The impact of sub-metering requirements on building electrical systems design

by

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Abstract

New energy codes and standards, including *ANSI/ASHRAE/IES Standard 90.1: Energy Standard For Buildings Except Low-Rise Residential Buildings* (ASHRAE 90.1), LEED and UK Building Regulations Type Part L2 have adopted requirements for electrical sub-metering to be installed within commercial buildings. It is no longer acceptable to only meter total building usage. Separate sub-meters must be installed to monitor where and how power is utilized within commercial buildings. The information provided by the use of these sub-meters can reduce energy usage in the building by informing building owners and occupants of how and where they are using the most energy, by alerting building owners to potential operating and/or maintenance issues and by identifying energy efficiency measures through the use of a building energy audit.

This paper identifies the requirements outlined in ASHRAE 90.1, LEED and the UK Building Regulations Part L2. The paper also identifies products and methods to integrate sub-metering into the electrical systems design as well as benefits to separately metering mechanical, electrical and receptacle loads within a building. A case study for a fictitious building is provided, identifying design solutions and costs associated with a sub-metering system meeting the requirements of ASHRAE 90.1.

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The author would especially like to acknowledge his wife for her continued support and dedication throughout this life changing process.

Dedication

Dedicated to my two daughters. May you continually seek out knowledge and never stop asking questions.

Chapter 1 - An Introduction to ASHRAE 90.1 and Metering Requirements

Over the past 40 years, energy consumption in the US has increased by 26% [1]. Buildings currently account for 40% of all energy consumed in the US[2]. Since 1975, the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) has published strict energy standards to reduce the impact commercial buildings have on energy consumption. The standards have continually been updated as construction methods have improved and technology advances have been made. For example, the allowable lighting power density requirements have decreased significantly as technology has moved the industry from incandescent lamps to fluorescent lamps to LED fixtures. Figure 1. shows the increased energy efficiency introduced with each updated version of *ANSI/ASHRAE/IES Standard 90.1: Energy Standard For Buildings Except Low-Rise Residential Buildings* (ASHRAE 90.1). A commercial building following the 2016 version of ASHRAE 90.1 would see more than a 40% reduction in its energy usage compared to the same building complying with the 1989 standard. It should be noted that ASHRAE has recently introduced the 2019 version of ASHRAE 90.1, however additional research is needed to determine the average energy use reduction a building would see by complying with the latest version.

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[1] Nadel, "35 Years of Energy Efficiency Progress, 35 More Years of Energy Efficiency Opportunity."

[2] "How Much Energy Is Consumed in U.S. Residential and Commercial Buildings? - FAQ - U.S. Energy Information Administration (EIA)."

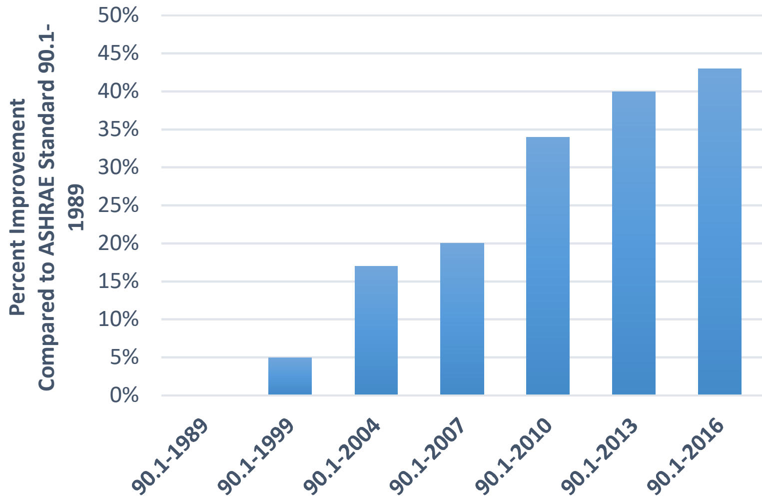

Figure 1.1. Percent Energy Efficiency Improvements of ASHRAE 90.1[3]

Some of the changes to the standard that have led to the improved efficiency of buildings include requirements to increase the insulation in walls, use of more efficient heating, ventilating and air-conditioning (HVAC) equipment, and reduce the lighting power density. The 2013 version of ASHRAE 90.1 was the first time that energy monitoring and metering requirements were included as part of the standard. In addition to requiring monitoring of the electrical use for the entire building, this update added a requirement for all commercial buildings larger than 25,000 square feet to separately meter the energy usage for HVAC, interior lighting, exterior lighting and receptacle (or plug load) circuits. A single meter at the electrical service entry is no longer enough to comply with the standard. Additionally, these loads must be separately metered for all tenant spaces larger than 10,000 square feet. Dwelling units are excluded from these requirements as are residential buildings if they have less than 10,000 square feet of common area.

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[3] Overbey, "Energy Efficiency Improvements in ASHRAE Standard 90.1."

The sub-meters for each of the above mentioned systems is also required to record energy usage data at least once every 15 minutes. The system must generate an hourly, daily, monthly and annual report. When following ASHRAE 90.1-2016, the same requirements apply as well as a new requirement for energy use data to be graphically displayed. Methods for meeting the metering and reporting requirements are addressed in Chapters 2 and 3 of this paper.

