benchmarking letters. Energy bills were collected for thirteen of the plants and nine showed an observed reduction in energy usage resulting in an approximate $39,000 of annual energy savings. The 13 plants reporting making changes showed an average 8.5% reduction in energy usage compared to a 1.2% reduction observed among a group of 16 plants reporting to have not made changes.
- There is a large diversity of barriers prohibiting the uptake of E2 related changes at small WWTPs. Financial related barriers and lack of staff and/or time by staff to implement changes appear as the most relevant barriers. Furthermore, there are clearly organizational barriers within municipalities that inhibit E2 from being considered a high priority. Lack of awareness on what opportunities exist and the understanding of the benefits of such opportunities by staff may be one of the largest barriers inhibiting whether any changes are made at plants.

5.2 Recommendations for Future Research

Additional research needs to be conducted to further understand energy efficiency of small wastewater treatment processes. Specific areas that merit further investigation include an understanding of factors impacting the E2 of processes and the plant, the complete economic analysis of specific E2 related changes, the numerous barriers that may limit the uptake of E2 changes that are cost-effective, and methods for overcoming these barriers to achieve change. The following ideas are suggestions for future research in these areas:

- Perceived payback on investment was noted as one of the largest barriers to implementing E2 changes in this study and also by Kuppig (2015). There is a lack of sufficient information in literature detailing the economics of common E2 changes at small plants. Quantification of actual paybacks on investment of such changes could potentially help reduce the uncertainty regarding such changes. Investigation of the economics of automation being employed on aeration processes specifically at plants of varying size, varying energy cost, and variable time of operator availability to perform process control should be investigated in more depth. This also should include a sensitivity analysis of how varying population growths and cost of energy impact the results.
- Further evaluation of the specific factors that impact energy intensity at WWTPs would aid greatly. Determining how much relative influence the original design, efficiency of the equipment, environmental conditions, and operational control has on the collective efficiency would help evaluate how much impact could be realized from specific changes made within this group and where efforts should

be focused to improve the overall efficiency of small WWTPs moving forward. The influence of operations could be evaluated by analyzing how efficiently unit processes are being optimized relative to theoretical optimal efficiency constrained by a given system. The impact of design could be evaluated by modeling how efficient different types of systems can operate under variable loading conditions based on variable population growth changes observed within many small communities. Finally, the influence of environmental conditions on efficiency would likely need to be studied on the unit process scale. This would include an analysis of how specific environmental factors such as air and water temperature can impact process energy efficiency.

- Appropriate benchmark metrics for overall plants and unit processes also need to be further evaluated due to uncertainty in which metrics may be most appropriate for plants as had been noted in previous studies (DOE, 2017; EPRI, 2013).
    - This needs to be further evaluated in benchmarking plants against each other, but also in evaluating changes within plants over time.
    - The type and level of control/ automation employed at plants should be specifically investigated when further evaluating appropriate benchmarks for small plants.
    - Aerobic sludge digestion was the only unit process identified by Foladori et al. (2015) that did not have any suitable benchmark metric for evaluating its energy efficiency. The process had an observed high energy use and variable levels of control at plants throughout Nebraska. Further work could be done to find suitable benchmarks for this process and

further investigation of optimization of the process should be carried out. One recommendation would be to evaluate if the mass of volatile suspended solids (VSS) being reduced could be used as an appropriate normalization parameter for benchmarking.

- In this study, the barriers to making E2 changes were only analyzed for relatively small communities and of all plant types. Some further investigation in how these barriers may exist at plants of varying size and type as had been done by Trianni et al. (2013) may provide more insight into what limits uptake of E2 related changes in municipal systems.
- Lagoon systems are a common alternative process employed at many small Nebraska communities to treat wastewater. Some future research could help investigate the sustainability of these systems compared to small mechanical treatment plants considering varying population growth trends and variable sources of energy that will be observed in the coming years. This could be carried out by first conducting Life Cycle Assessment (LCA) and Life Cycle Cost Assessments (LCCA) on the different systems. The impact of how town population growth changes impacts process energy use and pollutant loadings could be modeled and then several scenarios conducted evaluating how the LCA and LCCA results vary under differing population growth changes and cost energy sources.

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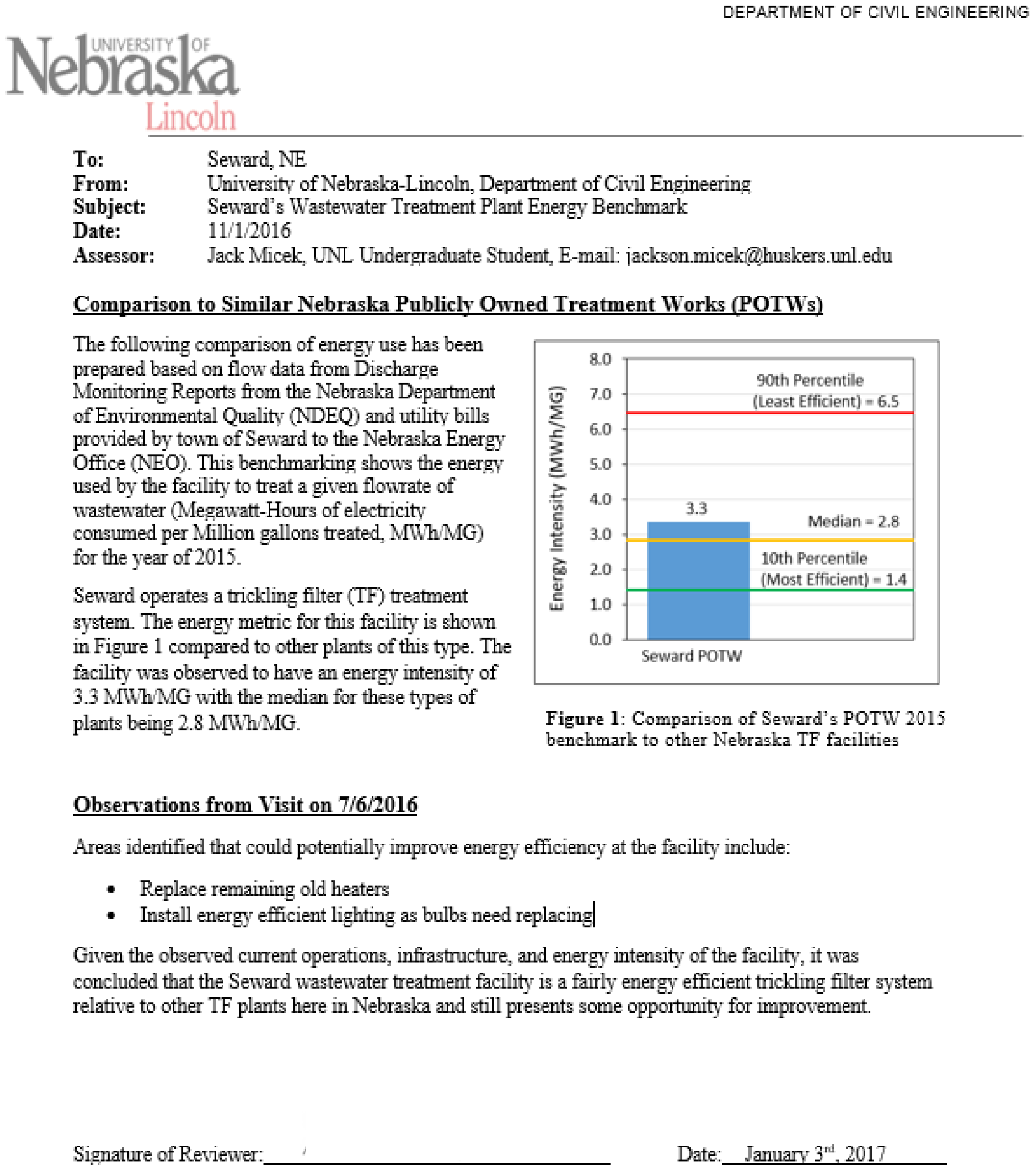
Appendices

Appendix A: Benchmarking Letter and Follow-up Survey Materials

This section includes information pertaining to the original benchmark letter sent out to plants, the follow-up survey materials and relevant information related to IRB, and the presentation provided on energy efficiency at the local operator trainings is also included at the end of the section. The original benchmarking letter provided to towns in shown below in Figure A.1.



DEPARTMENT OF CIVIL ENGINEERING

University of Nebraska Lincoln

To: Seward, NE
From: University of Nebraska-Lincoln, Department of Civil Engineering
Subject: Seward's Wastewater Treatment Plant Energy Benchmark
Date: 11/1/2016
Assessor: Jack Micek, UNL Undergraduate Student, E-mail: jackson.micek@huskers.unl.edu

Comparison to Similar Nebraska Publicly Owned Treatment Works (POTWs)

The following comparison of energy use has been prepared based on flow data from Discharge Monitoring Reports from the Nebraska Department of Environmental Quality (NDEQ) and utility bills provided by town of Seward to the Nebraska Energy Office (NEO). This benchmarking shows the energy used by the facility to treat a given flowrate of wastewater (Megawatt-Hours of electricity consumed per Million gallons treated, MWh/MG) for the year of 2015.

Seward operates a trickling filter (TF) treatment system. The energy metric for this facility is shown in Figure 1 compared to other plants of this type. The facility was observed to have an energy intensity of 3.3 MWh/MG with the median for these types of plants being 2.8 MWh/MG.

Figure 1: Comparison of Seward's POTW 2015 benchmark to other Nebraska TF facilities

Observations from Visit on 7/6/2016

Areas identified that could potentially improve energy efficiency at the facility include:

- Replace remaining old heaters
- Install energy efficient lighting as bulbs need replacing

Given the observed current operations, infrastructure, and energy intensity of the facility, it was concluded that the Seward wastewater treatment facility is a fairly energy efficient trickling filter system relative to other TF plants here in Nebraska and still presents some opportunity for improvement.

Signature of Reviewer:____________________ Date: January 3rd, 2017

Figure A.1: E2 Benchmarking Letter Provided to Municipalities

The IRB approved participant consent letter for the survey is shown below in Figure A.2.

University of Nebraska Lincoln

Partners in Pollution Prevention Program

IRB# 20170917354EX
Date Approved: 09/11/2017
Valid Until: 09/11/2022

PARTICIPANT INFORMED CONSENT FORM – SURVEY

IRB #: 17354

Identification of Project:
Partners in Pollution Prevention (P3) Program – Identifying Opportunities and Barriers to Energy Efficiency (E2) at Wastewater Treatment Facilities.

Purpose of the Research:
In 2016, the UNL P3 Program and the Nebraska Energy Office conducted a statewide energy efficiency benchmarking of small to medium sized mechanical wastewater treatment plants to help identify the least efficient and highest opportunity plants for subsequent energy audits. The project involved providing quantified metrics and specific observations from a site visit pertaining to the plant's energy efficiency in the form of a written letter. The purpose of this study is to evaluate if the benchmarking project had resulted in an increased awareness related to energy efficiency of participating plants, identifying whether any specific changes have been made because of the project, to identify if those changes or improved awareness resulted in a measurable improvement in energy efficiency, and to obtain a qualitative ranking of the perceived barriers to making energy efficiency changes at the treatment facilities. You must be 19 years of age or older to participate. You are invited to participate in this study because you are wastewater treatment plant operator for a plant in Nebraska.

Procedures:
Survey questions will be distributed among the plant operators that participated in the energy efficiency benchmarking project at operator training sessions provided by the Nebraska Rural Water Association that are held throughout the state. Attendees that were not previously benchmarked will be asked to fill in only a portion of the survey that relates to the perceived barriers. The survey will be prefaced with a presentation about energy efficiency, the benchmarking project conducted, and an open interactive session in which participants will be able to discuss any current E2 practices being conducted at their plant and their thoughts on what could be done to improve E2 in the future. Following this portion, a description of each of the barriers investigated for this study will be provided. Surveys will be provided at the end of the session and should take participants approximately 5-10 minutes to complete. The workshop will be advertised in a brochure for the operator trainings sent out by the Nebraska Rural Water Association with the title, "Identifying Opportunities and Barriers to Energy Efficiency". In addition to this data collection, some communities may have the survey sent out directly to the operators with a follow-up phone call to survey. The phone call would primarily be concerned with explaining the survey, describing specifically what the terms used mean, and answering any questions the participants may have. Publicly available utility bills of the facility's energy usage will be gathered for the facilities that noted becoming more aware. This will be gathered to assess if there was an identifiable impact from the project. A total of about 90 plants had participated in the benchmarking project in 2016 and the goal is to survey about 60 of these participating plants.

Benefits and Compensation:
Participants will have the opportunity to contribute to improving the education and awareness of energy efficiency opportunities and barriers to changes at wastewater treatment facilities. Attending the training will count towards credit for their operator training education.

Risks and/or Discomforts:
There are no known risks or discomforts associated with this research. In the event of problems resulting from participation in the study, you may contact Dr. Bruce Dvorak, P3 Program Director, for assistance or referral at 402-472-3431 or bdvorak1@unl.edu.

Confidentiality:
The data collected from the survey will be maintained confidentially by the Department of Civil Engineering. The surveys will be stored in a locked cabinet in the investigator's office and will only be seen by the research team during the study and for 5 years after the study is complete. The information obtained in this study may be published in a graduate student thesis, scientific journals or presented at scientific meetings, but the data will be reported as aggregated data (without individually identifiable information). The name of the participating entities (e.g., town or operator) will not be identified in the results of research or other possible reports.

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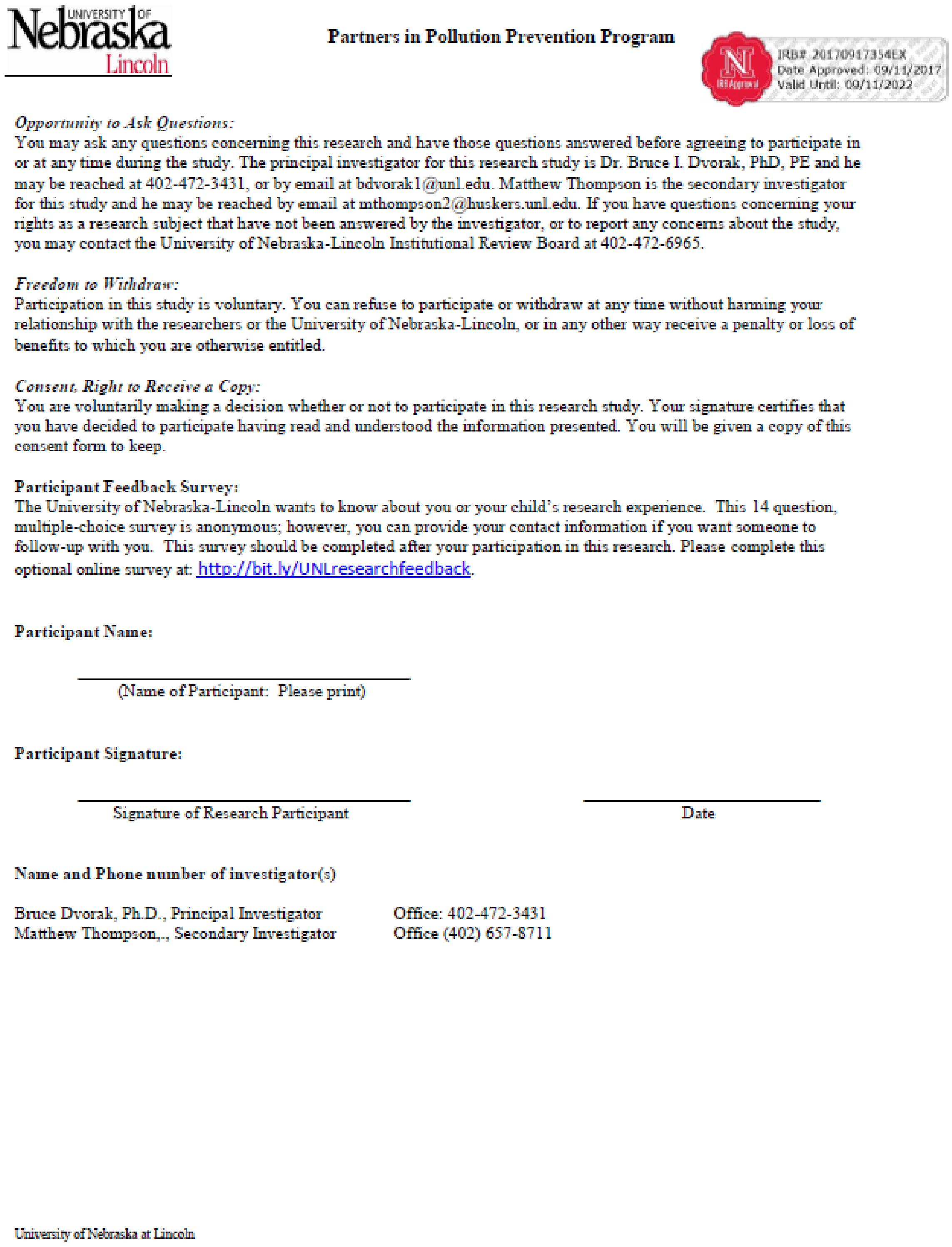
Figure A.2: IRB Approved Participant Consent Form for the Survey



University of Nebraska Lincoln

Partners in Pollution Prevention Program

IRB# 20170917354EX
Date Approved: 09/11/2017
Valid Until: 09/11/2022

Opportunity to Ask Questions:

You may ask any questions concerning this research and have those questions answered before agreeing to participate in or at any time during the study. The principal investigator for this research study is Dr. Bruce I. Dvorak, PhD, PE and he may be reached at 402-472-3431, or by email at bdvorak1@unl.edu. Matthew Thompson is the secondary investigator for this study and he may be reached by email at mthompson2@huskers.unl.edu. If you have questions concerning your rights as a research subject that have not been answered by the investigator, or to report any concerns about the study, you may contact the University of Nebraska-Lincoln Institutional Review Board at 402-472-6965.

Freedom to Withdraw:

Participation in this study is voluntary. You can refuse to participate or withdraw at any time without harming your relationship with the researchers or the University of Nebraska-Lincoln, or in any other way receive a penalty or loss of benefits to which you are otherwise entitled.

Consent, Right to Receive a Copy:

You are voluntarily making a decision whether or not to participate in this research study. Your signature certifies that you have decided to participate having read and understood the information presented. You will be given a copy of this consent form to keep.

Participant Feedback Survey:

The University of Nebraska-Lincoln wants to know about you or your child's research experience. This 14 question, multiple-choice survey is anonymous; however, you can provide your contact information if you want someone to follow-up with you. This survey should be completed after your participation in this research. Please complete this optional online survey at: http://bit.ly/UNLresearchfeedback.

Participant Name:

____
(Name of Participant: Please print)

Participant Signature:

________________________________ ____________________
Signature of Research Participant Date

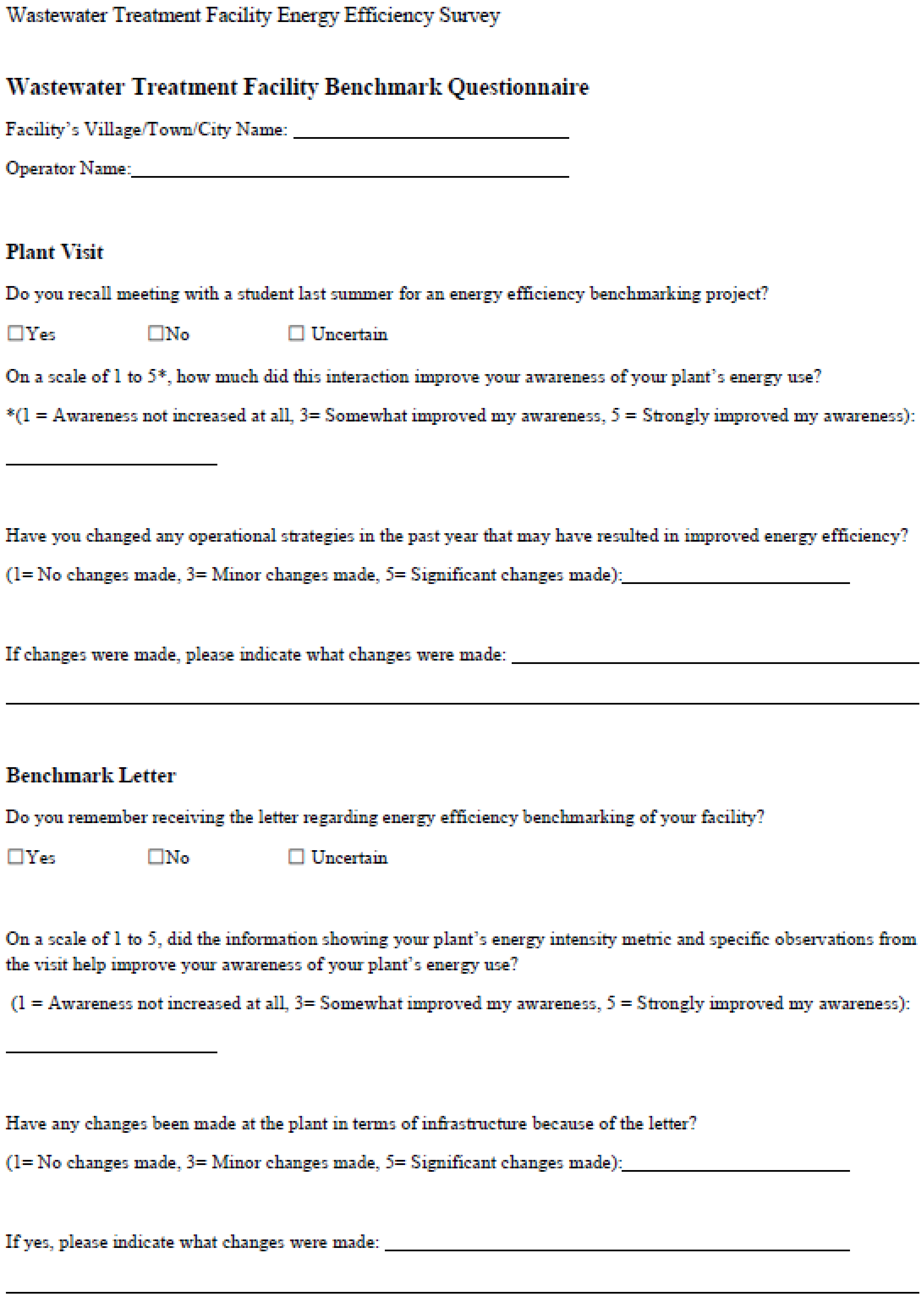
Name and Phone number of investigator(s)

Bruce Dvorak, Ph.D., Principal Investigator	Office: 402-472-3431
Matthew Thompson,., Secondary Investigator	Office (402) 657-8711

University of Nebraska at Lincoln

Figure A.2 (cont)

The 2-page survey used in this study is shown below in Figure A.3.



Wastewater Treatment Facility Energy Efficiency Survey

Wastewater Treatment Facility Benchmark Questionnaire

Facility's Village/Town/City Name: ____________________

Operator Name: ____________________

Plant Visit

Do you recall meeting with a student last summer for an energy efficiency benchmarking project?

☐Yes ☐No ☐ Uncertain

On a scale of 1 to 5*, how much did this interaction improve your awareness of your plant's energy use?

*(1 = Awareness not increased at all, 3= Somewhat improved my awareness, 5 = Strongly improved my awareness):

____

Have you changed any operational strategies in the past year that may have resulted in improved energy efficiency?

(1= No changes made, 3= Minor changes made, 5= Significant changes made):____________

If changes were made, please indicate what changes were made: ____________________

____

Benchmark Letter

Do you remember receiving the letter regarding energy efficiency benchmarking of your facility?

☐Yes ☐No ☐ Uncertain

On a scale of 1 to 5, did the information showing your plant's energy intensity metric and specific observations from the visit help improve your awareness of your plant's energy use?

(1 = Awareness not increased at all, 3= Somewhat improved my awareness, 5 = Strongly improved my awareness):

____

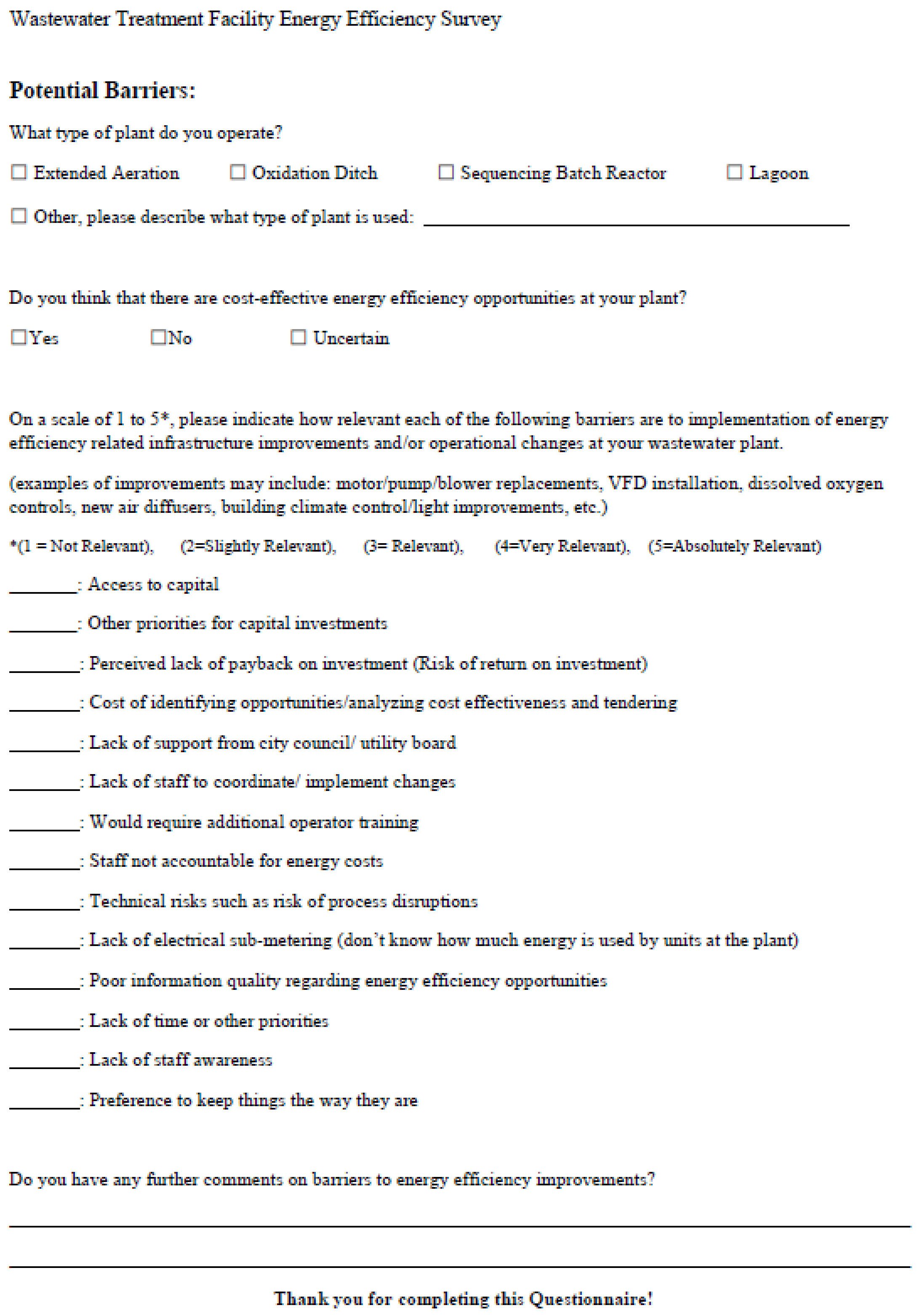
Have any changes been made at the plant in terms of infrastructure because of the letter?

(1= No changes made, 3= Minor changes made, 5= Significant changes made):____________

If yes, please indicate what changes were made: ____________________

____

Figure A.3: Follow-up Survey for WWTP Operators



Wastewater Treatment Facility Energy Efficiency Survey

Potential Barriers:

What type of plant do you operate?

☐ Extended Aeration ☐ Oxidation Ditch ☐ Sequencing Batch Reactor ☐ Lagoon

☐ Other, please describe what type of plant is used: ____

Do you think that there are cost-effective energy efficiency opportunities at your plant?

☐Yes ☐No ☐ Uncertain

On a scale of 1 to 5*, please indicate how relevant each of the following barriers are to implementation of energy efficiency related infrastructure improvements and/or operational changes at your wastewater plant.

(examples of improvements may include: motor/pump/blower replacements, VFD installation, dissolved oxygen controls, new air diffusers, building climate control/light improvements, etc.)

*(1 = Not Relevant), (2=Slightly Relevant), (3= Relevant), (4=Very Relevant), (5=Absolutely Relevant)

________: Access to capital

________: Other priorities for capital investments

________: Perceived lack of payback on investment (Risk of return on investment)

________: Cost of identifying opportunities/analyzing cost effectiveness and tendering

________: Lack of support from city council/ utility board

________: Lack of staff to coordinate/ implement changes

________: Would require additional operator training

________: Staff not accountable for energy costs

________: Technical risks such as risk of process disruptions

________: Lack of electrical sub-metering (don't know how much energy is used by units at the plant)

________: Poor information quality regarding energy efficiency opportunities

________: Lack of time or other priorities

________: Lack of staff awareness

________: Preference to keep things the way they are

Do you have any further comments on barriers to energy efficiency improvements?

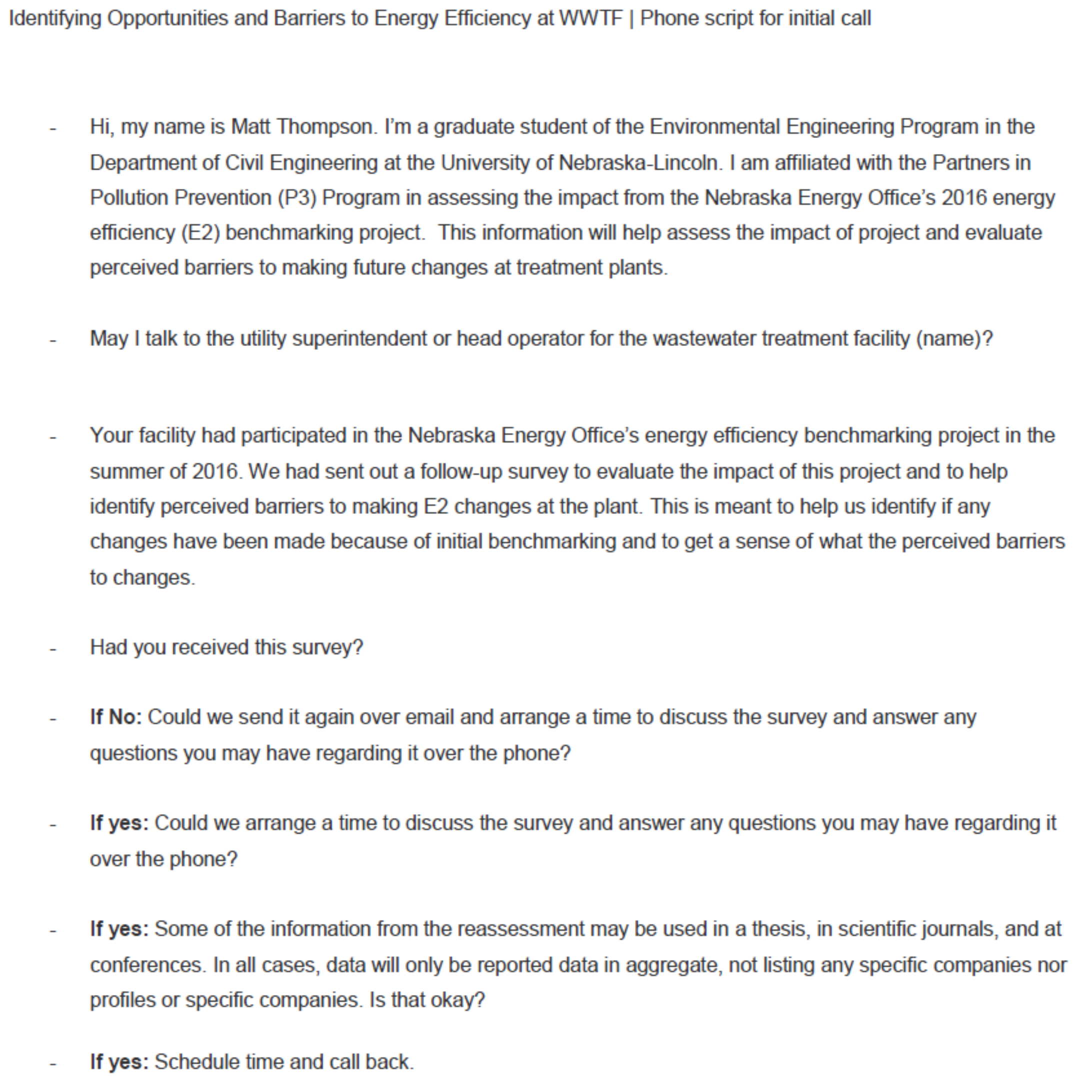
____

____

Thank you for completing this Questionnaire!

Figure A.3 (Cont)

The call script used as a guide for calling operators to discuss the survey is shown below in Figure A.4.

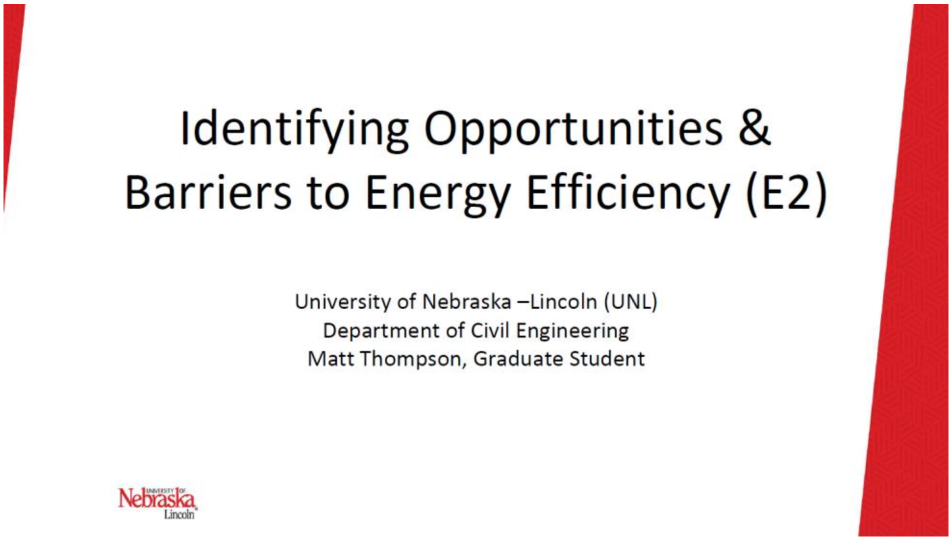


Identifying Opportunities and Barriers to Energy Efficiency at WWTF | Phone script for initial call

- Hi, my name is Matt Thompson. I'm a graduate student of the Environmental Engineering Program in the Department of Civil Engineering at the University of Nebraska-Lincoln. I am affiliated with the Partners in Pollution Prevention (P3) Program in assessing the impact from the Nebraska Energy Office's 2016 energy efficiency (E2) benchmarking project. This information will help assess the impact of project and evaluate perceived barriers to making future changes at treatment plants.
- May I talk to the utility superintendent or head operator for the wastewater treatment facility (name)?
- Your facility had participated in the Nebraska Energy Office's energy efficiency benchmarking project in the summer of 2016. We had sent out a follow-up survey to evaluate the impact of this project and to help identify perceived barriers to making E2 changes at the plant. This is meant to help us identify if any changes have been made because of initial benchmarking and to get a sense of what the perceived barriers to changes.
- Had you received this survey?
- **If No:** Could we send it again over email and arrange a time to discuss the survey and answer any questions you may have regarding it over the phone?
- **If yes:** Could we arrange a time to discuss the survey and answer any questions you may have regarding it over the phone?
- **If yes:** Some of the information from the reassessment may be used in a thesis, in scientific journals, and at conferences. In all cases, data will only be reported data in aggregate, not listing any specific companies nor profiles or specific companies. Is that okay?
- **If yes:** Schedule time and call back.

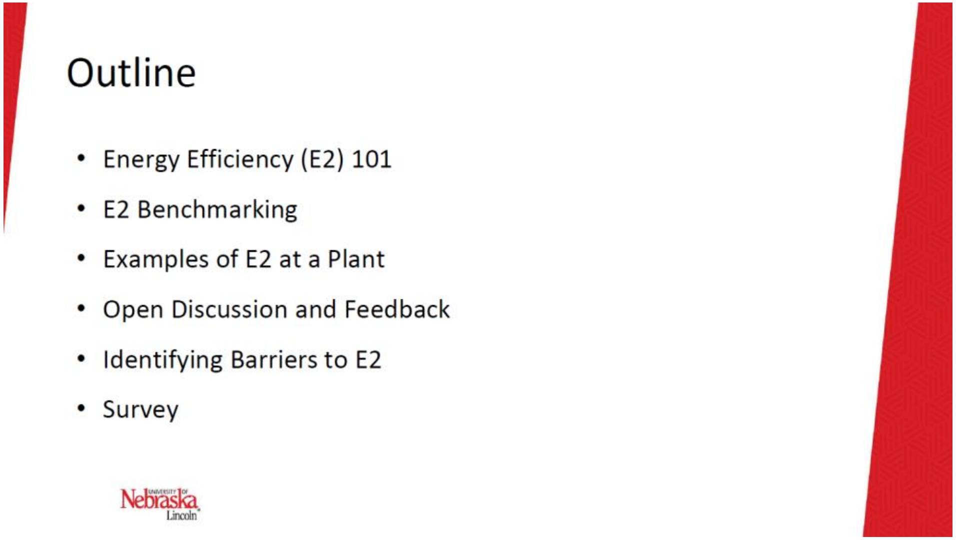
Figure A.4: Survey Follow-up Call Script

The following presentation slides utilized at operator trainings is shown on the next several pages.



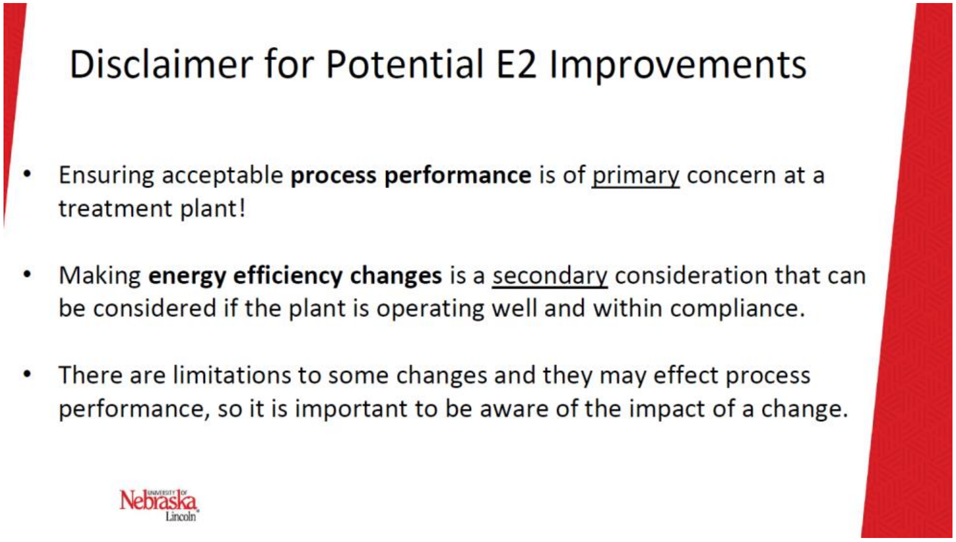
Identifying Opportunities & Barriers to Energy Efficiency (E2)

University of Nebraska –Lincoln (UNL)
Department of Civil Engineering
Matt Thompson, Graduate Student



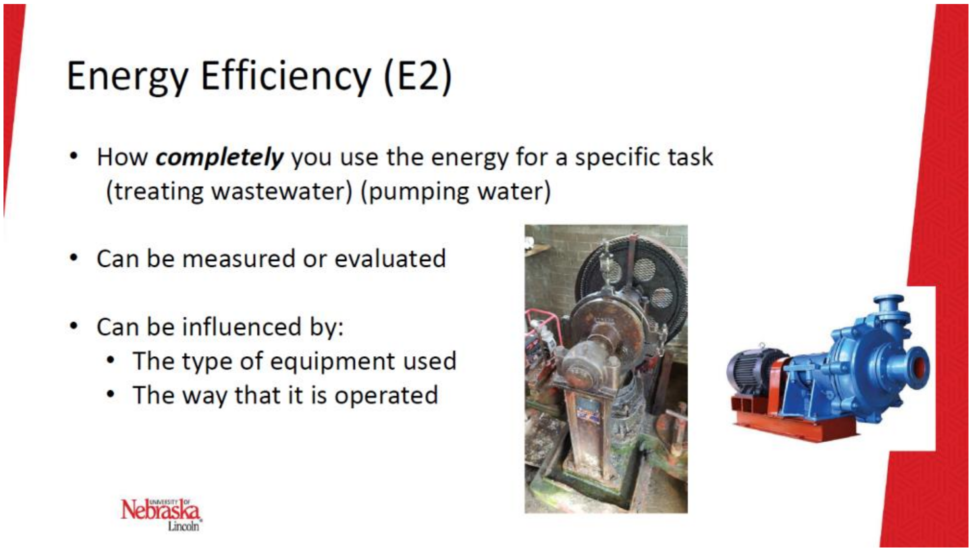
Outline

- Energy Efficiency (E2) 101
- E2 Benchmarking
- Examples of E2 at a Plant
- Open Discussion and Feedback
- Identifying Barriers to E2
- Survey



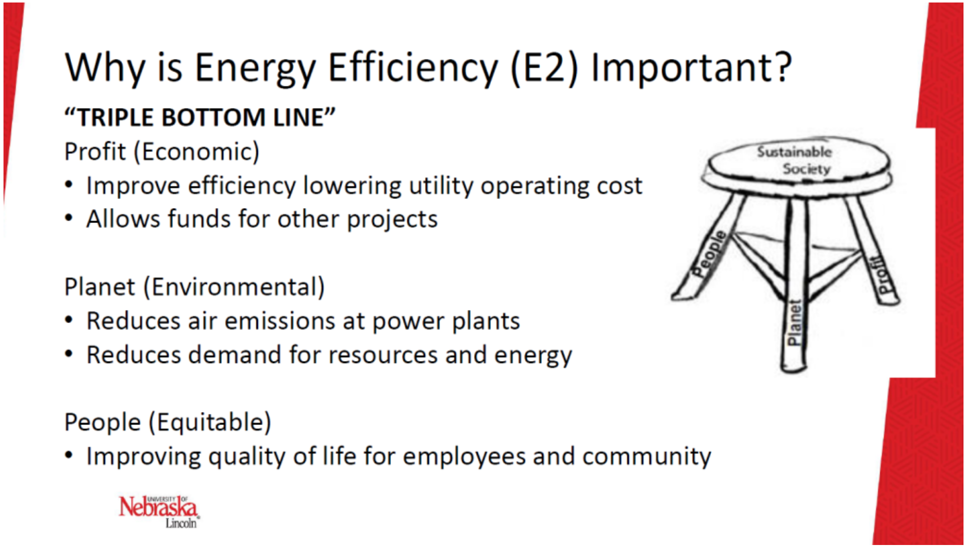
Disclaimer for Potential E2 Improvements

- Ensuring acceptable **process performance** is of primary concern at a treatment plant!
- Making **energy efficiency changes** is a secondary consideration that can be considered if the plant is operating well and within compliance.
- There are limitations to some changes and they may effect process performance, so it is important to be aware of the impact of a change.



Energy Efficiency (E2)

- How ***completely*** you use the energy for a specific task (treating wastewater) (pumping water)
- Can be measured or evaluated
- Can be influenced by:
  - The type of equipment used
  - The way that it is operated



Why is Energy Efficiency (E2) Important?

"TRIPLE BOTTOM LINE"

Profit (Economic)

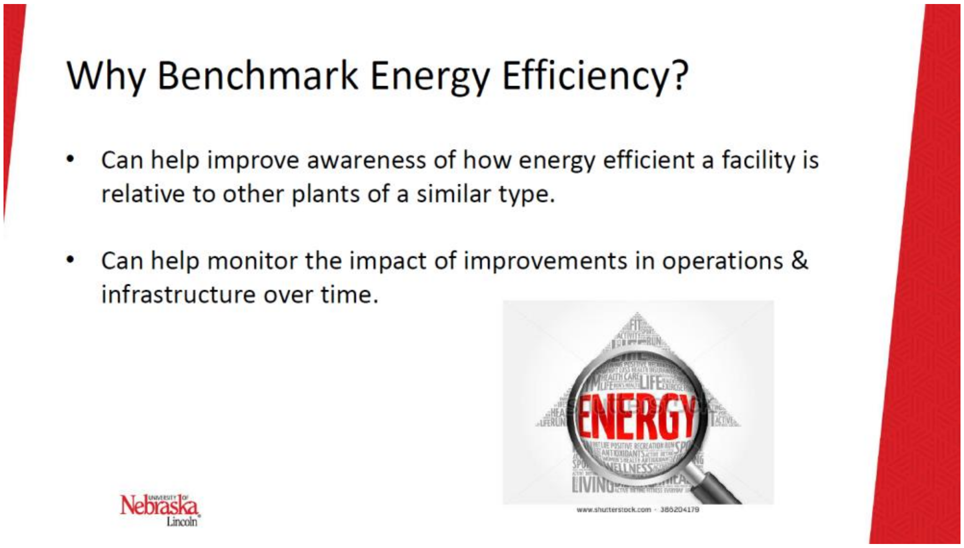
- Improve efficiency lowering utility operating cost
- Allows funds for other projects

Planet (Environmental)

- Reduces air emissions at power plants
- Reduces demand for resources and energy

People (Equitable)

- Improving quality of life for employees and community



Why Benchmark Energy Efficiency?

- Can help improve awareness of how energy efficient a facility is relative to other plants of a similar type.
- Can help monitor the impact of improvements in operations & infrastructure over time.

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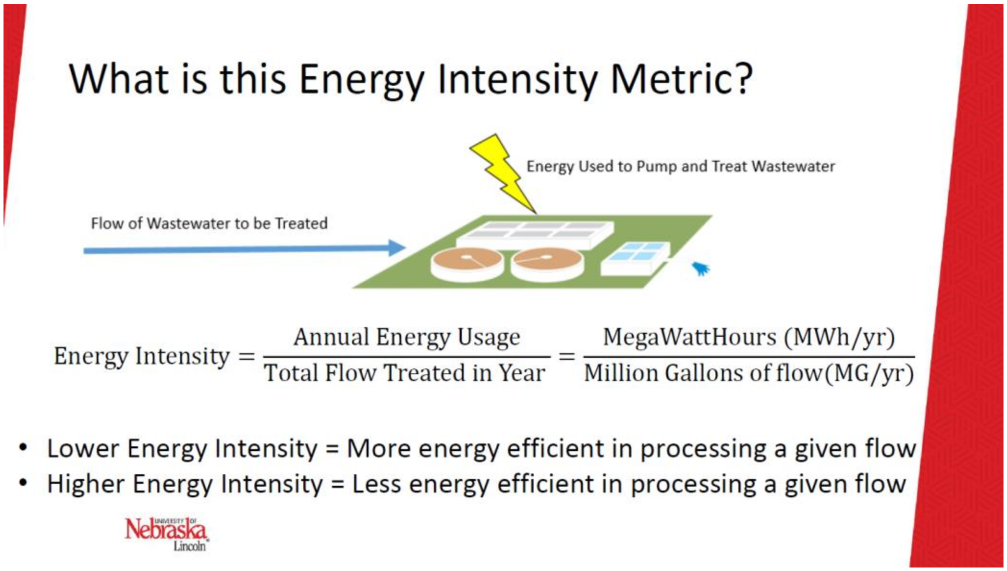
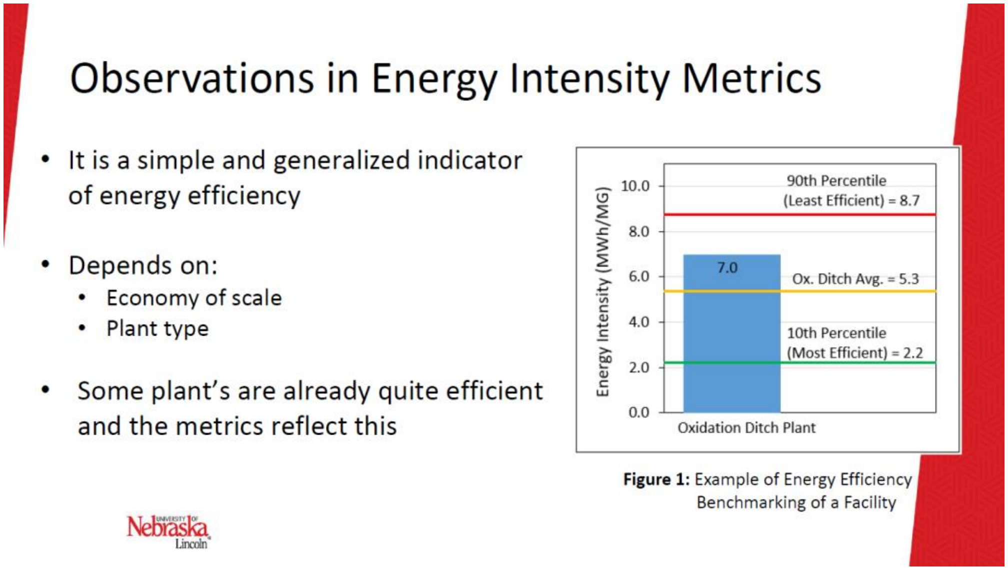


What is this Energy Intensity Metric?

$$\text{Energy Intensity} = \frac{\text{Annual Energy Usage}}{\text{Total Flow Treated in Year}} = \frac{\text{MegaWattHours (MWh/yr)}}{\text{Million Gallons of flow(MG/yr)}}$$

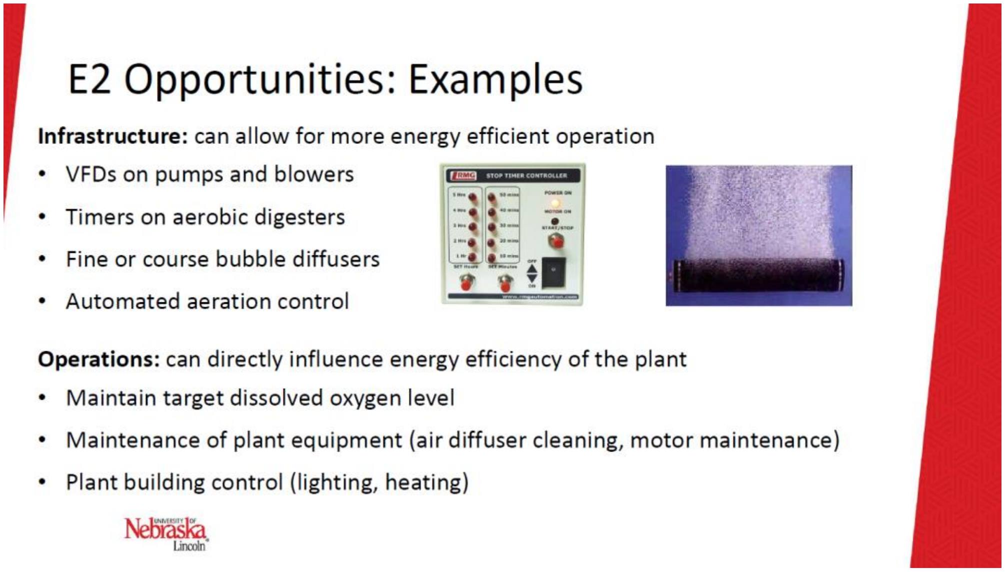
- Lower Energy Intensity = More energy efficient in processing a given flow
- Higher Energy Intensity = Less energy efficient in processing a given flow



Observations in Energy Intensity Metrics

- It is a simple and generalized indicator of energy efficiency
- Depends on:
  - Economy of scale
  - Plant type
- Some plant's are already quite efficient and the metrics reflect this

Figure 1: Example of Energy Efficiency Benchmarking of a Facility



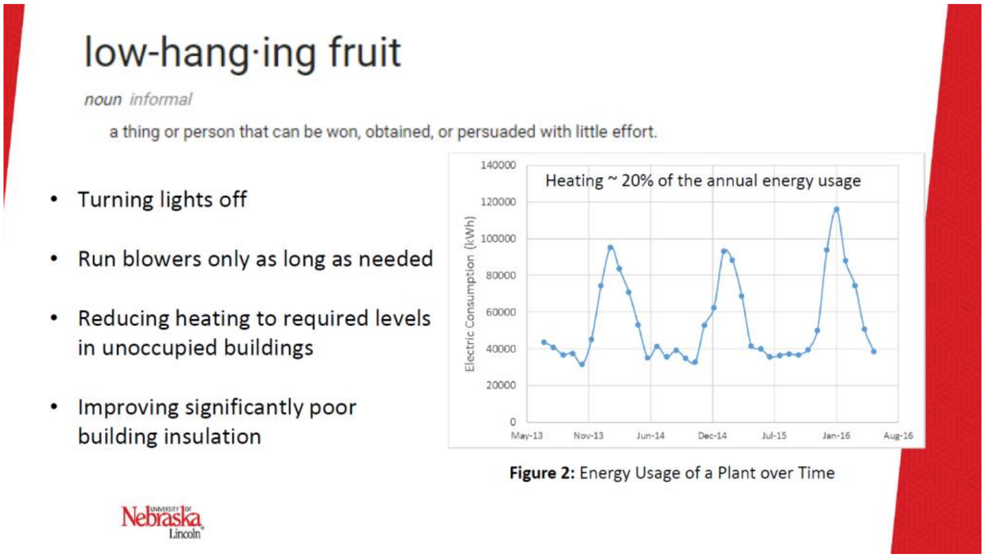
E2 Opportunities: Examples

Infrastructure: can allow for more energy efficient operation

- VFDs on pumps and blowers
- Timers on aerobic digesters
- Fine or course bubble diffusers
- Automated aeration control

Operations: can directly influence energy efficiency of the plant

- Maintain target dissolved oxygen level
- Maintenance of plant equipment (air diffuser cleaning, motor maintenance)
- Plant building control (lighting, heating)



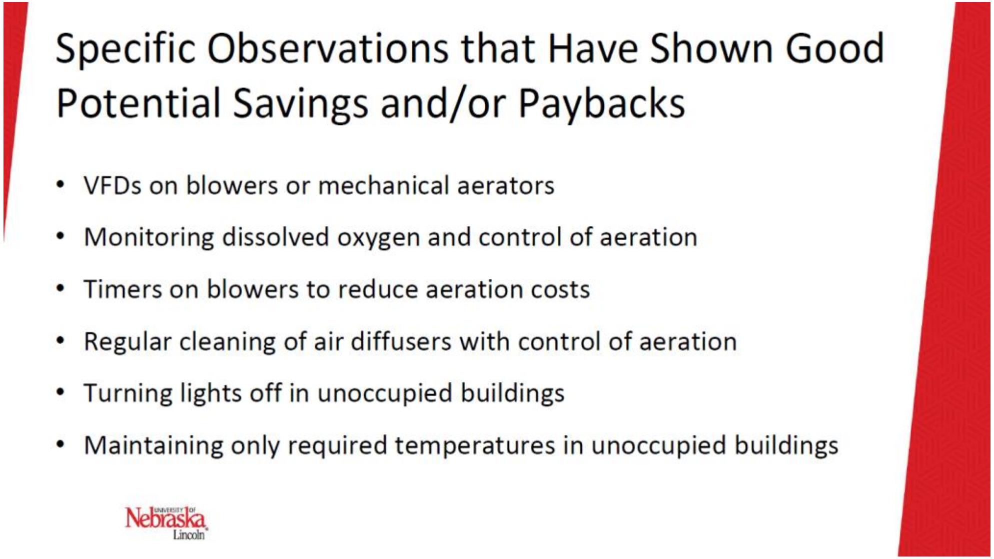
low-hang·ing fruit

noun informal

a thing or person that can be won, obtained, or persuaded with little effort.

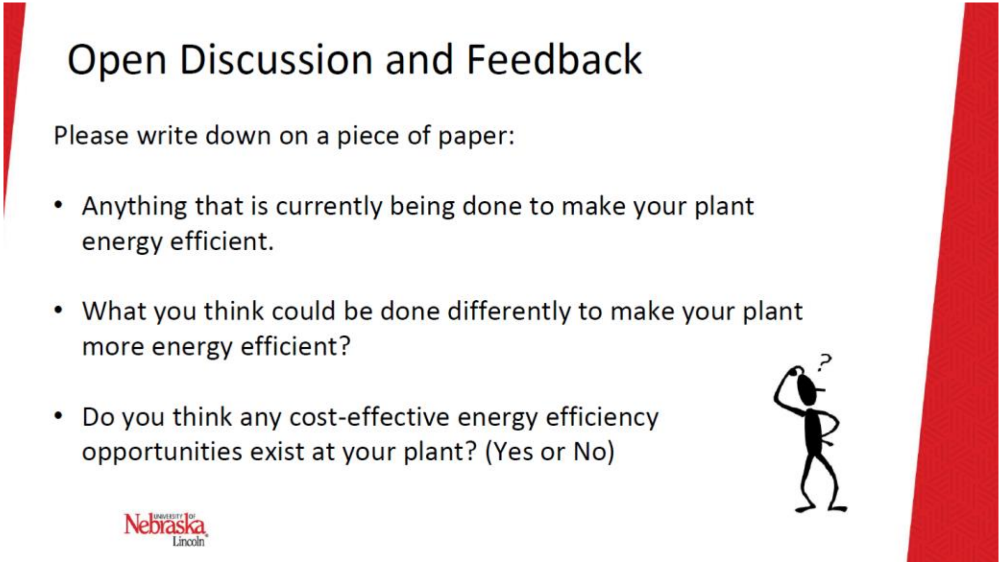
- Turning lights off
- Run blowers only as long as needed
- Reducing heating to required levels in unoccupied buildings
- Improving significantly poor building insulation

Figure 2: Energy Usage of a Plant over Time



Specific Observations that Have Shown Good Potential Savings and/or Paybacks

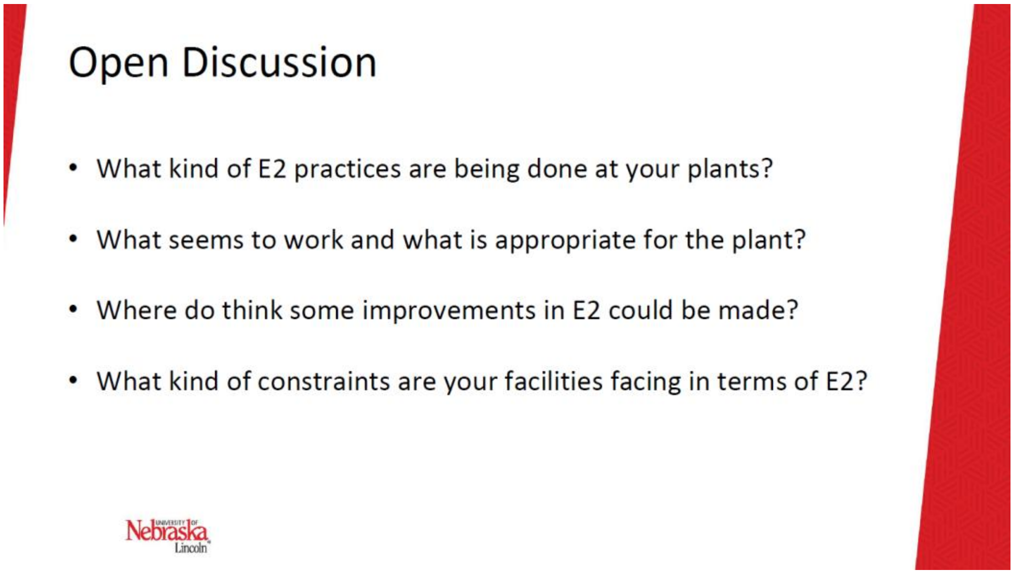
- VFDs on blowers or mechanical aerators
- Monitoring dissolved oxygen and control of aeration
- Timers on blowers to reduce aeration costs
- Regular cleaning of air diffusers with control of aeration
- Turning lights off in unoccupied buildings
- Maintaining only required temperatures in unoccupied buildings



Open Discussion and Feedback

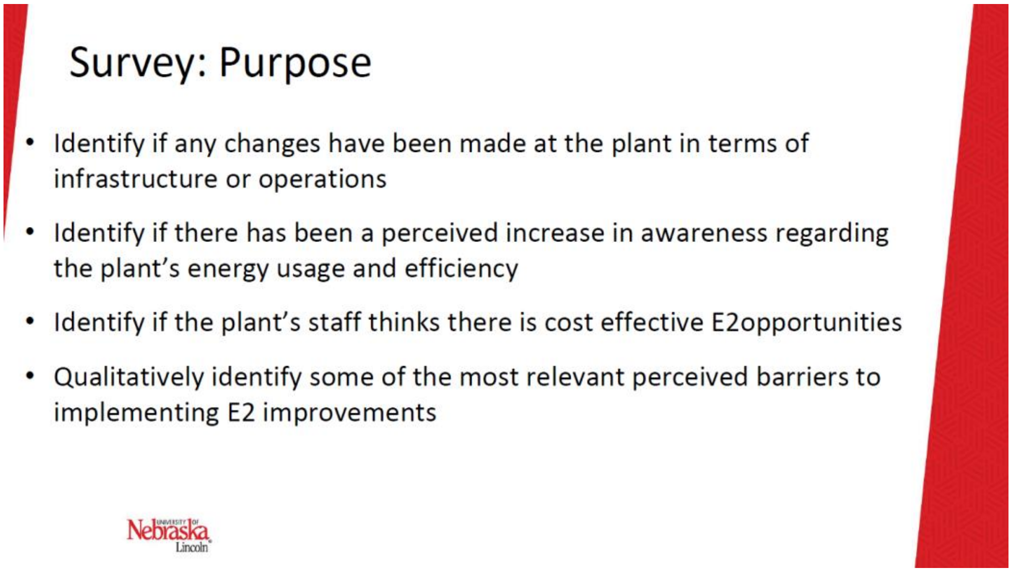
Please write down on a piece of paper:

- Anything that is currently being done to make your plant energy efficient.
- What you think could be done differently to make your plant more energy efficient?
- Do you think any cost-effective energy efficiency opportunities exist at your plant? (Yes or No)



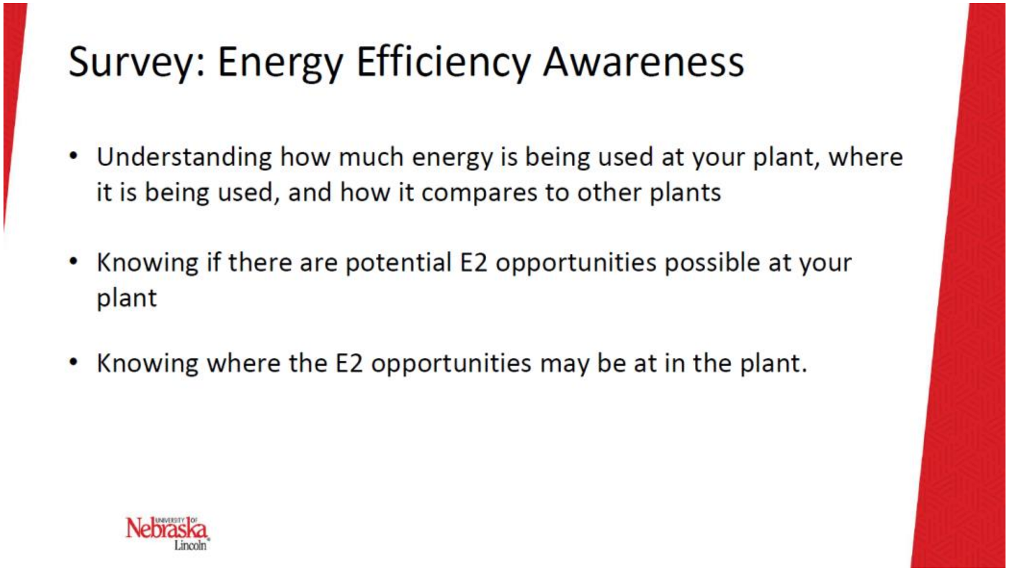
Open Discussion

- What kind of E2 practices are being done at your plants?
- What seems to work and what is appropriate for the plant?
- Where do think some improvements in E2 could be made?
- What kind of constraints are your facilities facing in terms of E2?



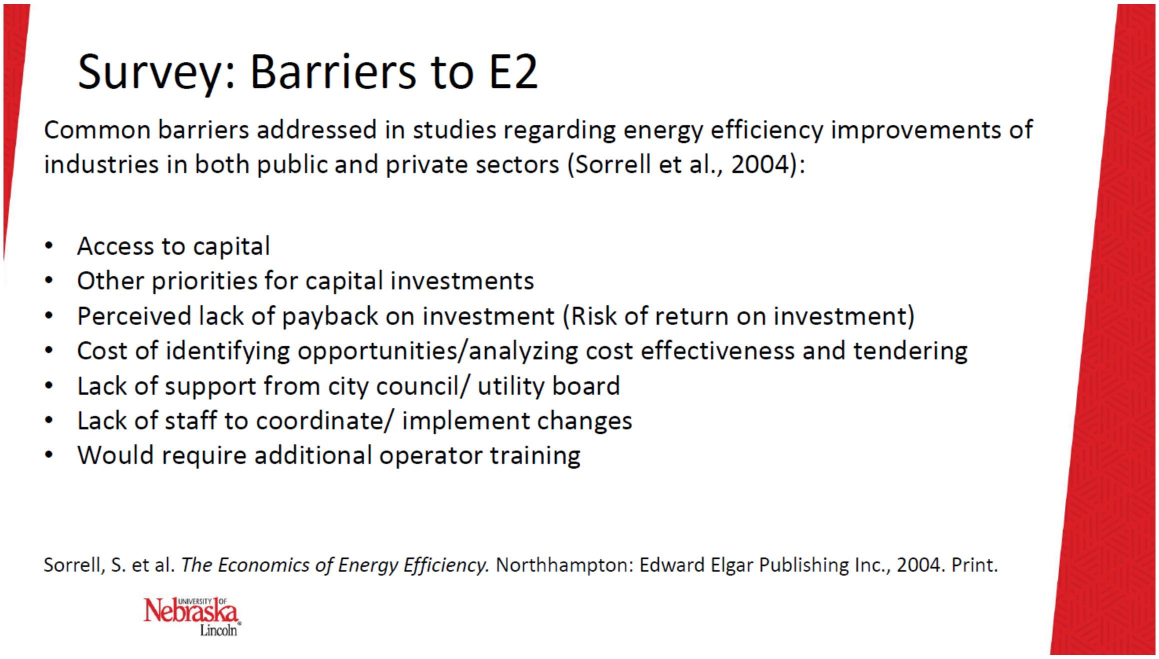
Survey: Purpose

- Identify if any changes have been made at the plant in terms of infrastructure or operations
- Identify if there has been a perceived increase in awareness regarding the plant’s energy usage and efficiency
- Identify if the plant’s staff thinks there is cost effective E2opportunities
- Qualitatively identify some of the most relevant perceived barriers to implementing E2 improvements



Survey: Energy Efficiency Awareness

- Understanding how much energy is being used at your plant, where it is being used, and how it compares to other plants
- Knowing if there are potential E2 opportunities possible at your plant
- Knowing where the E2 opportunities may be at in the plant.



Survey: Barriers to E2

Common barriers addressed in studies regarding energy efficiency improvements of industries in both public and private sectors (Sorrell et al., 2004):

- Access to capital
- Other priorities for capital investments
- Perceived lack of payback on investment (Risk of return on investment)
- Cost of identifying opportunities/analyzing cost effectiveness and tendering
- Lack of support from city council/ utility board
- Lack of staff to coordinate/ implement changes
- Would require additional operator training

Sorrell, S. et al. *The Economics of Energy Efficiency.* Northhampton: Edward Elgar Publishing Inc., 2004. Print.

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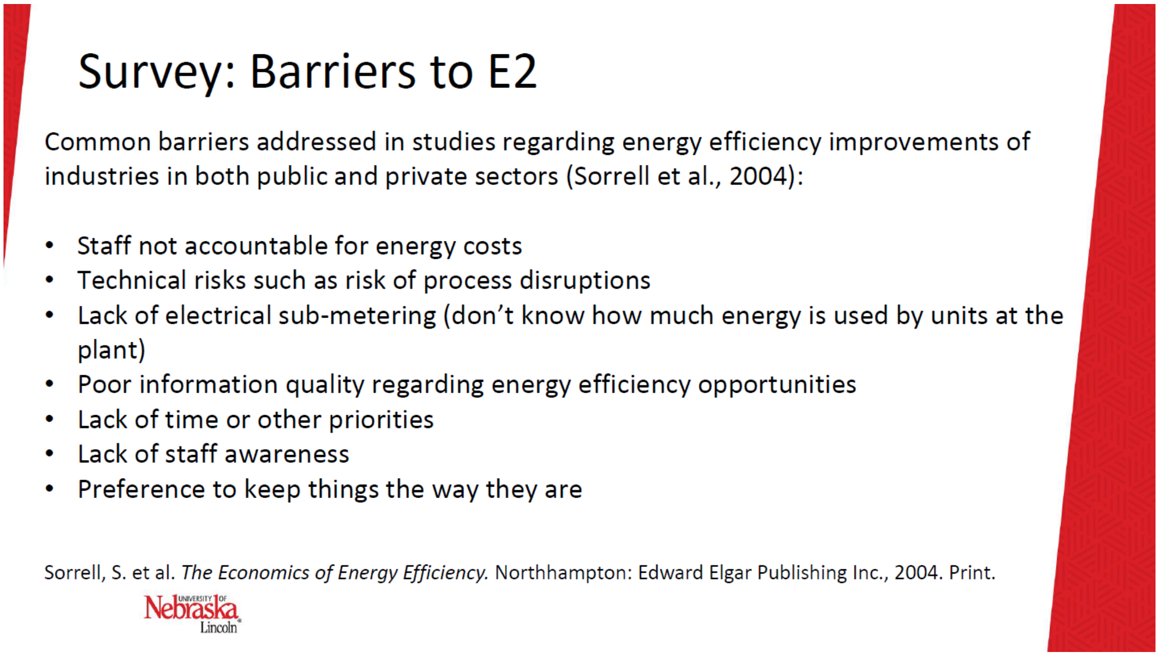


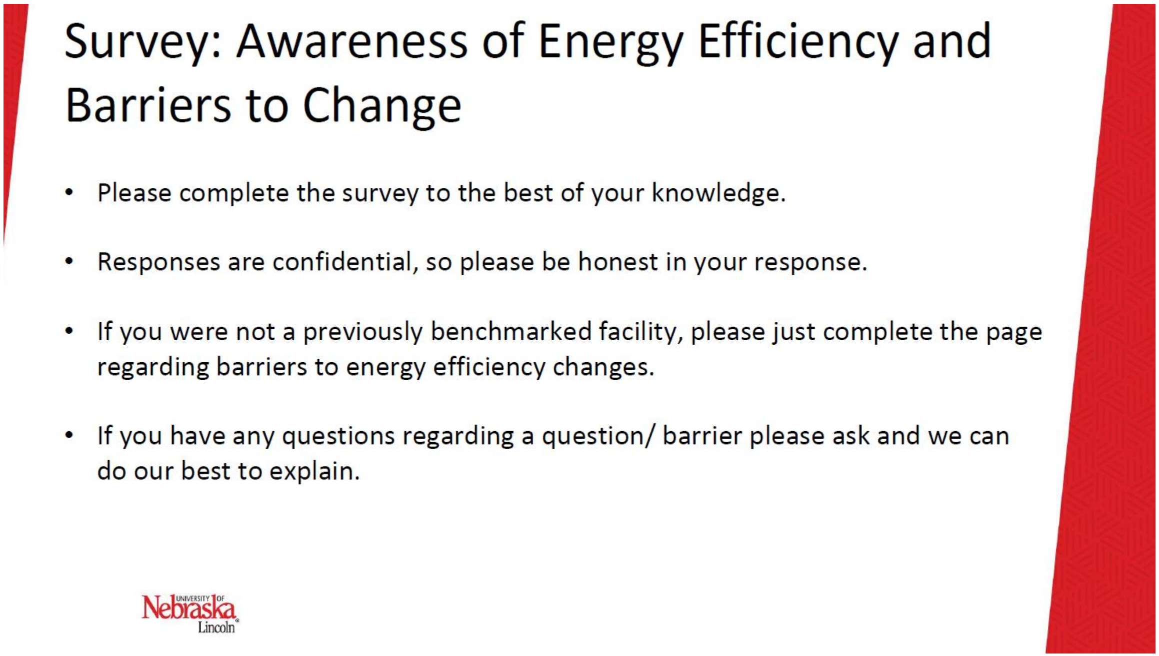
Survey: Barriers to E2

Common barriers addressed in studies regarding energy efficiency improvements of industries in both public and private sectors (Sorrell et al., 2004):

- Staff not accountable for energy costs
- Technical risks such as risk of process disruptions
- Lack of electrical sub-metering (don’t know how much energy is used by units at the plant)
- Poor information quality regarding energy efficiency opportunities
- Lack of time or other priorities
- Lack of staff awareness
- Preference to keep things the way they are

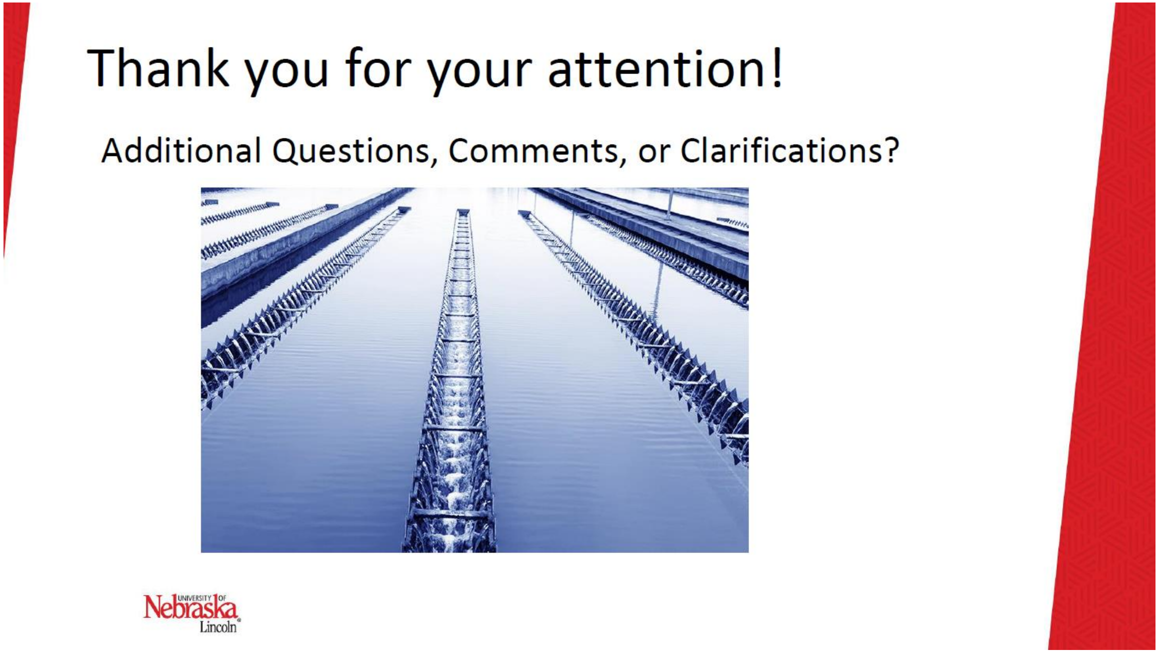
Sorrell, S. et al. *The Economics of Energy Efficiency.* Northhampton: Edward Elgar Publishing Inc., 2004. Print.

UNIVERSITY OF Nebraska Lincoln



Survey: Awareness of Energy Efficiency and Barriers to Change

- Please complete the survey to the best of your knowledge.
- Responses are confidential, so please be honest in your response.
- If you were not a previously benchmarked facility, please just complete the page regarding barriers to energy efficiency changes.
- If you have any questions regarding a question/ barrier please ask and we can do our best to explain.



Thank you for your attention!

Additional Questions, Comments, or Clarifications?

Appendix B: Survey Data and Energy Analysis

This section includes all data collected from the survey. The additional and past utility bill data and water characteristic data used to evaluate changes are also included.

Table B.1: Operator Responses to Survey Questions

Plant #	**Plant Type**	**Site Visit Interaction**			**Benchmarking Letter**		
		Recall meeting Student	**Improvement of awareness**	**Change made**	**Recall Letter**	**Improvement of awareness**	**Change made**
1	EA	Yes	3	1	Yes	4	1
2	EA	Yes	2	1	Yes	3	1
3	SBR	Yes	3	3	No		
4	EA	Yes	3	1	Yes	3	1
5	AS	Yes	3	5	Uncertain	3	1
6	OD	Yes	4	1		5	1
7	EA	Uncertain	1	1			
8	OD	No					
9	SBR	Yes	1	1	Yes	3	1
10	EA	Yes	3	3	Yes	5	1
11	OD	Yes	5	5	Yes	4	
12	SBR	No					
13	OD	Yes	1	1	Uncertain	1	1
14	CAS	Yes	1	1	No	1	1
15	OD	Yes	1	1	No	1	1
16	SBR	Yes	2	1	Yes	2	1
17	OD	Yes	3	1	Yes	3	1
18	EA	Yes	3	1	Yes	3	1
19	EA	Yes	5	3	Yes	5	3
20	OD	Yes	3	3	Yes	3	1
21	EA	Yes	3	1	Yes	3	1
22	TF	Yes	3	1	Yes	3	1
23	TF	Uncertain	3	1	Uncertain	3	1
24	Aquarius	Yes	3	1	Yes	3	1
25	EA	Yes	1	1	Yes	1	1
26	EA	Yes	3	3	Yes	3	1
27	EA	Yes	3	3	Yes	3	1
28	OD	Yes	2	1	No	3	1
29	EA	Yes	5	1	Yes	5	1
30	TF/RBC	Yes	3	5	Yes	3	1
31	EA	Yes	5	3	Uncertain	1	1
32	OD	Yes	3	1	Yes	3	1
33	TF	Uncertain	NA	3	Yes	5	3
34	OD	Yes	3	1	Yes	3	1
35	EA	Yes	1	1	Yes	1	1
36	VLR	Yes	3	1	Yes	3	
37	TF	Yes	3	5	Uncertain	3	3
38	EA/OD	Yes	3	1	Yes	3	1
39	EA	Yes	3	1	No	3	1
40	OD	Yes		1	Yes	3	1

Table B.1 (cont)

Plant #	Plant Type	Site Visit Interaction			Benchmarking Letter		
		Recall meeting Student	Improvement of awareness	Change Made	Recall meeting Student	Improvement of awareness	Change Made
41	EA	Yes	4	3	Uncertain	3	1
42	SBR	Yes	5	3	Yes	5	1
43	RBC	Yes	3	3	No	3	3
44	AeroMod	Yes	4	3	Yes	4	1
45	EA	Yes	4	1	Yes	3	1
46	EA	Yes	3	3	Yes	3	1
47	OD	Yes	3	3	Yes	3	1
48	CAS or EA	Yes	3	1	Yes	3	1
49	OD	Yes	3	3	Yes	3	3
50	SBR	Yes	3	3	Yes	3	1
51	EA	Yes	3	1	yes	3	1
52	EA	Yes	3	1	Yes	3	1

Table B.2: Reported Changes Being Made by Operators

Plant #	Changes in operations	Changes as result of the Letter	Changes noted in Letter
3	Timers on aeration, Lights off when not in building, (1/3: last couple weeks noted starting changing to LED)		
5	Fixed all air leaks		
10	Checking about LED lighting		LED lights
11	Replaced 2 motors on OD, Lighting upgrades, Put solar Panels in Power WWTP		Motors + lighting
19	Not too many made because of existing plant issues, most already	Lighting, blower operation	aeration, lighting
20	New Influent Pump + Sludge Pump		
26	Installed new diffusers in aeration basins. They were scheduled to be changed	Our plant is fairly new. Built in 2010	
27	Thermostat on cooling fan, new VFD, Regulate air more closely		VFD, Regulate air
30	The City of York is currently building a new water reclamation facility	Plans for the new WRF had already been in progress	
31	New Effluent Pumps w/ VFDs		VFDs on pumps
33	We began by using VFDs on pumps more efficiently, also we started a program to make sure we are not wasting electricity, shutting off lights in areas we aren't working and so on	Installed VFDs on pumps, we are also going to change to more efficient lighting and putting more or operation on VFD's as improvements are made	LEDs

Table B.2 (cont)

37	VFDs / LED lights, heater replacement, pump replacements	Always ongoing	Heaters + LED
41	VFD on 1 Blower		VFD on Blower
42	New Pumps and lower run times		New Pumps
43	Replaced overhead lighting in RBC building. Replaced all exterior flood lighting with LED wall packs.	New interior and exterior lighting	lighting
44	Properly programming the DO controls - LED lights will be updated as current lights go out		Programming controls, lights
47	Changing the speed of the mechanical aerators in the oxidation ditch varying dissolved oxygen		
49	Installed better overhead doors, doing some improvements on weatherization of facilities	Working on pumping improvements	Improved Insulation
50	Flow Switched for UV system Changed 2 motors		

To help better organize the data for presentation, the barriers are labeled below in Table B.3 by number for reference in the tables that follow.

Table B.3: Specific Barriers Investigated in the Survey

Barrier #	Specific Barrier Investigated
B1	Access to Capital
B2	Other Priorities for Capital Investment
B3	Perceived lack of Payback on investment (risk of R.O.I)
B4	Cost of identifying opportunities/analyzing cost effectiveness and tendering
B5	Lack of support from city council/ utility board
B6	Lack of staff to coordinate/ implement change
B7	Would require additional operator training
B8	Staff not accountable for energy costs
B9	Technical risks such as risks of process disruption
B10	Lack of electrical sub-metering
B11	Poor information quality regarding E2 opportunities
B12	Lack of time or other priorities
B13	Lack of staff awareness
B14	Preference to keep things the way they are

Operator responses to the barriers portion of the survey is presented in Table B.4 using the numbering presented above. Q1 is the refers to the question of whether operator thought cost-effective opportunities exist at their plant where Y=Yes, N=No, U=Uncertain, and a blank space indicates that they did not respond.

Table B.4: Operator Responses to Barriers Portion of Survey

Plant #	Q 1	B 1	B 2	B 3	B 4	B 5	B 6	B 7	B 8	B 9	B 10	B 11	B 12	B 13	B 14
1	Y	5	4	5	5	4	3	3	5	3	4	4	3	3	4
2	Y	5	4	3	4	4	4	2	2	4	4	3	3	3	3
3	Y	4	4	3	4	3	5	5	5	3	4	4	5	3	5
4	Y	5	2	2	2	4	2	2	2	2	3	3	2	3	5
5	Y	5	5	3	5	5	5	2	4	2	4	4	5	3	5
6	Y	5	5	5	1	1	1	1	1	3	3	1	5	1	1
9	Y	3	3	2	2	1	2	1	1	2	2	1	3	3	4
10	Y	2	1	2	1	3	2	2	1	1	1	1	3	1	2
11	Y	5	4	3	2	1	2	1	1	2	1	2	3	1	1
13	Y	2	2	2	3	2	1	1	1	1	1	2	3	1	2
14	N	1	1	4	1	3	3	1	1	1	1	5	4	3	2
15	Y	4	4	3	4	4	2	1	2	4	1	2	4	1	2
17	Y	4	5	2	1	3	2	1	4	2	1	2	5	3	1
18	Y	4	4	5	4	4	3	3	3	2	3	2	3	2	3
19	Y	5	3	5	3	4	5	2	3	3	1	3	1	1	1
20	Y	5	5	4	3	5	3	2	2	4	3	3	4	2	2
21	N	3	3	5	3	5	5	4	5		5	4	3	3	4
23	U	3	2	3	2	1	1	1	1	1	4	1	1	1	1
24	U	3	3	3	3	3	3	4	4	4	3	3	3	3	3
26		5	4	4	3	4	1	1	2	1	3		4		
27	Y	5	4	5	4	5	1	3	1	2	4	2	2	1	1
28	N	3	2	1	1	1	1	2	4	3	4	4	5	3	1
29	Y	4	2	1	1	2	1	2	1	2	3	1	2	4	3
30	Y	3	3	4	3	4	2	2	3	2	2	3	3	2	2
31	Y	2	3	1	1	1	1	1	1	2	1	1	1	1	1
32	Y														
33	Y	2	4	2	3	1	2	2	2	2	3	2	2	2	2
34	Y	5	4	4	2	1	2	1	2	1	3	2	2	4	2
36	U	5	5	3	2	4	4	1	2	1	2	4	5	3	1
37	N	3	3	4	4	2	2	2	2	2	2	2	2	2	2
38	Y	2	2	3	2	3	4	4	2	3	1	2	3	3	1
39	Y	3	1	3	3	1	4	3	1	1	3	2	2	2	2
40	N	3	3	3	3	1	1	1	1	1	1	3	3	3	3
41	Y	2	3	4	2	1	1	1	1	1	1	2	3	1	1
42	N	2	1	1	1	2	1	2	1	3	1	3	1	1	3
43	Y	5	5	2	2	3	1	1	1	1	1	1	1	1	1
44	Y	2	4	1	1	3	3	1	1	1	1	1	3	1	1
47	Y	5	5	3	2	4	2	1	1	1	3	3	1	1	3
48	N	2	3	4	1	1	1	1	1	1	3	2	1	1	2
49	Y	4	4	4	2	2	3	1	2	2	1	2	2	3	3
50	Y	3	3	1	3	3	1	1	3	3	1	1	2	1	3
52		5	4	3	3	1	3	3	3	3	3	2	4	3	1

Table B.4 on the next page summarizes the annual energy usage and flowrate data for plants that had utility bills collected

Table B.4: Energy and Water Flowrate Data for Plants with Utility Bills Collected

Plant #	Site Visit Interaction		Benchmarking Letter		Design Flow (MGD)	Average Effluent Flowrate (MGD)				Annual Energy Use (MWh/yr)			
	Improvement of awareness	Changes made	Improved awareness	Changes made		2017	2016	2015	2014	2017	2016	2015	2014
1	3	1	4	1		0.06	0.06	0.07	0.05	125	123	127	127
2	2	1	3	1	0.07	0.14	0.15	0.11		494	508	491	
3	3	3			0.20	0.11	0.11	0.11		319	290	301	
4	3	1	3	1	0.27	0.37	0.36	0.35		490	492	614	
5	1	1	3	1	0.60	0.53	0.58	0.61		1,038	1,249	1,247	
6	5	5	4		1.16	0.88	0.90	0.94		942	918	1,055	
7	1	1	1	1	1.80	1.35	1.39	1.14	0.95	1,020	896	842	797
8	1	1	1	1	2.00	0.67	0.57	0.46	0.45	1,090	1,038	1,053	1,027
9	5	3	5	3	0.75	0.37	0.40	0.38	0.44	596	659	662	637
10	3	3	3	1	0.50	0.14	0.13	0.14	0.14	167	172	178	183
11	3	1	3	1	0.25	0.02	0.02	0.02		144	129	112	
12	3	1	3	1	0.08	0.39	0.41	0.47		1,003	1,020		
13	1	1	1	1		0.22	0.19	0.18	0.12	140	148	150	150

Table B.4 (cont)

Plant #	Site Visit Interaction		Benchmarking Letter		Design Flow (MGD)	Average Effluent Flowrate (MGD)				Annual Energy Use (MWh/yr)			
	Improvement of awareness	**Changes made**	**Improved awareness**	**Changes made**		**2017**	**2016**	**2015**	**2014**	**2017**	**2016**	**2015**	**2014**
14	2	1	3	1		0.08	0.10	0.14		365	318	349	
15	3	5	3	1	0.11	0.96	0.92	1.06	1.21	852	819	856	917
16	5	3	1	1	3.00	0.48	0.50	0.59		763	724	774	
17	0	3	5	3	0.60	0.21		0.16	0.17	451		462	528
18	3	1	3	1	0.39	0.09	0.15	0.16	0.14	122	130	130	125
19	3	1	3		0.26	0.24	0.23	0.24		455	451	461	
20	3	1	3	1	0.36	0.25	0.25	0.25	0.27	503	573	535	580
21	3	1	3	1	0.37	0.07	0.08	0.04		187	196	196	
22	4	3	3	1	0.06	0.03	0.03	0.04	0.04	261	274	282	404
23	4	3	4	1	0.14	0.56		0.66	0.63	617		633	652
24	4	1	3	1	0.64	0.25	0.26	0.33	0.37	733	772	864	884
25	3	3	3	1	0.28	0.10	0.18	0.12		229	225	226	
26	3	3	3	1	0.20	0.11		0.12		197		303	

Table B.4 (cont)

Plant #	Site Visit Interaction		Benchmarking Letter		Design Flow (MGD)	Average Effluent Flowrate (MGD)				Annual Energy Use (MWh/yr)			
	Improved awareness	**Changes made**	**Improved awareness**	**Changes made**		**2017**	**2016**	**2015**	**2014**	**2017**	**2016**	**2015**	**2014**
27	3	3	3	1		0.14		0.12		181		208	
28	3	1	3	1	0.15	0.189	0.207	0.196	0.136	242	254	249	242
29	3	5	3	3	0.33	0.81	0.90	0.66	0.62	604	681	821	839

Table B.5: Calculated Energy Intensity and Average Energy, Flowrates, and Energy Intensity of 2014-2016

Plant #	**Energy Intensity (MWh/MG)**				**Average of 2014-2016**		
	2017	**2016**	**2015**	**2014**	**Energy (MWh)**	**Flowrate (MGD)**	**Energy Intensity (MWh/MG)**
1.00	5.80	5.35	5.35	6.96	126	0.06	5.80
2.00	9.94	9.53	12.12		500	0.13	10.65
3.00	7.87	7.49	7.28		296	0.11	7.38
4.00	3.60	3.77	4.85		553	0.35	4.30
5.00	5.36	5.90	5.60		1248	0.60	5.75
6.00	2.93	2.79	3.09		987	0.92	2.94
7.00	2.07	1.77	2.03	2.30	845	1.16	2.00
8.00	4.45	4.98	6.32	6.31	1039	0.49	5.80
9.00	4.44	4.55	4.77	3.99	653	0.41	4.41
10.00	3.33	3.56	3.50	3.66	178	0.14	3.58
11.00	19.66	15.66	16.54		120	0.02	16.06
12.00	7.04	6.83			1020	0.44	6.33
13.00	1.76	2.09	2.24	3.30	149	0.17	2.44
14.00	11.83	8.93	6.62		334	0.12	7.55
15.00	2.44	2.43	2.21	2.08	864	1.07	2.22
16.00	4.33	3.93	3.63		749	0.54	3.77
17.00	5.76		8.01	8.71	495	0.16	8.37
18.00	3.85	2.32	2.22	2.52	128	0.15	2.35
19.00	5.19	5.40	5.19		456	0.24	5.29
20.00	5.62	6.16	5.81	5.94	563	0.26	5.97
21.00	7.27	7.12	13.34		196	0.06	9.29
22.00	22.09	22.47	21.20	25.46	320	0.04	23.21
23.00	3.04		2.65	2.83	642	0.64	2.74
24.00	7.94	8.19	7.08	6.60	840	0.32	7.19
25.00	6.40	3.34	5.16		226	0.15	4.06
26.00	4.85		7.09		303	0.12	7.09
27.00	3.65		4.60		208	0.12	4.60
28.00	3.50	3.36	3.50	4.89	248	0.18	3.79
29.00	2.04	2.06	3.38	3.70	780	0.73	2.93

Table B.6: Calculated Changes and Percent Changes in Energy, Flowrate, and Energy Intensity