Although ASHRAE 90.1 is not yet widely adopted, this new metering requirement has the potential to change how the engineering industry designs the electrical infrastructure for a building and how users interact with the building. The ASHRAE design standard is referenced by the more widely adopted International Energy Conservation Code (IECC) as an alternative compliance option. In fact, the impact of ASHRAE 90.1 is evident when comparing new versions of ASHRAE 90.1 to new versions of IECC. Both are updated every three years, however the IECC lags behind ASHRAE 90.1 and references the standard 2 years prior. For example, the 2018 IECC references the 2016 version of ASHRAE 90.1 It is often recognized that ASHRAE 90.1 adopts new requirements that then find their way into future versions of the IECC. With each update to IECC, many of the requirements are changed to bring them more in line with the ASHRAE requirements. Examples of this include daylighting requirements, temperature control requirements for heated and cooled vestibules, and thermostat control requirements in hotel/motel guestrooms. Each of these were first introduced in ASHRAE 90.1 and adopted and modified in later versions of IECC. It is not out of the question to imagine a similar process may occur with respect to the sub-metering requirements.

Similar sub-metering requirements have been included in other design standards such as LEED and the Building Regulations for England and Wales. Later chapters of this paper will address both these standards.

Chapter 2 - Benefits of Sub-Metering

2.1-Purpose of Sub-Metering Requirements

The sub-metering requirements of energy efficiency standards will alone do nothing to reduce the energy usage of a building. However, the intent behind the requirements are to make occupants and building owners aware of their energy usage and allow them to strategically target ways to reduce their energy consumption. These strategies are commonly referred to as energy efficiency measures, or EEMs. As the old saying goes, "You can't manage what you don't measure". By metering the HVAC, lighting and plug loads separately, occupants and building owners will be able to more easily track the impact their EEMs have on energy usage. The recording and reporting requirements mean that information has the potential to be readily available and to provide near real-time tracking of energy usage.

ASHRAE has strategically targeted HVAC, lighting and receptacles for metering due to the fact that these systems account for the majority of the energy used within commercial buildings. According to the 2012 Commercial Buildings Energy Consumption Survey (CBECS) released by the US Energy Information Administration, HVAC (space heating, ventilation, cooling), plug loads (computing, office equipment), and lighting account for 63% of the total energy usage of a typical commercial building[4].

[4] "CBECS 2012: Energy Usage Summary."

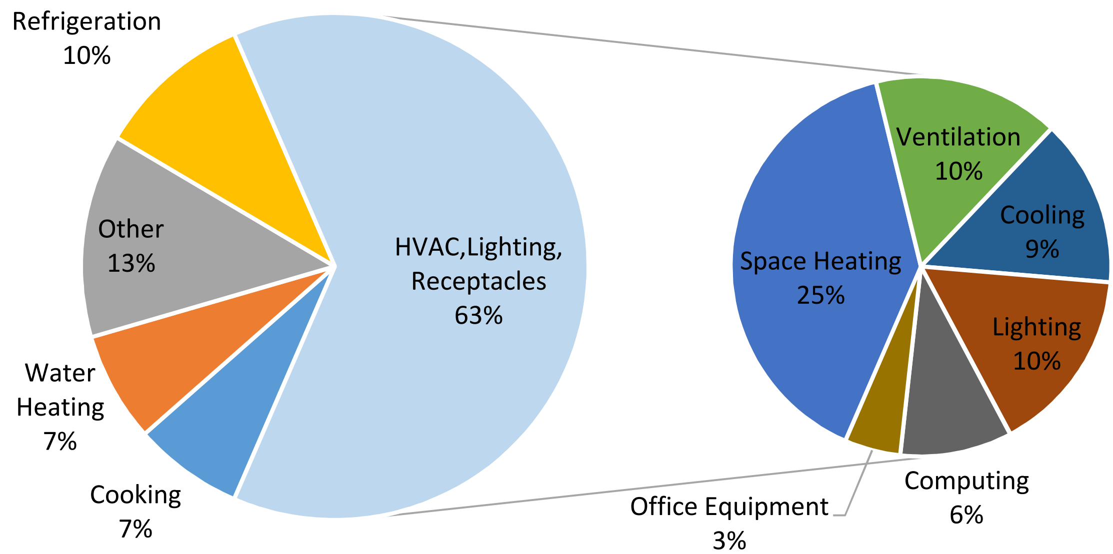

Figure 2.1. Commercial Building Energy Usage by System Type[5]

Building owners can best utilize their time, effort and money by targeting these three key areas, which will have the largest impact on their annual utility costs. Additionally, owners and occupants have more control over lighting, plug load usage and HVAC and can readily make changes that will impact the energy use in these areas. For example, an occupant can easily adjust the thermostat to cool to 75° instead of 73° in the summer, or they can turn off the lights when leaving the office. It would be much more difficult to reduce their water heating consumption as that may present sanitation concerns. Even more difficult would be for the occupant to attempt to reduce the pump and motor power used in the building, as these systems are typically located in locked rooms that are only accessible to maintenance personnel. Furthermore, allowing untrained occupants to access and change the operation of these systems

[5] "CBECS 2012: Energy Usage Summary."

would have significant negative consequences and could lead to damaged equipment, increased maintenance costs and/or increased energy consumption.

In addition to having access to the systems, building occupants and owners must also have access to the energy use data for each system. In theory, all of the data for every single device in the building could be captured and logged, but unless the occupants have ready access to this information and are educated on how to use it, the added cost of sub-metering will do nothing to reduce energy consumption. To help address this issue, ASHRAE 90.1 requires energy information to be displayed graphically. This graphic display makes the information easier to understand, however the standard does not address where the display must be located or who has access to view the data. By not specifying this information, these decisions are left to the engineer and owner to make based on what they deem best.

As an example, the energy consumption information could be displayed on a website, on a lobby welcome screen or it could be accessible via an app. A wide variety of templates exist from a variety of companies. The templates can be modified to show information in a very succinct and simple manner, for instance simply listing the kWh usage for the entire building. The display could be more complex by showing a breakdown of energy use by system, by floor or by tenant. Since the energy use information is required to be stored for 3 years, the display could also show how the energy usage has changed over time and could display trends in the data. Depending on how the system is set up, this display could show real time energy usage, or at a minimum, energy usage based on 15 minute intervals. Figure 2.2 shows an example energy graphic display created by Circuit Meter that displays near real time data of energy usage in an easy to read a visually pleasing manner. The display is intended to be installed in the building lobby for all building occupants to view and interact with.