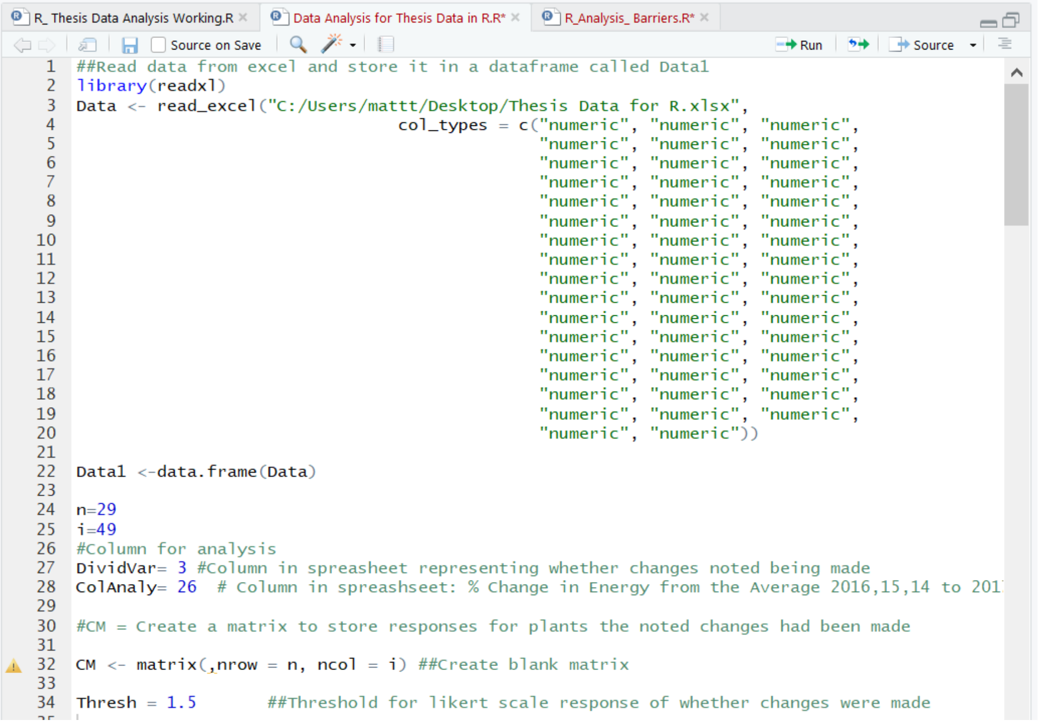
Plant #	Change in 2017 from Average Value of 2014-2016			Percent Change (%)		
	Energy (MWh)	**Flowrate (MGD)**	**Energy Intensity (MWh/MG)**	**Energy (MWh)**	**Flowrate (MGD)**	**Energy Intensity (MWh/MG)**
1.00	-0.7	0.000	0.00	-1%	-1%	0%
2.00	-5.7	0.008	-0.71	-1%	6%	-7%
3.00	23.5	0.001	0.49	8%	1%	7%
4.00	-63.7	0.020	-0.70	-12%	6%	-16%
5.00	-209.7	-0.065	-0.38	-17%	-11%	-7%
6.00	-44.3	-0.037	-0.01	-4%	-4%	0%
7.00	174.6	0.190	0.07	21%	16%	4%
8.00	50.3	0.179	-1.34	5%	36%	-23%
9.00	-56.5	-0.037	0.02	-9%	-9%	1%
10.00	-10.6	0.002	-0.25	-6%	1%	-7%
11.00	23.5	0.000	3.60	20%	-2%	22%
12.00	-17.2	-0.052	0.72	-2%	-12%	11%
13.00	-9.0	0.051	-0.68	-6%	30%	-28%
14.00	31.5	-0.036	4.27	9%	-30%	57%
15.00	-12.0	-0.109	0.22	-1%	-10%	10%
16.00	13.5	-0.062	0.56	2%	-11%	15%
17.00	-43.6	0.053	-2.61	-9%	33%	-31%
18.00	-6.6	-0.063	1.51	-5%	-42%	64%
19.00	-0.9	0.004	-0.10	0%	2%	-2%
20.00	-59.9	-0.013	-0.35	-11%	-5%	-6%
21.00	-9.1	0.013	-2.02	-5%	22%	-22%
22.00	-58.9	-0.005	-1.12	-18%	-14%	-5%
23.00	-25.3	-0.087	0.30	-4%	-13%	11%
24.00	-107.0	-0.067	0.74	-13%	-21%	10%
25.00	3.4	-0.054	2.35	2%	-36%	58%
26.00	-106.6	-0.006	-2.24	-35%	-5%	-32%
27.00	-26.6	0.012	-0.96	-13%	10%	-21%
28.00	-6.8	0.010	-0.29	-3%	5%	-8%
29.00	-176.2	0.083	-0.89	-23%	11%	-30%

Table B.7: Perceived Barriers of Plants with Energy Bills Collected

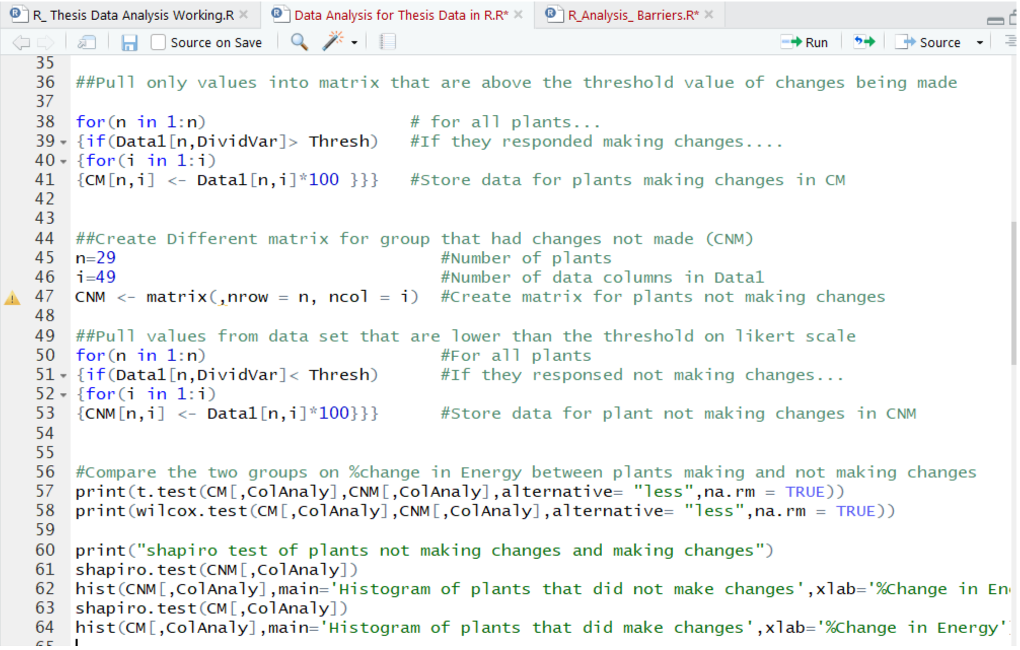
Plant #	B 1	B 2	B 3	B 4	B 5	B 6	B 7	B 8	B 9	B 10	B 11	B 12	B 13	B 14
1	5	4	5	5	4	3	3	5	3	4	4	3	3	4
2	5	4	3	4	4	4	2	2	4	4	3	3	3	3
3	4	4	3	4	3	5	5	5	3	4	4	5	3	5
4	5	2	2	2	4	2	2	2	2	3	3	2	3	5
5	3	3	2	2	1	2	1	1	2	2	1	3	3	4
6	5	4	3	2	1	2	1	1	2	1	2	3	1	1
7	1	1	4	1	3	3	1	1	1	1	5	4	3	2
8	4	4	3	4	4	2	1	2	4	1	2	4	1	2
9	5	3	5	3	4	5	2	3	3	1	3	1	1	1
10	5	5	4	3	5	3	2	2	4	3	3	4	2	2
11	3	3	5	3	5	5	4	5		5	4	3	3	4
12	3	3	3	3	3	3	4	4	4	3	3	3	3	3
14	3	2	1	1	1	1	2	4	3	4	4	5	3	1
15	3	3	4	3	4	2	2	3	2	2	3	3	2	2
16	2	3	1	1	1	1	1	1	2	1	1	1	1	1
17	2	4	2	3	1	2	2	2	2	3	2	2	2	2
18	5	4	4	2	1	2	1	2	1	3	2	2	4	2
19	5	5	3	2	4	4	1	2	1	2	4	5	3	1
20	2	2	3	2	3	4	4	2	3	1	2	3	3	1
21	3	1	3	3	1	4	3	1	1	3	2	2	2	2
22	2	3	4	2	1	1	1	1	1	1	2	3	1	1
23	2	4	1	1	3	3	1	1	1	1	1	3	1	1
26	5	5	3	2	4	2	1	1	1	3	3	1	1	3
27	3	3	1	3	3	1	1	3	3	1	1	2	1	3
28	5	4	3	3	1	3	3	3	3	3	2	4	3	1
29	3	3	4	4	2	2	2	2	2	2	2	2	2	2

Appendix C: Code in R and Output for Survey Study

Code for comparing energy reduction of plants making changes and not making changes is shown below in Figure C.1. Data are imported from excel and matrices are created for the two groups. A t-test, Wilcoxon rank-sum test, and Shapiro-Wilk normality test are performed and histograms are generated for the data sets.



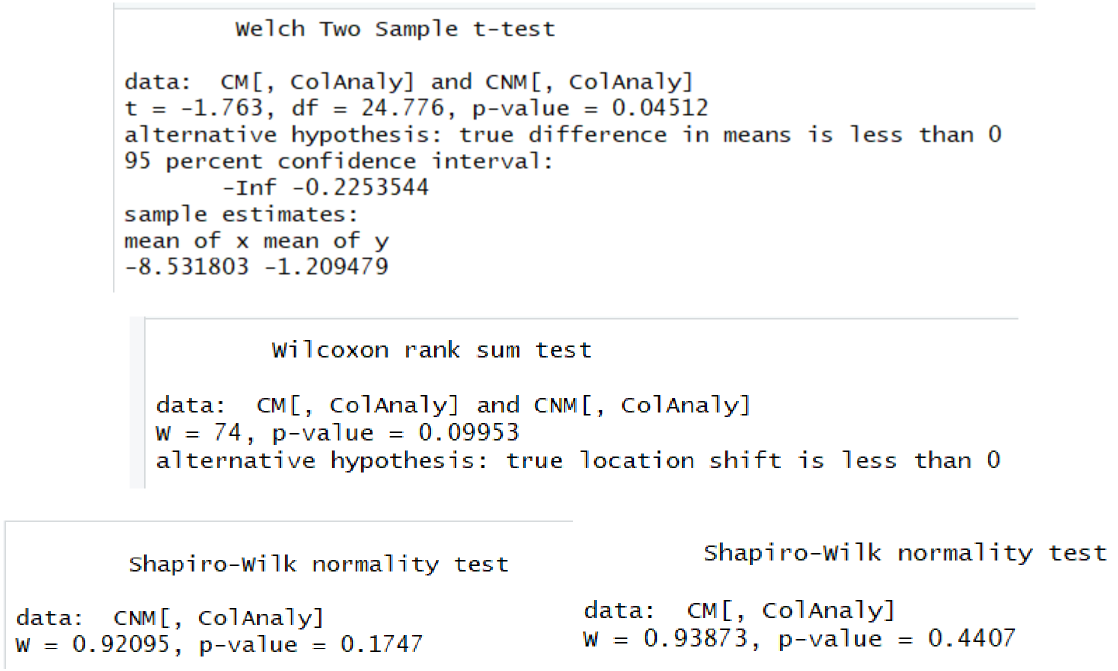
```r
##Read data from excel and store it in a dataframe called Data1
library(readxl)
Data <- read_excel("C:/Users/mattt/Desktop/Thesis Data for R.xlsx",
                                col_types = c("numeric", "numeric", "numeric",
                                              "numeric", "numeric", "numeric",
                                              "numeric", "numeric", "numeric",
                                              "numeric", "numeric", "numeric",
                                              "numeric", "numeric", "numeric",
                                              "numeric", "numeric", "numeric",
                                              "numeric", "numeric", "numeric",
                                              "numeric", "numeric", "numeric",
                                              "numeric", "numeric", "numeric",
                                              "numeric", "numeric", "numeric",
                                              "numeric", "numeric", "numeric",
                                              "numeric", "numeric", "numeric",
                                              "numeric", "numeric", "numeric",
                                              "numeric", "numeric", "numeric",
                                              "numeric", "numeric", "numeric",
                                              "numeric", "numeric", "numeric",
                                              "numeric", "numeric"))

Data1 <-data.frame(Data)

n=29
i=49
#Column for analysis
DividVar= 3 #Column in spreasheet representing whether changes noted being made
ColAnaly= 26  # Column in spreashseet: % Change in Energy from the Average 2016,15,14 to 201

#CM = Create a matrix to store responses for plants the noted changes had been made

CM <- matrix(,nrow = n, ncol = i) ##Create blank matrix

Thresh = 1.5       ##Threshold for likert scale response of whether changes were made
```



```r

##Pull only values into matrix that are above the threshold value of changes being made

for(n in 1:n)                    # for all plants...
{if(Data1[n,DividVar]> Thresh)   #If they responded making changes....
{for(i in 1:i)
{CM[n,i] <- Data1[n,i]*100 }}}   #Store data for plants making changes in CM


##Create Different matrix for group that had changes not made (CNM)
n=29                                #Number of plants
i=49                                #Number of data columns in Data1
CNM <- matrix(,nrow = n, ncol = i)  #Create matrix for plants not making changes

##Pull values from data set that are lower than the threshold on likert scale
for(n in 1:n)                       #For all plants
{if(Data1[n,DividVar]< Thresh)      #If they responsed not making changes...
{for(i in 1:i)
{CNM[n,i] <- Data1[n,i]*100}}}      #Store data for plant not making changes in CNM


#Compare the two groups on %change in Energy between plants making and not making changes
print(t.test(CM[,ColAnaly],CNM[,ColAnaly],alternative= "less",na.rm = TRUE))
print(wilcox.test(CM[,ColAnaly],CNM[,ColAnaly],alternative= "less",na.rm = TRUE))

print("shapiro test of plants not making changes and making changes")
shapiro.test(CNM[,ColAnaly])
hist(CNM[,ColAnaly],main='Histogram of plants that did not make changes',xlab='%Change in En
shapiro.test(CM[,ColAnaly])
hist(CM[,ColAnaly],main='Histogram of plants that did make changes',xlab='%Change in Energy'
```

Figure C.1: Code for Analyzing the Percent Energy Reduction of Plants Making and Not Making Changes

Figure C.2 below shows the resulting output from the code shown in Figure C.1 utilizing data shown in Table B.4. The result from the t-test is shown first and the result of the Wilcoxon rank sum test follows. The result of the shapiro-Wilk normality test is shown at the end for analyzing the normality of the data sets for plants not making changes (CNM, on the left) and plants making changes (CM, on the right).



```
        Welch Two Sample t-test

data:  CM[, ColAnaly] and CNM[, ColAnaly]
t = -1.763, df = 24.776, p-value = 0.04512
alternative hypothesis: true difference in means is less than 0
95 percent confidence interval:
       -Inf -0.2253544
sample estimates:
mean of x mean of y
-8.531803 -1.209479
```

```
        Wilcoxon rank sum test

data:  CM[, ColAnaly] and CNM[, ColAnaly]
W = 74, p-value = 0.09953
alternative hypothesis: true location shift is less than 0
```

```
        Shapiro-Wilk normality test

data:  CNM[, ColAnaly]
W = 0.92095, p-value = 0.1747
```

```
        Shapiro-Wilk normality test

data:  CM[, ColAnaly]
W = 0.93873, p-value = 0.4407
```

Figure C.2: Resulting Output from Data Analysis

Histograms illustrating the distribution of the plants making changes and the plants not making changes are shown on the next page in Figures C.1 and C.2 respectively.

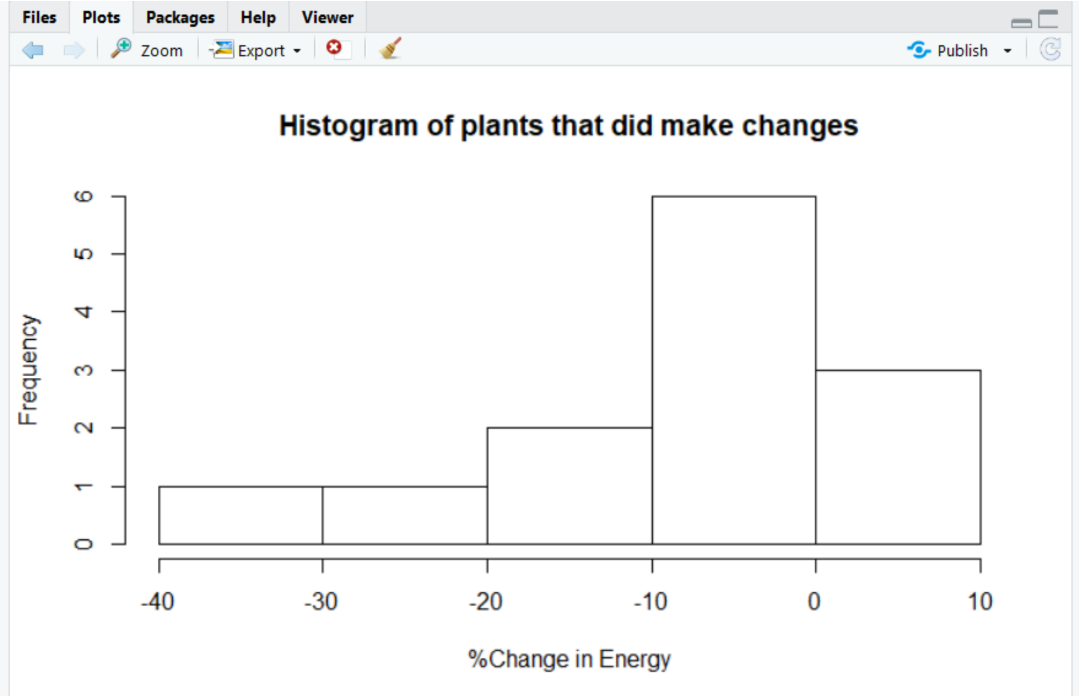


Figure C.2: Histogram of the Percent Change in Energy of Plants Reporting to Have Made Changes

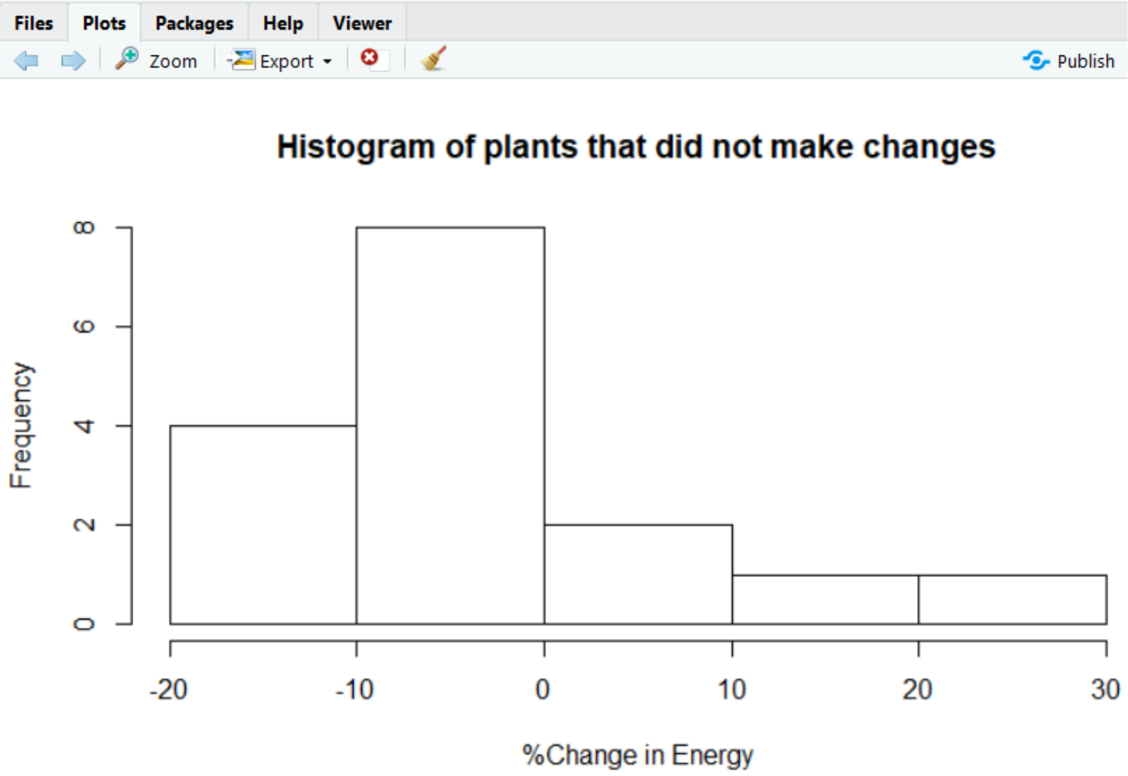


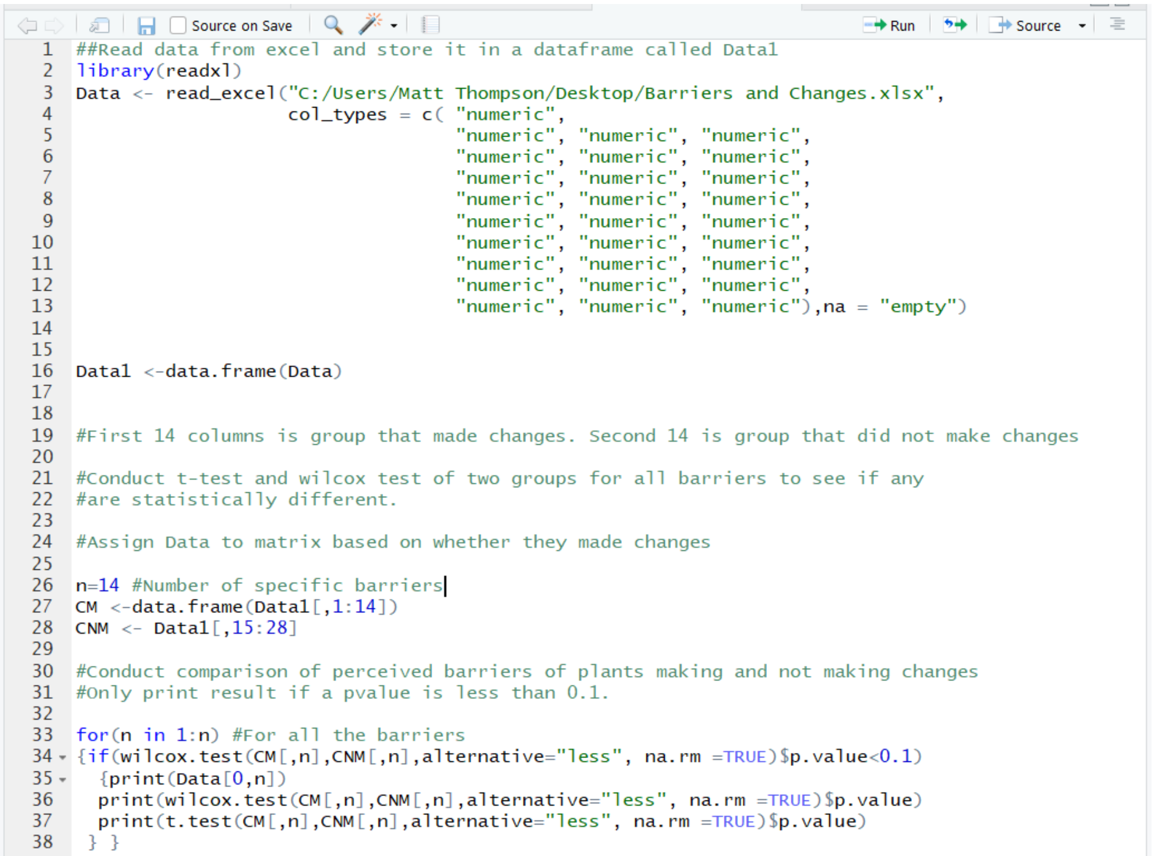
Figure C.3: Histogram of the Percent Change in Energy of Plants Reporting to Have Not Made Changes

The estimated cost savings associated with the calculated energy reduction is shown below in Table C.1. The energy unit cost was calculated based on the most recent bill. The annual cost of electricity usage ($) was divided by the annual usage (kWh). It can be observed that the energy cost are very low.

Table C.1: Cost Savings Based on Billed Energy Reduction and Unit Electricity Cost

Plant	Plant # from previous list	Design Flow (MGD)	Percent Change in Energy	Change in Energy (MWh/yr)	Energy Unit Cost ($/kWh)	Cost Savings ($/yr)
1	26	0.255	-35%	-107	$0.09	$9,064
2	29	1.010	-23%	-176	$0.07	$11,451
3	22	0.140	-18%	-59	$0.08	$4,594
4	27	0.149	-13%	-27	$0.11	$ 2,926
5	17	0.390	-9%	-44	$0.08	$3,402
6	9	0.504	-9%	-57	$0.04	$2,261
7	10	0.250	-6%	-11	$0.05	$529
8	5	1.800	-4%	-44	$0.08	$3,408
9	23	0.635	-4%	-25	$0.06	$1,595

The code for comparing the barriers of plants making and not making changes is shown below in Figure C.4. Data are imported from an excel sheet. Two matrices are created to store results from the two groups. A one-sided Wilcoxon rank-sum test and t-test is then performed on the data set and only results that exhibit p-values less than 0.10 are printed. The resulting output is summarized in Table C.2 that follows.



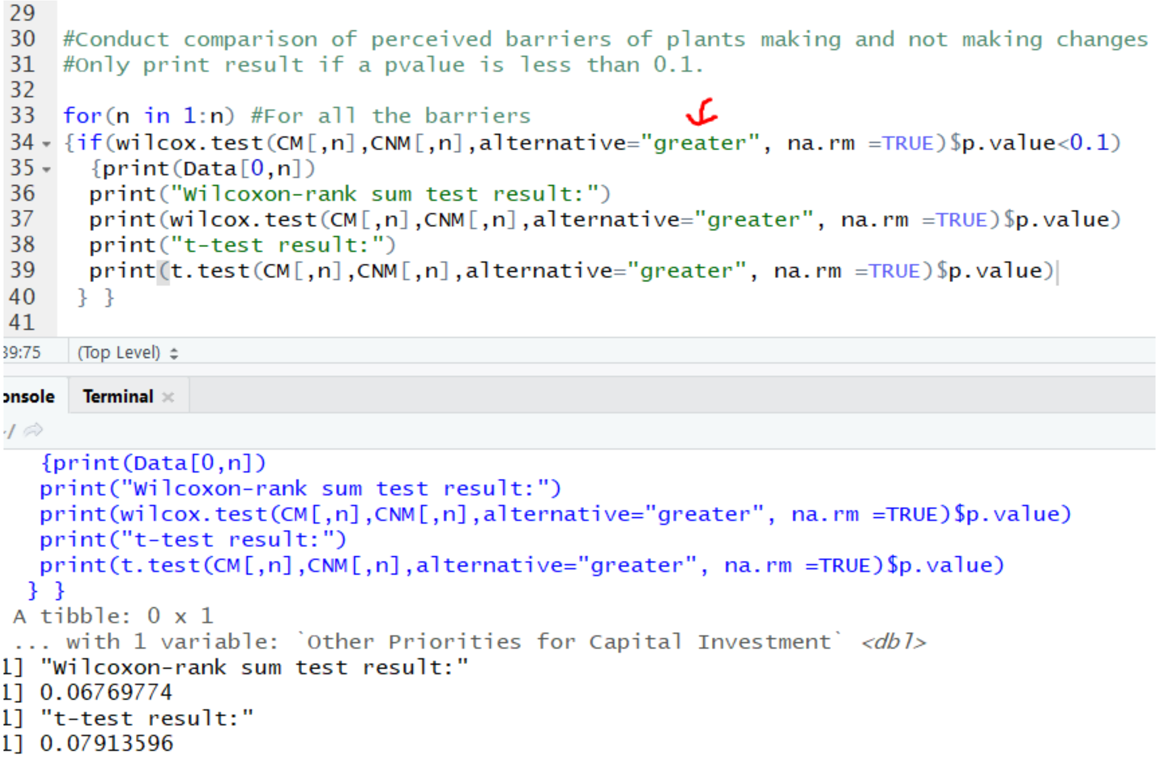
```r
##Read data from excel and store it in a dataframe called Data1
library(readxl)
Data <- read_excel("C:/Users/Matt Thompson/Desktop/Barriers and Changes.xlsx",
                   col_types = c( "numeric",
                                  "numeric", "numeric", "numeric",
                                  "numeric", "numeric", "numeric",
                                  "numeric", "numeric", "numeric",
                                  "numeric", "numeric", "numeric",
                                  "numeric", "numeric", "numeric",
                                  "numeric", "numeric", "numeric",
                                  "numeric", "numeric", "numeric",
                                  "numeric", "numeric", "numeric",
                                  "numeric", "numeric", "numeric"),na = "empty")


Data1 <-data.frame(Data)


#First 14 columns is group that made changes. Second 14 is group that did not make changes

#Conduct t-test and wilcox test of two groups for all barriers to see if any
#are statistically different.

#Assign Data to matrix based on whether they made changes

n=14 #Number of specific barriers
CM <-data.frame(Data1[,1:14])
CNM <- Data1[,15:28]

#Conduct comparison of perceived barriers of plants making and not making changes
#Only print result if a pvalue is less than 0.1.

for(n in 1:n) #For all the barriers
{if(wilcox.test(CM[,n],CNM[,n],alternative="less", na.rm =TRUE)$p.value<0.1)
  {print(Data[0,n])
  print(wilcox.test(CM[,n],CNM[,n],alternative="less", na.rm =TRUE)$p.value)
  print(t.test(CM[,n],CNM[,n],alternative="less", na.rm =TRUE)$p.value)
 } }
```

Figure C.4: Code for Analyzing Differences in Barriers of Plants Making Changes and Plants Not Making Changes

Table C.2: Analysis of Differences in Barriers Among Plants Making and Not Making Changes

Barrier	Wilcoxon-rank sum test	t-test
Lack of Staff Awareness	0.001	0.0004
Lack of Time or Other Priorities	0.067	0.079
Lack of Electrical Sub-Metering	0.07	0.064

Analysis conducted when the hypothesis is reversed (e.g. plants that made changes perceive barriers as more relevant) was done by modifying one portion of the code and is shown below in Figure C.5. The resulting output is also shown.

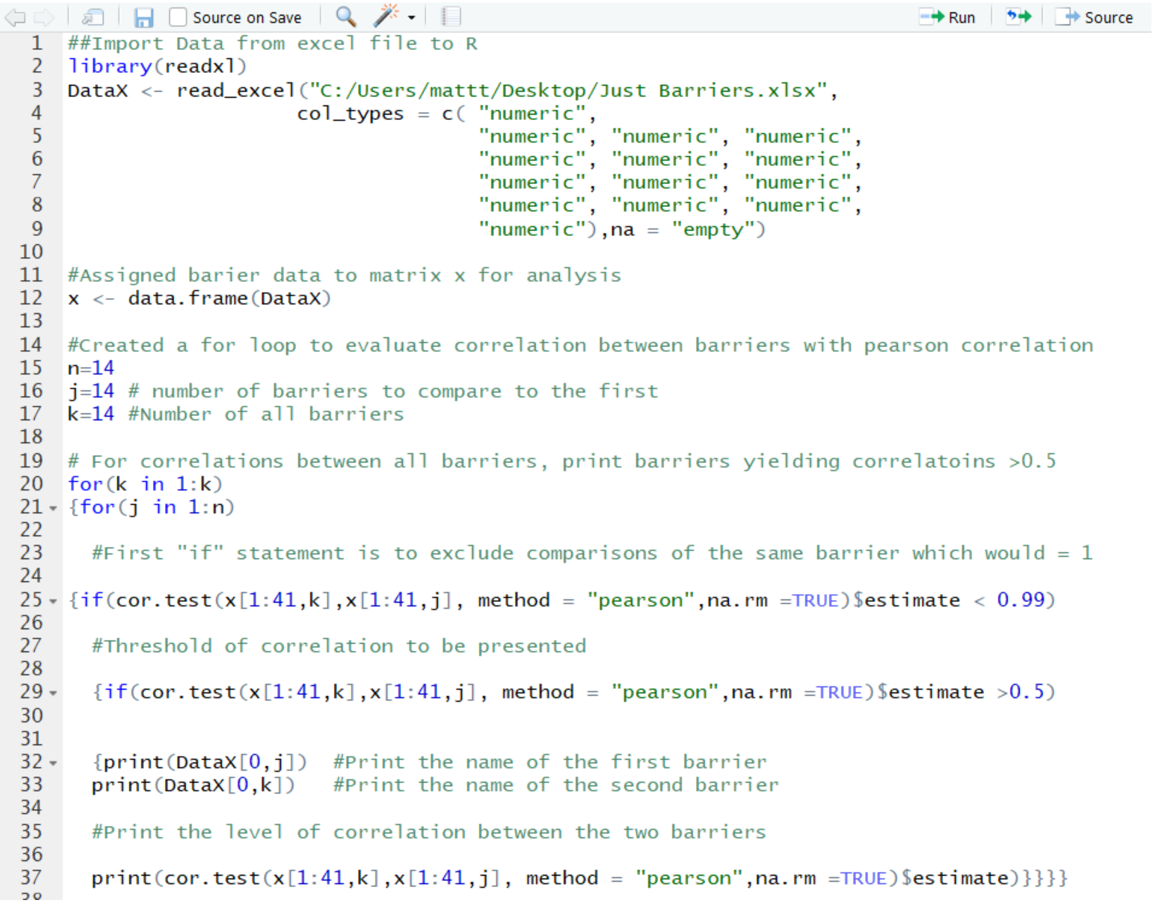


```
#Conduct comparison of perceived barriers of plants making and not making changes
#Only print result if a pvalue is less than 0.1.

for(n in 1:n) #For all the barriers
{if(wilcox.test(CM[,n],CNM[,n],alternative="greater", na.rm =TRUE)$p.value<0.1)
  {print(Data[0,n])
  print("Wilcoxon-rank sum test result:")
  print(wilcox.test(CM[,n],CNM[,n],alternative="greater", na.rm =TRUE)$p.value)
  print("t-test result:")
  print(t.test(CM[,n],CNM[,n],alternative="greater", na.rm =TRUE)$p.value)
 } }
```

```
   {print(Data[0,n])
   print("Wilcoxon-rank sum test result:")
   print(wilcox.test(CM[,n],CNM[,n],alternative="greater", na.rm =TRUE)$p.value)
   print("t-test result:")
   print(t.test(CM[,n],CNM[,n],alternative="greater", na.rm =TRUE)$p.value)
  } }
 A tibble: 0 x 1
 ... with 1 variable: `Other Priorities for Capital Investment` <dbl>
1] "Wilcoxon-rank sum test result:"
1] 0.06769774
1] "t-test result:"
1] 0.07913596
```

Figure C.5: Modified Code for Analyzing Differences in Barriers of Plants Making Changes and Plants Not Making Changes and Output Result

Code for analyzing correlations between barriers is shown below Figure C.6. Data from Table B.4 is imported into R and all the barriers are correlated with each other and only results showing correlations greater than 0.5 are shown. The analysis was also performed using the Kendall Tau correlation and the code modification is shown in Figure C.7. The resulting code output of the analysis is summarized in Tables C.3 and C.4 that follow the code.

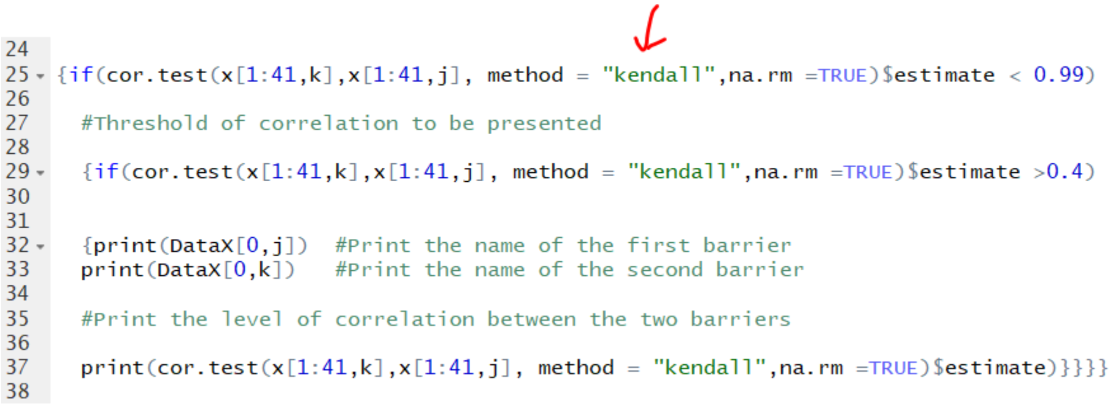


```r
##Import Data from excel file to R
library(readxl)
DataX <- read_excel("C:/Users/mattt/Desktop/Just Barriers.xlsx",
                   col_types = c( "numeric",
                                  "numeric", "numeric", "numeric",
                                  "numeric", "numeric", "numeric",
                                  "numeric", "numeric", "numeric",
                                  "numeric", "numeric", "numeric",
                                  "numeric"),na = "empty")

#Assigned barier data to matrix x for analysis
x <- data.frame(DataX)

#Created a for loop to evaluate correlation between barriers with pearson correlation
n=14
j=14 # number of barriers to compare to the first
k=14 #Number of all barriers

# For correlations between all barriers, print barriers yielding correlatoins >0.5
for(k in 1:k)
{for(j in 1:n)

  #First "if" statement is to exclude comparisons of the same barrier which would = 1

{if(cor.test(x[1:41,k],x[1:41,j], method = "pearson",na.rm =TRUE)$estimate < 0.99)

  #Threshold of correlation to be presented

  {if(cor.test(x[1:41,k],x[1:41,j], method = "pearson",na.rm =TRUE)$estimate >0.5)


  {print(DataX[0,j])  #Print the name of the first barrier
  print(DataX[0,k])   #Print the name of the second barrier

  #Print the level of correlation between the two barriers

  print(cor.test(x[1:41,k],x[1:41,j], method = "pearson",na.rm =TRUE)$estimate)}}}}
```

Figure C.6: Code Analyzing Pearson Correlation Coefficient Between Barriers

Table C.3: Summary of Resulting Code Output of Pearson Correlations Between Barriers

Barriers Correlated	B1, B2	B6, B7	B6, B8	B6, B11	B7, B8	B8, B9	B8, B11
Pearson Correlation Coefficient	0.67	0.57	0.54	0.55	0.60	0.51	0.53



```

{if(cor.test(x[1:41,k],x[1:41,j], method = "kendall",na.rm =TRUE)$estimate < 0.99)

  #Threshold of correlation to be presented

  {if(cor.test(x[1:41,k],x[1:41,j], method = "kendall",na.rm =TRUE)$estimate >0.4)


  {print(DataX[0,j])  #Print the name of the first barrier
  print(DataX[0,k])   #Print the name of the second barrier

  #Print the level of correlation between the two barriers

  print(cor.test(x[1:41,k],x[1:41,j], method = "kendall",na.rm =TRUE)$estimate)}}}}

```

Figure C.6: Code Analyzing Kendall Tau Correlation Coefficient Between Barriers

Table C.4: Summary of Resulting Code Output of Kendall Tau Correlations Between Barriers

Barriers Correlated	B1, B2	B4, B8	B6, B8	B6, B11	B7, B8	B7, B9	B7, B10	B8, B9
Kendall Tau Correlation Coefficient	0.58	0.45	0.46	0.45	0.47	0.46	0.45	0.48

The Pearson Correlation is also shown for all the barriers on the next page in Table C.5.

Table C.5: Pearson Correlation Coefficient Between all Barriers

Barriers	**B2**	**B3**	**B4**	**B5**	**B6**	**B7**	**B8**	**B9**	**B10**	**B11**	**B12**	**B13**	**B14**
B1	**0.67**	0.34	0.39	0.39	0.20	0.03	0.24	0.24	0.38	0.12	0.18	0.20	0.14
B2		0.28	0.31	0.31	0.15	-0.14	0.24	0.15	0.18	0.01	0.31	0.02	-0.03
B3			0.44	0.32	0.32	0.23	0.21	0.04	0.32	0.31	0.10	0.04	0.01
B4				0.48	0.43	0.44	0.49	0.34	0.40	0.32	0.15	0.13	0.43
B5					0.47	0.30	0.41	0.26	0.24	0.44	0.20	0.06	0.33
B6						**0.57**	**0.54**	0.29	0.26	**0.53**	0.30	0.40	0.34
B7							**0.60**	0.47	**0.50**	0.35	0.15	0.35	0.36
B8								**0.51**	0.45	**0.54**	0.44	0.46	0.42
B9									0.20	0.19	0.25	0.15	0.18
B10										0.35	0.16	0.36	0.39
B11											0.40	0.44	0.39
B12												0.39	0.06
B13													0.43

Appendix D: Data Collection Checklist for Energy Assessments

In this Appendix, the specific checklists used during the energy assessments in evaluating operations and equipment information. The forms used for cataloging water characteristic data, energy data, Heating Degree Day (HDD) data, and electrical measurement are also provided.

Wastewater Facility Energy Assessment Checklist

Assessor and Reviewer Information

Assessor: ____

Date and Time of Visit: ___________ 6/9/2017 at 8:00 a.m ___________

Assessment Form Reviewer: ____________________________________

Date of Review: ____

Data Collection during Initial Meeting/ Walkthrough:

Contact info:

Facility Name: ___________ Wastewater Treatment Facility ___________

Facility Address: ____

Key Facility Contacts			
Town Contact	Position	# Number	Email
	Head Operator / Utility Superintendent		
	Town Hall		
	Electrical		
	Engineer		

General Plant Info:

How old is the facility? Built in 1990

Have any major upgrades been made since construction? If yes, what changes were made and when were they made?

Aerification system was updated: replaced with stationary diffusers because moving diffusers led to air leaks

Has there been any replacement or rebuilding of large equipment such as blowers or pumps?

Blowers get replaced frequently

Have any specific changes been made in the plant's operations since last summer? If yes, what was changed?

☐Yes ☒No

Have there been any significant events that may have influenced the energy usage during the billing cycle obtained? If yes, explain:

☐Yes ☒No

Are the facilities equipment and buildings the only units metered? If no, explain what else is connected to the meter (If possible, estimate a usage of the other connected units):

☒Yes ☐No

1 lift station is metered with the wastewater facility (for the effluent flow to golf course) the community has 5 additional lift stations that are individually metered

Are design specifications and/or summary of the facility available?

☒Yes ☐No

Is there an Operations & Maintenance (O&M) Manual available or the facility?

☒Yes ☐No

Are there specific parts of the plant that the operator thinks are inefficient and would merit investigation? If yes, please describe:

☒Yes ☐No

Blower upgrade, VFDs

Does the town or operator have any specific E2 improvements that they are planning to implement at the facility or wishes to have investigated? If yes, please describe:

☒Yes ☐No

Get bigger blowers, getting a screen instead of grinding

Sub-metering Info:

Would the facility be okay with sub-metering of units at the facility?

☒Yes ☐No

Does the facility have a local certified electrician that they would prefer to use for installation of electric meters? If yes, please provide contact information:

☒Yes ☐No

Contact Name: Would prefer to have city workers, but if certified electrician is required, contact Anderson electric

Contact Phone: ____________ E-mail: ____________

If the facility tests a backup generator regularly that would disrupt energy usage, how often and on what day? Would the facility be able to not test during the metering period to prevent disrupting measurement?

Facility tests generator 45 minutes every Monday, but the generator is very seldom used (3 times in past 2 years, and twice for electric line work. Runs on diesel

Operations:

Has there been any recent changes in staff at the plant (Retirement, turnover, firings, etc.)?

Former second operator -NAME- has transferred departments after 15 years, 2 years ago (will still work some weekends). Hired -NAME-

How long has each operator worked at the plant? What level of operator certification? (I, II , II, IV, or V)

NAME, 23 years, level III NAME, 2 years, level I next month

How much time does the operator spend at the plant per day and what activities are performed?

NAME and NAME work 8 hours 5 days a week and one hour each on the weekend (sometimes NAME works the weekend shifts.

Duties: Take samples, process/operations, maintenance, cleaning (clean for algae 2x per year), water yard, perform lab work

Does the operator perform other duties for the city? If yes, what other duties?

Have been working on the golf course irrigation system lately, also do snow removal in the winter

Is the facility having trouble with any aspect related to operations? (Retaining staff, maintaining records, maintenance of equipment, controlling the process, etc.)

No

If we make a recommendation pertaining to operations, what labor cost could be used for the operator's time? ($/hour) (If requiring more time for control, not automation)

$15 - $20

Flow Metering

What kind of flowmeter(s) are used at the plant? Are the meters on the influent or effluent?

Open Channel

☒ Flumes (Parshall flume + ultrasonic flow meter) ☐ Weirs ☐Open Flow Nozzle Location: influent

Closed Conduit

☐Venturi ☐Orifice ☐Flow Nozzle ☐Electromagnetic

Location: in line

When was the last time the flowmeter was calibrated? ____year to year and a half ago___

How often is the flowmeter calibrated? _____every year to year and a half___

Pumping Equipment:

Is there technical information available on the pumping equipment at the facility (ex. Pumping hours, Pump curves, heads to be overcome, operating parameters such as % load, flows, etc.). If yes, describe and attach a copy/pic at end of document. If no, try and obtain contact information for the vendor who sold the equipment.

☒Yes ☐ No

Books on-site

Are their lift stations present in town? How many lift stations? ☒Yes ☐ No
#: ____5_____

What is the hydraulic head for the influent pumps to overcome? Unknown, about 12-25 ft for the lift stations in town, one at 30 ft

How are the influent pumps controlled?

Ball floats

Is return sludge recycled back to the aeration basin? If yes, indicate how much is returned?

☐Yes ☒ No
Some material from the bottom of the clarifier is returned to the CSR

Aeration Equipment:

Is there technical information available on the specific aeration equipment or process at the facility (ex. DO data, fan curves for blowers, SOTR/SOTE values for aerators, pressure measurements, flowrates, etc.) If yes, describe and attach a copy/pic at end of document. If no, try and obtain contact information for vendor who sold equipment.

☒Yes ☐No

What method(s) of aeration are used at the facility and location?

Mechanical Aerators	☐	
Fine Bubble Diffused Air	☒	Location(s): ______
Coarse Bubble Diffused Air	☐	Location(s): ______

How often are the air diffusers cleaned? Twice a year

How old are the diffusers? Replace every 5 years (currently 4.5 years old)

How is aeration controlled at the facility for the specific processes?

CSR

1 blower runs 24/7, the other runs according to operator judgement

Sludge Digestion

1 blower runs 24/7, the other runs according to operator judgement

Are there separate blowers and/or separate air supply lines used for both sludge digestion and the secondary aeration basin?

Yes

What is the hydraulic retention time of the secondary aeration basin? (if not known, try to get the dimensions of the basin to determine it)

12 – 17 days (takes 12 – 20 days to get through the plant total)

What is the solids retention time for the aerobic digestion process? (What are the pumping rates of sludge into/out of the process? Try to get dimensions of the basin)

About 3 months

Is the time for sludge stabilization known (How long the Sludge needs to stay in the digester)?

☒Yes ☐No 30 days after full

Other Equipment:

Is there any technical information available on other equipment at the facility (grinders, mixers, dewatering units)? If yes, describe and attach a copy/pic at end of document.

☒Yes ☐No

All equipment

Heating, Air conditioning, and Lighting:

Are the building design specs available? ☒Yes ☐No

Are all heated buildings controlled by thermostat control? If no, describe which ones are not and how are they are set:

☒Yes ☐No Location/method: ____________________________________

Do all the lights have a switch that turns them on and off? If No, note which ones:

☒Yes ☐No Location: ________________________________

Are the outdoor lights controlled by photo cells? ☒Yes ☐No

Equipment Checklists:

For each large piece of equipment, fill in the information below as best as possible. Also, obtain pictures of all rooms, specific equipment, and nameplate data in subsequent order to better recall what data was collected. If info is unavailable, indicate N/A and note reason. (**Most Critical Information)

Aeration Equipment Checklist

Location: Aeration Basin/CSR

Aeration Equipment Type: ☒ Blower ☐ Mechanical Aerator

Provides Air To: ☒ Main aeration basin (not a digester) ☐ Aerobic Digester

Blower Type (if Applicable): ☐ Single-stage Centrifugal ☐ Multistage Centrifugal

☐ High Speed Turbo ☒ Rotary Lobe Positive Displacement

☐ Other: ____

Mechancial Aerator Type (if Applicable): ☐Brush Aerator ☐ Disk Aerator

Number of Units: 3 Number of Active Units**: 2 Age of Unit(s): ____

Operating Time**: See run time logs if they exist; one runs 24/7, other runs 12-16 hours/day in the summer and 2-4 hours/day in the winter

How is the unit controlled? Operator judgement

Manufacturer: Semblex/Sutorbilt FramSN/Blower SN/Model Number: 892010701/287209/5M-F

Nameplate Full Load Flowrate: ____ Nameplate Pressure: ____

Discharge Pressure Gauge Present? ☐ Yes ☒ No If yes, Reading (psi): ____

Discharge Flowrate Gauge Present? ☐ Yes ☒ No If yes, Reading (CFM): ____

Unit's Motor:

Nameplate Power of Motor**: 20 Units: [✓ HP] / kW Nameplate Efficiency (%): 92.4

Nameplate Full Load Speed (RPM): 1760

Nameplate Full Load Voltage (Volts): 200-208

Nameplate Full Load Amperage (Amps): 53.1

Manufacturer: Reliance Electric Model Number: P25G5102A

Motor Enclosure Type (motor shell):

☐ Open Drip Proof (ODP) ☐ Totally Enclosed Forced Air (TEFC)

Belt Drive Type**:**

☐ V-Belt ☐ Notched (Cogged) Belt ☐ Synchronous Belt ☐ Shaft Drive

Equipped with VFD? ☐ Yes ☒ No If yes, list typical operating frequency? ____

notes: ____

Pump Checklist

Location: WAS/RAS pumps

Pump Function:

☐ Lift Station (not at plant) ☐ Headworks Lift Station ☒ Return Activated Sludge (RAS)
☒ Waste Activated Sludge (WAS) ☐ Digester Sludge Pump ☐ Other: ____________

Pump Type:

☐ Centrifugal ☒ Rotary Lob Positive Displacement ☐ Plunger Positive Displacement

☐ Other, ____________________

Number of Units: 2? Number of Active Units**: 2 Age of Unit(s): ________

Operating Time**: ____________________

How is the unit controlled? ____________________

Manufacturer: Fairbanks Morse Pump Corp Size &Frame#: 6” A5433M – 21 Frame

Nameplate Full Load Flowrate (GPM): 800

Nameplate Pressure (psi): ____________

Required pressure or head to overcome: ____________

Pump’s Motor:

Nameplate Power of Motor**: 7.5 Units: [✓ HP] / kW Nameplate Efficiency (%): ________

Nameplate Full Load Speed (RPM): 865

Nameplate Full Load Voltage (Volts): 208/416

Nameplate Full Load Amperage (Amps): 28.7/14.3

Manufacturer: Reliance Model Number: X210TY

Motor Enclosure Type (motor shell):

☐ Open Drip Proof (ODP) ☒ Totally Enclosed Forced Air (TEFC)

***Belt Drive Type*:**

☐ V-Belt ☐ Notched (Cogged) Belt ☐ Synchronous Belt ☒ Shaft Drive

Equipped with VFD? ☐ Yes ☒ No If yes, list typical operating frequency? ________

notes:

____

____

____

Other Mechanical Equipment Checklist

Location: Influent grinder

Type of Unit:

☒ Communitor (grinder) ☐ Mixer ☐ Clarifier Skimmer Motor ☐ Mechanical Screen

☐ Dewatering/Thickening Equipment ☐ Grit Removal Unit ☐ Air Compressor

☐ Other: ____

Type of Dewatering/Thickening Equipment (if applicable):

☐ Centrifuge ☐ Belt Filter Press ☐ Rotary Drum Thickener

Number of units: 1 Number of Active Units: 1

Motor Nameplate Power**: 5 Units: [✓ HP] / kW Nameplate Efficiency (%): 87.5

Operating Time**: 24/7

Notes: ***will be putting in a screen system soon***

Please fill in as much of this form for each of the buildings on site. If data is unavailable, indicate N/A and note why the data was unavailable. ***Also collect data on outside lighting!

Lighting, Insulation, and HVAC

Location: Lab/ Office

How long is the building typically occupied? .5 hour/day

Under thermostat control? ☐ Yes ☒ No

If yes, what temperature is the building set to be at? ____________

Does the building have be heated (e.g. to keep pipes/equipment from freezing)? ☒ Yes ☐ No

Please indicate if there is another reason for keeping the building heated (ex. Operator comfort):

Operator Comfort

Type of Lighting:

Mark the types of lights used at the facility:

☒Fluorescent ☒Incandescent ☐Halogen ☐ Mercury Vapor ☐LED

☐Other:____________

Number of Lights: 4 (2 on) 1 in restroom Light Bulb Power (Watts): 40 W/ 60 W

Frequency of Replacement? Every 10 years

Heating Units:

Heating Unit Present? ☒ Yes ☐ No ***Uses:*** ☒ Electricity or ☐ Gas

If yes, how many: 2 Nameplate power of unit(s): 0.5 kW

Does the staff have an estimate of the operating time? No

Insulation: (for heated buildings)

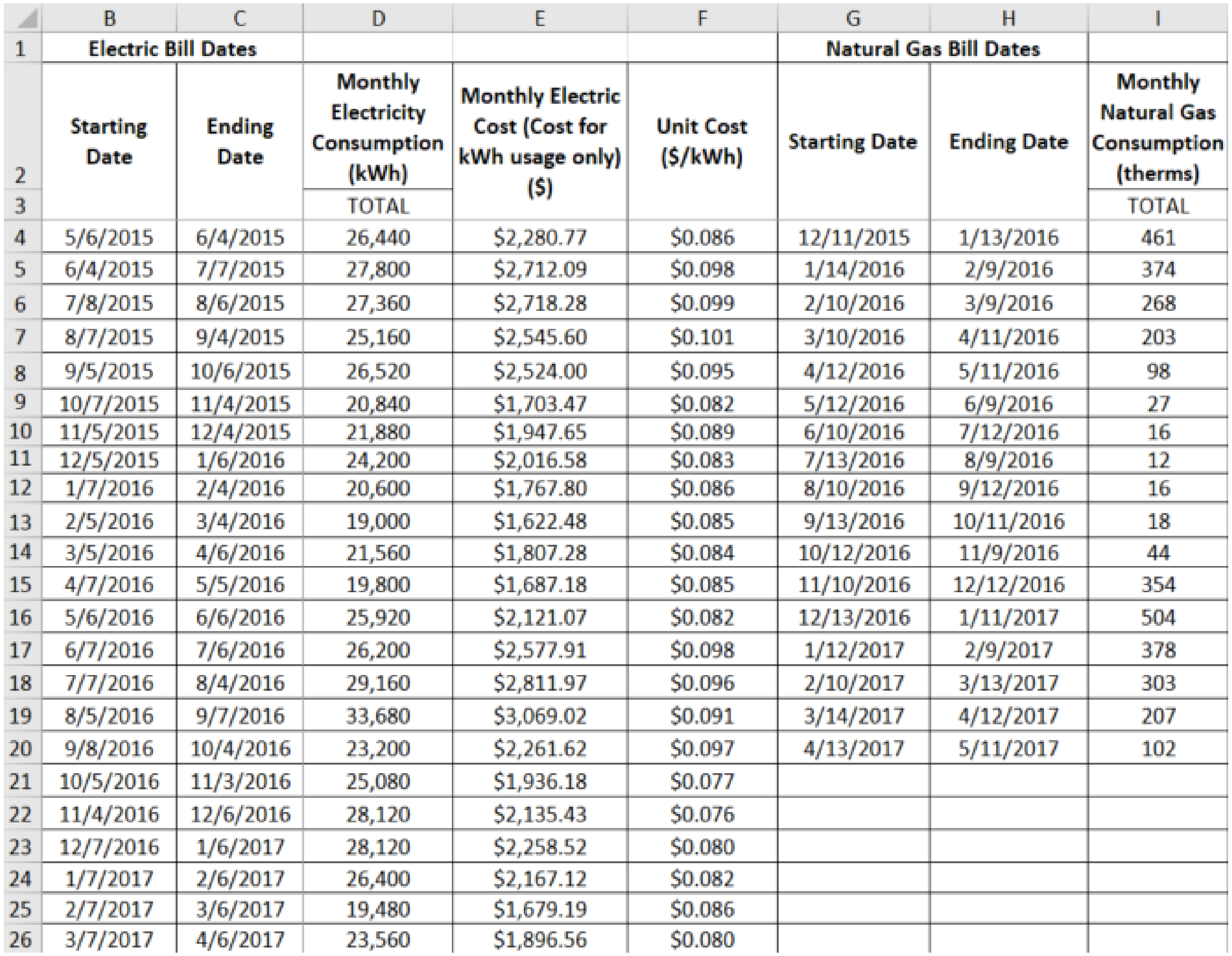
Does the building have insulation material present on the inside? ☒ Yes ☐ No

Are there any apparent openings/gaps in the insulation to the outside (ex. Broken window, cracks in walls/doors/windows, etc.)?

☐ Yes ☒ No, If yes, take pictures and note: ____________

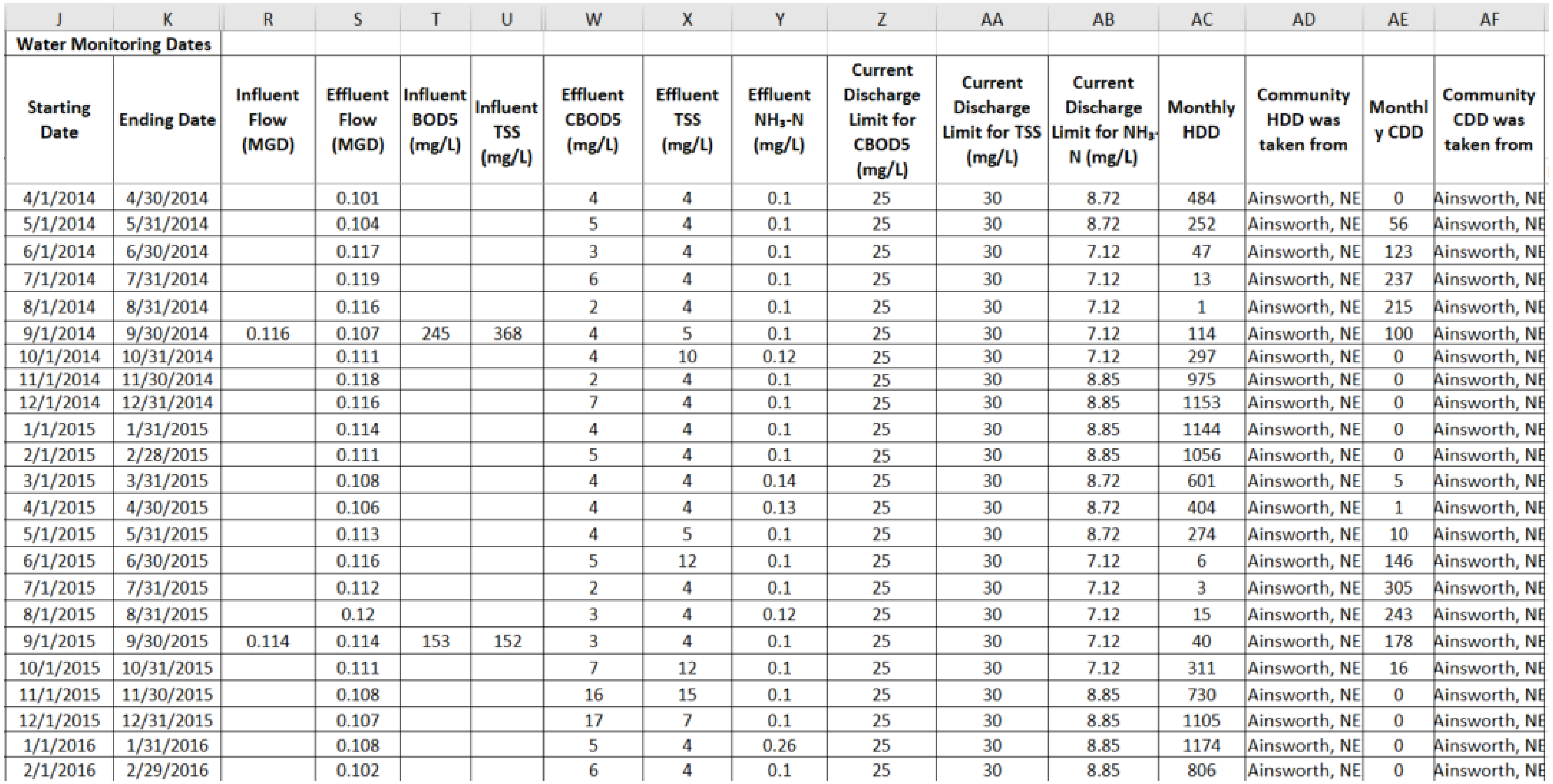
An example of the energy and water characteristic spreadsheet used are shown in Tables D.1 and D.2 Respectively.

Table D.1: Example Energy Data Collection Spreadsheet



	B	C	D	E	F	G	H	I
1	Electric Bill Dates					Natural Gas Bill Dates		
2	Starting Date	Ending Date	Monthly Electricity Consumption (kWh)	Monthly Electric Cost (Cost for kWh usage only) ($)	Unit Cost ($/kWh)	Starting Date	Ending Date	Monthly Natural Gas Consumption (therms)
3			TOTAL					TOTAL
4	5/6/2015	6/4/2015	26,440	$2,280.77	$0.086	12/11/2015	1/13/2016	461
5	6/4/2015	7/7/2015	27,800	$2,712.09	$0.098	1/14/2016	2/9/2016	374
6	7/8/2015	8/6/2015	27,360	$2,718.28	$0.099	2/10/2016	3/9/2016	268
7	8/7/2015	9/4/2015	25,160	$2,545.60	$0.101	3/10/2016	4/11/2016	203
8	9/5/2015	10/6/2015	26,520	$2,524.00	$0.095	4/12/2016	5/11/2016	98
9	10/7/2015	11/4/2015	20,840	$1,703.47	$0.082	5/12/2016	6/9/2016	27
10	11/5/2015	12/4/2015	21,880	$1,947.65	$0.089	6/10/2016	7/12/2016	16
11	12/5/2015	1/6/2016	24,200	$2,016.58	$0.083	7/13/2016	8/9/2016	12
12	1/7/2016	2/4/2016	20,600	$1,767.80	$0.086	8/10/2016	9/12/2016	16
13	2/5/2016	3/4/2016	19,000	$1,622.48	$0.085	9/13/2016	10/11/2016	18
14	3/5/2016	4/6/2016	21,560	$1,807.28	$0.084	10/12/2016	11/9/2016	44
15	4/7/2016	5/5/2016	19,800	$1,687.18	$0.085	11/10/2016	12/12/2016	354
16	5/6/2016	6/6/2016	25,920	$2,121.07	$0.082	12/13/2016	1/11/2017	504
17	6/7/2016	7/6/2016	26,200	$2,577.91	$0.098	1/12/2017	2/9/2017	378
18	7/7/2016	8/4/2016	29,160	$2,811.97	$0.096	2/10/2017	3/13/2017	303
19	8/5/2016	9/7/2016	33,680	$3,069.02	$0.091	3/14/2017	4/12/2017	207
20	9/8/2016	10/4/2016	23,200	$2,261.62	$0.097	4/13/2017	5/11/2017	102
21	10/5/2016	11/3/2016	25,080	$1,936.18	$0.077			
22	11/4/2016	12/6/2016	28,120	$2,135.43	$0.076			
23	12/7/2016	1/6/2017	28,120	$2,258.52	$0.080			
24	1/7/2017	2/6/2017	26,400	$2,167.12	$0.082			
25	2/7/2017	3/6/2017	19,480	$1,679.19	$0.086			
26	3/7/2017	4/6/2017	23,560	$1,896.56	$0.080			

Table D.2: Water and Climate Data Collection Spreadsheet



J	K	R	S	T	U	W	X	Y	Z	AA	AB	AC	AD	AE	AF
Water Monitoring Dates															
Starting Date	Ending Date	Influent Flow (MGD)	Effluent Flow (MGD)	Influent BOD5 (mg/L)	Influent TSS (mg/L)	Effluent CBOD5 (mg/L)	Effluent TSS (mg/L)	Effluent NH_3-N (mg/L)	Current Discharge Limit for CBOD5 (mg/L)	Current Discharge Limit for TSS (mg/L)	Current Discharge Limit for NH_3-N (mg/L)	Monthly HDD	Community HDD was taken from	Monthly CDD	Community CDD was taken from
4/1/2014	4/30/2014		0.101			4	4	0.1	25	30	8.72	484	Ainsworth, NE	0	Ainsworth, NE
5/1/2014	5/31/2014		0.104			5	4	0.1	25	30	8.72	252	Ainsworth, NE	56	Ainsworth, NE
6/1/2014	6/30/2014		0.117			3	4	0.1	25	30	7.12	47	Ainsworth, NE	123	Ainsworth, NE
7/1/2014	7/31/2014		0.119			6	4	0.1	25	30	7.12	13	Ainsworth, NE	237	Ainsworth, NE
8/1/2014	8/31/2014		0.116			2	4	0.1	25	30	7.12	1	Ainsworth, NE	215	Ainsworth, NE
9/1/2014	9/30/2014	0.116	0.107	245	368	4	5	0.1	25	30	7.12	114	Ainsworth, NE	100	Ainsworth, NE
10/1/2014	10/31/2014		0.111			4	10	0.12	25	30	7.12	297	Ainsworth, NE	0	Ainsworth, NE
11/1/2014	11/30/2014		0.118			2	4	0.1	25	30	8.85	975	Ainsworth, NE	0	Ainsworth, NE
12/1/2014	12/31/2014		0.116			7	4	0.1	25	30	8.85	1153	Ainsworth, NE	0	Ainsworth, NE
1/1/2015	1/31/2015		0.114			4	4	0.1	25	30	8.85	1144	Ainsworth, NE	0	Ainsworth, NE
2/1/2015	2/28/2015		0.111			5	4	0.1	25	30	8.85	1056	Ainsworth, NE	0	Ainsworth, NE
3/1/2015	3/31/2015		0.108			4	4	0.14	25	30	8.72	601	Ainsworth, NE	5	Ainsworth, NE
4/1/2015	4/30/2015		0.106			4	4	0.13	25	30	8.72	404	Ainsworth, NE	1	Ainsworth, NE
5/1/2015	5/31/2015		0.113			4	5	0.1	25	30	8.72	274	Ainsworth, NE	10	Ainsworth, NE
6/1/2015	6/30/2015		0.116			5	12	0.1	25	30	7.12	6	Ainsworth, NE	146	Ainsworth, NE
7/1/2015	7/31/2015		0.112			2	4	0.1	25	30	7.12	3	Ainsworth, NE	305	Ainsworth, NE
8/1/2015	8/31/2015		0.12			3	4	0.12	25	30	7.12	15	Ainsworth, NE	243	Ainsworth, NE
9/1/2015	9/30/2015	0.114	0.114	153	152	3	4	0.1	25	30	7.12	40	Ainsworth, NE	178	Ainsworth, NE
10/1/2015	10/31/2015		0.111			7	12	0.1	25	30	7.12	311	Ainsworth, NE	16	Ainsworth, NE
11/1/2015	11/30/2015		0.108			16	15	0.1	25	30	8.85	730	Ainsworth, NE	0	Ainsworth, NE
12/1/2015	12/31/2015		0.107			17	7	0.1	25	30	8.85	1105	Ainsworth, NE	0	Ainsworth, NE
1/1/2016	1/31/2016		0.108			5	4	0.26	25	30	8.85	1174	Ainsworth, NE	0	Ainsworth, NE
2/1/2016	2/29/2016		0.102			6	4	0.1	25	30	8.85	806	Ainsworth, NE	0	Ainsworth, NE

The form for use when carrying out electrical measurements at plants is shown below in Figure D.1. (Note: All electrical equipment used for measurements were installed by a certified electrician.)

Communities with Sub-Metering:

Document the following data for each of the following communities on the table on the next page.

Plant:

Summary of Extra Data:

Conduct Electrical Metering of each piece of major mechanical equipment while active unless it is equipped with a VFD (e.g. influent pumps, WAS/RAS pump, blower, grinder, mixers, clarifier, etc.):

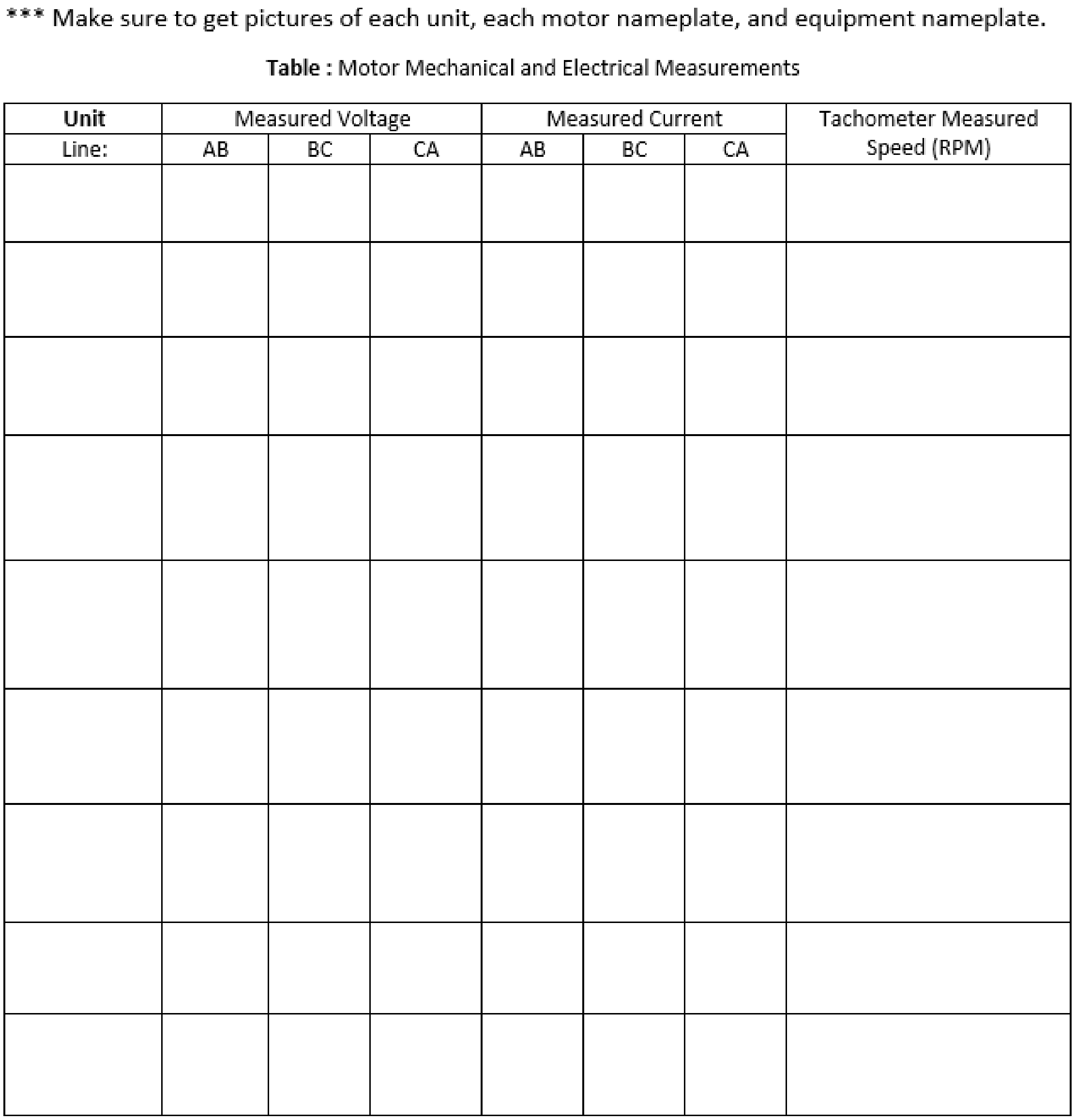
- **Measure current and voltage across each line of each motor**
- **Document full-load voltage, current, and rpm from each metered motor's nameplate**
- If VFD is present, document the display: frequency, current reading, voltage reading
- Place the current meter on the influent pump first and let it collect a few cycles of influent pumping data while documenting flowrate data from a flowmeter
- Use the other meter on other equipment while this is running
- Confirm documented operating times

Make a tachometer measurement on each motor while conducting electrical metering measurement. If there are redundant units, measure just one unit (Ex. Influent pumps)

Document the flowrate of the influent pumps during the metering process (ex. from flowmeter)

Document Dissolved Oxygen Readings in the Digester and Main Aeration Basin

Figure D.1: Form for Collecting Electrical Measurement, Nameplate, and Operational Data of Unit Processes



*** Make sure to get pictures of each unit, each motor nameplate, and equipment nameplate.

Table : Motor Mechanical and Electrical Measurements

Unit	Measured Voltage			Measured Current			Tachometer Measured Speed (RPM)
Line:	AB	BC	CA	AB	BC	CA	

Figure D.1 (Cont)

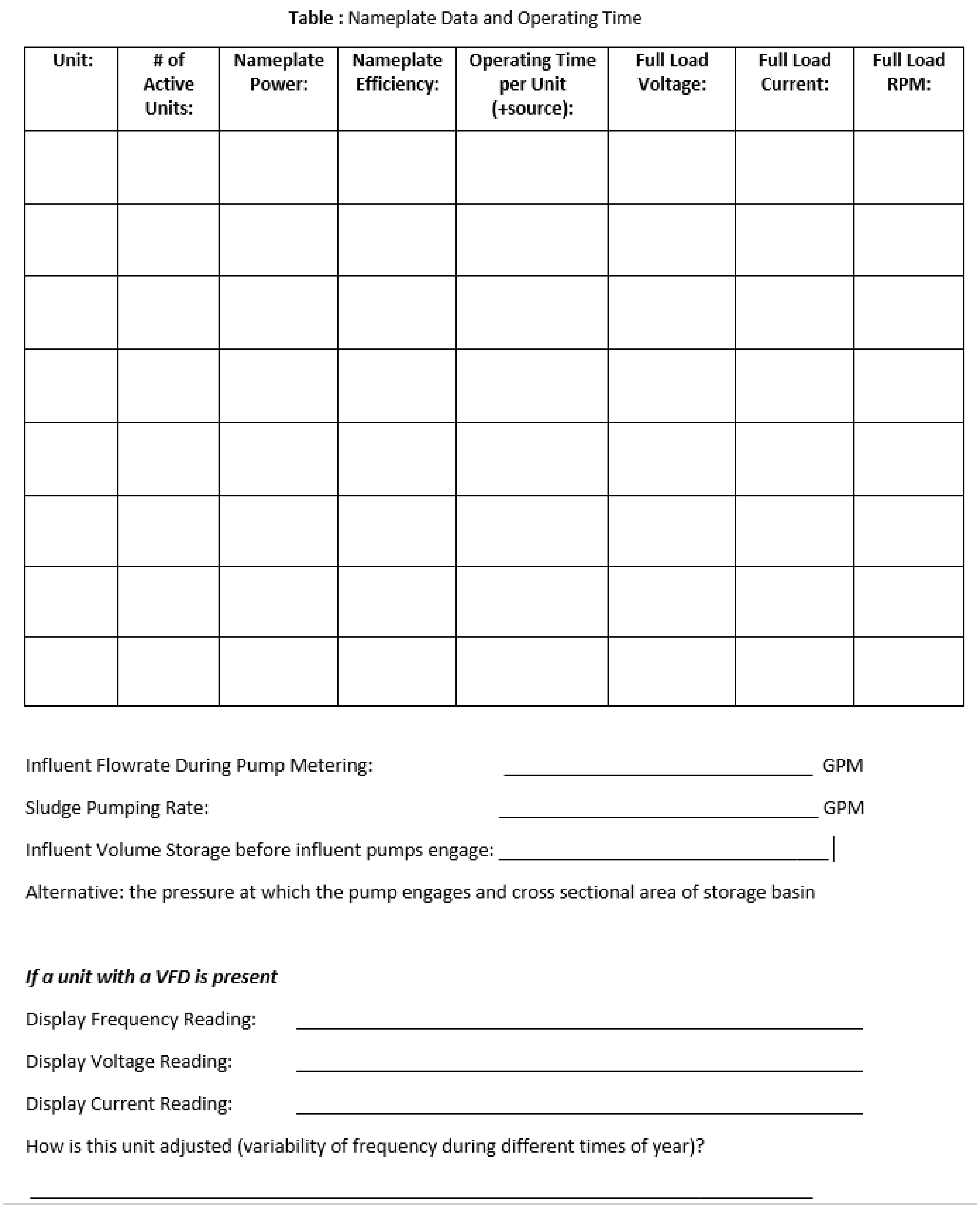


Table : Nameplate Data and Operating Time

Unit:	# of Active Units:	Nameplate Power:	Nameplate Efficiency:	Operating Time per Unit (+source):	Full Load Voltage:	Full Load Current:	Full Load RPM:

Influent Flowrate During Pump Metering: ______________________________ GPM

Sludge Pumping Rate: _______________________________ GPM

Influent Volume Storage before influent pumps engage: ________________________________

Alternative: the pressure at which the pump engages and cross sectional area of storage basin

If a unit with a VFD is present

Display Frequency Reading: ____

Display Voltage Reading: ____

Display Current Reading: ____

How is this unit adjusted (variability of frequency during different times of year)?

____

Figure D.1 (Cont)

Appendix E: Unit Process Energy Estimates and Benchmarks

The following appendix presents the equipment energy use estimates, energy intensity benchmarks, and comparison of these estimates to the billed energy usage. For each plant, the electrical measurements and estimated load of motors is presented first. The use of this data to estimated unit process energy use and the normalization of this energy use by flow is then presented. Finally, utility bills are summarized and compared against the equipment estimates.

Table E.1: Plant A Electrical Measurement Data

Unit	**Measured Voltage (Volts)**			**Measured Current (Amps)**		
	AB	**BC**	**CA**	**A Phase**	**B Phase**	**C Phase**
Grinder	205.6	206.3	206.4	1.3	1.2	1.4
Digester Blower	205.8	207	207.1	39.6	40	41.4
Main Aeration Basin Blower	206.1	207.3	207.3	44.6	45.3	46.2
Sludge transfer Pump	206.9	207.8	207.6	5.2	4.3	5
Clarifier	206	206.9	206.8	0.8	0.7	0.8
Lagoon Pumps	**					
Headworks Pump (East)	206.7	207.6	207.6	17.8	18	18.5
Headworks Pump (West)	206.3	207.3	207.2	22.2	22	23.1

Table E.2: Plant A Nameplate Data

Unit:	# of Active Units:	Nameplate Power:	Nameplate Efficiency:	Full Load Voltage:	Full Load Current:	Full Load RPM:
Grinder	1	0.75 HP	75.5	230	3.2	1725
Aerobic Digester Blower	1	15 HP	90	200	48.2	1170
Main Aeration Basin Blower	1	15 HP	90	200	48.2	1170
Sludge Transfer Pump	1	2 HP	90	200	7.4	1730
Clarifier	1	0.5 HP	75	208	2.2	1745
Lagoon Pump	2	3 HP	80	240	4.6	1170
Headworks Pumps	2	7.5 HP	84	208	21	1740
Headworks Pumps	2	7.5 HP	84	208	21	1740

Table E.3: Plant A Motor Load Estimates

Unit	Average Current (Amps)	Average Voltage (Volts)	Estimated Load Based on Current	Estimated Load Based on Current and Voltage
Grinder	**1.3**	**206.1**	**41%**	**36%**
Aerobic Digester Blower	**40.3**	**206.6**	**84%**	**86%**
Main Aeration Basin Blower	**45.4**	**206.9**	**94%**	**97%**
Sludge Transfer Pump	**4.8**	**207.4**	**65%**	**68%**
Clarifier	**0.8**	**206.6**	**35%**	**35%**
Lagoon Pump	**-**	**-**	**-**	**-**
Headworks Pumps	**18.1**	**207.3**	**86%**	**86%**
Headworks Pumps	**22.4**	**206.9**	**107%**	**106%**

Plant A: Equipment Energy Use Estimates and Benchmarks

Daily Energy Usage of Influent Pumps based on documented motor run times and load measurement plotted against measured flowrate by the flow meter are shown below in Figure E.1. The slope represents the Specific Energy Consumption of the pump (270 kWh/MG). Based on 713 days of data.

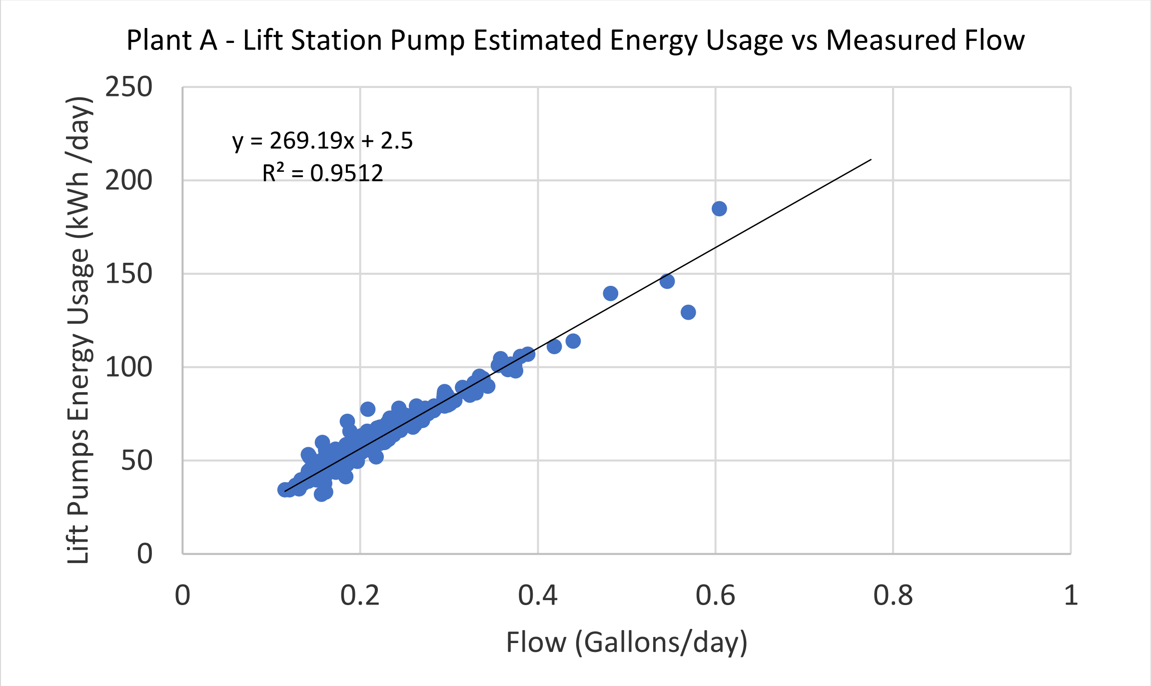
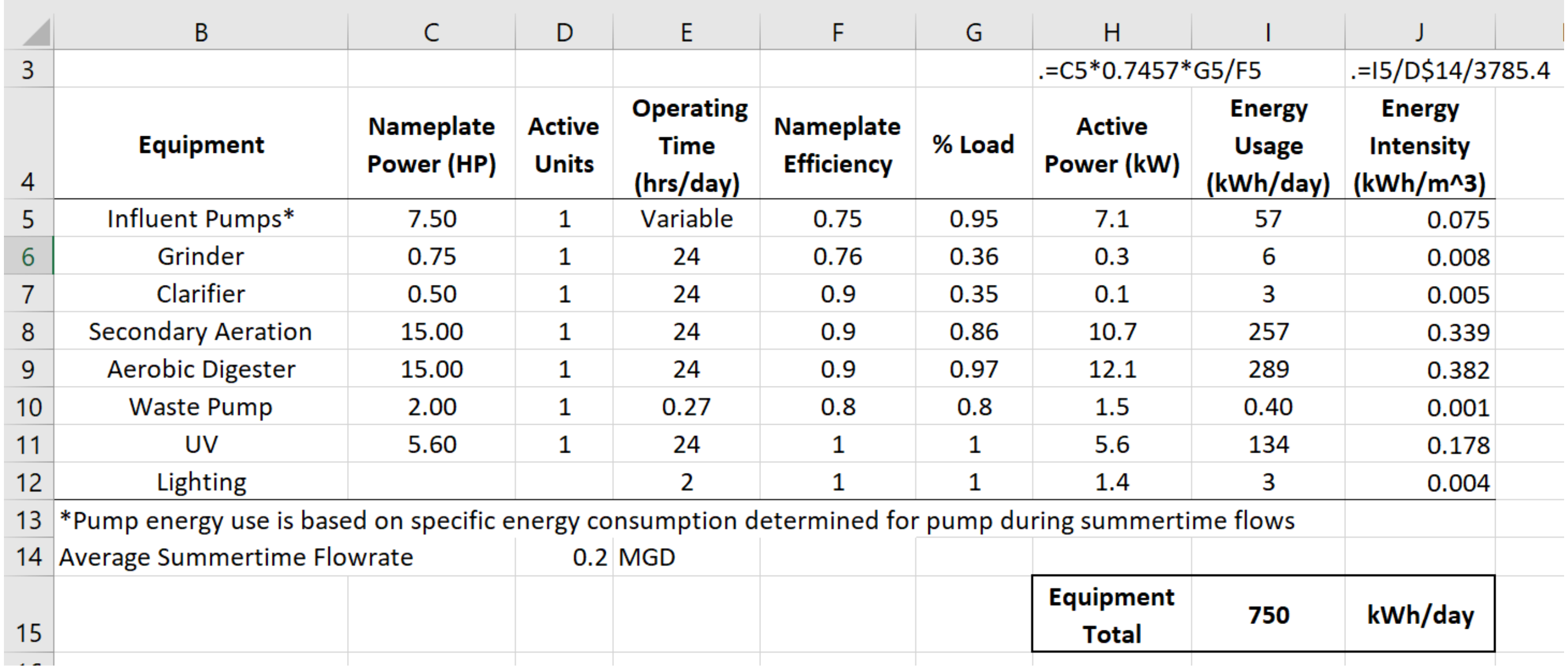


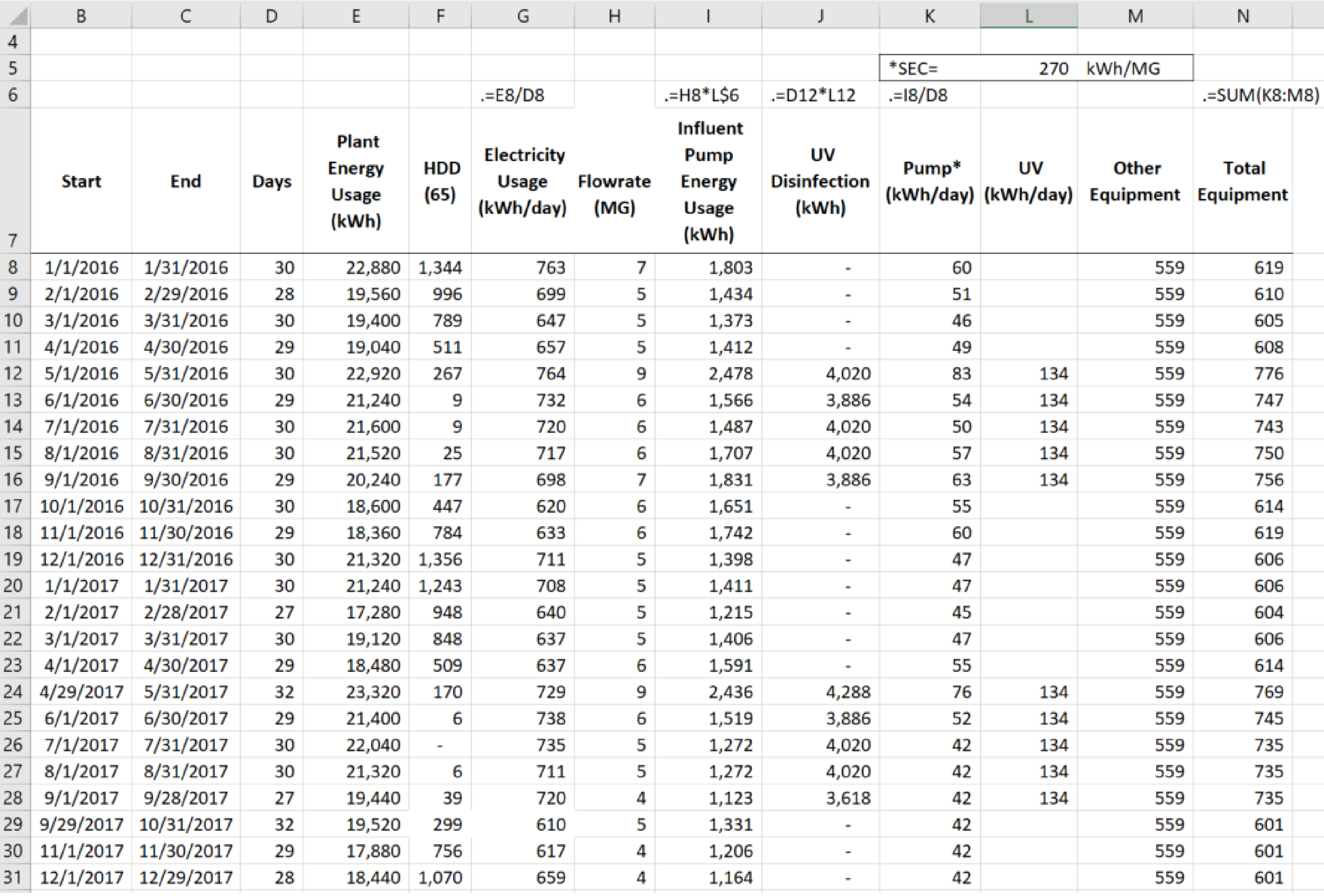
Figure E.1: Influent Pump Daily Energy Use of Pump Correlated with Measured Flowrate



	B	C	D	E	F	G	H	I	J
3							.=C5*0.7457*G5/F5		.=I5/D$14/3785.4
4	Equipment	Nameplate Power (HP)	Active Units	Operating Time (hrs/day)	Nameplate Efficiency	% Load	Active Power (kW)	Energy Usage (kWh/day)	Energy Intensity (kWh/m^3)
5	Influent Pumps*	7.50	1	Variable	0.75	0.95	7.1	57	0.075
6	Grinder	0.75	1	24	0.76	0.36	0.3	6	0.008
7	Clarifier	0.50	1	24	0.9	0.35	0.1	3	0.005
8	Secondary Aeration	15.00	1	24	0.9	0.86	10.7	257	0.339
9	Aerobic Digester	15.00	1	24	0.9	0.97	12.1	289	0.382
10	Waste Pump	2.00	1	0.27	0.8	0.8	1.5	0.40	0.001
11	UV	5.60	1	24	1	1	5.6	134	0.178
12	Lighting			2	1	1	1.4	3	0.004
13	*Pump energy use is based on specific energy consumption determined for pump during summertime flows								
14	Average Summertime Flowrate		0.2	MGD					
15							**Equipment Total**	**750**	**kWh/day**

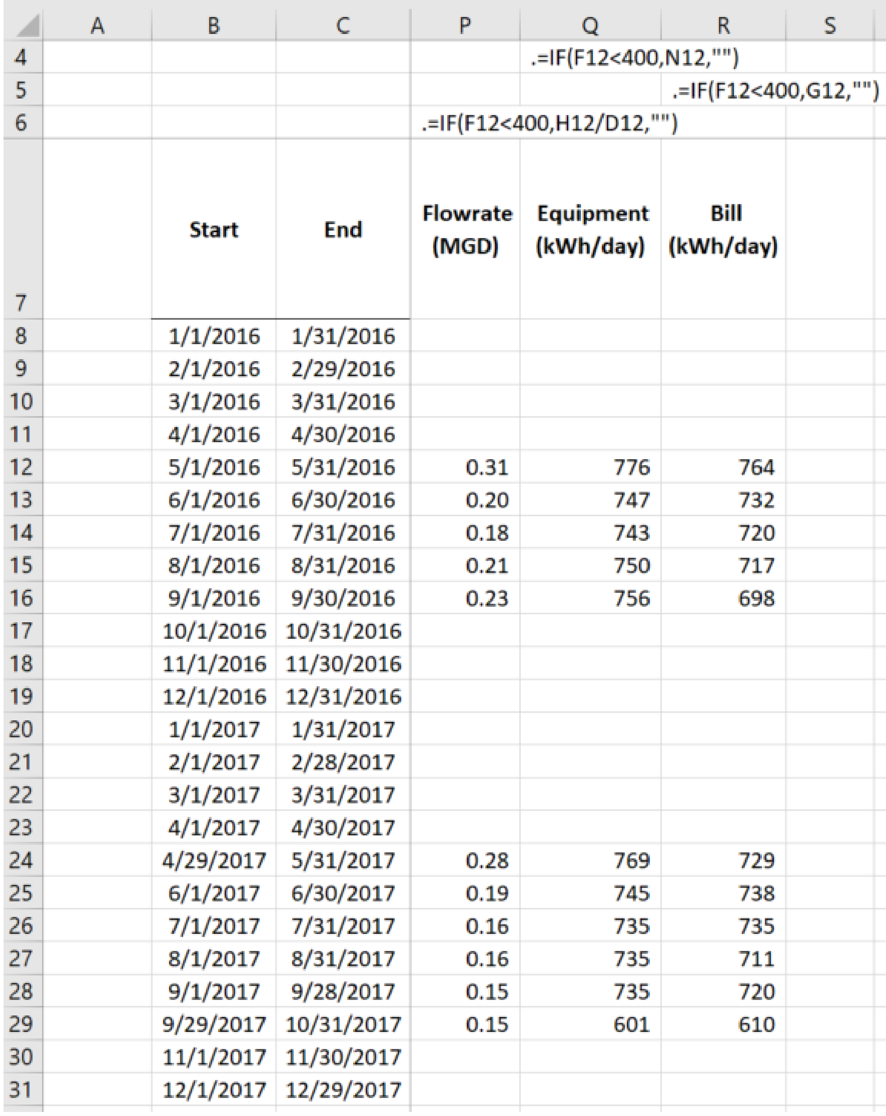
Figure E.2: Screenshot of Plant A Analysis of Equipment Energy Use and Benchmarks