Figure 2.2. Sample Graphic Display Interface[6]

With all the information that can be pulled from the HVAC, lighting and plug load systems, it is important to identify who needs access to the data and what information they need. While it is certainly possible to send an e-mail to all building occupants an hourly update on the energy use of every piece of HVAC equipment, most occupants have little to no control over these pieces of equipment. Additionally, an hourly update would overwhelm even the most energy conscious occupants.

Perhaps a better option would be to send this information to the building manager on a weekly basis. Since the building manager typically has the ability to adjust and modify HVAC controls and settings, they are the ones that are most likely to act on the information. Knowing the energy usage may be helpful, but without having a baseline to compare against, it is difficult to get a sense of how the building is performing. Rather than just sending the energy usage for the week, it would be helpful to compare against the energy usage from last week, or the energy

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[6] "EnergyWindow™ Overview."

usage from the same week one year ago. Even better would be to include a summary of the weather in this report so that the building manager could identify if changes to weather are potentially the cause for increased energy consumption. For example if the energy report showed that HVAC usage was significantly higher during a given week than during the same week one year prior, but the outside air temperatures were approximately the same during both time frames, the building manager could assume that there is another factor at play. Perhaps the air filters are dirty, windows have been left open, or the equipment is beginning to fail. Without an understanding of the current energy usage and the previous energy usage, it would be much more difficult to troubleshoot and identify potential issues. Additionally, by identifying issues in a timely manner, failing equipment can be maintained in a timely manner, extending its life and preventing early replacement. Longer lasting equipment further increases the sustainability of the building systems.

Educating building occupants on how much energy they are consuming can also have a significant impact on the overall energy usage of the building. A 2011 initiative entitled "I Will if You Will" sought to educate tenants occupying more than 1 million square feet in Shorenstein Properties[7]. Energy meters were installed to allow the property manager to provide up to date energy usage information to building tenants. Property managers were tasked with training tenants via workshops, pamphlets and posters emphasizing strategies to reduce energy consumption. Example solutions included turning off computers at the end of the workday, setting thermostats to a few degrees higher in the summer and lower in the winter, reducing the number of printers in the space and connecting water coolers and coffee machines to timers to shut down at night. Furthermore, property managers were given flexibility in providing

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[7] Talbot and Love, "I Will If You Will: A Replicable Strategy for Tenant Behavior Change."

incentives to encourage participation. Example incentives included gift cards, ice cream socials and pizza parties. The result of the education and incentive program was a reduction of 27% of plug load energy usage[8]. An additional campaign by the same company entitled “Flip the Switch”, which encourages tenants to turn off lights and office equipment when not in use, has led to a more than 20% total energy reduction in Shorenstein’s properties[9]. These savings would not have been possible without the real time feedback of sub-meters within the building.

A study conducted by researchers at Pennsylvania State University went beyond educating occupants and sought to actively engage them in reducing their energy usage. Researchers developed a video game that provided individuals with a virtual farm of chickens. Each chicken represented a single piece of equipment in the workspace. As the energy consumed by the equipment increased, the health of the chicken in the virtual environment would diminish. All participants in the study were educated via a poster campaign on their ability to reduce their energy consumption. Approximately 70% of the participants were invited to also play the video game and were given the task to raise healthy chickens over the course of 14 weeks. Researchers ultimately found that the game resulted in minor energy savings compared to simply educating participants; however, both groups reduced their energy usage by approximately 10%. Although the game did not have the impact researchers hoped for, one key takeaway from the study was the need for a continual education and campaign program. An 8-week follow up with all participants showed that energy consumption had returned to similar levels as it had been at the beginning of the study.

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[8] Schantz and Langner, Rois, “Engaging Tenants in Reducing Plug Load Energy Use.”

[9] “‘Flip the Switch’ Tenant Engagement Program | Better Buildings Initiative.”

2.2 Energy Audits

Another ASHRAE publication, *Procedures for Commercial Building Energy Audits, Second Edition, ASHRAE, 2011* (*Procedures*) identifies the importance of, and best practices for completing an energy audit on existing buildings. An energy audit is an examination and study of an existing building with the intent to identify potential problems with the building operation and identify energy efficiency measures (EEMs) that can be performed to increase energy efficiency and decrease energy costs. These EEMs may include adjustments to the maintenance and/or operation of a given system, replacing failing or faulty equipment, adjustments to the building's control system, replacing equipment with new and more energy efficient equipment and so forth. A list of common EEMs can be found in Appendix B -

Common practice requires a building to have been occupied for a period of at least 1 year, prior to performing an energy audit to identify where, when and how energy is used throughout the building. This 1-year minimum period establishes a baseline to compare energy consumption against. According to *Procedures*, there are three Audit Levels, each more in depth than the previous. Table 2.1 describes each level.

Audits are typically performed by a third party consultant, often times an engineer. The engineer will consult with the building owner, building manager and in some cases, the building occupants in order to perform their audit. The initial step is to evaluate the total energy usage intensity (EUI) of the building on a kBtu/SF or kW/SF basis. This can be done without stepping foot in the building. All that is needed are the utility bills for the building, preferably for at least the past 1 year of building operation. A quick calculation leads to an understanding of how efficient the building is compared to other similar buildings. This energy use information is compared to the CBECS information, previously mentioned in Chapter 2 - for similar buildings in similar climate areas. The end result is a basic understanding of how the building is performing overall. This can help determine whether or not it makes sense to proceed with further analysis. A building with an above average EUI may benefit from a more intense energy audit since it is clear that there is room for improvement. A building with an EUI far below the average may already be operating at close to peak efficiency and further investigation may not be worth the added costs associated with a level 1, 2 or 3 audit.