Plant A: Utility Bills, Flowrate, and HDD Data



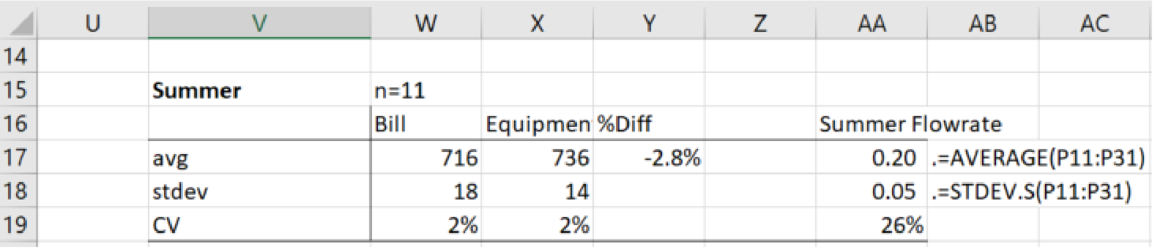
	B	C	D	E	F	G	H	I	J	K	L	M	N
4													
5										*SEC=	270	kWh/MG	
6						.=E8/D8		.=H8*L$6	.=D12*L12	.=I8/D8			.=SUM(K8:M8)
7	Start	End	Days	Plant Energy Usage (kWh)	HDD (65)	Electricity Usage (kWh/day)	Flowrate (MG)	Influent Pump Energy Usage (kWh)	UV Disinfection (kWh)	Pump* (kWh/day)	UV (kWh/day)	Other Equipment	Total Equipment
8	1/1/2016	1/31/2016	30	22,880	1,344	763	7	1,803	-	60		559	619
9	2/1/2016	2/29/2016	28	19,560	996	699	5	1,434	-	51		559	610
10	3/1/2016	3/31/2016	30	19,400	789	647	5	1,373	-	46		559	605
11	4/1/2016	4/30/2016	29	19,040	511	657	5	1,412	-	49		559	608
12	5/1/2016	5/31/2016	30	22,920	267	764	9	2,478	4,020	83	134	559	776
13	6/1/2016	6/30/2016	29	21,240	9	732	6	1,566	3,886	54	134	559	747
14	7/1/2016	7/31/2016	30	21,600	9	720	6	1,487	4,020	50	134	559	743
15	8/1/2016	8/31/2016	30	21,520	25	717	6	1,707	4,020	57	134	559	750
16	9/1/2016	9/30/2016	29	20,240	177	698	7	1,831	3,886	63	134	559	756
17	10/1/2016	10/31/2016	30	18,600	447	620	6	1,651	-	55		559	614
18	11/1/2016	11/30/2016	29	18,360	784	633	6	1,742	-	60		559	619
19	12/1/2016	12/31/2016	30	21,320	1,356	711	5	1,398	-	47		559	606
20	1/1/2017	1/31/2017	30	21,240	1,243	708	5	1,411	-	47		559	606
21	2/1/2017	2/28/2017	27	17,280	948	640	5	1,215	-	45		559	604
22	3/1/2017	3/31/2017	30	19,120	848	637	5	1,406	-	47		559	606
23	4/1/2017	4/30/2017	29	18,480	509	637	6	1,591	-	55		559	614
24	4/29/2017	5/31/2017	32	23,320	170	729	9	2,436	4,288	76	134	559	769
25	6/1/2017	6/30/2017	29	21,400	6	738	6	1,519	3,886	52	134	559	745
26	7/1/2017	7/31/2017	30	22,040	-	735	5	1,272	4,020	42	134	559	735
27	8/1/2017	8/31/2017	30	21,320	6	711	5	1,272	4,020	42	134	559	735
28	9/1/2017	9/28/2017	27	19,440	39	720	4	1,123	3,618	42	134	559	735
29	9/29/2017	10/31/2017	32	19,520	299	610	5	1,331	-	42		559	601
30	11/1/2017	11/30/2017	29	17,880	756	617	4	1,206	-	42		559	601
31	12/1/2017	12/29/2017	28	18,440	1,070	659	4	1,164	-	42		559	601

Figure E.3: Screenshot of Plant A Utility Bill Analysis in Excel



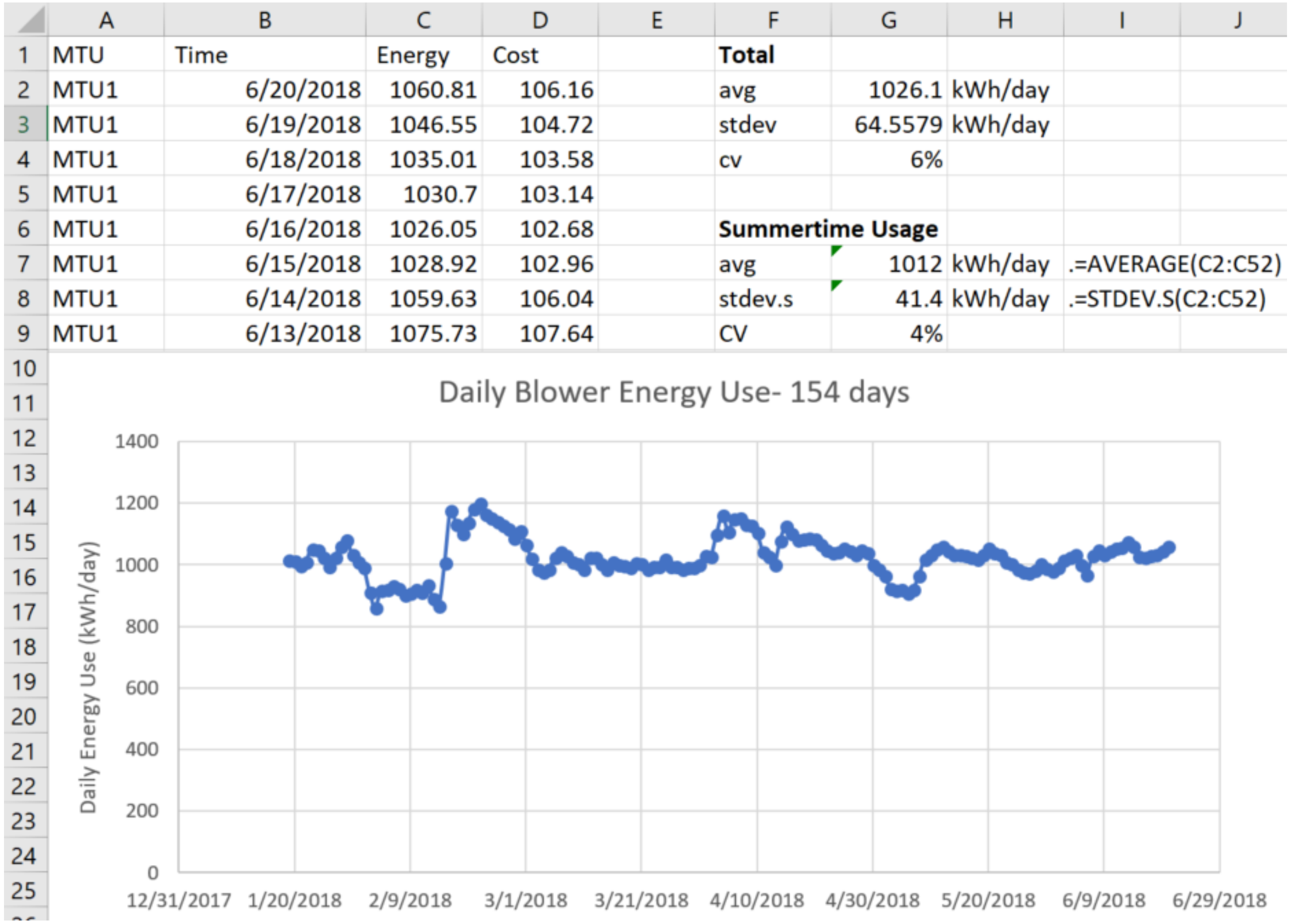
	A	B	C	P	Q	R	S
4					.=IF(F12<400,N12,"")		
5						.=IF(F12<400,G12,"")	
6				.=IF(F12<400,H12/D12,"")			
7		**Start**	**End**	**Flowrate (MGD)**	**Equipment (kWh/day)**	**Bill (kWh/day)**	
8		1/1/2016	1/31/2016				
9		2/1/2016	2/29/2016				
10		3/1/2016	3/31/2016				
11		4/1/2016	4/30/2016				
12		5/1/2016	5/31/2016	0.31	776	764	
13		6/1/2016	6/30/2016	0.20	747	732	
14		7/1/2016	7/31/2016	0.18	743	720	
15		8/1/2016	8/31/2016	0.21	750	717	
16		9/1/2016	9/30/2016	0.23	756	698	
17		10/1/2016	10/31/2016				
18		11/1/2016	11/30/2016				
19		12/1/2016	12/31/2016				
20		1/1/2017	1/31/2017				
21		2/1/2017	2/28/2017				
22		3/1/2017	3/31/2017				
23		4/1/2017	4/30/2017				
24		4/29/2017	5/31/2017	0.28	769	729	
25		6/1/2017	6/30/2017	0.19	745	738	
26		7/1/2017	7/31/2017	0.16	735	735	
27		8/1/2017	8/31/2017	0.16	735	711	
28		9/1/2017	9/28/2017	0.15	735	720	
29		9/29/2017	10/31/2017	0.15	601	610	
30		11/1/2017	11/30/2017				
31		12/1/2017	12/29/2017				

Figure E.3 (cont)



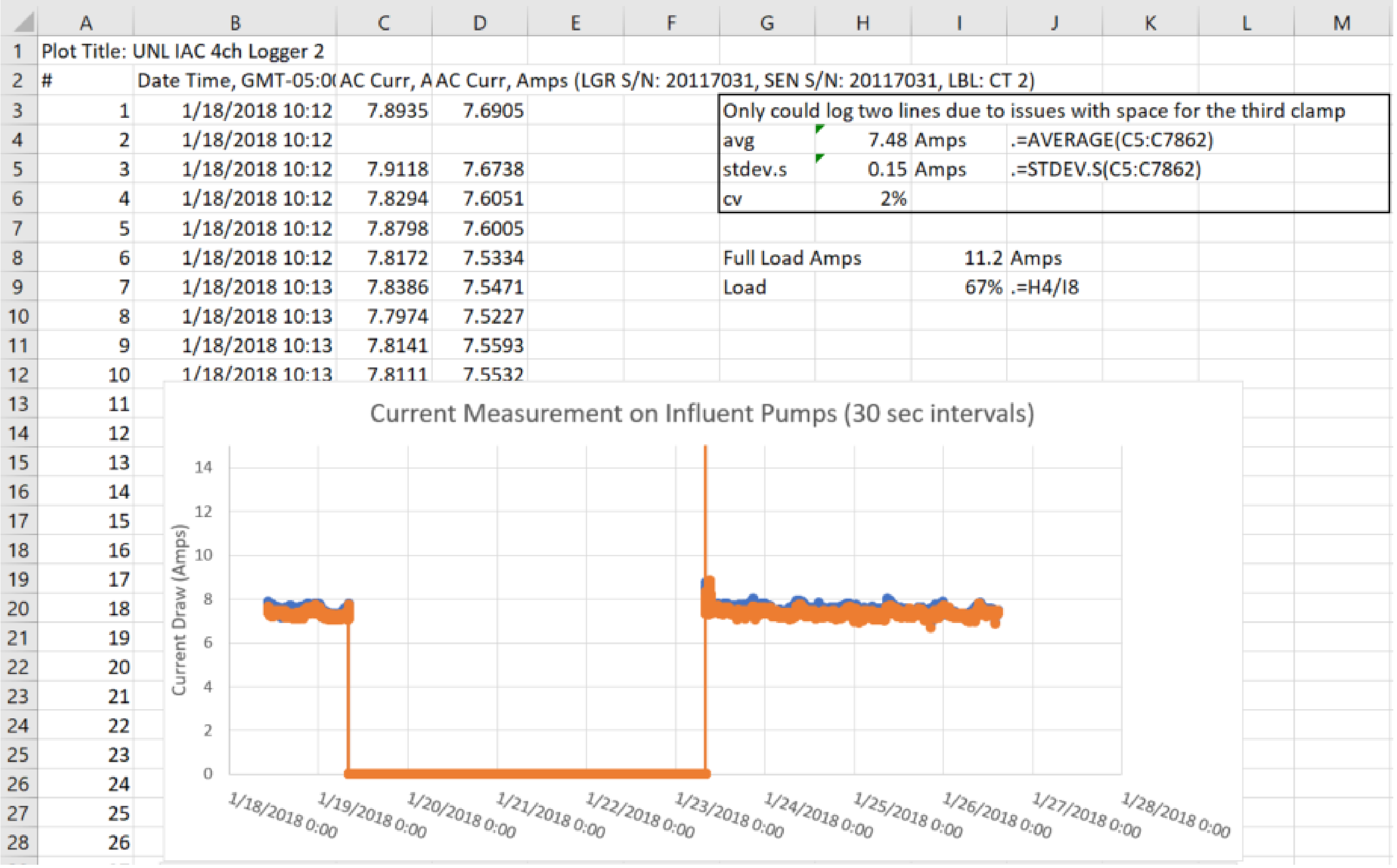
	U	V	W	X	Y	Z	AA	AB	AC
14									
15		**Summer**	n=11						
16			Bill	Equipmen	%Diff		Summer Flowrate		
17		avg	716	736	-2.8%		0.20	.=AVERAGE(P11:P31)	
18		stdev	18	14			0.05	.=STDEV.S(P11:P31)	
19		CV	2%	2%			26%		

Figure E.4: Plant A Screen Shot of Equipment and Bill Comparison in Excel



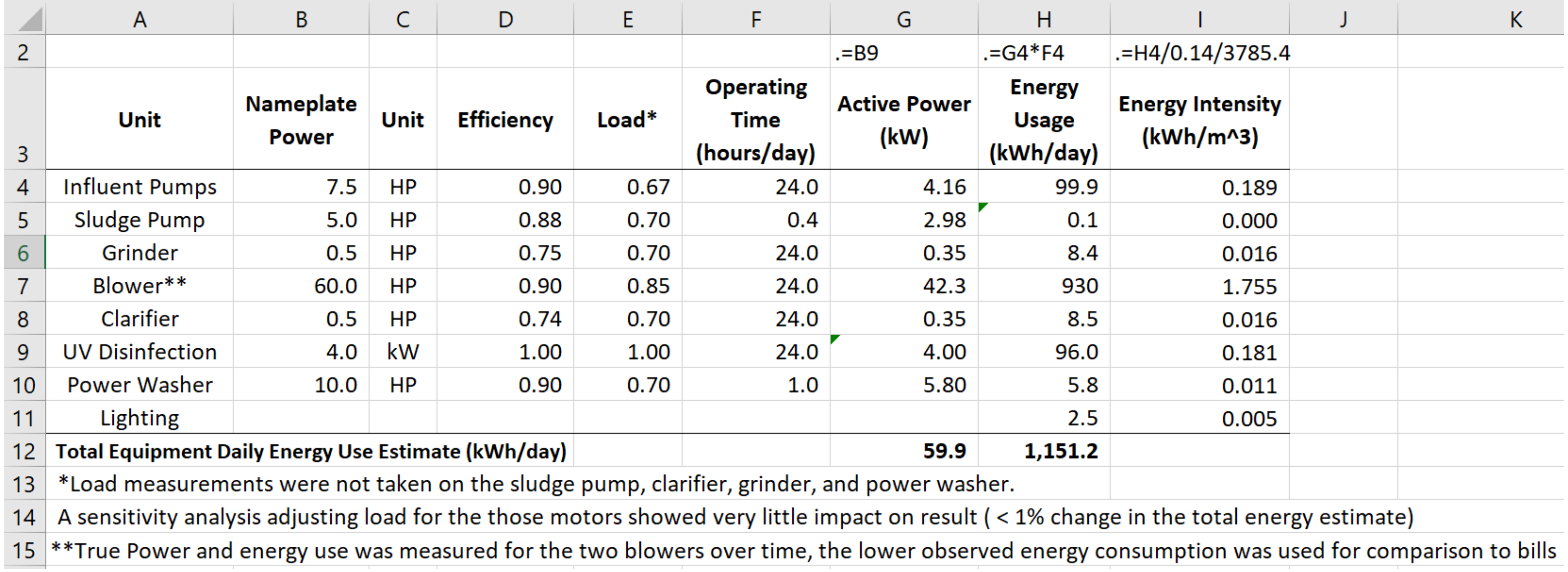
	A	B	C	D	E	F	G	H	I	J
1	MTU	Time	Energy	Cost		**Total**				
2	MTU1	6/20/2018	1060.81	106.16		avg	1026.1	kWh/day		
3	MTU1	6/19/2018	1046.55	104.72		stdev	64.5579	kWh/day		
4	MTU1	6/18/2018	1035.01	103.58		cv	6%			
5	MTU1	6/17/2018	1030.7	103.14						
6	MTU1	6/16/2018	1026.05	102.68		**Summertime Usage**				
7	MTU1	6/15/2018	1028.92	102.96		avg	1012	kWh/day	.=AVERAGE(C2:C52)	
8	MTU1	6/14/2018	1059.63	106.04		stdev.s	41.4	kWh/day	.=STDEV.S(C2:C52)	
9	MTU1	6/13/2018	1075.73	107.64		CV	4%			

Figure E.5: Screenshot of Plant B Measured Blower Energy Use



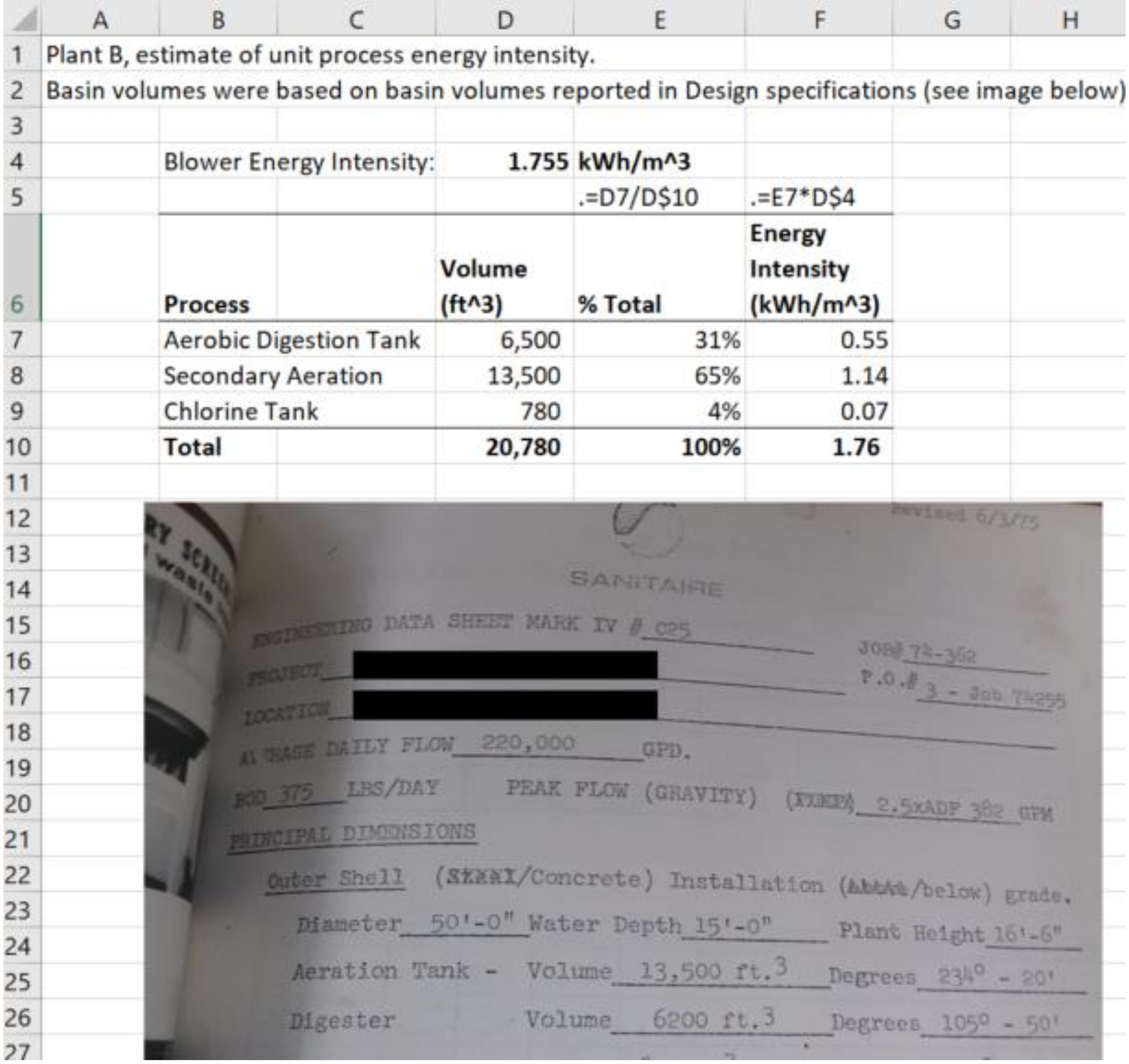
	A	B	C	D	E	F	G	H	I	J	K	L	M
1	Plot Title: UNL IAC 4ch Logger 2												
2	#	Date Time, GMT-05:0(	AC Curr, A	AC Curr, Amps (LGR S/N: 20117031, SEN S/N: 20117031, LBL: CT 2)									
3	1	1/18/2018 10:12	7.8935	7.6905			Only could log two lines due to issues with space for the third clamp						
4	2	1/18/2018 10:12					avg	7.48	Amps	.=AVERAGE(C5:C7862)			
5	3	1/18/2018 10:12	7.9118	7.6738			stdev.s	0.15	Amps	.=STDEV.S(C5:C7862)			
6	4	1/18/2018 10:12	7.8294	7.6051			cv	2%					
7	5	1/18/2018 10:12	7.8798	7.6005									
8	6	1/18/2018 10:12	7.8172	7.5334			Full Load Amps		11.2	Amps			
9	7	1/18/2018 10:13	7.8386	7.5471			Load		67%	.=H4/I8			
10	8	1/18/2018 10:13	7.7974	7.5227									
11	9	1/18/2018 10:13	7.8141	7.5593									
12	10	1/18/2018 10:13	7.8111	7.5532									
13	11												
14	12												
15	13												
16	14												
17	15												
18	16												
19	17												
20	18												
21	19												
22	20												
23	21												
24	22												
25	23												
26	24												
27	25												
28	26												

Figure E.6: Screenshot of Plant B Measured Influent Pump Current Draw



	A	B	C	D	E	F	G	H	I	J	K
2							.=B9	.=G4*F4	.=H4/0.14/3785.4		
3	**Unit**	**Nameplate Power**	**Unit**	**Efficiency**	**Load***	**Operating Time (hours/day)**	**Active Power (kW)**	**Energy Usage (kWh/day)**	**Energy Intensity (kWh/m^3)**		
4	Influent Pumps	7.5	HP	0.90	0.67	24.0	4.16	99.9	0.189		
5	Sludge Pump	5.0	HP	0.88	0.70	0.4	2.98	0.1	0.000		
6	Grinder	0.5	HP	0.75	0.70	24.0	0.35	8.4	0.016		
7	Blower**	60.0	HP	0.90	0.85	24.0	42.3	930	1.755		
8	Clarifier	0.5	HP	0.74	0.70	24.0	0.35	8.5	0.016		
9	UV Disinfection	4.0	kW	1.00	1.00	24.0	4.00	96.0	0.181		
10	Power Washer	10.0	HP	0.90	0.70	1.0	5.80	5.8	0.011		
11	Lighting							2.5	0.005		
12	**Total Equipment Daily Energy Use Estimate (kWh/day)**						**59.9**	**1,151.2**			
13	*Load measurements were not taken on the sludge pump, clarifier, grinder, and power washer.										
14	A sensitivity analysis adjusting load for the those motors showed very little impact on result (< 1% change in the total energy estimate)										
15	**True Power and energy use was measured for the two blowers over time, the lower observed energy consumption was used for comparison to bills										

Figure E.7: Screenshot of Plant B Analysis of Equipment Energy Use and Benchmarks



Plant B, estimate of unit process energy intensity.

Basin volumes were based on basin volumes reported in Design specifications (see image below)

Blower Energy Intensity: **1.755** **kWh/m^3**

Process	Volume (ft^3)	% Total	Energy Intensity (kWh/m^3)
		.=D7/D$10	.=E7*D$4
Aerobic Digestion Tank	6,500	31%	0.55
Secondary Aeration	13,500	65%	1.14
Chlorine Tank	780	4%	0.07
Total	**20,780**	**100%**	**1.76**

Revised 6/3/75

SANITAIRE

ENGINEERING DATA SHEET MARK IV # C25 JOB# 74-362

PROJECT [redacted] P.O.# 3 - Job 74255

LOCATION [redacted]

AVERAGE DAILY FLOW 220,000 GPD.

BOD 375 LBS/DAY PEAK FLOW (GRAVITY) (XXXXX) 2.5xADF 382 GPM

PRINCIPAL DIMENSIONS

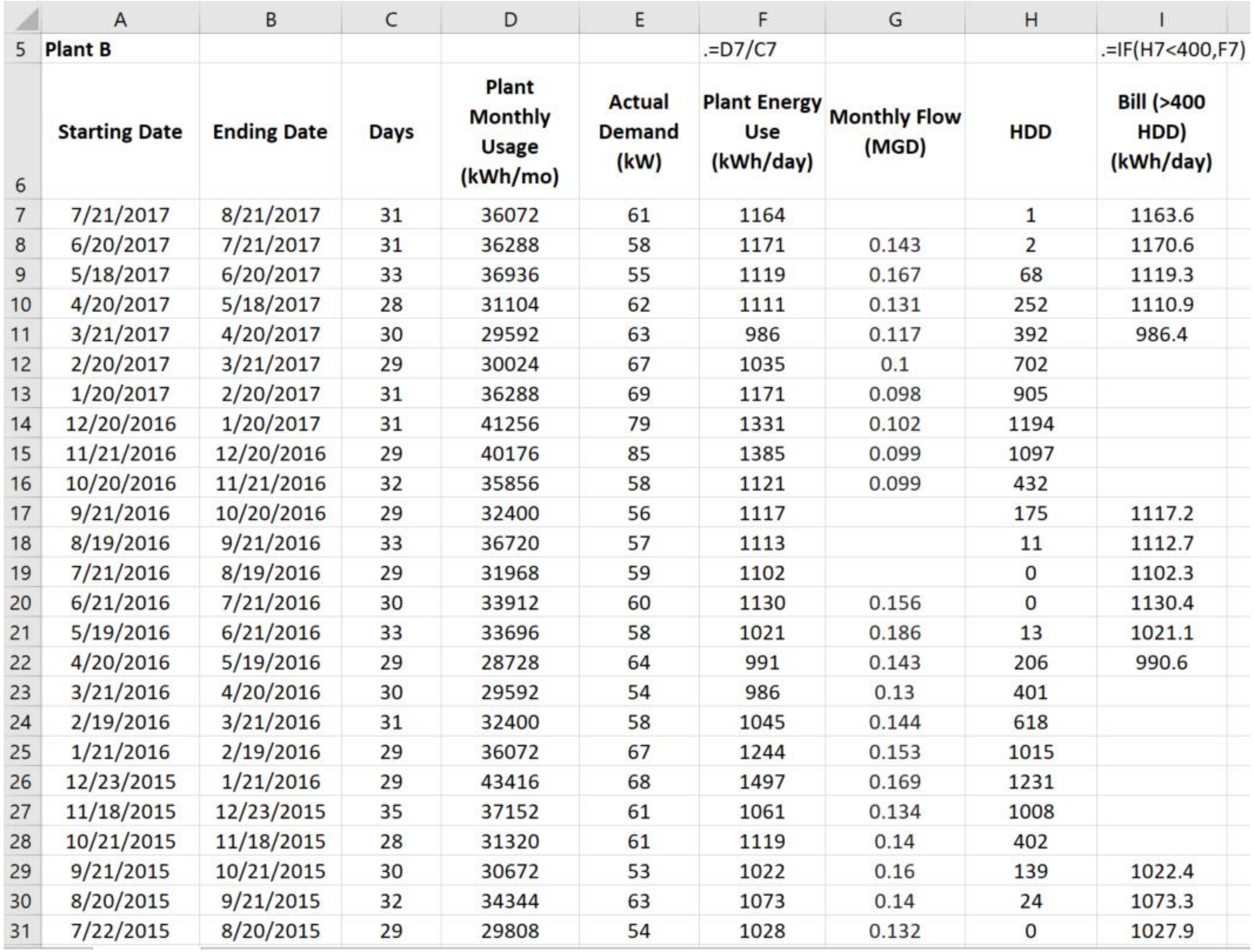
Outer Shell (XXXXX/Concrete) Installation (XXXXX/below) grade.

Diameter 50'-0" Water Depth 15'-0" Plant Height 16'-6"

Aeration Tank - Volume 13,500 ft.^{3} Degrees 234° - 20'

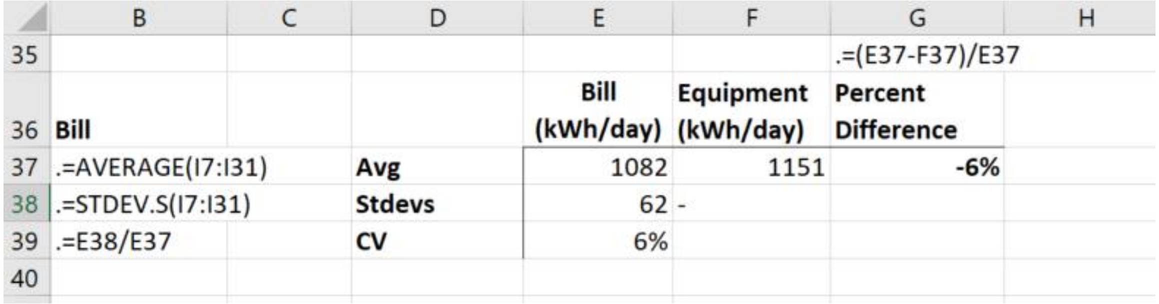
Digester Volume 6200 ft.^{3} Degrees 105° - 50'

Figure E.8: Plant B Screen Shot of Aeration Energy Intensity Division Among Different Processes



	A	B	C	D	E	F	G	H	I
5	**Plant B**					.=D7/C7			.=IF(H7<400,F7)
6	**Starting Date**	**Ending Date**	**Days**	**Plant Monthly Usage (kWh/mo)**	**Actual Demand (kW)**	**Plant Energy Use (kWh/day)**	**Monthly Flow (MGD)**	**HDD**	**Bill (>400 HDD) (kWh/day)**
7	7/21/2017	8/21/2017	31	36072	61	1164		1	1163.6
8	6/20/2017	7/21/2017	31	36288	58	1171	0.143	2	1170.6
9	5/18/2017	6/20/2017	33	36936	55	1119	0.167	68	1119.3
10	4/20/2017	5/18/2017	28	31104	62	1111	0.131	252	1110.9
11	3/21/2017	4/20/2017	30	29592	63	986	0.117	392	986.4
12	2/20/2017	3/21/2017	29	30024	67	1035	0.1	702	
13	1/20/2017	2/20/2017	31	36288	69	1171	0.098	905	
14	12/20/2016	1/20/2017	31	41256	79	1331	0.102	1194	
15	11/21/2016	12/20/2016	29	40176	85	1385	0.099	1097	
16	10/20/2016	11/21/2016	32	35856	58	1121	0.099	432	
17	9/21/2016	10/20/2016	29	32400	56	1117		175	1117.2
18	8/19/2016	9/21/2016	33	36720	57	1113		11	1112.7
19	7/21/2016	8/19/2016	29	31968	59	1102		0	1102.3
20	6/21/2016	7/21/2016	30	33912	60	1130	0.156	0	1130.4
21	5/19/2016	6/21/2016	33	33696	58	1021	0.186	13	1021.1
22	4/20/2016	5/19/2016	29	28728	64	991	0.143	206	990.6
23	3/21/2016	4/20/2016	30	29592	54	986	0.13	401	
24	2/19/2016	3/21/2016	31	32400	58	1045	0.144	618	
25	1/21/2016	2/19/2016	29	36072	67	1244	0.153	1015	
26	12/23/2015	1/21/2016	29	43416	68	1497	0.169	1231	
27	11/18/2015	12/23/2015	35	37152	61	1061	0.134	1008	
28	10/21/2015	11/18/2015	28	31320	61	1119	0.14	402	
29	9/21/2015	10/21/2015	30	30672	53	1022	0.16	139	1022.4
30	8/20/2015	9/21/2015	32	34344	63	1073	0.14	24	1073.3
31	7/22/2015	8/20/2015	29	29808	54	1028	0.132	0	1027.9

Figure E.9: Screenshot of Plant B Utility Bill Analysis in Excel



	B	C	D	E	F	G	H
35						.=(E37-F37)/E37	
36	**Bill**			**Bill (kWh/day)**	**Equipment (kWh/day)**	**Percent Difference**	
37	.=AVERAGE(I7:I31)		**Avg**	1082	1151	**-6%**	
38	.=STDEV.S(I7:I31)		**Stdevs**	62	-		
39	.=E38/E37		**CV**	6%			
40							

Figure E.10: Screenshot of Plant B Equipment and Bill Energy Use

Table E.4: Electrical Measurements for Plant C

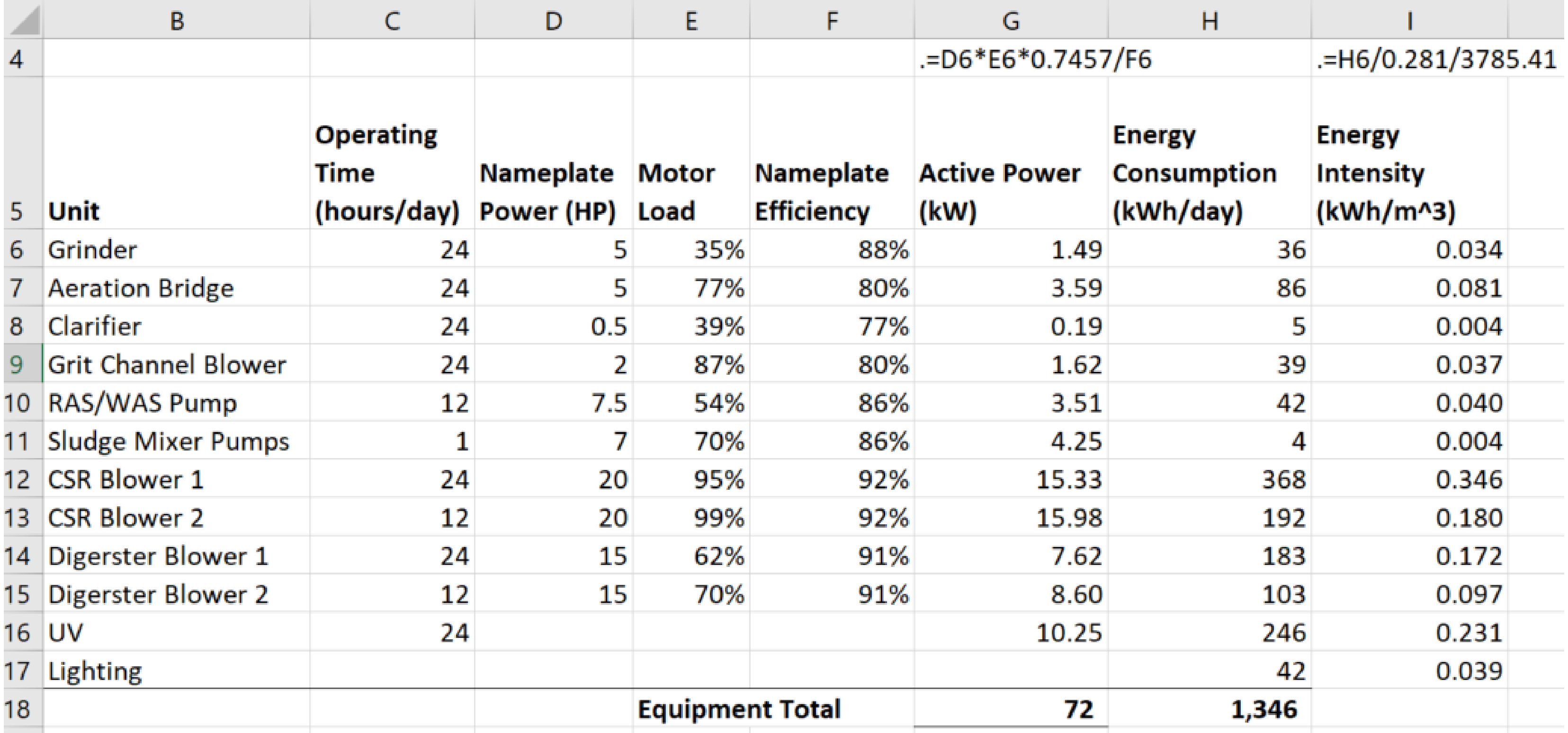
Unit	**Measured Voltage (volts)**			**Measured Current (amps)**		
	AB	**BC**	**CA**	**AB**	**BC**	**CA**
Grinder	214.6	212.8	209.3	2.88	3.17	2.74
Aeration bridge rotation motor	212.8	214	209.1	10.7	12	11.2
Clarifier skimmer motor	212.4	214	208.8	0.6	0.69	0.62
Aeration basin/CSR Blower 1	212.2	213.9	208.5	47.1	55.3	53.8
Aeration basin/CSR Blower 2	211.2	212.8	207.8	47.5	55.9	54.8
Digester Blower 1	213.3	214.6	209.8	22.25	25.92	25.63
Digester Blower 2	212.5	214	209	25.3	30.02	28.68
Grit Channel Blower	209.1	212.7	212.5	4.48	5.23	5.74
RAS pump VFD	250.8	252.6	252.4	11.9	11.9	11.86
RAS pump full	213.1	214.9	209.5	14.03	16	15.27
WAS pump	213.3	214.7	209.4	21	24.14	22.15
Sludge mixer pumps	212	213.5	208.2	27.2	32.1	31.3

Table E.5: Equipment Nameplate Data for Plant C

Unit	Nameplate Power (HP)	Nameplate Efficiency	Full Load Voltage:	Full Load Current:	Full Load RPM:
Grinder	5	88%	208	8.58	1765
Aeration bridge rotation motor	5	80%	230	13.6	1680
Clarifier skimmer motor	0.5	77%	208	1.65	1750
Aeration basin/CSR Blower 1	20	92%	200	58	1760
Aeration basin/CSR Blower 2	20	92%	208	53.1	1760
Digester Blower 1	15	91%	230	36.8	1750
Digester Blower 2	15	91%	230	36.8	1750
Grit Channel Blower	2	80%	208	6.0	1705
RAS pump VFD	7.5	86%	208	24	
RAS pump full	7.5	86%	208	28.7	865
WAS pump	7.5	86%	208	28.7	865
Sludge mixer pumps	7	86%	-	-	-

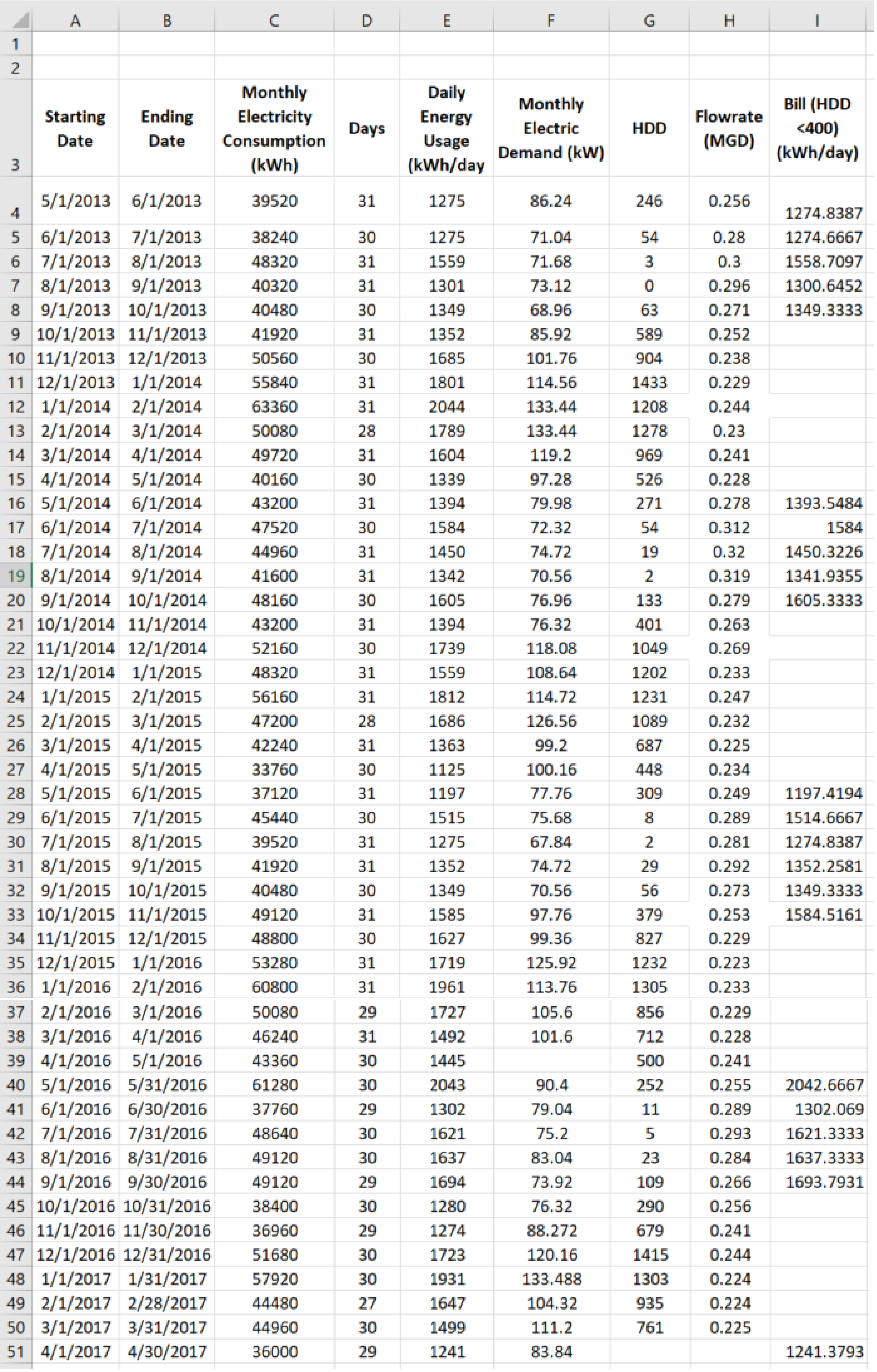
Table E.6: Motor Load Estimates for Plant C

Unit	Average voltage (volts)	Average Current (amps)	Load Based on Current	Load Based on Current and Voltage
Grinder	212.2	2.9	34%	35%
Aeration bridge rotation motor	212.0	11.3	83%	77%
Clarifier skimmer motor	211.7	0.6	39%	39%
Aeration basin/CSR Blower 1	211.5	52.1	90%	95%
Aeration basin/CSR Blower 2	210.6	52.7	99%	101%
Digester Blower 1	212.6	24.6	67%	62%
Digester Blower 2	211.8	28.0	76%	70%
Grit Channel Blower	211.4	5.2	86%	87%
RAS pump VFD	251.9	11.9	50%	60%
RAS pump full	212.5	15.1	53%	54%
WAS pump	212.5	22.4	78%	80%
Sludge mixer pumps	211.2	30.2	-	-



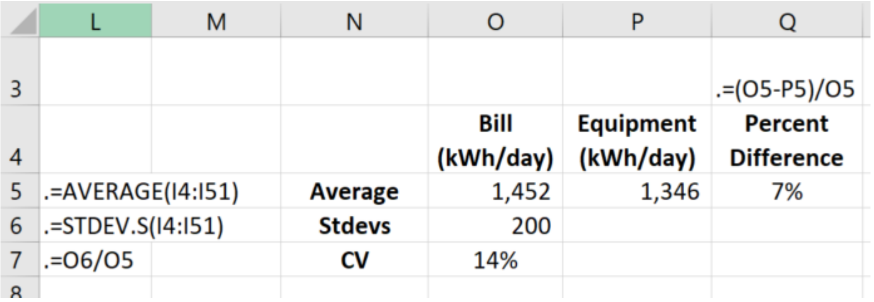
	B	C	D	E	F	G	H	I
4						.=D6*E6*0.7457/F6		.=H6/0.281/3785.41
5	**Unit**	**Operating Time (hours/day)**	**Nameplate Power (HP)**	**Motor Load**	**Nameplate Efficiency**	**Active Power (kW)**	**Energy Consumption (kWh/day)**	**Energy Intensity (kWh/m^3)**
6	Grinder	24	5	35%	88%	1.49	36	0.034
7	Aeration Bridge	24	5	77%	80%	3.59	86	0.081
8	Clarifier	24	0.5	39%	77%	0.19	5	0.004
9	Grit Channel Blower	24	2	87%	80%	1.62	39	0.037
10	RAS/WAS Pump	12	7.5	54%	86%	3.51	42	0.040
11	Sludge Mixer Pumps	1	7	70%	86%	4.25	4	0.004
12	CSR Blower 1	24	20	95%	92%	15.33	368	0.346
13	CSR Blower 2	12	20	99%	92%	15.98	192	0.180
14	Digerster Blower 1	24	15	62%	91%	7.62	183	0.172
15	Digerster Blower 2	12	15	70%	91%	8.60	103	0.097
16	UV	24				10.25	246	0.231
17	Lighting						42	0.039
18				**Equipment Total**		**72**	**1,346**	

Figure E.11: Screenshot of Plant C Analysis of Equipment Energy Use and Benchmarks