For this preliminary energy use analysis, the only pieces of metering equipment required are the utility meters. These are required for all buildings connected to public utilities for billing purposes, and a preliminary energy use analysis could be performed for any building. However, in order to get more in depth, additional steps must be taken to identify cost effective EEMs.

Table 2.1 Relationships of ASHRAE Energy Audit Levels 1, 2 and 3[10]

Audit Level	Scope of Work
Preliminary Energy-Use Analysis	• Calculate kBtu/SF • Compare to similar buildings
Level 1: Walk Through	Preliminary Energy Use Analysis plus: • Estimate costs and savings for EEMs • Identify capital projects
Level 2: Energy Survey and Analysis	Level 1 Analysis plus: • End-use breakdown • Detailed analysis • Cost and savings for EEMs • Operation and maintenance changes
Level 3: Detailed Survey and Analysis	Level 2 Analysis plus: • Refined analysis • Additional measurements • Hourly simulation (energy model)

[10] Deru, Kelsey, and ASHRAE Technical Committee 7.6, Building Energy Performance, *Procedures for Commercial Building Energy Audits*.

A Level 1 audit includes a building walkthrough that helps identify EEMs on a general level. The hired third party consultant will visit the building, looking at the envelope, HVAC system, lighting system, building controls, heating hot water and chilled water systems, domestic water heating system and other process type loads. The consultant may bring data loggers to track usage of various systems in the building over a period of a few weeks. They may interview building maintenance crews and building occupants to get an understanding of how systems are typically operated. They are looking initially for low and no cost EEMs that can be implemented. Following the walkthrough, the consultant may produce simple payback calculations for these EEMs.

A Level 1energy audit mainly addresses issues that can be visually identified. Similar to a preliminary audit, it too does not provide an in depth analysis for systems. Again, this level of auditing can be provided for any building with little need for any additional monitoring or metering, other than simple data loggers mentioned previously.

Level 2 audits require the ability to break down end energy usage in order to more clearly understand where and how power is being used. At a minimum, the audit should identify the energy usage for lighting, heating, cooling and receptacle loads[11]. Clearly, a building complying with the sub-metering requirements found in ASHRAE 90.1 would be well suited for a Level 2 audit. Depending on how the sub-metering is set up, it may be possible to break down energy usage of nearly every circuit within the building. The more items that are metered, the easier it will be to identify end-use energy and identify areas for improvement. Additionally, the recorded history from the meters will be extremely helpful. Since ASHRAE 90.1 requires data to be logged at least every 15 minutes and stored for a minimum of three years, trends can easily be

[11] Baechler and Strecker, "A Guide to Energy Audits."

identified in the metering data. Due to the additional sub-metering equipment, the cost for a Level 2 audit are significantly reduced since the third party consultant may not need to supply any additional metering equipment to pull data from.

In contrast, a building that does not already have sub-meters installed in accordance with ASHRAE 90.1 will require the third party consultant to install temporary meters. These meters will need to track data over a period of time, determined by the consultant and building owner. Not only will these additional meters require added costs, but the data logged may not be as useful compared to a building with permanent sub-meters. Tracking the energy usage for a period of days, weeks or months won't give the same level of detail as having data that's been logged for the past three years.

Table 2.2. Sample End Use Energy Data

End Use	kWh	% of Total
Cooling	72,829	24.7%
Fans	84,367	28.6%
Heating	39,869	13.5%
Lighting	66,522	22.6%
Process/Receptacle	16,063	5.5%
Pumps	1,910	0.6%
Water Heating	13,046	4.4%
Total	**294,606**	**100.0%**

After collecting information from the metering equipment, the data must be reviewed and analyzed. This analysis will break down energy use by category. An example is shown in **Error! Reference source not found.**. The auditor should be familiar enough with the building to be able to identify potential concerns based on this data. For example, looking at the data in **Error! Reference source not found.**, if this building is located in a cool climate and the measurements were taken in the middle of December, the fact that 24.7% of the total energy use comes from cooling should be a potential red flag. Perhaps there are several server rooms located in the building and the thermostats in these rooms are set to 60°F. A potential EEM would be to increase the thermostat setpoints to 70°F. Another potential red flag is the lighting usage of 22.6%. Metering data could be further analyzed to identify the time of day that these loads run. Maybe some of the lighting in this instance is found to be running in the middle of the night, when the building is not occupied. These EEMs are simple no or low cost options with immediate payback.

A Level 2 audit may also identify more complex EEMs that involve replacing old equipment with more energy efficient equipment. For example, adding variable frequency drives (VFD) to the fans in the building will help reduce the overall fan power. The energy audit should also identify the initial costs associated with the EEMs and the energy savings potential. A simple payback should be calculated to identify the return on investment for each EEM.

Moving from a Level 2 audit to a Level 3 audit may require additional monitoring and metering. A Level 3 audit may require an understanding of very specific systems within the building. For instance a chiller may require monitoring of not only the electrical energy usage, but the efficiency, entering and leaving water temperatures and weather data to correlate usage to outside air conditions. A Level 3 audit also involves creating an energy model for the building. The model should be calibrated to closely match the actual energy usage of the building, which requires a precise understanding of all energy end usages. This model is used to further examine potential EEMs. Potential EEMs can quickly be tested in the model to almost immediately see the impact they will have on building energy usage. A significant amount of time and money can be spent setting up the energy model, but once it has been created, an unlimited number of EEMs can be tested with very little time and effort involved for each.

Regardless of the which level of auditing is done, the end goal is the same: to reduce energy usage of the building and reduce utility costs. This is where the true value of sub-metering comes into play. A building only capable of monitoring total energy usage is limited in the ability to identify and implement EEMs. The more points within the building that are sub-metered, the easier it will be to quickly and accurately identify energy savings strategies.

Chapter 3 - Sub-Metering Methods

If the requirement to add sub-meters provides substantial benefits to a building and can aid in reducing energy consumption and increase the lifespan of equipment, why wasn't this strategy implemented several years ago? Up until recently, the cost to provide additional meters did not justify the savings they could provide. In the past, the entire electrical distribution system would need to change drastically to allow HVAC, lighting and receptacle loads to be separately metered. In order to accomplish this, these three systems would need to be completely independent of one another, meaning separate panelboards would be required for each. The cost implications extend beyond the cost of the panelboards. Additional wiring is required to feed the added panels and additional overcurrent protection devices (OCPDs) are required to protect the panels. Depending on the building size and layout, the additional OCPDs could lead to requiring more or physically larger pieces of distribution equipment. All of the added equipment leads to larger electrical rooms and reduced rentable square footage. All of these costs combined make it difficult to justify the use of sub-metering.

However, with the implementation of now readily available multi-point meters, the additional infrastructure to allow separate metering of HVAC, lighting and receptacles has been substantially reduced. Multi-point meters allow each OCPD within a panelboard or distribution board to be independently metered. Mechanical loads can be intermingled on the same panel as lighting or receptacle loads and still be metered separately. Rather than adding panels, the design simply needs to add small meters within the electrical rooms.

In order to individually meter each circuit, the multi-point meters require current transformers (CTs) to be installed for each OCPD. These CTs are placed around the conductors immediately before they tie into the OCPD. A separate CT is required for each phase conductor, so a three-pole breaker would require three current transformers. Each CT connects into the multi-point meter via low-voltage cabling. In some cases, this meter can be integral to the panel with CTs factory installed and wired to the integral meter. However, not all panels can be configured with an integral meter, so to reduce costs, the meter should be mounted as close to the panel as possible. Figure 3.1 shows both options, a panel with integral metering, as well as a panel with remote multi-point metering. Both options function essentially the same and either, or a combination of the two, could be used throughout the building.

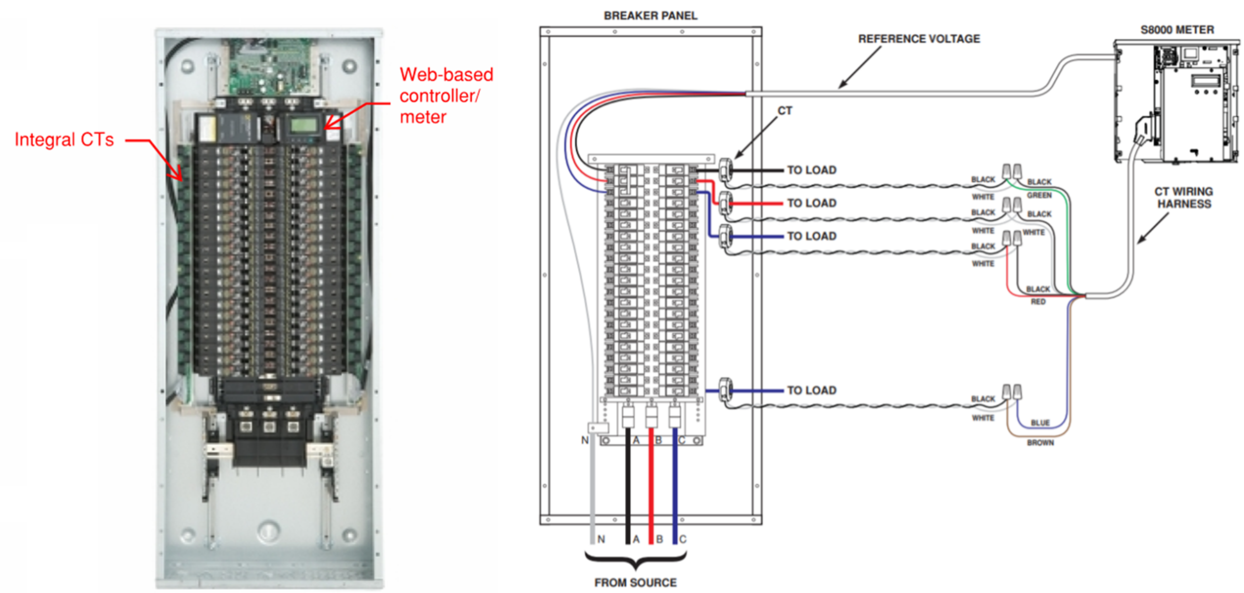

Figure 3.1. Panel with Integral Meter (Left)[12] and Panel with Externally Mounted Multi-Point Meter (Right)[13]

A disadvantage of the multi-point meter is the requirement for current transformers to be installed for each metered load. These CTs come with a cost, but they also take up space within the panelboard. In some situations, it may be difficult or impossible to fit enough CTs within the

[12] "Powerlink MVP - Documents and Downloads | Schneider Electric."

[13] Leviton, "Leviton Series 8000 Meter Quick Start Guide."

panel to be able to properly meter the required HVAC, lighting or receptacle systems. In this case, larger panels or additional panels may be required.

Another concern is the space required for the meter. Whether the meter is integral to the panel or external, appropriate planning must be done to ensure proper space is allocated for installation. An integral meter may lead to a taller and/or wider panel or a reduced number of poles. An externally mounted meter will take up wall space within the electrical room and will require code working space in front of the meter (between 3'-0" to 4'-0", depending on the conditions). Dimensions of the meter will vary by manufacturer, but the enclosure may be approximately 14"W x 10" H x 6"D. The meter should be mounted at least 6" from the panel to allow EMT conduit to be run from the panel to meter.