	A	B	C	D	E	F	G	H	I
1									
2									
3	Starting Date	Ending Date	Monthly Electricity Consumption (kWh)	Days	Daily Energy Usage (kWh/day	Monthly Electric Demand (kW)	HDD	Flowrate (MGD)	Bill (HDD <400) (kWh/day)
4	5/1/2013	6/1/2013	39520	31	1275	86.24	246	0.256	1274.8387
5	6/1/2013	7/1/2013	38240	30	1275	71.04	54	0.28	1274.6667
6	7/1/2013	8/1/2013	48320	31	1559	71.68	3	0.3	1558.7097
7	8/1/2013	9/1/2013	40320	31	1301	73.12	0	0.296	1300.6452
8	9/1/2013	10/1/2013	40480	30	1349	68.96	63	0.271	1349.3333
9	10/1/2013	11/1/2013	41920	31	1352	85.92	589	0.252	
10	11/1/2013	12/1/2013	50560	30	1685	101.76	904	0.238	
11	12/1/2013	1/1/2014	55840	31	1801	114.56	1433	0.229	
12	1/1/2014	2/1/2014	63360	31	2044	133.44	1208	0.244	
13	2/1/2014	3/1/2014	50080	28	1789	133.44	1278	0.23	
14	3/1/2014	4/1/2014	49720	31	1604	119.2	969	0.241	
15	4/1/2014	5/1/2014	40160	30	1339	97.28	526	0.228	
16	5/1/2014	6/1/2014	43200	31	1394	79.98	271	0.278	1393.5484
17	6/1/2014	7/1/2014	47520	30	1584	72.32	54	0.312	1584
18	7/1/2014	8/1/2014	44960	31	1450	74.72	19	0.32	1450.3226
19	8/1/2014	9/1/2014	41600	31	1342	70.56	2	0.319	1341.9355
20	9/1/2014	10/1/2014	48160	30	1605	76.96	133	0.279	1605.3333
21	10/1/2014	11/1/2014	43200	31	1394	76.32	401	0.263	
22	11/1/2014	12/1/2014	52160	30	1739	118.08	1049	0.269	
23	12/1/2014	1/1/2015	48320	31	1559	108.64	1202	0.233	
24	1/1/2015	2/1/2015	56160	31	1812	114.72	1231	0.247	
25	2/1/2015	3/1/2015	47200	28	1686	126.56	1089	0.232	
26	3/1/2015	4/1/2015	42240	31	1363	99.2	687	0.225	
27	4/1/2015	5/1/2015	33760	30	1125	100.16	448	0.234	
28	5/1/2015	6/1/2015	37120	31	1197	77.76	309	0.249	1197.4194
29	6/1/2015	7/1/2015	45440	30	1515	75.68	8	0.289	1514.6667
30	7/1/2015	8/1/2015	39520	31	1275	67.84	2	0.281	1274.8387
31	8/1/2015	9/1/2015	41920	31	1352	74.72	29	0.292	1352.2581
32	9/1/2015	10/1/2015	40480	30	1349	70.56	56	0.273	1349.3333
33	10/1/2015	11/1/2015	49120	31	1585	97.76	379	0.253	1584.5161
34	11/1/2015	12/1/2015	48800	30	1627	99.36	827	0.229	
35	12/1/2015	1/1/2016	53280	31	1719	125.92	1232	0.223	
36	1/1/2016	2/1/2016	60800	31	1961	113.76	1305	0.233	
37	2/1/2016	3/1/2016	50080	29	1727	105.6	856	0.229	
38	3/1/2016	4/1/2016	46240	31	1492	101.6	712	0.228	
39	4/1/2016	5/1/2016	43360	30	1445		500	0.241	
40	5/1/2016	5/31/2016	61280	30	2043	90.4	252	0.255	2042.6667
41	6/1/2016	6/30/2016	37760	29	1302	79.04	11	0.289	1302.069
42	7/1/2016	7/31/2016	48640	30	1621	75.2	5	0.293	1621.3333
43	8/1/2016	8/31/2016	49120	30	1637	83.04	23	0.284	1637.3333
44	9/1/2016	9/30/2016	49120	29	1694	73.92	109	0.266	1693.7931
45	10/1/2016	10/31/2016	38400	30	1280	76.32	290	0.256	
46	11/1/2016	11/30/2016	36960	29	1274	88.272	679	0.241	
47	12/1/2016	12/31/2016	51680	30	1723	120.16	1415	0.244	
48	1/1/2017	1/31/2017	57920	30	1931	133.488	1303	0.224	
49	2/1/2017	2/28/2017	44480	27	1647	104.32	935	0.224	
50	3/1/2017	3/31/2017	44960	30	1499	111.2	761	0.225	
51	4/1/2017	4/30/2017	36000	29	1241	83.84			1241.3793

Figure E.12: Screenshot of Plant C Utility Bill Analysis in Excel



	L	M	N	O	P	Q
3						.=(O5-P5)/O5
4				**Bill (kWh/day)**	**Equipment (kWh/day)**	**Percent Difference**
5	.=AVERAGE(I4:I51)		**Average**	1,452	1,346	7%
6	.=STDEV.S(I4:I51)		**Stdevs**	200		
7	.=O6/O5		**CV**	14%		

Figure E.13: Screenshot of Plant C Equipment and Bill Energy Use

Table E.7: Electrical Measurements for Plant D

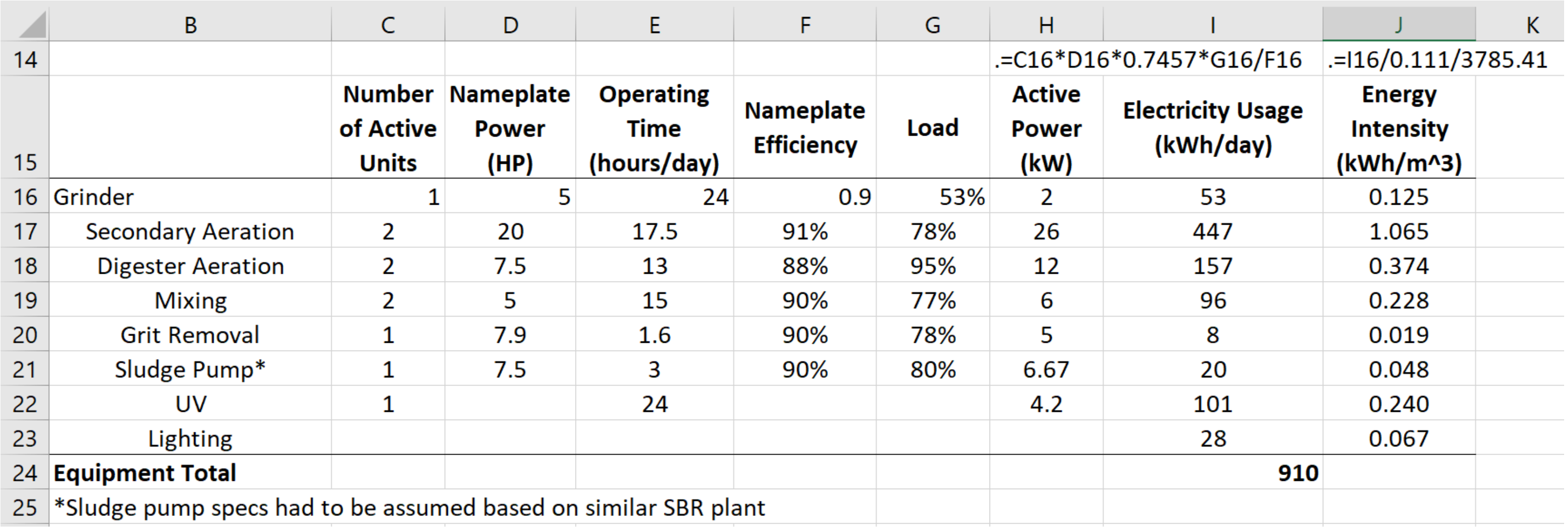
Unit	**Measured Voltage (volts)**			**Measured Current (amps)**		
	AB	**BC**	**CA**	**A**	**B**	**C**
Grinder	244	243.9	242	6.8	7.5	6.9
SBR mixer	243.9	244	242.2	14.2	15.1	14.4
Grit paddle motor	243.4	243.2	241.2	2	2.2	1.8
SBR blower	242.6	242	240.4	36.7	36.6	33.9
Sludge blower	243.2	242.6	240.9	11.7	21.7	21.3

Table E.8: Equipment Nameplate Data for Plant D

Unit	Full Load Voltage	Full load Amperage	Nameplate HP	Nameplate Efficiency
Grinder	230.00	14.20	5.00	Not Listed
SBR mixer	230.00	20	5	Not Listed
Grit paddle motor	230.00	2.70	0.75	Not Listed
SBR blower	230	48	20	91%
Sludge blower	230	20.2	7.5	88%

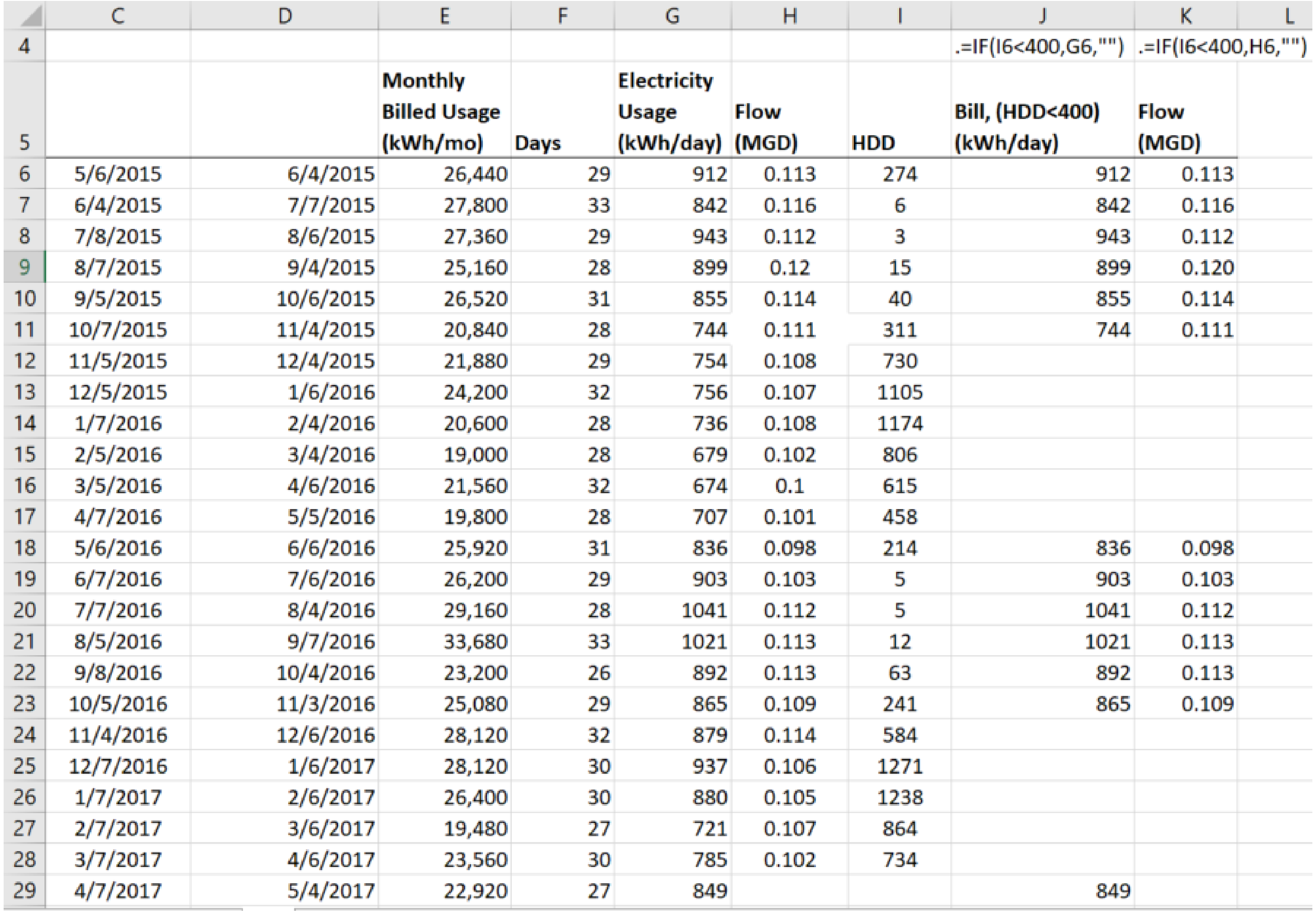
Table E.9: Motor Load Estimates for Plant D

Unit	Average voltage (volts)	Average current (amps)	Load Based on Current	Load Based on Current and Voltage
Grinder	243.30	7.07	50%	53%
SBR mixer	243.37	14.57	73%	77%
Grit paddle motor	242.60	2.00	74%	78%
SBR blower	241.67	35.73	74%	78%
Sludge blower	242.23	18.23	90%	95%



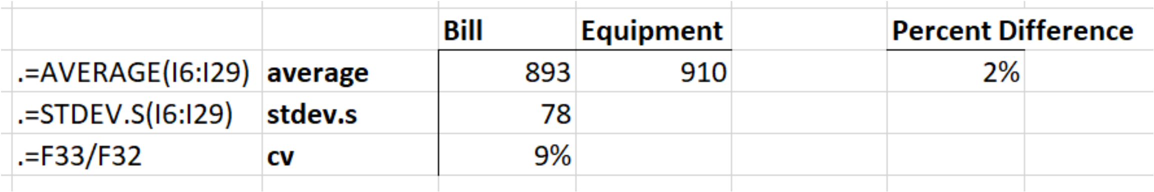
	B	C	D	E	F	G	H	I	J	K
14							.=C16*D16*0.7457*G16/F16		.=I16/0.111/3785.41	
15		**Number of Active Units**	**Nameplate Power (HP)**	**Operating Time (hours/day)**	**Nameplate Efficiency**	**Load**	**Active Power (kW)**	**Electricity Usage (kWh/day)**	**Energy Intensity (kWh/m^3)**	
16	Grinder	1	5	24	0.9	53%	2	53	0.125	
17	Secondary Aeration	2	20	17.5	91%	78%	26	447	1.065	
18	Digester Aeration	2	7.5	13	88%	95%	12	157	0.374	
19	Mixing	2	5	15	90%	77%	6	96	0.228	
20	Grit Removal	1	7.9	1.6	90%	78%	5	8	0.019	
21	Sludge Pump*	1	7.5	3	90%	80%	6.67	20	0.048	
22	UV	1		24			4.2	101	0.240	
23	Lighting							28	0.067	
24	**Equipment Total**							**910**		
25	*Sludge pump specs had to be assumed based on similar SBR plant									

Figure E.14: Screenshot of Plant D Analysis of Equipment Energy Use and Benchmarks



	C	D	E	F	G	H	I	J	K	L
4								.=IF(I6<400,G6,"")	.=IF(I6<400,H6,"")	
5			**Monthly Billed Usage (kWh/mo)**	**Days**	**Electricity Usage (kWh/day)**	**Flow (MGD)**	**HDD**	**Bill, (HDD<400) (kWh/day)**	**Flow (MGD)**	
6	5/6/2015	6/4/2015	26,440	29	912	0.113	274	912	0.113	
7	6/4/2015	7/7/2015	27,800	33	842	0.116	6	842	0.116	
8	7/8/2015	8/6/2015	27,360	29	943	0.112	3	943	0.112	
9	8/7/2015	9/4/2015	25,160	28	899	0.12	15	899	0.120	
10	9/5/2015	10/6/2015	26,520	31	855	0.114	40	855	0.114	
11	10/7/2015	11/4/2015	20,840	28	744	0.111	311	744	0.111	
12	11/5/2015	12/4/2015	21,880	29	754	0.108	730			
13	12/5/2015	1/6/2016	24,200	32	756	0.107	1105			
14	1/7/2016	2/4/2016	20,600	28	736	0.108	1174			
15	2/5/2016	3/4/2016	19,000	28	679	0.102	806			
16	3/5/2016	4/6/2016	21,560	32	674	0.1	615			
17	4/7/2016	5/5/2016	19,800	28	707	0.101	458			
18	5/6/2016	6/6/2016	25,920	31	836	0.098	214	836	0.098	
19	6/7/2016	7/6/2016	26,200	29	903	0.103	5	903	0.103	
20	7/7/2016	8/4/2016	29,160	28	1041	0.112	5	1041	0.112	
21	8/5/2016	9/7/2016	33,680	33	1021	0.113	12	1021	0.113	
22	9/8/2016	10/4/2016	23,200	26	892	0.113	63	892	0.113	
23	10/5/2016	11/3/2016	25,080	29	865	0.109	241	865	0.109	
24	11/4/2016	12/6/2016	28,120	32	879	0.114	584			
25	12/7/2016	1/6/2017	28,120	30	937	0.106	1271			
26	1/7/2017	2/6/2017	26,400	30	880	0.105	1238			
27	2/7/2017	3/6/2017	19,480	27	721	0.107	864			
28	3/7/2017	4/6/2017	23,560	30	785	0.102	734			
29	4/7/2017	5/4/2017	22,920	27	849			849		

Figure E.15: Screenshot of Plant B Utility Bill Analysis in Excel



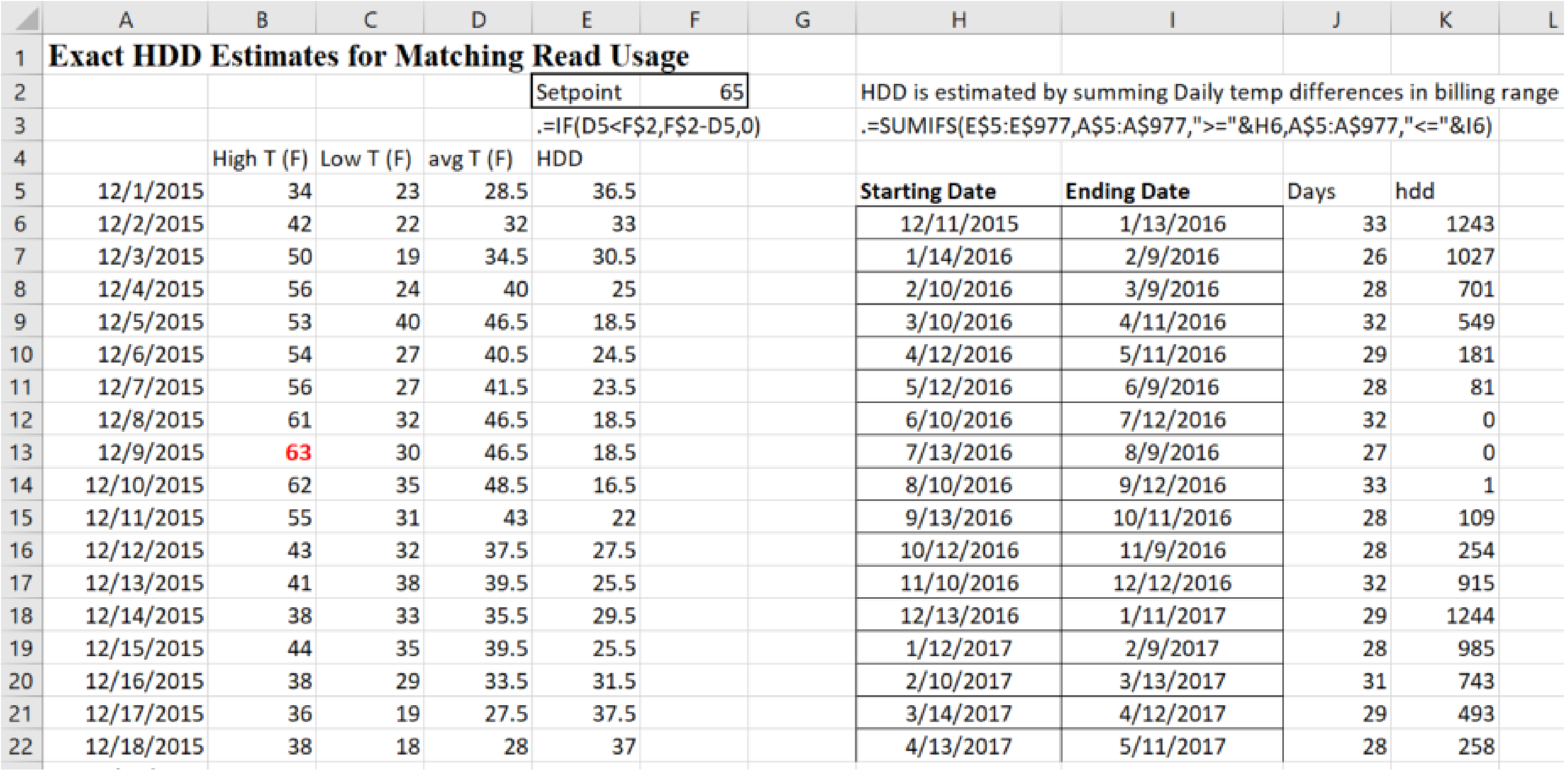
		Bill	Equipment		Percent Difference
.=AVERAGE(I6:I29)	**average**	893	910		2%
.=STDEV.S(I6:I29)	**stdev.s**	78			
.=F33/F32	**cv**	9%			

Figure E.16: Screenshot of Plant D Equipment and Bill Energy Use Comparison

Appendix F: Plant Heating Estimates and Benchmarks

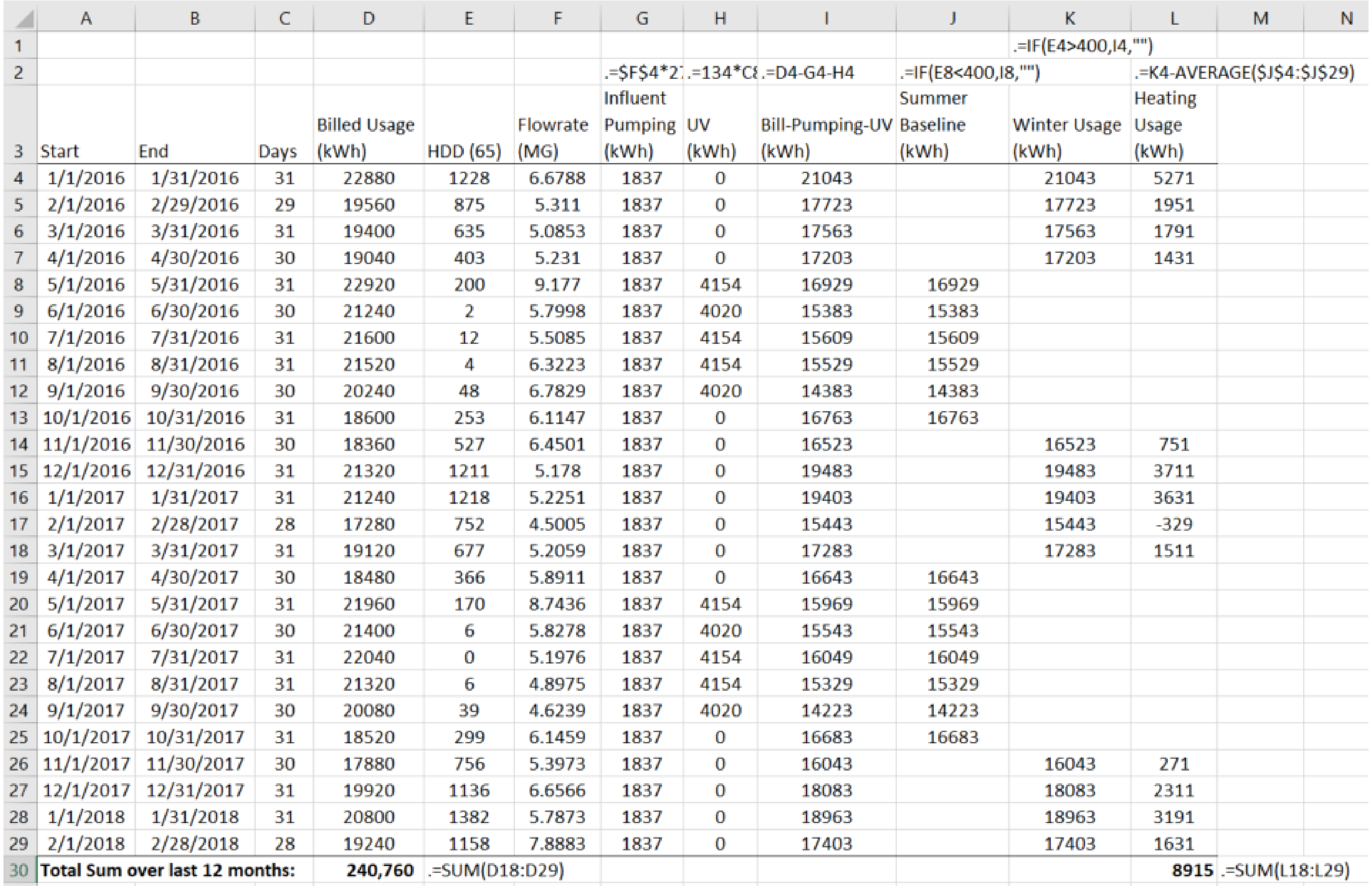
The analysis of energy used for space heating through analysis of utility bills with heating degree data are presented in this section. The monthly billed energy use, HDD data, and flowrate are provided for each plant. Any well documented variable process energy use is also shown and is then subtracted from the billed usage. The adjusted billed usage is then correlated with HDD data. Heating estimates are made by subtracting heating months (>400 HDD) from the average value of non-heating months (<400 HDD). The past 12 months of this estimated usage is then summed and compared to the plants total energy usage and also normalized by the heated floor area.

Some plants had billed energy usage that did not align exactly with the HDD data gathered from NOAA on a monthly basis. In these cases, HDD data was calculated by gathering daily temperature data and summing the temperature differences during the exact billing period. The spreadsheet for calculating Heating Degree Days for exact billing period of bills is shown below. The adjusted energy use and HDD are shown plotted over time and against each other after each dataset and calculations are shown.



	A	B	C	D	E	F	G	H	I	J	K	L
1	**Exact HDD Estimates for Matching Read Usage**											
2					Setpoint	65		HDD is estimated by summing Daily temp differences in billing range				
3					.=IF(D5<F$2,F$2-D5,0)			.=SUMIFS(E$5:E$977,A$5:A$977,">="&H6,A$5:A$977,"<="&I6)				
4		High T (F)	Low T (F)	avg T (F)	HDD							
5	12/1/2015	34	23	28.5	36.5			**Starting Date**	**Ending Date**	Days	hdd	
6	12/2/2015	42	22	32	33			12/11/2015	1/13/2016	33	1243	
7	12/3/2015	50	19	34.5	30.5			1/14/2016	2/9/2016	26	1027	
8	12/4/2015	56	24	40	25			2/10/2016	3/9/2016	28	701	
9	12/5/2015	53	40	46.5	18.5			3/10/2016	4/11/2016	32	549	
10	12/6/2015	54	27	40.5	24.5			4/12/2016	5/11/2016	29	181	
11	12/7/2015	56	27	41.5	23.5			5/12/2016	6/9/2016	28	81	
12	12/8/2015	61	32	46.5	18.5			6/10/2016	7/12/2016	32	0	
13	12/9/2015	**63**	30	46.5	18.5			7/13/2016	8/9/2016	27	0	
14	12/10/2015	62	35	48.5	16.5			8/10/2016	9/12/2016	33	1	
15	12/11/2015	55	31	43	22			9/13/2016	10/11/2016	28	109	
16	12/12/2015	43	32	37.5	27.5			10/12/2016	11/9/2016	28	254	
17	12/13/2015	41	38	39.5	25.5			11/10/2016	12/12/2016	32	915	
18	12/14/2015	38	33	35.5	29.5			12/13/2016	1/11/2017	29	1244	
19	12/15/2015	44	35	39.5	25.5			1/12/2017	2/9/2017	28	985	
20	12/16/2015	38	29	33.5	31.5			2/10/2017	3/13/2017	31	743	
21	12/17/2015	36	19	27.5	37.5			3/14/2017	4/12/2017	29	493	
22	12/18/2015	38	18	28	37			4/13/2017	5/11/2017	28	258	

Figure F.1: Spreadsheet for Calculating HDD for Exact Billing Period Using Daily Average Temperature Data



	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1											.=IF(E4>400,I4,"")			
2							.=$F$4*2	.=134*C	.=D4-G4-H4	.=IF(E8<400,I8,"")		.=K4-AVERAGE($J$4:$J$29)		
3	Start	End	Days	Billed Usage (kWh)	HDD (65)	Flowrate (MG)	Influent Pumping (kWh)	UV (kWh)	Bill-Pumping-UV (kWh)	Summer Baseline (kWh)	Winter Usage (kWh)	Heating Usage (kWh)		
4	1/1/2016	1/31/2016	31	22880	1228	6.6788	1837	0	21043		21043	5271		
5	2/1/2016	2/29/2016	29	19560	875	5.311	1837	0	17723		17723	1951		
6	3/1/2016	3/31/2016	31	19400	635	5.0853	1837	0	17563		17563	1791		
7	4/1/2016	4/30/2016	30	19040	403	5.231	1837	0	17203		17203	1431		
8	5/1/2016	5/31/2016	31	22920	200	9.177	1837	4154	16929	16929				
9	6/1/2016	6/30/2016	30	21240	2	5.7998	1837	4020	15383	15383				
10	7/1/2016	7/31/2016	31	21600	12	5.5085	1837	4154	15609	15609				
11	8/1/2016	8/31/2016	31	21520	4	6.3223	1837	4154	15529	15529				
12	9/1/2016	9/30/2016	30	20240	48	6.7829	1837	4020	14383	14383				
13	10/1/2016	10/31/2016	31	18600	253	6.1147	1837	0	16763	16763				
14	11/1/2016	11/30/2016	30	18360	527	6.4501	1837	0	16523		16523	751		
15	12/1/2016	12/31/2016	31	21320	1211	5.178	1837	0	19483		19483	3711		
16	1/1/2017	1/31/2017	31	21240	1218	5.2251	1837	0	19403		19403	3631		
17	2/1/2017	2/28/2017	28	17280	752	4.5005	1837	0	15443		15443	-329		
18	3/1/2017	3/31/2017	31	19120	677	5.2059	1837	0	17283		17283	1511		
19	4/1/2017	4/30/2017	30	18480	366	5.8911	1837	0	16643	16643				
20	5/1/2017	5/31/2017	31	21960	170	8.7436	1837	4154	15969	15969				
21	6/1/2017	6/30/2017	30	21400	6	5.8278	1837	4020	15543	15543				
22	7/1/2017	7/31/2017	31	22040	0	5.1976	1837	4154	16049	16049				
23	8/1/2017	8/31/2017	31	21320	6	4.8975	1837	4154	15329	15329				
24	9/1/2017	9/30/2017	30	20080	39	4.6239	1837	4020	14223	14223				
25	10/1/2017	10/31/2017	31	18520	299	6.1459	1837	0	16683	16683				
26	11/1/2017	11/30/2017	30	17880	756	5.3973	1837	0	16043		16043	271		
27	12/1/2017	12/31/2017	31	19920	1136	6.6566	1837	0	18083		18083	2311		
28	1/1/2018	1/31/2018	31	20800	1382	5.7873	1837	0	18963		18963	3191		
29	2/1/2018	2/28/2018	28	19240	1158	7.8883	1837	0	17403		17403	1631		
30	**Total Sum over last 12 months:**			**240,760**	.=SUM(D18:D29)							**8915**	.=SUM(L18:L29)	

Figure F.2: Screenshot of Spreadsheet Estimating Plant A Heating Energy Use

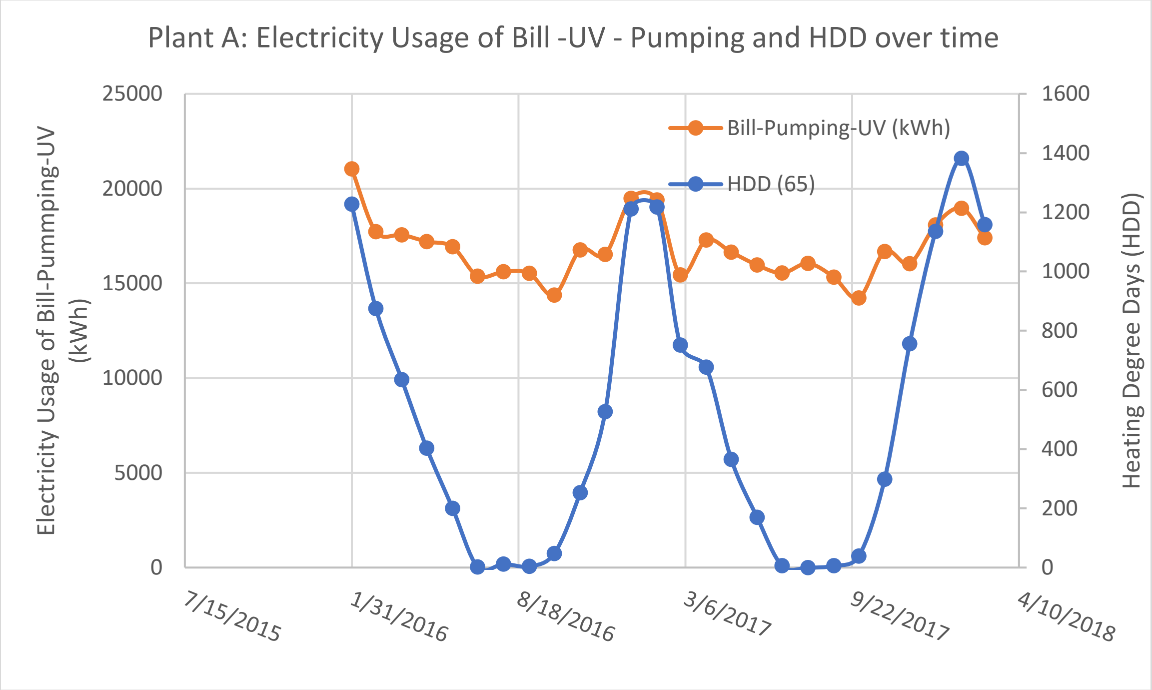


Figure F.3: Plant A Adjusted Billed Energy Usage and HDD Plotted Over Time

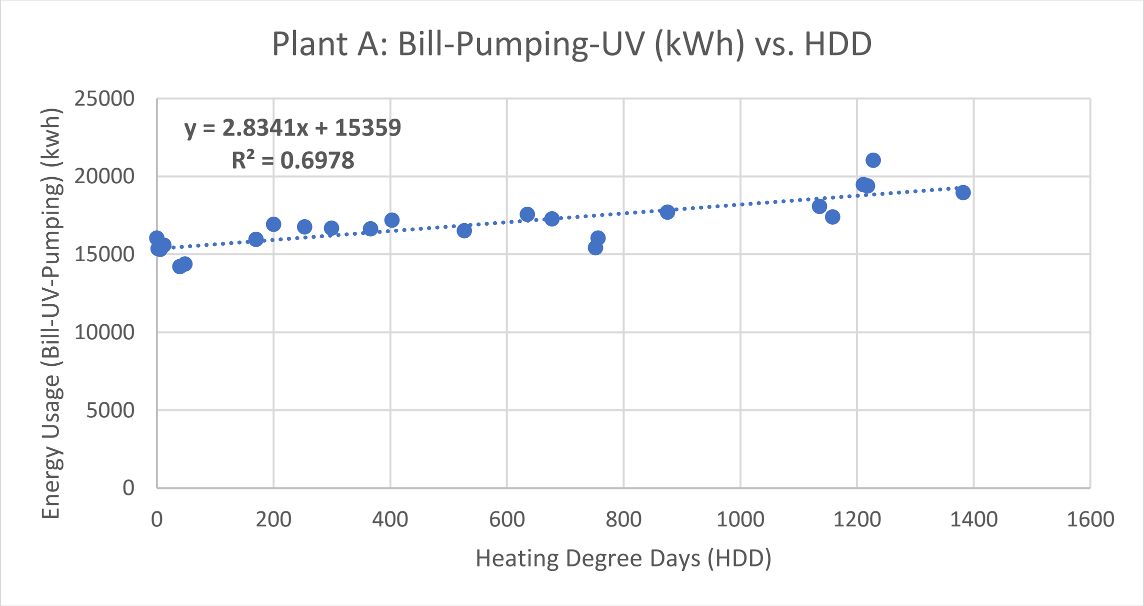
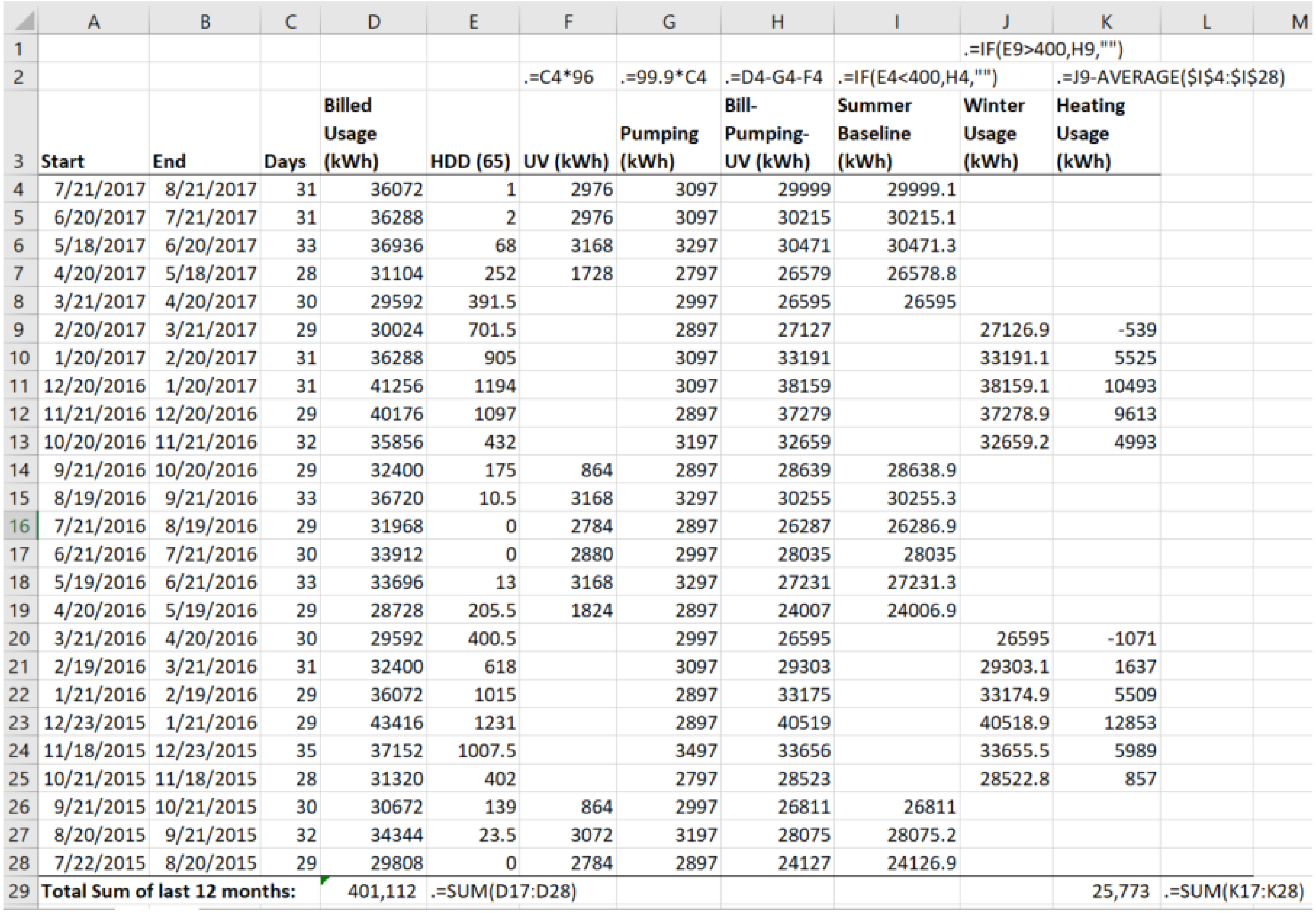


Figure F.4: Plant A Adjusted Billed Energy Usage Plotted Against HDD



	A	B	C	D	E	F	G	H	I	J	K	L	M
1										.=IF(E9>400,H9,"")			
2						.=C4*96	.=99.9*C4	.=D4-G4-F4	.=IF(E4<400,H4,"")		.=J9-AVERAGE($I$4:$I$28)		
3	**Start**	**End**	**Days**	**Billed Usage (kWh)**	**HDD (65)**	**UV (kWh)**	**Pumping (kWh)**	**Bill-Pumping-UV (kWh)**	**Summer Baseline (kWh)**	**Winter Usage (kWh)**	**Heating Usage (kWh)**		
4	7/21/2017	8/21/2017	31	36072	1	2976	3097	29999	29999.1				
5	6/20/2017	7/21/2017	31	36288	2	2976	3097	30215	30215.1				
6	5/18/2017	6/20/2017	33	36936	68	3168	3297	30471	30471.3				
7	4/20/2017	5/18/2017	28	31104	252	1728	2797	26579	26578.8				
8	3/21/2017	4/20/2017	30	29592	391.5		2997	26595	26595				
9	2/20/2017	3/21/2017	29	30024	701.5		2897	27127		27126.9	-539		
10	1/20/2017	2/20/2017	31	36288	905		3097	33191		33191.1	5525		
11	12/20/2016	1/20/2017	31	41256	1194		3097	38159		38159.1	10493		
12	11/21/2016	12/20/2016	29	40176	1097		2897	37279		37278.9	9613		
13	10/20/2016	11/21/2016	32	35856	432		3197	32659		32659.2	4993		
14	9/21/2016	10/20/2016	29	32400	175	864	2897	28639	28638.9				
15	8/19/2016	9/21/2016	33	36720	10.5	3168	3297	30255	30255.3				
16	7/21/2016	8/19/2016	29	31968	0	2784	2897	26287	26286.9				
17	6/21/2016	7/21/2016	30	33912	0	2880	2997	28035	28035				
18	5/19/2016	6/21/2016	33	33696	13	3168	3297	27231	27231.3				
19	4/20/2016	5/19/2016	29	28728	205.5	1824	2897	24007	24006.9				
20	3/21/2016	4/20/2016	30	29592	400.5		2997	26595		26595	-1071		
21	2/19/2016	3/21/2016	31	32400	618		3097	29303		29303.1	1637		
22	1/21/2016	2/19/2016	29	36072	1015		2897	33175		33174.9	5509		
23	12/23/2015	1/21/2016	29	43416	1231		2897	40519		40518.9	12853		
24	11/18/2015	12/23/2015	35	37152	1007.5		3497	33656		33655.5	5989		
25	10/21/2015	11/18/2015	28	31320	402		2797	28523		28522.8	857		
26	9/21/2015	10/21/2015	30	30672	139	864	2997	26811	26811				
27	8/20/2015	9/21/2015	32	34344	23.5	3072	3197	28075	28075.2				
28	7/22/2015	8/20/2015	29	29808	0	2784	2897	24127	24126.9				
29	**Total Sum of last 12 months:**			401,112	.=SUM(D17:D28)						25,773	.=SUM(K17:K28)	

Figure F.5: Screenshot of Spreadsheet Estimating Plant B Heating Energy Use

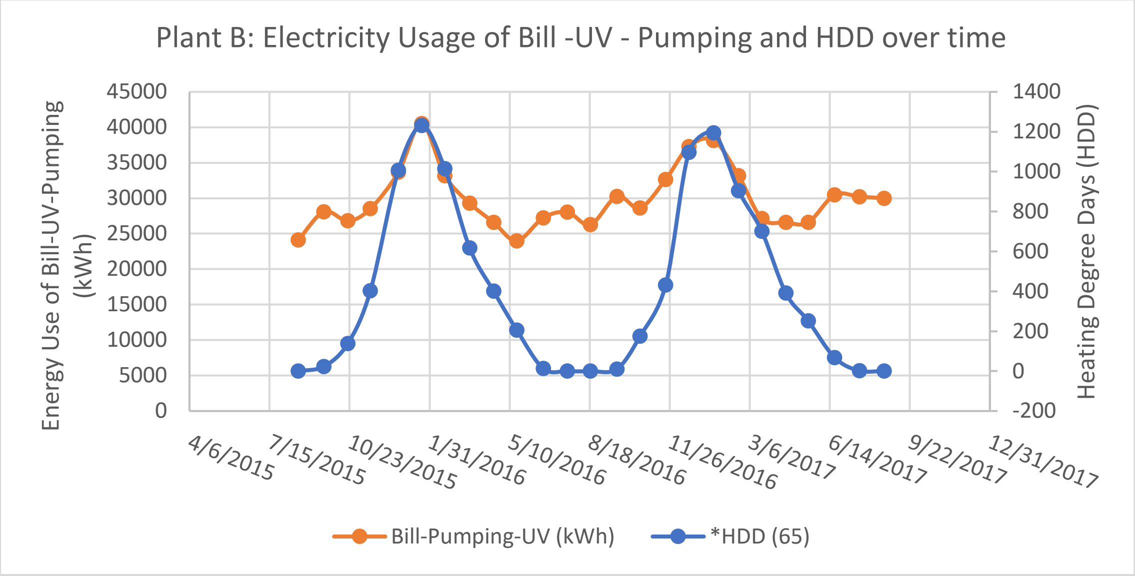


Figure F.6: Plant B Adjusted Billed Energy Usage and HDD Plotted Over Time

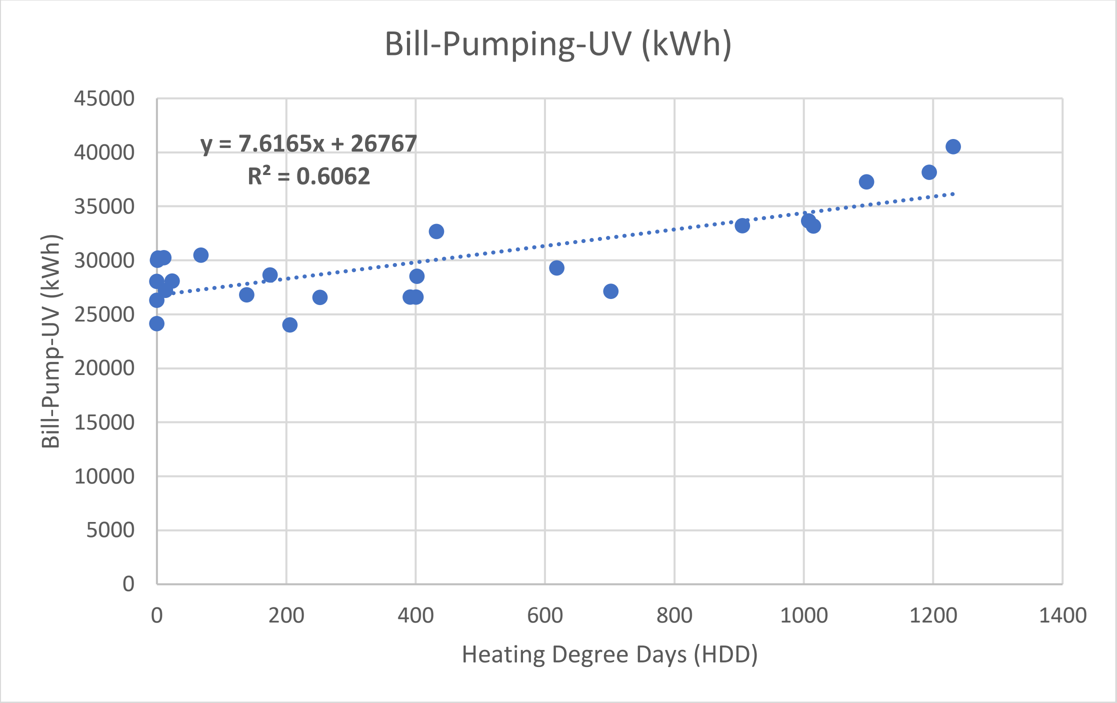
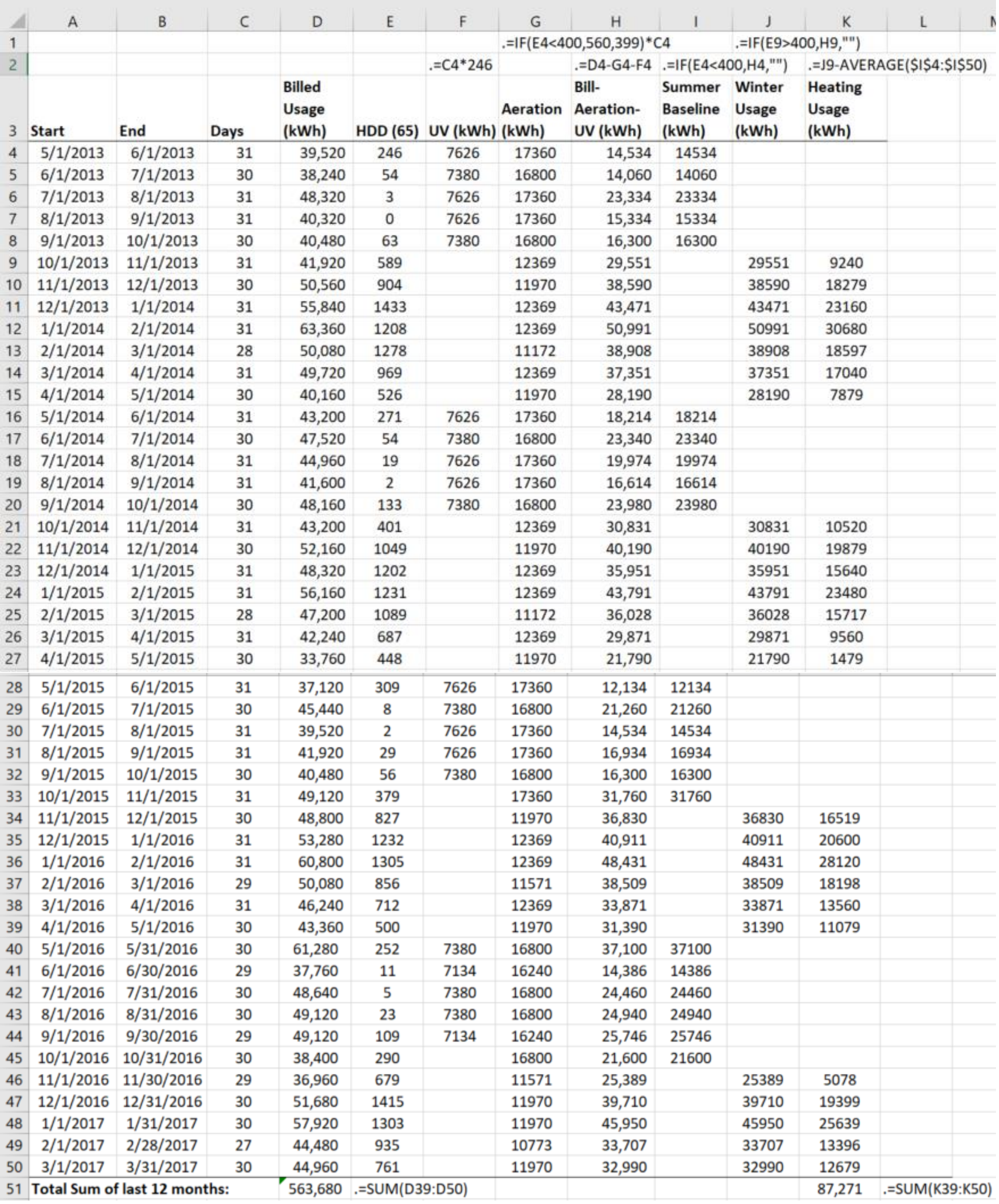


Figure F.7: Plant B Adjusted Billed Energy Usage Plotted Against HDD

The wintertime aeration energy use for plant C was estimated to be 399 kWh/day relative to the 560 kWh/day during the summer due to only being reported to be operating one blower 2 hours/day instead of 12 hours/day.