In addition to the physical dimensions of the multi-point meter, the meter must be connected to a three-pole breaker within the panel. This effectively reduces the number of branch circuits that can be fed out of the panel, so a standard 42-pole panel will only have 39 available poles to serve branch circuits. The three-pole breaker serves two purposes. First, it provides power to the meter, allowing it to function properly. And second, it allows the meter to calibrate and sense each phase voltage properly. If the phases are not properly terminated in the meter, for instance if the A-phase and C-phase conductors are switched around and terminate on the wrong terminal blocks, the meter readings for these phases will be incorrect.

New "smart" breakers eliminate the need for individual CTs and multi-point meters. Several manufacturers including Leviton, Eaton and Siemens, are developing individual breakers with the ability to meter and control each independently via a smartphone or tablet. The breakers can be turned on, off or reset remotely simply by using an app. Because the breakers include integral metering, the app can also show power usage for each circuit and can alert the user to problems, such as when a device trips off, or when a circuit is using more current than usual. Some of the above listed manufacturers have begun selling load centers with integral smart breakers, however the systems tend to be geared toward residential panels intended to be used in single-family homes.

Another new product that several manufacturers are working to bring to market are solid state breakers. These breakers replace the mechanical trip mechanism found in traditional breakers with semi-conductors to digitally control the current. These devices are significantly faster acting than mechanical breakers, resulting in a safer and more effective option. At least one manufacturer is also working on including the ability to control, modify and meter their solid state breakers remotely. Metering is built into each breaker and the information is stored and accessible via an online web application. Further, the panel and breakers can be set up with load shedding capabilities. From the web interface, the building owner can establish a maximum amperage or kVA that they do not want to exceed. Each breaker is assigned a priority level and if demand is high on any given day, the lowest priority breakers will trip off to ensure the maximum amperage of the panel is not exceeded. The panel calculates when to turn the breakers back on to ensure the maximum demand is not exceeded. This process clips the peak demand for the system resulting in lower energy usage and reduced utility costs. The downside of this process is that there is no notice of which circuits will be turned off at any given point in time. If, for instance, a computer was connected to one of the low priority circuits, power could be abruptly shut off, causing frustration to the user.

Some utility companies offer financial incentives for users that participate in peak shaving. Electricity storage does not typically exist within a utility grid. This means that the electric utility company must match their electricity supplied to the demand on the grid. During periods of high energy usage, the utility may struggle to match the demand. The result can be rolling brownouts within communities. However, before brownouts occur, utility companies turn to peaking power plants to attempt to match the increased demand for electricity. These peaking power plants typically utilize natural gas and are unable to utilize renewable sources of energy such as wind or solar energy[14]. Additionally, these plants are significantly more expensive to run, which is why they are utilized only when absolutely necessary. The previously mentioned load shaving system not only impacts the energy usage of the building, but if the technology was widely adopted, it could significantly reduce the impact of rolling blackouts within communities. It could also reduce the need for utility companies to run their peaking power plants. By reducing the need to run peaking plants, the peak shaving allowed by these new breakers extends their benefit beyond just the building and can create positive externalities to the community. Additionally, utility companies often set in place agreements with building owners wherein the utility company will pay the owner to participate in peak shaving and reduce their energy consumption during high demand periods. Building owners are financially compensated for their participation, which is another added benefit to these new breakers.

Regardless of the method used for metering, it is clear that there exist multiple strategies today that did not exist when the first ASHRAE energy standard was introduced in 1975. New metering methods continue to be developed each year, bringing with them additional capabilities and a reduction in cost. Implementing sub-metering into commercial buildings is more feasible today than it has ever been.

[14] St. John, "Dueling Charts of the Day: Peaker Plants vs. Green Power."

Chapter 4 - Tenant Sub-metering

Buildings designed for office use are commonly leased out to multiple tenants. Rather than meter each tenant's electrical usage individually, leases are often written to allow the building owner to bill each tenant based on their square footage. An example of lease language is shown in Figure 4.1. In this instance, the landlord would choose one of the available choices prior to presenting the contract to the tenant. A flat rate per month can be charged or the monthly utility bill for the entire building can be divided and allocated based solely on square footage of each tenant. In either case, there is little incentive for individual tenants to reduce their energy consumption. In economic terms, this is commonly referred to as "the tragedy of the commons". Where a shared resource exists, in this case electricity usage, each tenant has the incentive to increase their consumption at the expense of the other tenants.

1. Tenant Electricity. Section 13.1 of the Lease is hereby amended to reflect that, as of the Additional Space Commencement Date, Tenant shall pay an initial cost of **[Select One: {One and 50/100 Dollars ($1.50) per rentable square footage}** or **{total energy cost of the building multiplied by percentage of square footage occupied by tenant}]** in addition to any electricity related to Tenant's signage if the same is installed. Said amount shall be paid, as additional rent, on the same date as the Monthly Installments of Rent are due.

Figure 4.1. Sample Tenant Electricity Lease Language[15]

As an example, assume a building with only two tenants occupying equal square footage (Tenant A and Tenant B) has a monthly utility bill of $1,000. If tenants split the bill based on square footage, each tenant will pay $500. Assuming both tenants have essentially the same energy use profile, then this method of billing is fair and equal. However, if Tenant A decides to begin mining for bitcoin and doubles their usage for the month, the monthly bill increases to $1,500. Although Tenant A has doubled their energy consumption, they only have to pay $750

[15] "Amendment to Lease."

for the month, a 50% increase. Tenant B is stuck paying for Tenant A's increased energy usage. Conversely, if Tenant A reduces their consumption by 50%, the total monthly bill would decrease to $750 and each tenant would pay $375. Tenant A only realizes a 25% reduction in their monthly energy cost.

ASHRAE 90.1 recognizes the issue that multi-tenant buildings create. The standard requires additional meters for buildings that will be leased out to tenants. Each individual tenant space greater than 10,000 square feet is required to have separate HVAC, lighting and receptacle meters for their space. It should be noted that often a building will contain several shared systems, such as central HVAC systems (i.e. chillers, cooling towers, pumps, boilers, air handling units, etc.), outdoor or parking garage lighting, and central domestic water heating. Where systems are shared, they are not required to be separately metered by each individual tenant, however they still must be metered separately for the overall building. This may create a "hybrid" billing system where tenants are billed for the shared systems on a square footage basis in addition to being billed for their actual metered usage in their space. Regardless of how this is accomplished, the end result will often be a reduction in total energy usage. By metering each individual tenant and billing them for their actual use, the effect of the "tragedy of the commons" is drastically reduced.

The New York State Energy Research and Development authority estimates that users who pay for each kWh of energy they use consume 15-30% less electricity compared to users who pay for their usage based on square footage[16]. An additional study by WegoWise, a utility tracking tool, found similar results with a 20% delta between owner paid utilities vs tenant paid

[16] Hughes, "Electricity: Saving by Submetering."

utilities[17]. This is a drastic reduction, considering it simply requires a change in billing and metering. In the author's professional experience, a 30% reduction goal typically requires the implementation of multiple EEMs. Increased insulation, high efficiency glazing, low lighting power density and high efficiency HVAC systems would all be required to achieve the same level of energy use reduction. These studies highlight the need for tenants to be responsible for their own energy usage and the need for sub-meters to be installed per the ASHRAE 90.1 standard.

[17] O'Donovan, "The Case for Submetering."

Chapter 5 - Sub-metering for LEED

In 1998, the U.S. Green Building Council (USGBC) introduced a pilot program called Leadership in Energy and Environmental Design version 1.0 (LEED)[18]. The pilot program included just 19 projects, all new construction, commercial buildings. In 2000, the pilot program was publicly released as LEED v2.0, allowing any interested parties to participate. LEED v2.0 included extensive changes to the program based on feedback from the pilot program. The new version expanded the program's reach by adding separate rating systems for new construction, existing buildings and commercial interiors. Project registration continued at a steady pace of approximately 60 new projects registered each month from 2000 to 2006. In 2007 and 2008 the number of projects registering to use the LEED rating system rose to an average of 700 new registrations per month[19]. Growth slowed during 2009 and 2010, shortly after the introduction of LEED v2009, however the LEED rating system is widely utilized today across the world and now boasts that more than 69,000 projects have been registered as of 2019[20].

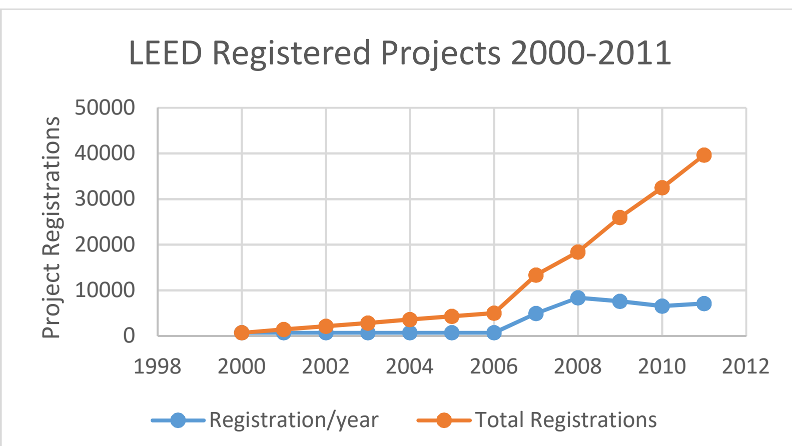

Figure 5.1. LEED growth between 2001 and 2009[21]

[18] "About: Brand | USGBC."

[19] "LEED by the Numbers."

[20] "LEED-Registered Projects United States 2019."

[21] "LEED by the Numbers."

The latest version of LEED, V4.1, was introduced in October of 2019. With each new version, the standard has evolved and been updated to reflect a higher standard of energy efficiency while allowing more flexibility for more project types. When originally introduced, LEED was limited to only three rating systems- New Construction, Interior Design and Construction and Neighborhood development. Under V4.1, there exist five overarching rating systems with a combined 21 different standards based on building types. The complete list of V4.1 rating systems is shown in **Error! Reference source not found.** below.

Table 5.1. LEED V4.1 Rating Systems[22]

LEED for Building Design and Construction (BD+C)	**LEED for Interior Design and Construction (ID+C)**
New Construction	Commercial Interiors
Core and Shell	Hospitality
Data Centers	Retail
Healthcare	
Hospitality	**LEED for Building Operations and Maintenance (O+M)**
Retail	Existing Buildings
Schools	Data Centers
Warehouses and Distribution Centers	Hospitality
Homes	Retail
Multifamily Midrise	Schools
	Warehouses and Distribution Centers
LEED for Neighborhood Development (ND)	**LEED for Cities and Communities**
Plan and Built Project	

The LEED standard has, in many ways, become the new standard to which commercial buildings are designed to, regardless of if they are pursuing LEED or not. As an example, energy

[22] "LEED v4.1 | U.S. Green Building Council."

modeling, or running a computer simulation of a building's anticipated energy usage, was once a niche market. Since its inception, the LEED standard has emphasized the importance of performing an energy model in order to guide the design. Today, this practice has become a standard part of design. Another LEED credit that has potential to change the standard practice of electrical design deals with providing sub-meters to measure individual end use loads.