	A	B	C	D	E	F	G	H	I	J	K	L
1							.=IF(E4<400,560,399)*C4			.=IF(E9>400,H9,"")		
2						.=C4*246		.=D4-G4-F4	.=IF(E4<400,H4,"")		.=J9-AVERAGE($I$4:$I$50)	
3	Start	End	Days	Billed Usage (kWh)	HDD (65)	UV (kWh)	Aeration (kWh)	Bill-Aeration-UV (kWh)	Summer Baseline (kWh)	Winter Usage (kWh)	Heating Usage (kWh)	
4	5/1/2013	6/1/2013	31	39,520	246	7626	17360	14,534	14534			
5	6/1/2013	7/1/2013	30	38,240	54	7380	16800	14,060	14060			
6	7/1/2013	8/1/2013	31	48,320	3	7626	17360	23,334	23334			
7	8/1/2013	9/1/2013	31	40,320	0	7626	17360	15,334	15334			
8	9/1/2013	10/1/2013	30	40,480	63	7380	16800	16,300	16300			
9	10/1/2013	11/1/2013	31	41,920	589		12369	29,551		29551	9240	
10	11/1/2013	12/1/2013	30	50,560	904		11970	38,590		38590	18279	
11	12/1/2013	1/1/2014	31	55,840	1433		12369	43,471		43471	23160	
12	1/1/2014	2/1/2014	31	63,360	1208		12369	50,991		50991	30680	
13	2/1/2014	3/1/2014	28	50,080	1278		11172	38,908		38908	18597	
14	3/1/2014	4/1/2014	31	49,720	969		12369	37,351		37351	17040	
15	4/1/2014	5/1/2014	30	40,160	526		11970	28,190		28190	7879	
16	5/1/2014	6/1/2014	31	43,200	271	7626	17360	18,214	18214			
17	6/1/2014	7/1/2014	30	47,520	54	7380	16800	23,340	23340			
18	7/1/2014	8/1/2014	31	44,960	19	7626	17360	19,974	19974			
19	8/1/2014	9/1/2014	31	41,600	2	7626	17360	16,614	16614			
20	9/1/2014	10/1/2014	30	48,160	133	7380	16800	23,980	23980			
21	10/1/2014	11/1/2014	31	43,200	401		12369	30,831		30831	10520	
22	11/1/2014	12/1/2014	30	52,160	1049		11970	40,190		40190	19879	
23	12/1/2014	1/1/2015	31	48,320	1202		12369	35,951		35951	15640	
24	1/1/2015	2/1/2015	31	56,160	1231		12369	43,791		43791	23480	
25	2/1/2015	3/1/2015	28	47,200	1089		11172	36,028		36028	15717	
26	3/1/2015	4/1/2015	31	42,240	687		12369	29,871		29871	9560	
27	4/1/2015	5/1/2015	30	33,760	448		11970	21,790		21790	1479	
28	5/1/2015	6/1/2015	31	37,120	309	7626	17360	12,134	12134			
29	6/1/2015	7/1/2015	30	45,440	8	7380	16800	21,260	21260			
30	7/1/2015	8/1/2015	31	39,520	2	7626	17360	14,534	14534			
31	8/1/2015	9/1/2015	31	41,920	29	7626	17360	16,934	16934			
32	9/1/2015	10/1/2015	30	40,480	56	7380	16800	16,300	16300			
33	10/1/2015	11/1/2015	31	49,120	379		17360	31,760	31760			
34	11/1/2015	12/1/2015	30	48,800	827		11970	36,830		36830	16519	
35	12/1/2015	1/1/2016	31	53,280	1232		12369	40,911		40911	20600	
36	1/1/2016	2/1/2016	31	60,800	1305		12369	48,431		48431	28120	
37	2/1/2016	3/1/2016	29	50,080	856		11571	38,509		38509	18198	
38	3/1/2016	4/1/2016	31	46,240	712		12369	33,871		33871	13560	
39	4/1/2016	5/1/2016	30	43,360	500		11970	31,390		31390	11079	
40	5/1/2016	5/31/2016	30	61,280	252	7380	16800	37,100	37100			
41	6/1/2016	6/30/2016	29	37,760	11	7134	16240	14,386	14386			
42	7/1/2016	7/31/2016	30	48,640	5	7380	16800	24,460	24460			
43	8/1/2016	8/31/2016	30	49,120	23	7380	16800	24,940	24940			
44	9/1/2016	9/30/2016	29	49,120	109	7134	16240	25,746	25746			
45	10/1/2016	10/31/2016	30	38,400	290		16800	21,600	21600			
46	11/1/2016	11/30/2016	29	36,960	679		11571	25,389		25389	5078	
47	12/1/2016	12/31/2016	30	51,680	1415		11970	39,710		39710	19399	
48	1/1/2017	1/31/2017	30	57,920	1303		11970	45,950		45950	25639	
49	2/1/2017	2/28/2017	27	44,480	935		10773	33,707		33707	13396	
50	3/1/2017	3/31/2017	30	44,960	761		11970	32,990		32990	12679	
51	**Total Sum of last 12 months:**			563,680	.=SUM(D39:D50)						87,271	.=SUM(K39:K50)

Figure F.8: Screenshot of Spreadsheet Estimating Plant C Heating Energy Use

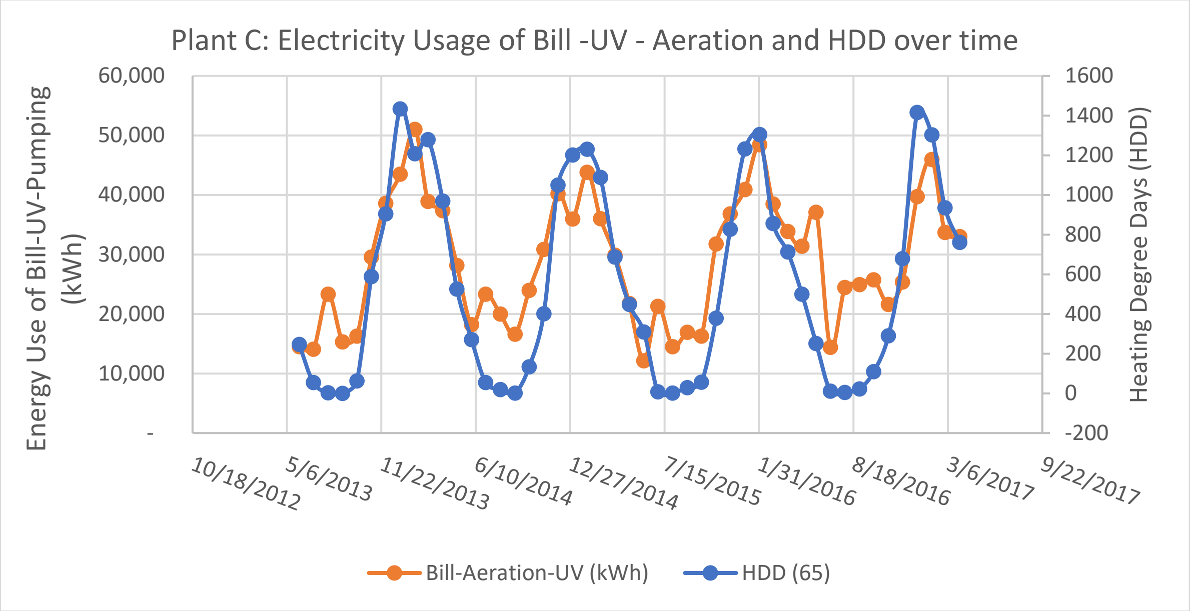


Figure F.9: Plant C Adjusted Billed Energy Usage and HDD Plotted Over Time

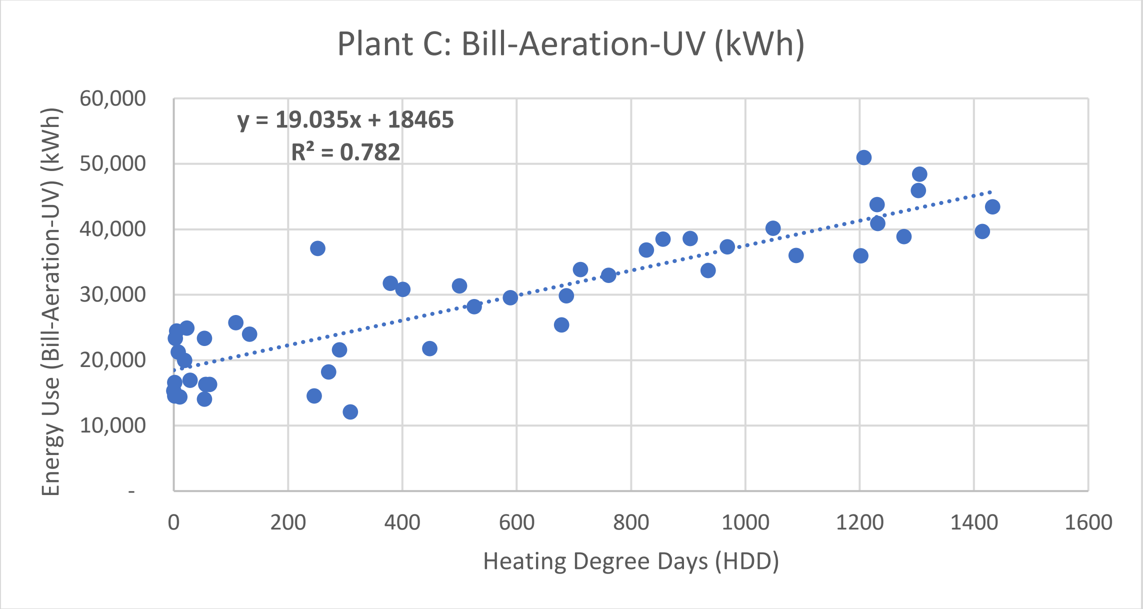
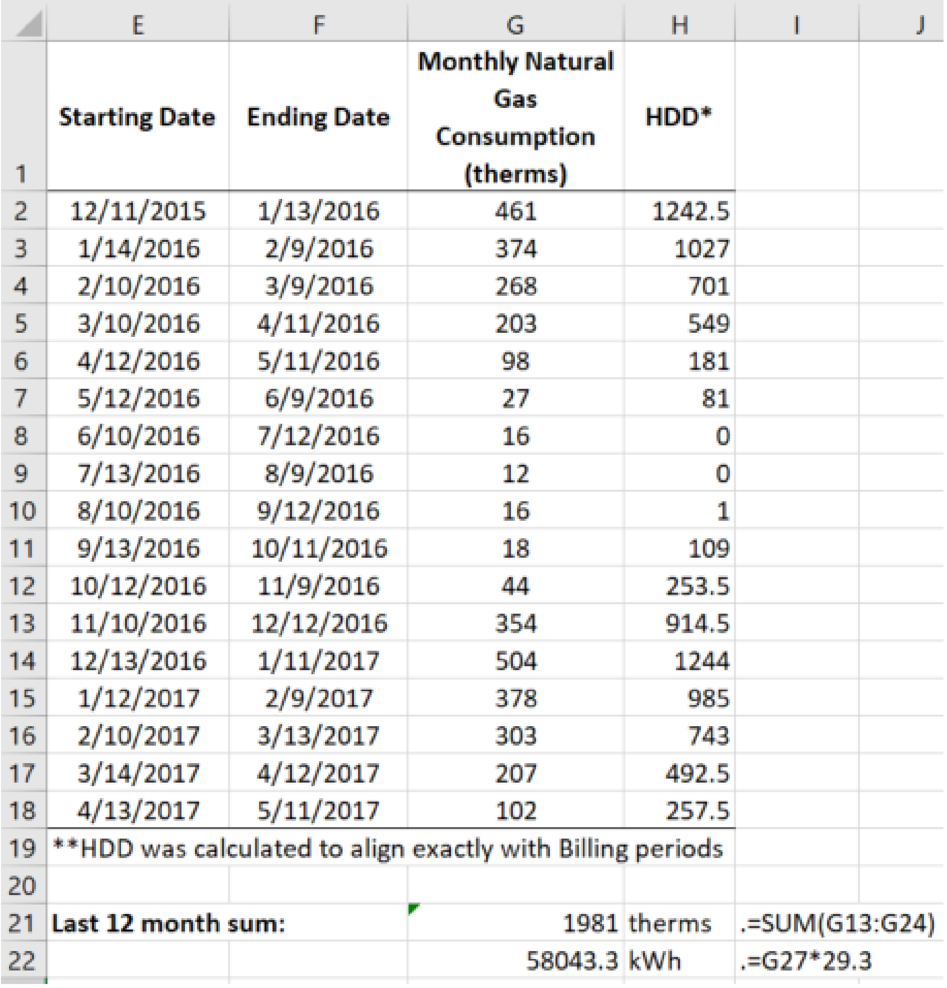
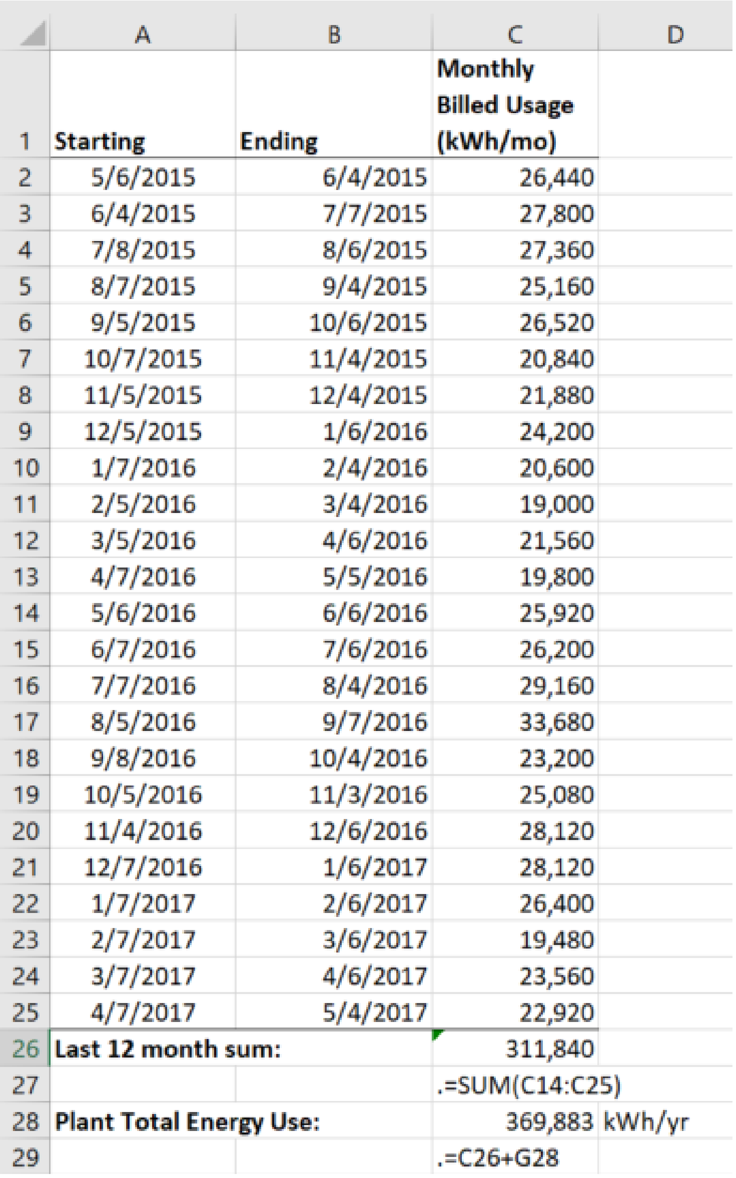


Figure F.10: Plant C Adjusted Billed Energy Usage and HDD Plotted Over Time



	E	F	G	H	I	J
1	**Starting Date**	**Ending Date**	**Monthly Natural Gas Consumption (therms)**	**HDD***		
2	12/11/2015	1/13/2016	461	1242.5		
3	1/14/2016	2/9/2016	374	1027		
4	2/10/2016	3/9/2016	268	701		
5	3/10/2016	4/11/2016	203	549		
6	4/12/2016	5/11/2016	98	181		
7	5/12/2016	6/9/2016	27	81		
8	6/10/2016	7/12/2016	16	0		
9	7/13/2016	8/9/2016	12	0		
10	8/10/2016	9/12/2016	16	1		
11	9/13/2016	10/11/2016	18	109		
12	10/12/2016	11/9/2016	44	253.5		
13	11/10/2016	12/12/2016	354	914.5		
14	12/13/2016	1/11/2017	504	1244		
15	1/12/2017	2/9/2017	378	985		
16	2/10/2017	3/13/2017	303	743		
17	3/14/2017	4/12/2017	207	492.5		
18	4/13/2017	5/11/2017	102	257.5		
19	**HDD was calculated to align exactly with Billing periods					
20						
21	**Last 12 month sum:**		1981	therms	.=SUM(G13:G24)	
22			58043.3	kWh	.=G27*29.3	

Figure F.11: Screenshot of Plant D Natural Gas Heating Energy Use and HDD



	A	B	C	D
1	**Starting**	**Ending**	**Monthly Billed Usage (kWh/mo)**	
2	5/6/2015	6/4/2015	26,440	
3	6/4/2015	7/7/2015	27,800	
4	7/8/2015	8/6/2015	27,360	
5	8/7/2015	9/4/2015	25,160	
6	9/5/2015	10/6/2015	26,520	
7	10/7/2015	11/4/2015	20,840	
8	11/5/2015	12/4/2015	21,880	
9	12/5/2015	1/6/2016	24,200	
10	1/7/2016	2/4/2016	20,600	
11	2/5/2016	3/4/2016	19,000	
12	3/5/2016	4/6/2016	21,560	
13	4/7/2016	5/5/2016	19,800	
14	5/6/2016	6/6/2016	25,920	
15	6/7/2016	7/6/2016	26,200	
16	7/7/2016	8/4/2016	29,160	
17	8/5/2016	9/7/2016	33,680	
18	9/8/2016	10/4/2016	23,200	
19	10/5/2016	11/3/2016	25,080	
20	11/4/2016	12/6/2016	28,120	
21	12/7/2016	1/6/2017	28,120	
22	1/7/2017	2/6/2017	26,400	
23	2/7/2017	3/6/2017	19,480	
24	3/7/2017	4/6/2017	23,560	
25	4/7/2017	5/4/2017	22,920	
26	**Last 12 month sum:**		311,840	
27			.=SUM(C14:C25)	
28	**Plant Total Energy Use:**		369,883	kWh/yr
29			.=C26+G28	

Figure F.12: Screenshot of Plant D Total Energy Use Including Heating

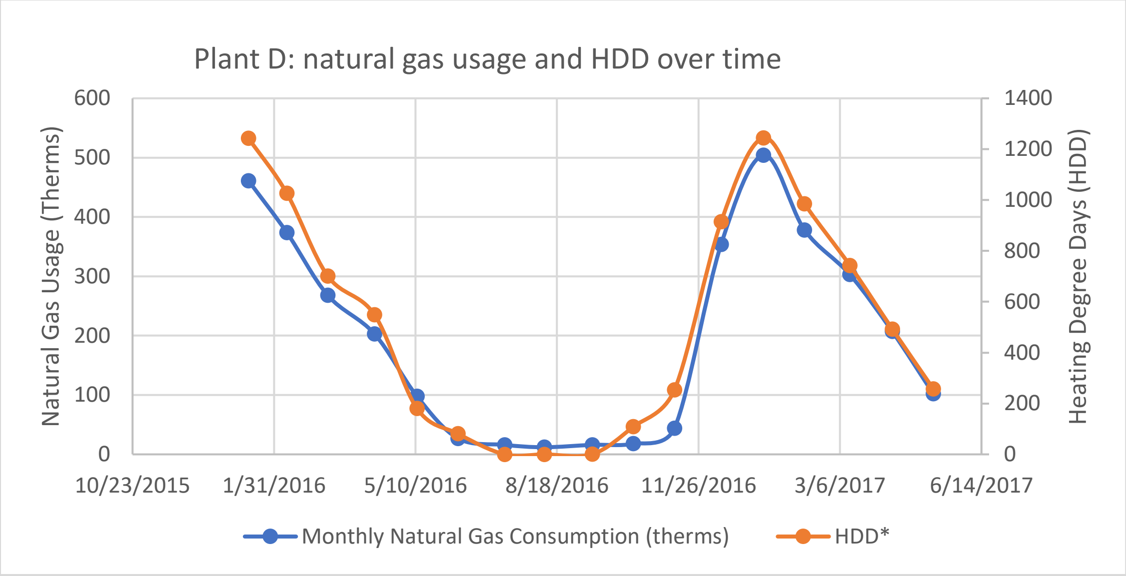


Figure F.13: Plant D Heating Energy Usage and HDD Plotted Over Time

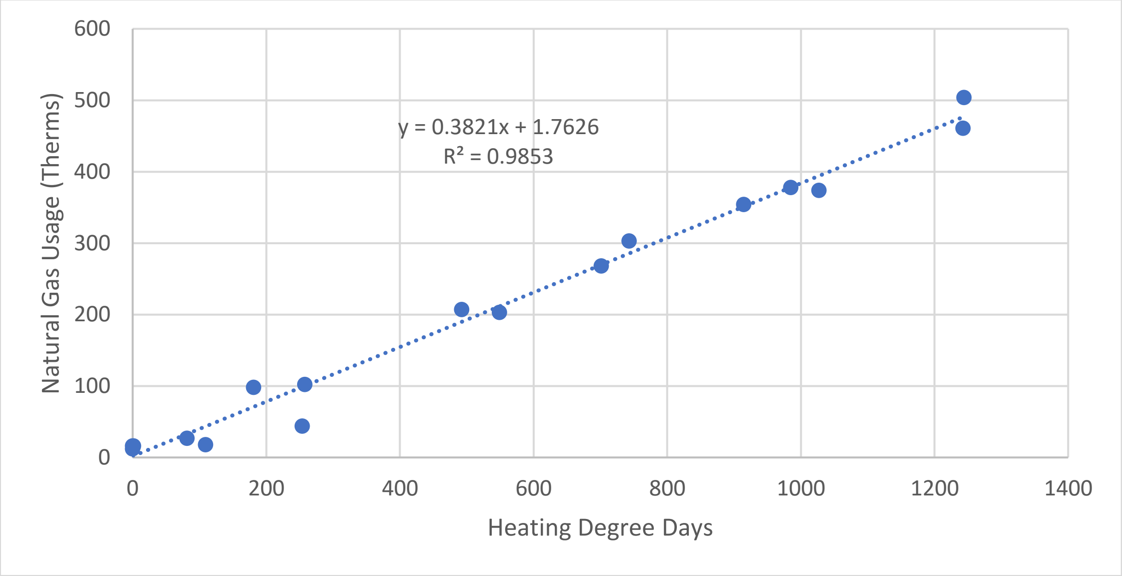
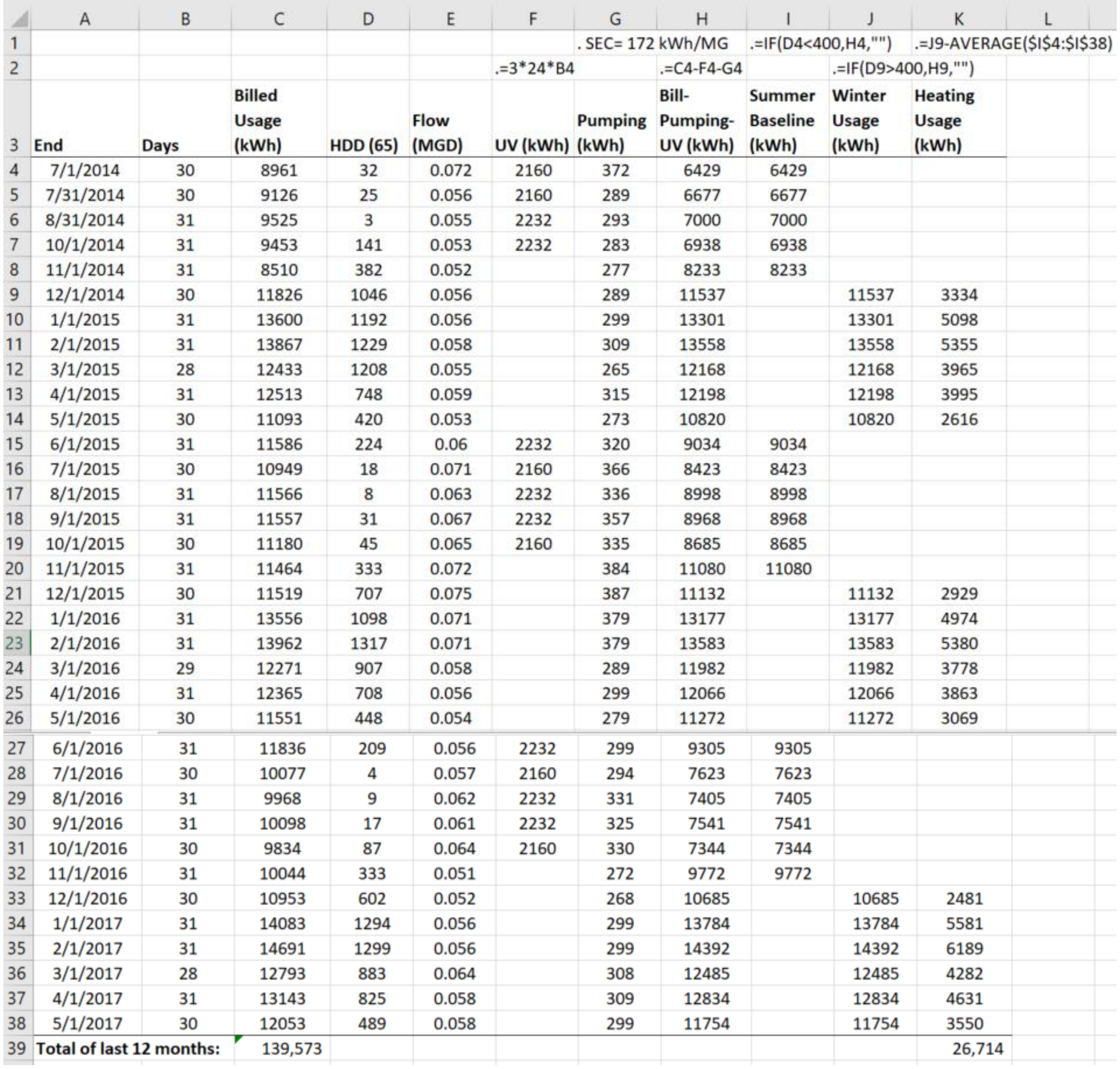


Figure F.14: Plant D Heating Energy Usage and HDD Plotted Over Time



	A	B	C	D	E	F	G	H	I	J	K	L
1							. SEC= 172	kWh/MG	.=IF(D4<400,H4,"")		.=J9-AVERAGE($I$4:$I$38)	
2						.=3*24*B4		.=C4-F4-G4		.=IF(D9>400,H9,"")		
3	**End**	**Days**	**Billed Usage (kWh)**	**HDD (65)**	**Flow (MGD)**	**UV (kWh)**	**Pumping (kWh)**	**Bill-Pumping-UV (kWh)**	**Summer Baseline (kWh)**	**Winter Usage (kWh)**	**Heating Usage (kWh)**	
4	7/1/2014	30	8961	32	0.072	2160	372	6429	6429			
5	7/31/2014	30	9126	25	0.056	2160	289	6677	6677			
6	8/31/2014	31	9525	3	0.055	2232	293	7000	7000			
7	10/1/2014	31	9453	141	0.053	2232	283	6938	6938			
8	11/1/2014	31	8510	382	0.052		277	8233	8233			
9	12/1/2014	30	11826	1046	0.056		289	11537		11537	3334	
10	1/1/2015	31	13600	1192	0.056		299	13301		13301	5098	
11	2/1/2015	31	13867	1229	0.058		309	13558		13558	5355	
12	3/1/2015	28	12433	1208	0.055		265	12168		12168	3965	
13	4/1/2015	31	12513	748	0.059		315	12198		12198	3995	
14	5/1/2015	30	11093	420	0.053		273	10820		10820	2616	
15	6/1/2015	31	11586	224	0.06	2232	320	9034	9034			
16	7/1/2015	30	10949	18	0.071	2160	366	8423	8423			
17	8/1/2015	31	11566	8	0.063	2232	336	8998	8998			
18	9/1/2015	31	11557	31	0.067	2232	357	8968	8968			
19	10/1/2015	30	11180	45	0.065	2160	335	8685	8685			
20	11/1/2015	31	11464	333	0.072		384	11080	11080			
21	12/1/2015	30	11519	707	0.075		387	11132		11132	2929	
22	1/1/2016	31	13556	1098	0.071		379	13177		13177	4974	
23	2/1/2016	31	13962	1317	0.071		379	13583		13583	5380	
24	3/1/2016	29	12271	907	0.058		289	11982		11982	3778	
25	4/1/2016	31	12365	708	0.056		299	12066		12066	3863	
26	5/1/2016	30	11551	448	0.054		279	11272		11272	3069	
27	6/1/2016	31	11836	209	0.056	2232	299	9305	9305			
28	7/1/2016	30	10077	4	0.057	2160	294	7623	7623			
29	8/1/2016	31	9968	9	0.062	2232	331	7405	7405			
30	9/1/2016	31	10098	17	0.061	2232	325	7541	7541			
31	10/1/2016	30	9834	87	0.064	2160	330	7344	7344			
32	11/1/2016	31	10044	333	0.051		272	9772	9772			
33	12/1/2016	30	10953	602	0.052		268	10685		10685	2481	
34	1/1/2017	31	14083	1294	0.056		299	13784		13784	5581	
35	2/1/2017	31	14691	1299	0.056		299	14392		14392	6189	
36	3/1/2017	28	12793	883	0.064		308	12485		12485	4282	
37	4/1/2017	31	13143	825	0.058		309	12834		12834	4631	
38	5/1/2017	30	12053	489	0.058		299	11754		11754	3550	
39	**Total of last 12 months:**		139,573								26,714	

Figure F.15: Screenshot of Spreadsheet Estimating Plant E Heating Energy Use

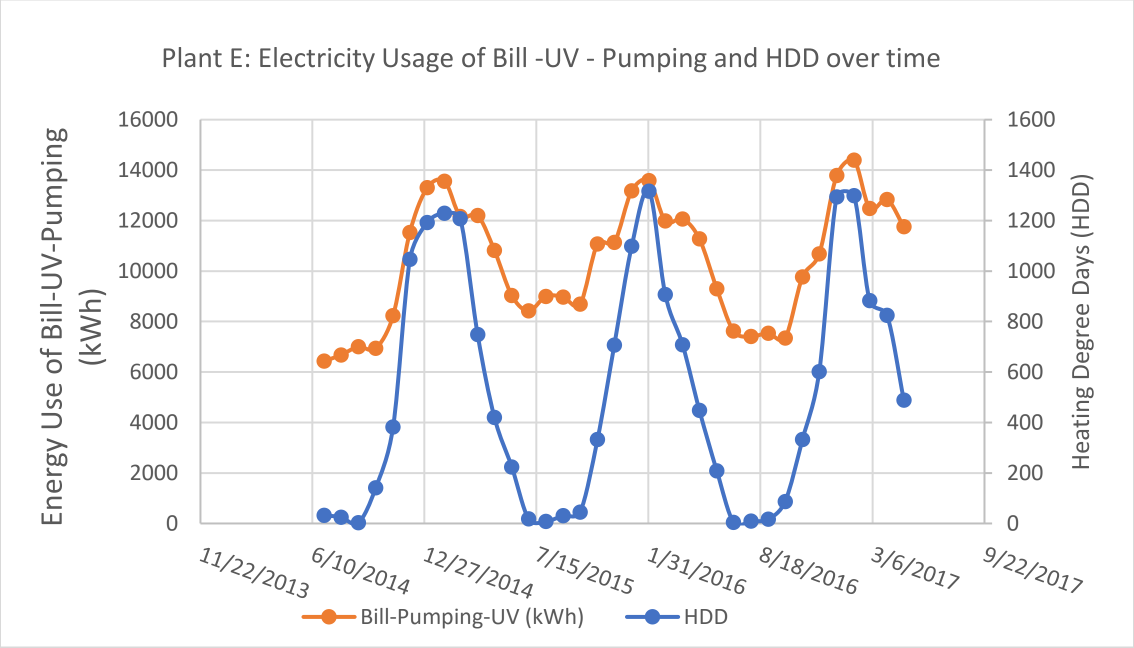


Figure F.16: Plant E Adjusted Billed Energy Usage and HDD Plotted Over Time

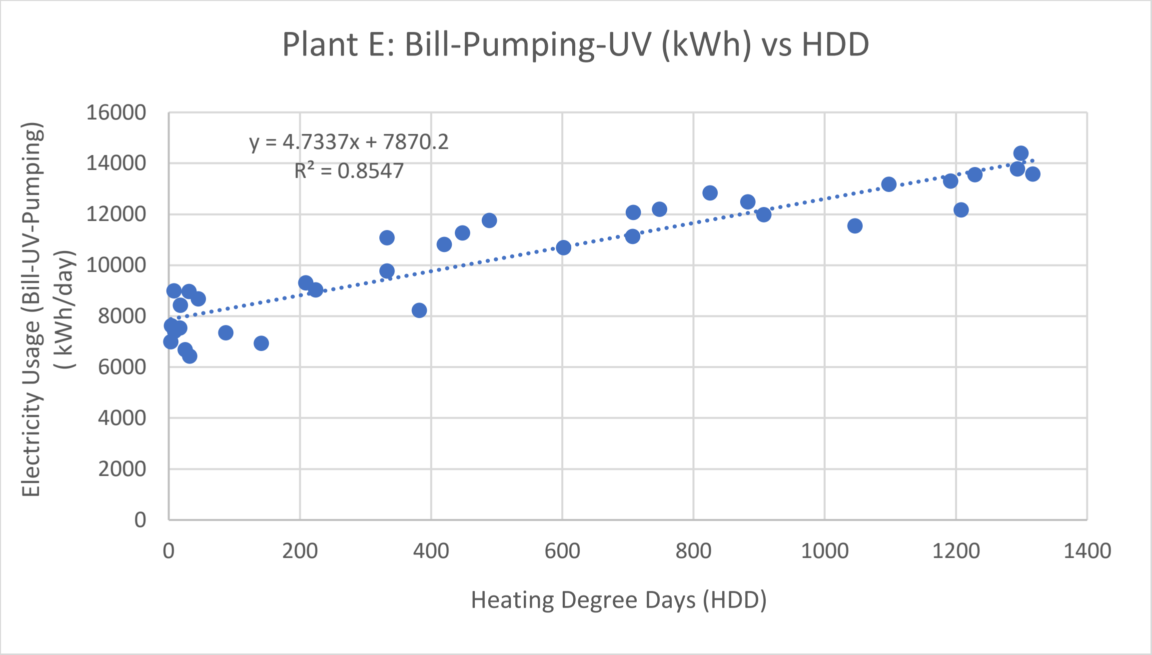
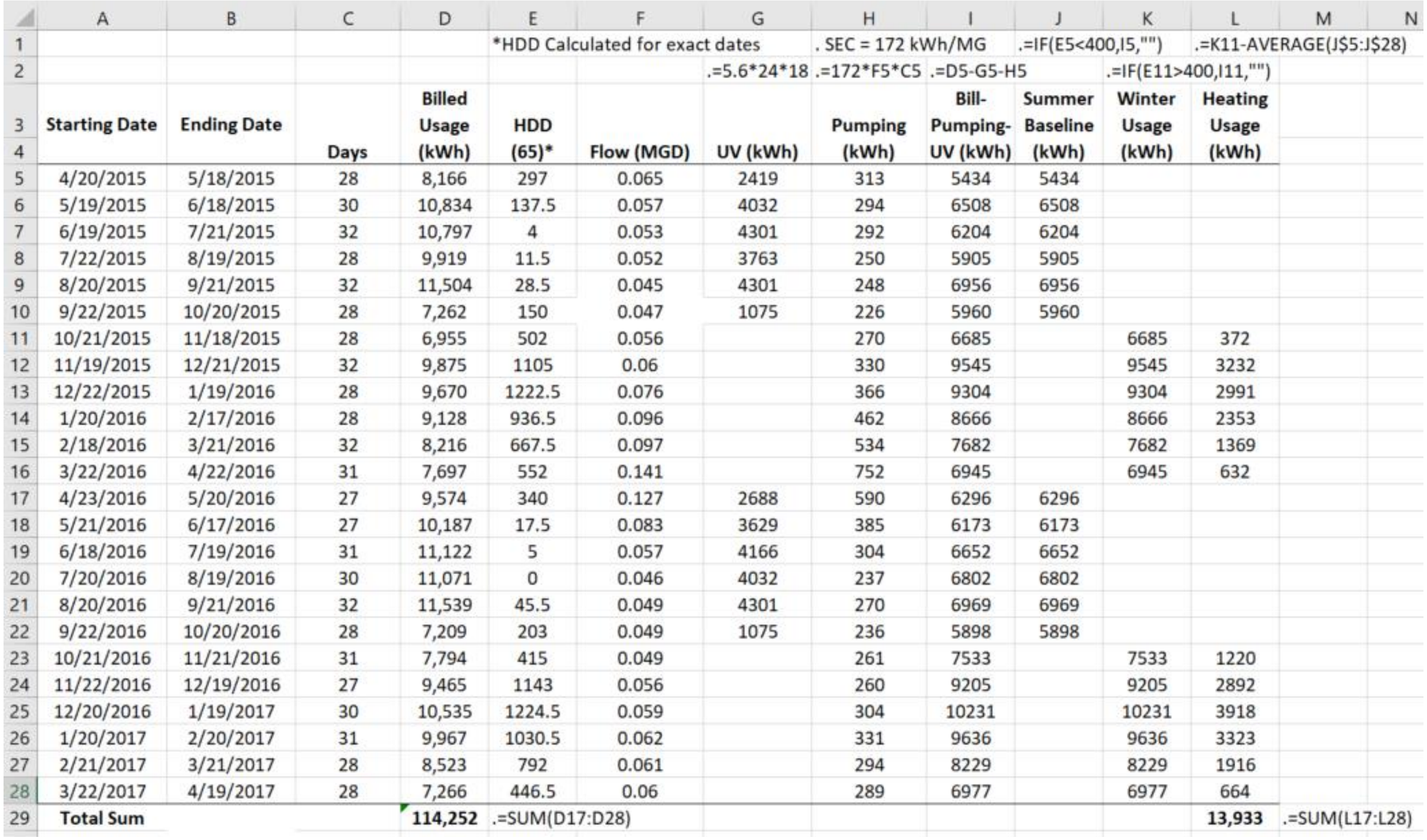


Figure F.17: Plant E Adjusted Billed Energy Usage and HDD Plotted Over Time



	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1					*HDD Calculated for exact dates			. SEC = 172 kWh/MG		.=IF(E5<400,I5,"")		.=K11-AVERAGE(J$5:J$28)		
2							.=5.6*24*18	.=172*F5*C5	.=D5-G5-H5		.=IF(E11>400,I11,"")			
3 4	Starting Date	Ending Date	Days	Billed Usage (kWh)	HDD (65)*	Flow (MGD)	UV (kWh)	Pumping (kWh)	Bill-Pumping-UV (kWh)	Summer Baseline (kWh)	Winter Usage (kWh)	Heating Usage (kWh)		
5	4/20/2015	5/18/2015	28	8,166	297	0.065	2419	313	5434	5434				
6	5/19/2015	6/18/2015	30	10,834	137.5	0.057	4032	294	6508	6508				
7	6/19/2015	7/21/2015	32	10,797	4	0.053	4301	292	6204	6204				
8	7/22/2015	8/19/2015	28	9,919	11.5	0.052	3763	250	5905	5905				
9	8/20/2015	9/21/2015	32	11,504	28.5	0.045	4301	248	6956	6956				
10	9/22/2015	10/20/2015	28	7,262	150	0.047	1075	226	5960	5960				
11	10/21/2015	11/18/2015	28	6,955	502	0.056		270	6685		6685	372		
12	11/19/2015	12/21/2015	32	9,875	1105	0.06		330	9545		9545	3232		
13	12/22/2015	1/19/2016	28	9,670	1222.5	0.076		366	9304		9304	2991		
14	1/20/2016	2/17/2016	28	9,128	936.5	0.096		462	8666		8666	2353		
15	2/18/2016	3/21/2016	32	8,216	667.5	0.097		534	7682		7682	1369		
16	3/22/2016	4/22/2016	31	7,697	552	0.141		752	6945		6945	632		
17	4/23/2016	5/20/2016	27	9,574	340	0.127	2688	590	6296	6296				
18	5/21/2016	6/17/2016	27	10,187	17.5	0.083	3629	385	6173	6173				
19	6/18/2016	7/19/2016	31	11,122	5	0.057	4166	304	6652	6652				
20	7/20/2016	8/19/2016	30	11,071	0	0.046	4032	237	6802	6802				
21	8/20/2016	9/21/2016	32	11,539	45.5	0.049	4301	270	6969	6969				
22	9/22/2016	10/20/2016	28	7,209	203	0.049	1075	236	5898	5898				
23	10/21/2016	11/21/2016	31	7,794	415	0.049		261	7533		7533	1220		
24	11/22/2016	12/19/2016	27	9,465	1143	0.056		260	9205		9205	2892		
25	12/20/2016	1/19/2017	30	10,535	1224.5	0.059		304	10231		10231	3918		
26	1/20/2017	2/20/2017	31	9,967	1030.5	0.062		331	9636		9636	3323		
27	2/21/2017	3/21/2017	28	8,523	792	0.061		294	8229		8229	1916		
28	3/22/2017	4/19/2017	28	7,266	446.5	0.06		289	6977		6977	664		
29	Total Sum			114,252	.=SUM(D17:D28)							13,933	.=SUM(L17:L28)	

Figure F.18: Screenshot of Spreadsheet Estimating Plant F Heating Energy Use

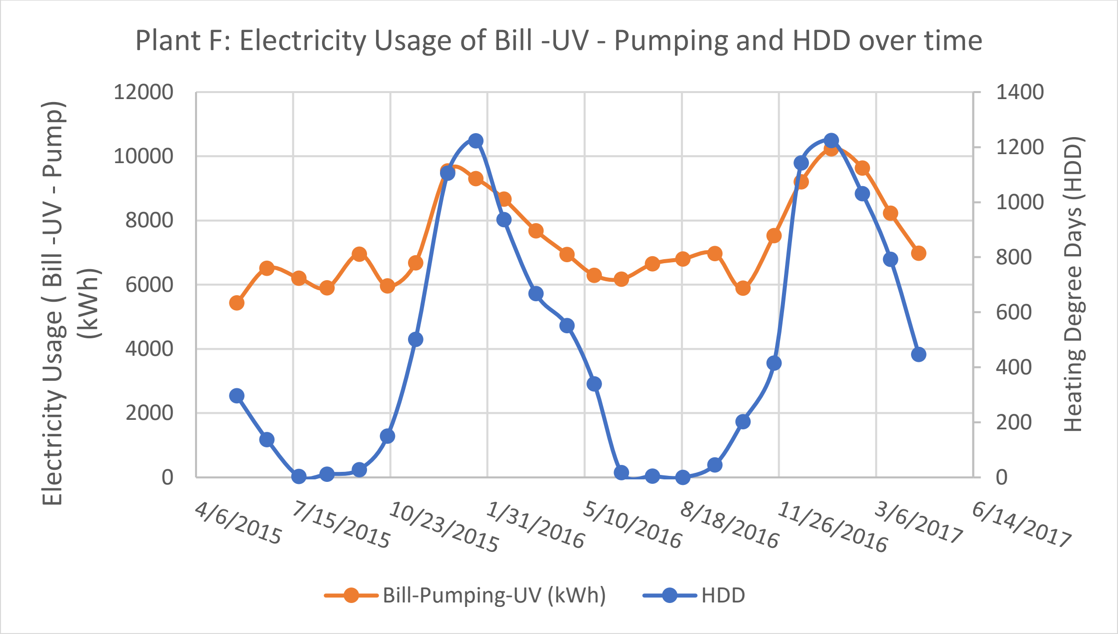


Figure F.19: Plant F Adjusted Billed Energy Usage and HDD Plotted Over Time

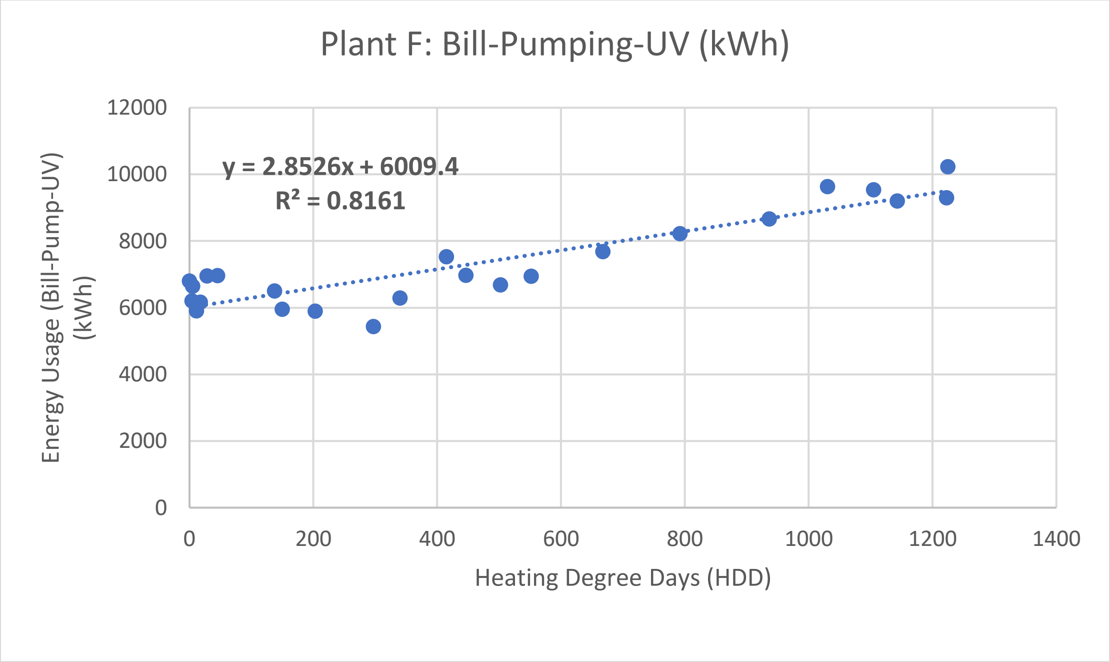


Figure F.20: Plant F Adjusted Billed Energy Usage and HDD Plotted Over Time

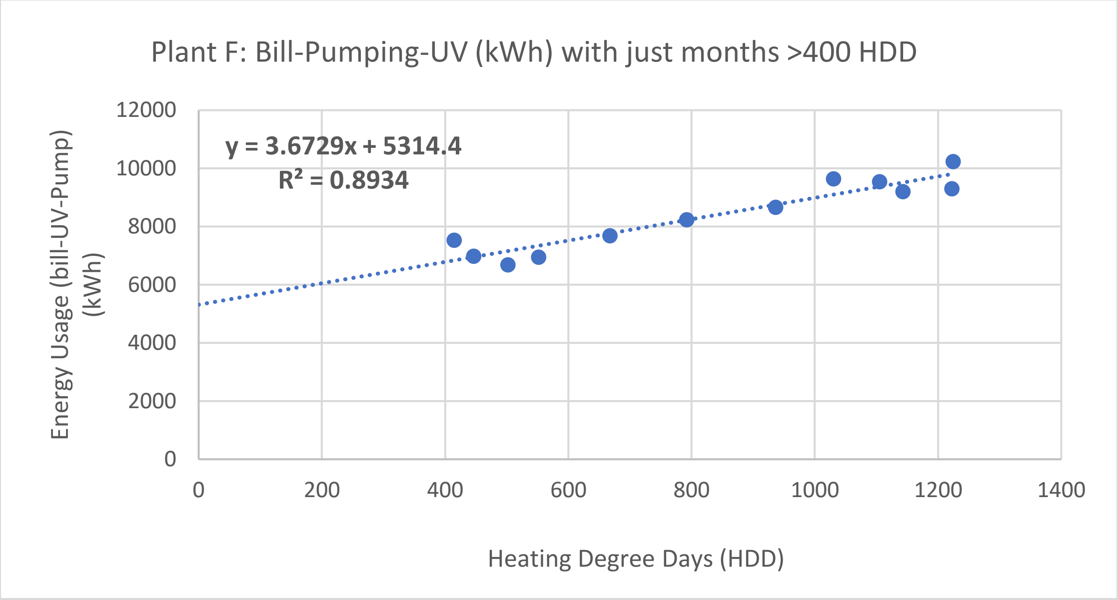
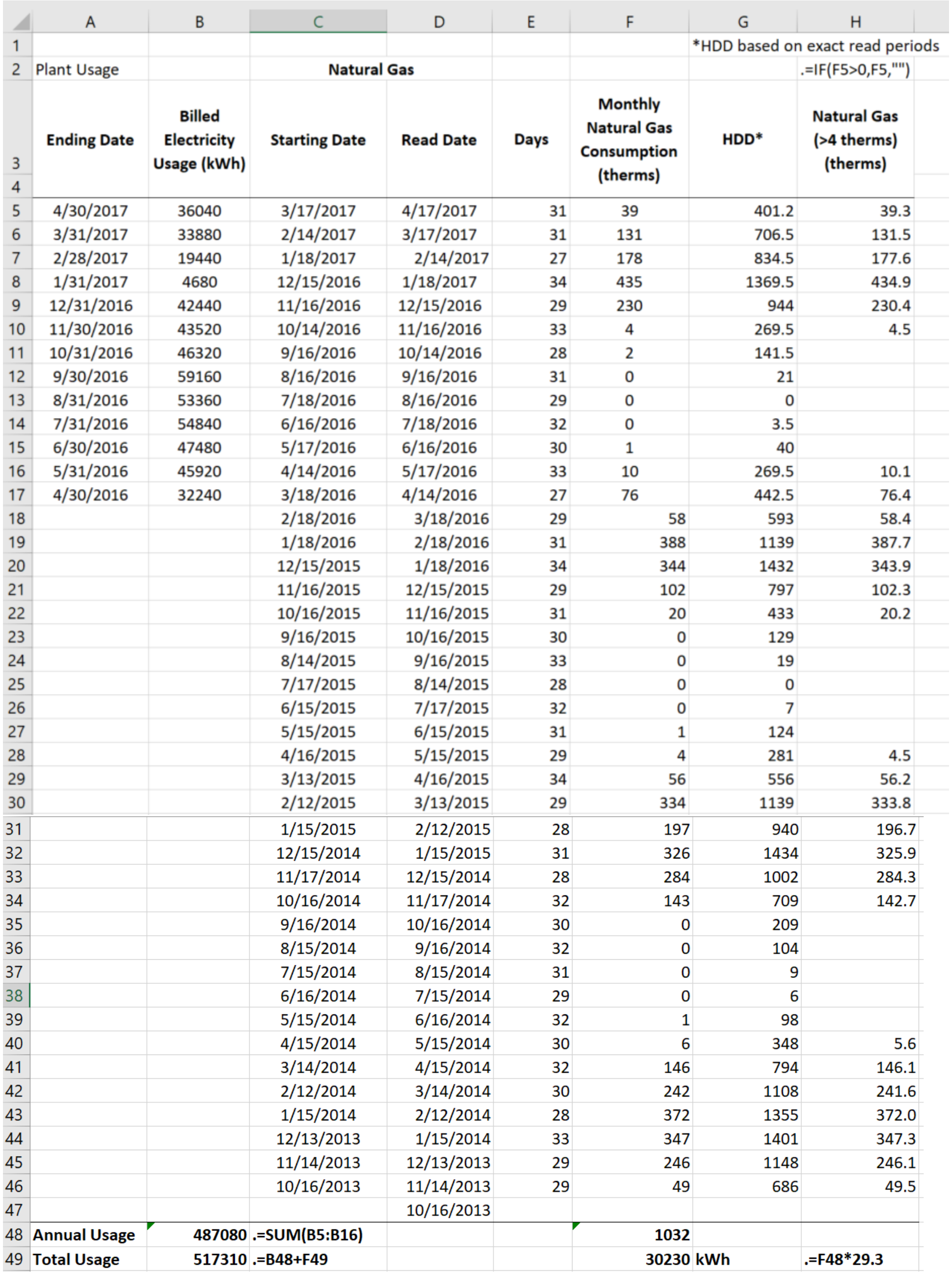


Figure F.21: Plant F Adjusted Billed Energy Usage and HDD Plotted Over Time (with only data for >400HDD shown)



	A	B	C	D	E	F	G	H
1							*HDD based on exact read periods	
2	Plant Usage		Natural Gas					.=IF(F5>0,F5,"")
3	**Ending Date**	**Billed Electricity Usage (kWh)**	**Starting Date**	**Read Date**	**Days**	**Monthly Natural Gas Consumption (therms)**	**HDD***	**Natural Gas (>4 therms) (therms)**
4								
5	4/30/2017	36040	3/17/2017	4/17/2017	31	39	401.2	39.3
6	3/31/2017	33880	2/14/2017	3/17/2017	31	131	706.5	131.5
7	2/28/2017	19440	1/18/2017	2/14/2017	27	178	834.5	177.6
8	1/31/2017	4680	12/15/2016	1/18/2017	34	435	1369.5	434.9
9	12/31/2016	42440	11/16/2016	12/15/2016	29	230	944	230.4
10	11/30/2016	43520	10/14/2016	11/16/2016	33	4	269.5	4.5
11	10/31/2016	46320	9/16/2016	10/14/2016	28	2	141.5	
12	9/30/2016	59160	8/16/2016	9/16/2016	31	0	21	
13	8/31/2016	53360	7/18/2016	8/16/2016	29	0	0	
14	7/31/2016	54840	6/16/2016	7/18/2016	32	0	3.5	
15	6/30/2016	47480	5/17/2016	6/16/2016	30	1	40	
16	5/31/2016	45920	4/14/2016	5/17/2016	33	10	269.5	10.1
17	4/30/2016	32240	3/18/2016	4/14/2016	27	76	442.5	76.4
18			2/18/2016	3/18/2016	29	58	593	58.4
19			1/18/2016	2/18/2016	31	388	1139	387.7
20			12/15/2015	1/18/2016	34	344	1432	343.9
21			11/16/2015	12/15/2015	29	102	797	102.3
22			10/16/2015	11/16/2015	31	20	433	20.2
23			9/16/2015	10/16/2015	30	0	129	
24			8/14/2015	9/16/2015	33	0	19	
25			7/17/2015	8/14/2015	28	0	0	
26			6/15/2015	7/17/2015	32	0	7	
27			5/15/2015	6/15/2015	31	1	124	
28			4/16/2015	5/15/2015	29	4	281	4.5
29			3/13/2015	4/16/2015	34	56	556	56.2
30			2/12/2015	3/13/2015	29	334	1139	333.8
31			1/15/2015	2/12/2015	28	197	940	196.7
32			12/15/2014	1/15/2015	31	326	1434	325.9
33			11/17/2014	12/15/2014	28	284	1002	284.3
34			10/16/2014	11/17/2014	32	143	709	142.7
35			9/16/2014	10/16/2014	30	0	209	
36			8/15/2014	9/16/2014	32	0	104	
37			7/15/2014	8/15/2014	31	0	9	
38			6/16/2014	7/15/2014	29	0	6	
39			5/15/2014	6/16/2014	32	1	98	
40			4/15/2014	5/15/2014	30	6	348	5.6
41			3/14/2014	4/15/2014	32	146	794	146.1
42			2/12/2014	3/14/2014	30	242	1108	241.6
43			1/15/2014	2/12/2014	28	372	1355	372.0
44			12/13/2013	1/15/2014	33	347	1401	347.3
45			11/14/2013	12/13/2013	29	246	1148	246.1
46			10/16/2013	11/14/2013	29	49	686	49.5
47				10/16/2013				
48	**Annual Usage**	**487080**	**.=SUM(B5:B16)**			**1032**		
49	**Total Usage**	**517310**	**.=B48+F49**			**30230**	**kWh**	**.=F48*29.3**

Figure F.22: Screenshot of Plant G Total Energy Use Including Heating

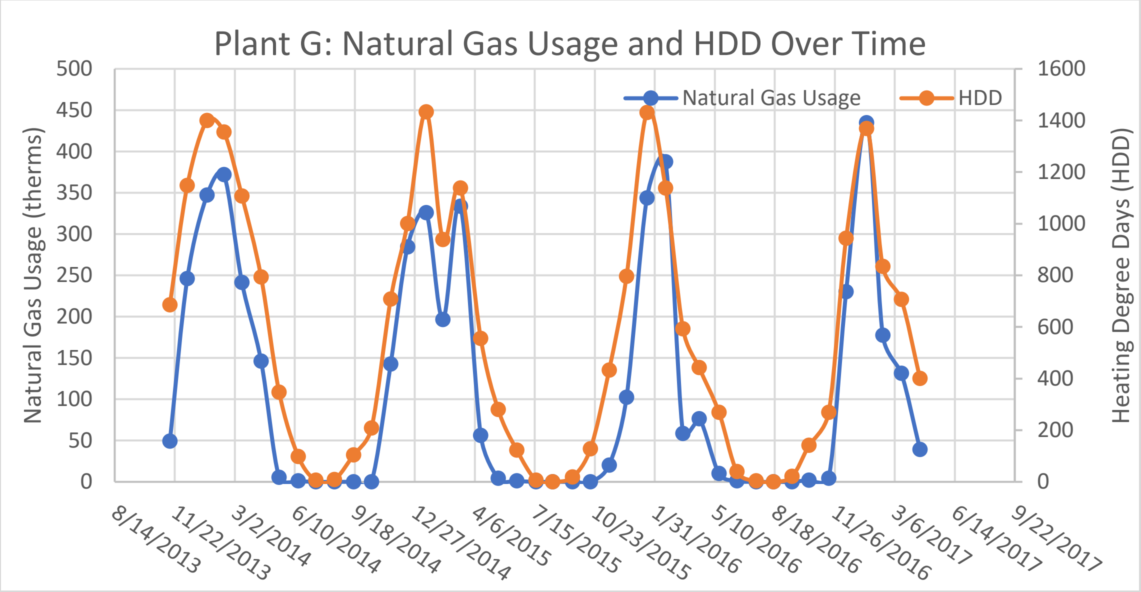


Figure F.22: Plant G Heating Energy Usage and HDD Plotted Over Time

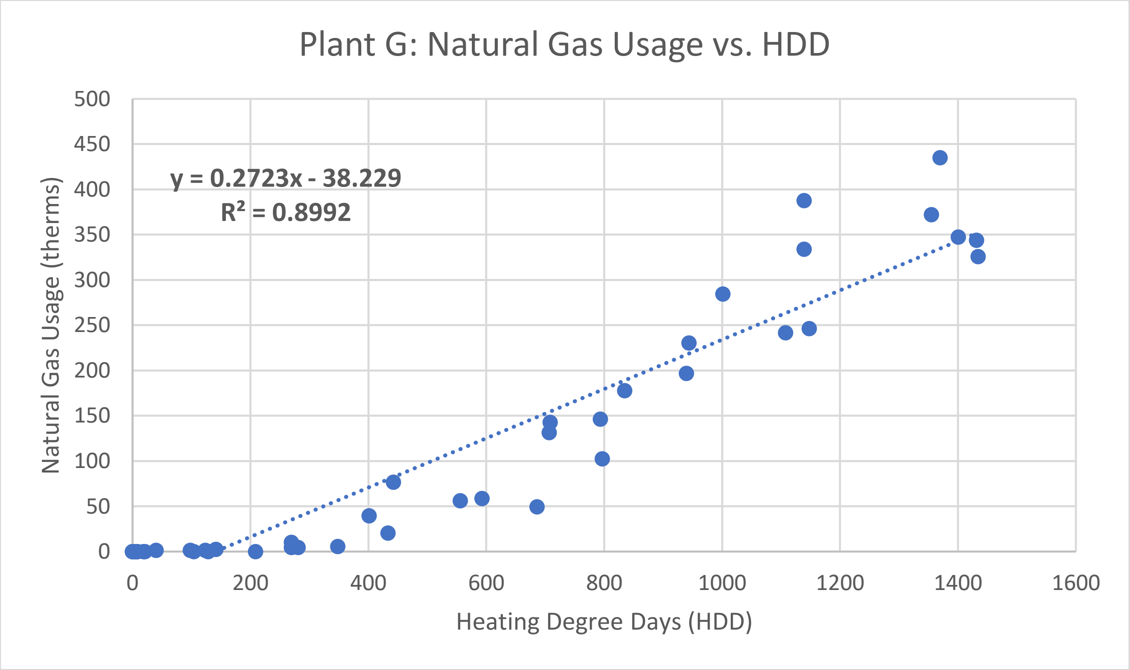


Figure F.23: Plant G Heating Energy Usage and HDD Plotted Over Time

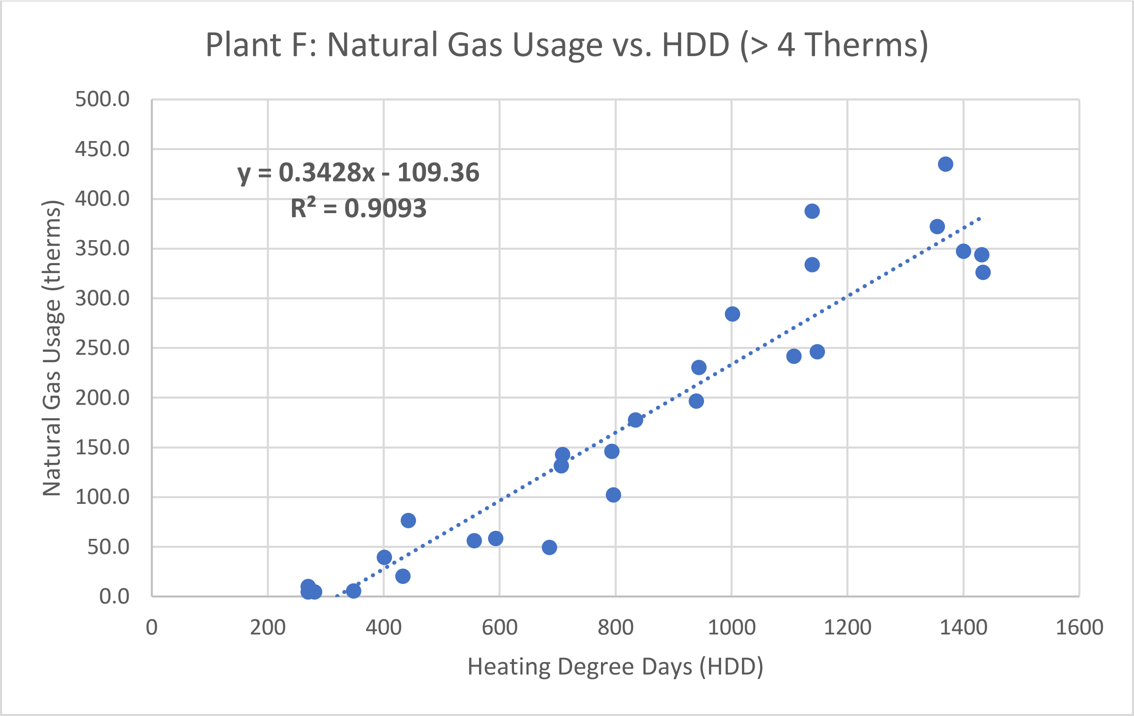
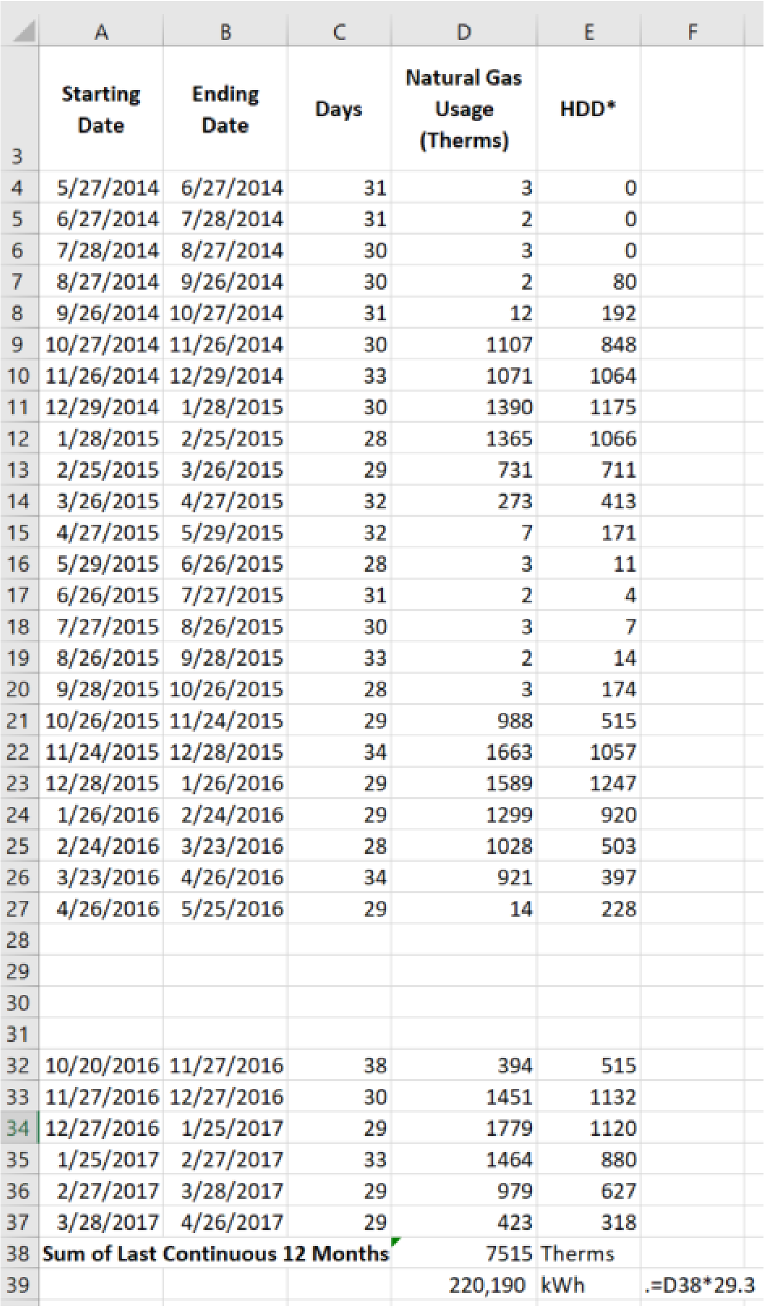
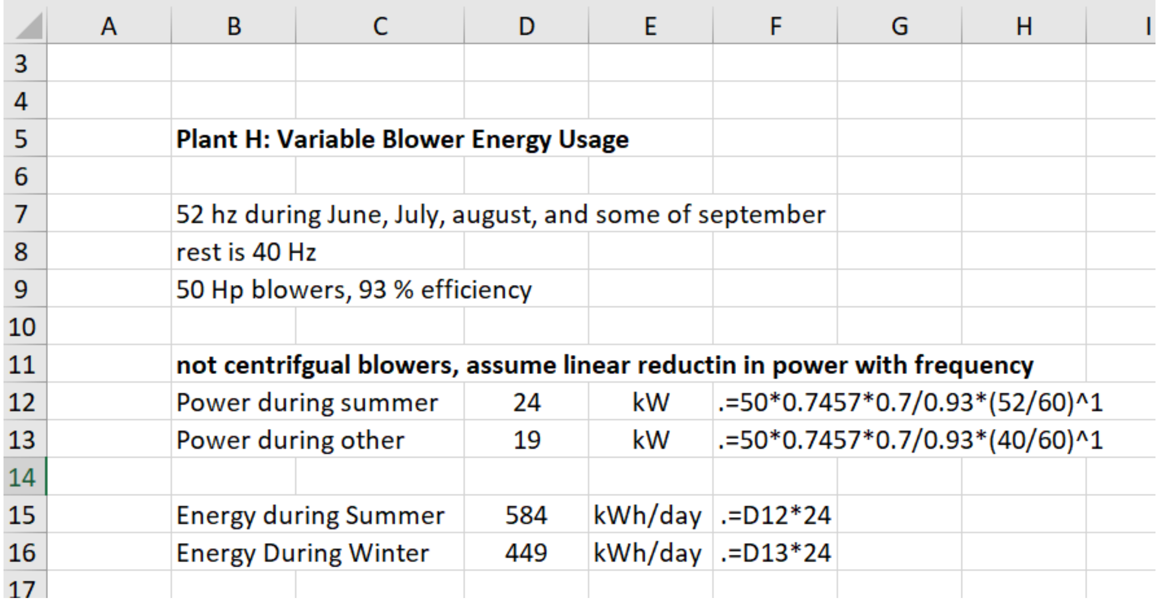


Figure F.24: Plant G Heating Energy Usage and HDD Plotted Over Time (with only data for >200HDD shown)



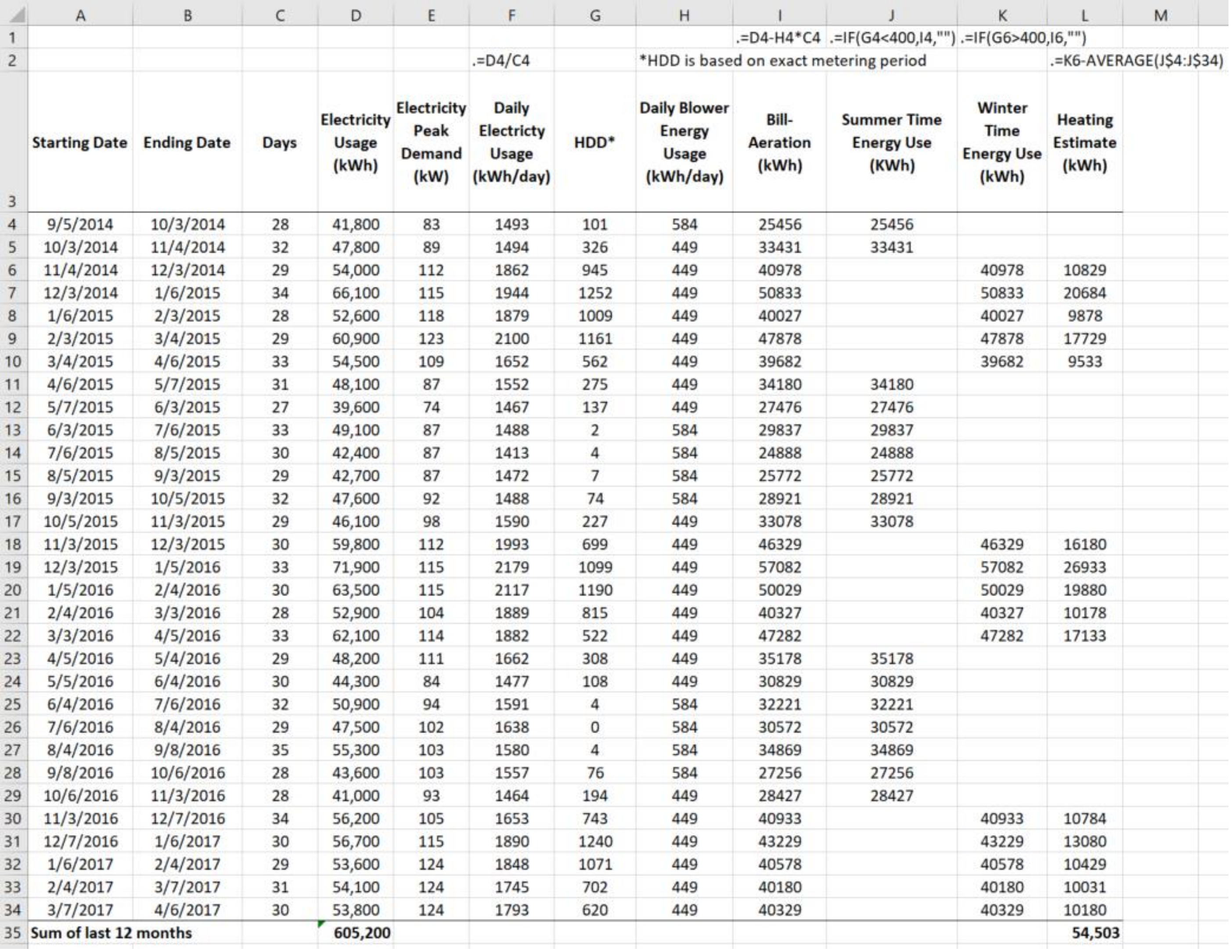
	A	B	C	D	E	F
3	Starting Date	Ending Date	Days	Natural Gas Usage (Therms)	HDD*	
4	5/27/2014	6/27/2014	31	3	0	
5	6/27/2014	7/28/2014	31	2	0	
6	7/28/2014	8/27/2014	30	3	0	
7	8/27/2014	9/26/2014	30	2	80	
8	9/26/2014	10/27/2014	31	12	192	
9	10/27/2014	11/26/2014	30	1107	848	
10	11/26/2014	12/29/2014	33	1071	1064	
11	12/29/2014	1/28/2015	30	1390	1175	
12	1/28/2015	2/25/2015	28	1365	1066	
13	2/25/2015	3/26/2015	29	731	711	
14	3/26/2015	4/27/2015	32	273	413	
15	4/27/2015	5/29/2015	32	7	171	
16	5/29/2015	6/26/2015	28	3	11	
17	6/26/2015	7/27/2015	31	2	4	
18	7/27/2015	8/26/2015	30	3	7	
19	8/26/2015	9/28/2015	33	2	14	
20	9/28/2015	10/26/2015	28	3	174	
21	10/26/2015	11/24/2015	29	988	515	
22	11/24/2015	12/28/2015	34	1663	1057	
23	12/28/2015	1/26/2016	29	1589	1247	
24	1/26/2016	2/24/2016	29	1299	920	
25	2/24/2016	3/23/2016	28	1028	503	
26	3/23/2016	4/26/2016	34	921	397	
27	4/26/2016	5/25/2016	29	14	228	
28						
29						
30						
31						
32	10/20/2016	11/27/2016	38	394	515	
33	11/27/2016	12/27/2016	30	1451	1132	
34	12/27/2016	1/25/2017	29	1779	1120	
35	1/25/2017	2/27/2017	33	1464	880	
36	2/27/2017	3/28/2017	29	979	627	
37	3/28/2017	4/26/2017	29	423	318	
38	**Sum of Last Continuous 12 Months**			7515	Therms	
39				220,190	kWh	.=D38*29.3

Figure F.25: Screenshot of Plant H Heating Energy Use



	A	B	C	D	E	F	G	H	I
3									
4									
5		**Plant H: Variable Blower Energy Usage**							
6									
7		52 hz during June, July, august, and some of september							
8		rest is 40 Hz							
9		50 Hp blowers, 93 % efficiency							
10									
11		**not centrifgual blowers, assume linear reductin in power with frequency**							
12		Power during summer		24	kW	.=50*0.7457*0.7/0.93*(52/60)^1			
13		Power during other		19	kW	.=50*0.7457*0.7/0.93*(40/60)^1			
14									
15		Energy during Summer		584	kWh/day	.=D12*24			
16		Energy During Winter		449	kWh/day	.=D13*24			
17									

Figure F.26: Screenshot of Plant H Blower Energy Use Estimate Based on Documented Operating Conditions



	A	B	C	D	E	F	G	H	I	J	K	L	M
1									.=D4-H4*C4	.=IF(G4<400,I4,"")	.=IF(G6>400,I6,"")		
2						.=D4/C4		*HDD is based on exact metering period				.=K6-AVERAGE(J$4:J$34)	
3	Starting Date	Ending Date	Days	Electricity Usage (kWh)	Electricity Peak Demand (kW)	Daily Electricty Usage (kWh/day)	HDD*	Daily Blower Energy Usage (kWh/day)	Bill-Aeration (kWh)	Summer Time Energy Use (KWh)	Winter Time Energy Use (kWh)	Heating Estimate (kWh)	
4	9/5/2014	10/3/2014	28	41,800	83	1493	101	584	25456	25456			
5	10/3/2014	11/4/2014	32	47,800	89	1494	326	449	33431	33431			
6	11/4/2014	12/3/2014	29	54,000	112	1862	945	449	40978		40978	10829	
7	12/3/2014	1/6/2015	34	66,100	115	1944	1252	449	50833		50833	20684	
8	1/6/2015	2/3/2015	28	52,600	118	1879	1009	449	40027		40027	9878	
9	2/3/2015	3/4/2015	29	60,900	123	2100	1161	449	47878		47878	17729	
10	3/4/2015	4/6/2015	33	54,500	109	1652	562	449	39682		39682	9533	
11	4/6/2015	5/7/2015	31	48,100	87	1552	275	449	34180	34180			
12	5/7/2015	6/3/2015	27	39,600	74	1467	137	449	27476	27476			
13	6/3/2015	7/6/2015	33	49,100	87	1488	2	584	29837	29837			
14	7/6/2015	8/5/2015	30	42,400	87	1413	4	584	24888	24888			
15	8/5/2015	9/3/2015	29	42,700	87	1472	7	584	25772	25772			
16	9/3/2015	10/5/2015	32	47,600	92	1488	74	584	28921	28921			
17	10/5/2015	11/3/2015	29	46,100	98	1590	227	449	33078	33078			
18	11/3/2015	12/3/2015	30	59,800	112	1993	699	449	46329		46329	16180	
19	12/3/2015	1/5/2016	33	71,900	115	2179	1099	449	57082		57082	26933	
20	1/5/2016	2/4/2016	30	63,500	115	2117	1190	449	50029		50029	19880	
21	2/4/2016	3/3/2016	28	52,900	104	1889	815	449	40327		40327	10178	
22	3/3/2016	4/5/2016	33	62,100	114	1882	522	449	47282		47282	17133	
23	4/5/2016	5/4/2016	29	48,200	111	1662	308	449	35178	35178			
24	5/5/2016	6/4/2016	30	44,300	84	1477	108	449	30829	30829			
25	6/4/2016	7/6/2016	32	50,900	94	1591	4	584	32221	32221			
26	7/6/2016	8/4/2016	29	47,500	102	1638	0	584	30572	30572			
27	8/4/2016	9/8/2016	35	55,300	103	1580	4	584	34869	34869			
28	9/8/2016	10/6/2016	28	43,600	103	1557	76	584	27256	27256			
29	10/6/2016	11/3/2016	28	41,000	93	1464	194	449	28427	28427			
30	11/3/2016	12/7/2016	34	56,200	105	1653	743	449	40933		40933	10784	
31	12/7/2016	1/6/2017	30	56,700	115	1890	1240	449	43229		43229	13080	
32	1/6/2017	2/4/2017	29	53,600	124	1848	1071	449	40578		40578	10429	
33	2/4/2017	3/7/2017	31	54,100	124	1745	702	449	40180		40180	10031	
34	3/7/2017	4/6/2017	30	53,800	124	1793	620	449	40329		40329	10180	
35	Sum of last 12 months			605,200								54,503	

Figure F.27: Screenshot of Spreadsheet Estimating Plant H Heating Energy Use

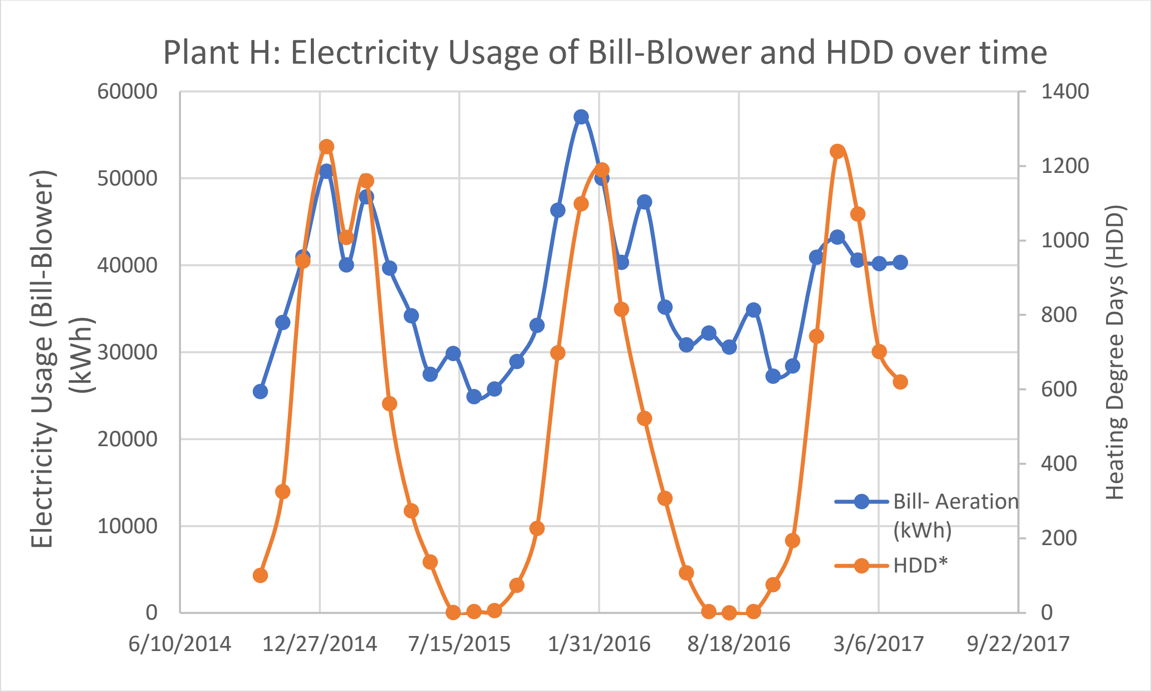


Figure F.28: Plant H Adjusted Billed Energy Usage and HDD Plotted Over Time

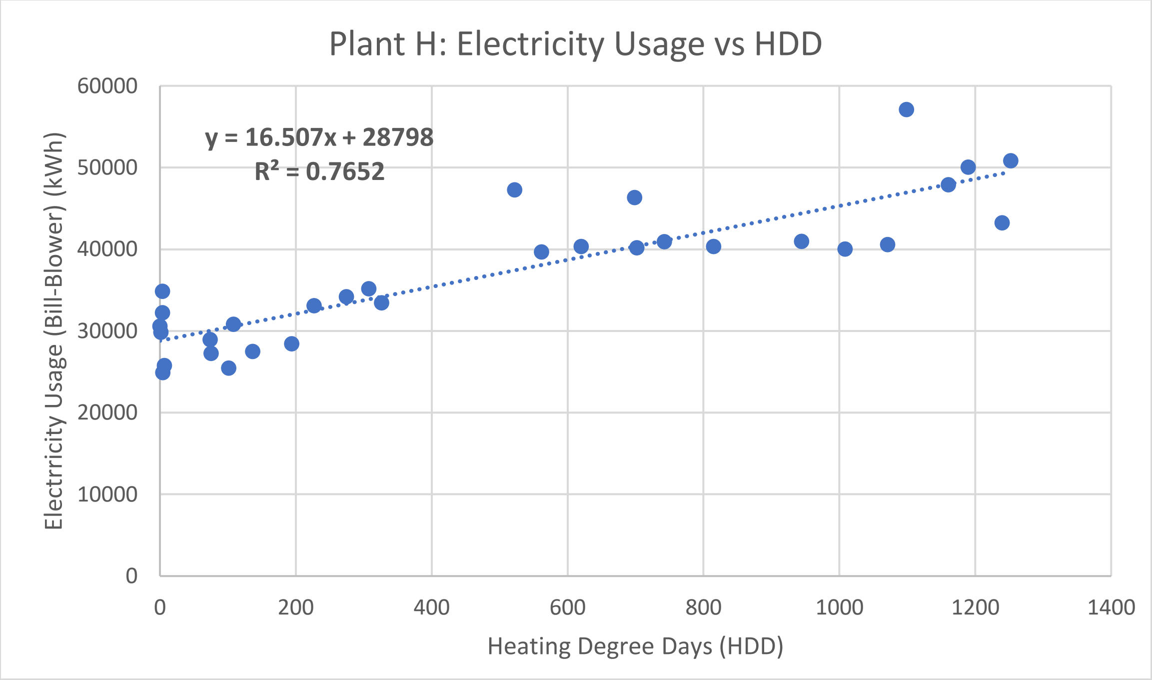


Figure F.29: Plant H Adjusted Billed Energy Usage and HDD Plotted Over Time

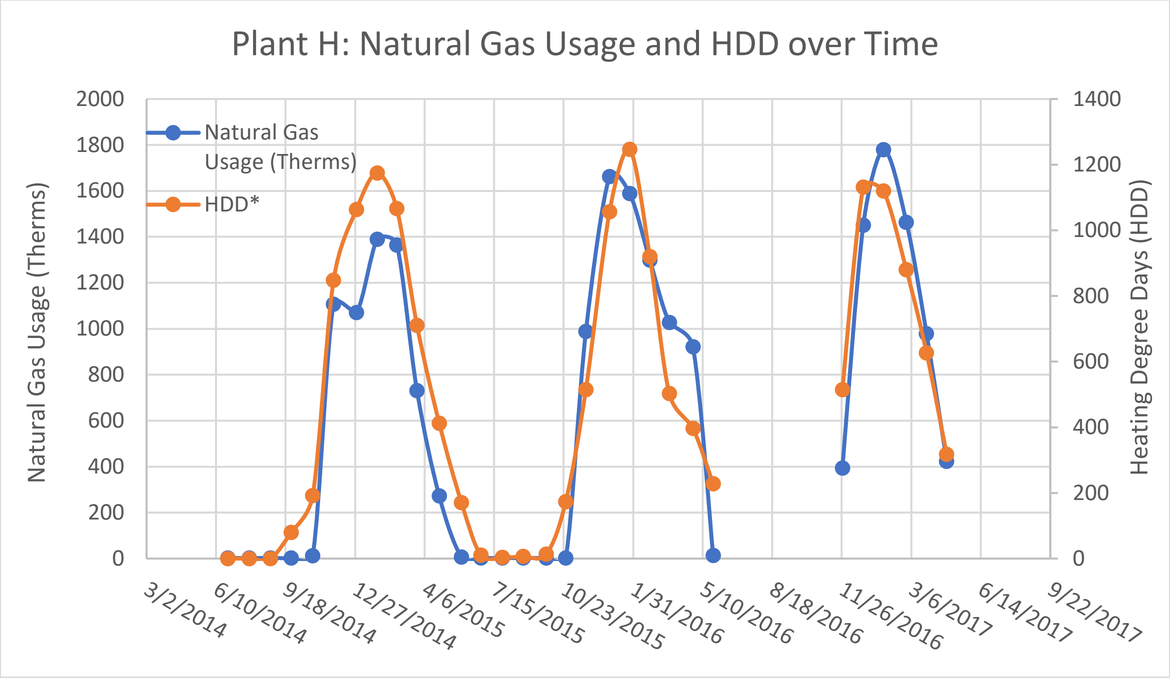


Figure F.30: Plant H Heating Energy Usage and HDD Plotted Over Time

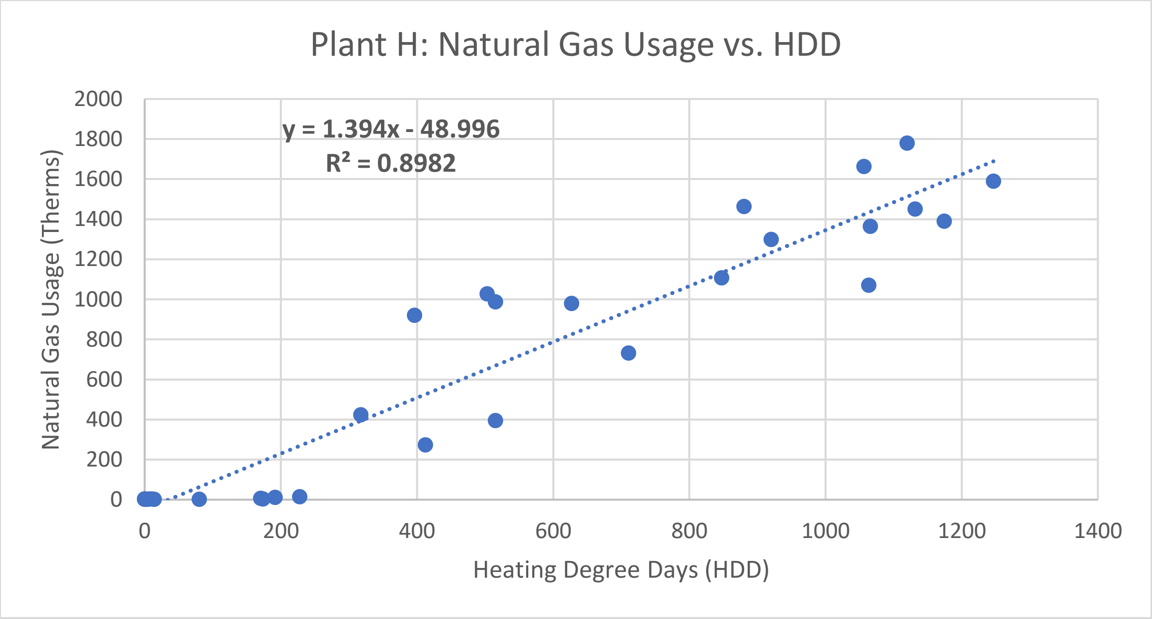


Figure F.31: Plant H Heating Energy Usage and HDD Plotted Over Time

Table F.1: Summary of Space Heating Estimates and Correlations with HDD

Plant	**Type of Energy for Heating**	**Slope (kWh/HDD)**	**R^2 fit**	**Months of Data**	**Past 12 Months Energy Usage (kWh)**	**Estimated Heating Usage (kWh/yr)**	**% Plant Energy Usage**	**Heated Floor Area (ft^2)**	**Building Heating Intensity (kWh/(yr-ft^2))**
A	Electric	2.83	0.70	26	240,760	8,915	4%	1,830	5
B	Electric	7.62	0.61	25	401,112	25,773	6%	2,975	9
C	Electric	19.04	0.78	48	563,680	87,271	15%	2,810	31
D	Gas	11.20	0.99	17	369,883	58,043	16%	3,160	18
E	Electric	4.73	0.85	35	139,573	26,714	19%	670	40
F	Electric	2.85	0.82	35	114,252	13,933	12%	938	15
G	Gas	7.98	0.90	43	517,310	30,230	6%	6,830	4
H	Electric	16.51	0.77	31	825,390	54,503	7%	2,000	27
H	Gas	26.32	0.90	27	825,390	220,190	27%	3,100	71