Sub-metering has been addressed as part of the LEED rating system since its inception. Under LEED for Interior Design and Construction version 1.0, owners and designers could pursue an optional credit entitled "Energy and Atmosphere Credit 3: Energy use, measurement and payment accountability". For projects where the tenant space was less than 75% of the total building area, the credit required projects to include sub-metering of energy uses within tenant spaces. Where an individual tenant took up more than 75% of the total building area, a measurement and verification plan was required to be created and implemented following the International Performance Measurement and Verification Protocol (IPMVP). Additional sub-metering was also required for the following end-uses:

- Tenant sub-metering
- Lighting systems and controls
- Motor loads
- VFD drives
- Chiller efficiency
- Cooling loads
- Air and water economizer and heat recovery cycles
- Air distribution static pressures and ventilation air volumes
- Boiler efficiencies
- Building-related process energy systems and equipment
- Indoor water riser and outdoor irrigation systems

LEED V2.0 expanded the scope of sub-metering to new buildings following the Core and Shell rating system. A new optional credit entitled "Energy and Atmosphere Credit 5.2: Measurement and verification-tenant sub-metering" required a centrally monitored metering network to be installed in the core and shell building that would allow future tenants to meet the sub-metering requirements outlined in the Commercial Interior Design rating system referenced above. The goal of this new credit was to minimize the cost and labor involved when new tenants want to sub-meter their own energy usage.

The sub-metering requirements remained unchanged in subsequent versions of LEED until 2009. While the Core and Shell requirements did not change, LEED 2009 made it easier to meet the sub-metering requirements under Commercial Interior Design. Energy and Atmosphere Credit 3-Measurement and Verification under the new version left the sub-metering requirement for projects less than 75% of the total building area untouched, but removed the sub-metering of end-use requirements for projects greater than 75% of the total building area. It is unclear why the sub-metering requirements were removed in the 2009 version of LEED, however they returned in a modified form as part of LEED V4.

The new credit in LEED V4, titled "Energy and Atmosphere credit 3: Advanced Energy Metering" now applies to all projects following the LEED for Building Design and Construction as well as all projects following LEED for Interior Design and Construction. Rather than focusing on a given list of energy usages that require metering, the new credit requires metering for "any individual energy end uses that represent 10% or more of the total annual consumption of the building". The requirement goes beyond just electrical sub-metering as it requires separate metering for all energy sources, be that electric, natural gas, propane, steam, etc. By focusing on sources using at least 10% of the building energy use rather than a set list of items that must be metered, the standard is more flexible and more applicable to a wide variety of buildings. For instance a typical commercial building will often be dominated by HVAC, lighting and plug loads and may have very little motor load (see Figure 2.1). Under the old rating system, all motor loads would still be required to be metered. The added cost for the additional metering could sway the building owner to simply not pursue this credit at all and abandon all sub-metering requirements. Under the revised credit, only the HVAC, lighting, plug load and refrigeration loads would require separate sub-meters. Although these meters will still come at a cost, they will be metering the most energy intensive loads and will provide significant benefits to the owner, as outlined in Chapter 2 - Benefits of Sub-Metering.

All of these sub-metering requirements would be for naught if projects chose not to pursue these optional credits. Information is not available to determine how many registered LEED projects have met the sub-metering requirements under the new V4 and V4.1 rating since they are relatively new systems, but LEED 2009 showed promising adoption rates. Under LEED for Commercial Interiors buildings, 50% of projects achieved EAc3-Measurement and Verification[23]. Since the sub-metering requirement only applied to projects with less than 75% of the total building area, it's difficult to know how many projects utilized sub-metering and how many simply provided a measurement and verification plan. When looking at Core and Shell projects, the adoption rate is significantly higher, with 77% of projects achieving EAc5.2-Measurement and Verification-Tenant Sub-metering[24]. This is encouraging as it shows that the majority of new LEED certified core and shell buildings have been designed to allow tenant sub-metering in the future. It is hopeful that this trend will continue and that sub-metering will soon become part of standard design practices for all new buildings.

[23] "LEED2009-CI-EAc3: Measurement and Verification."

[24] "LEED2009-CS-EAc5.2: Measurement and Verification-Tenant Submetering."

Chapter 6 - Building Regulations for England and Wales Part L2

The United Kingdom has become a leader in addressing climate change. In 2008, the Climate Change Act set a goal for the country to reduce carbon emissions by 80% compared to 1990 levels. By 2018, emissions had already been reduced by 44%[25]. In 2019, the goal was amended for the country to be net-zero and offset 100% of emissions by 2050[26]. In February of 2020, the U.K. announced that it would ban the sale of new gas and diesel cars by 2035[27]. With this type of forward thinking, it should come as no surprise that Britain adopted requirements for new commercial buildings to integrate sub-metering into their standard design more than seven years before sub-metering was addressed in ASHRAE 90.1. In 2006, the Building Regulations of England and Wales introduced Part L2, focusing on conservation of fuel and power. The standard addresses new buildings as part of L2A and the renovation of existing buildings as part of L2B.

The L2 standard is similar to ASHRAE 90.1 in that it addresses energy efficiency through mandated requirements. Both standards have provisions for minimum envelope insulation R-values, mechanical efficiencies and electrical efficiencies. Both have provisions for energy modeling to prove compliance, however L2 focuses on CO_2 reduction while ASHRAE 90.1 focuses on energy costs. Both are updated on a regular basis, with the latest L2 being the 2016 version. Both standards require sub-metering, however the L2 standard goes about this in a very different way from ASHRAE 90.1.

[25] "How the UK Is Progressing - Committee on Climate Change."

[26] "Climate Change: UK Government to Commit to 2050 Target - BBC News."

[27] "U.K. to Ban New Gas Vehicles, Diesel Cars by 2035 - MarketWatch."

Rather than focusing solely on electrical monitoring and metering, the L2 standard addresses all fuel sources, whether that be electricity, gas, steam, etc. This metering should be capable of accounting for 90% of the end use categories of energy usage. In other words, simply metering HVAC, lighting and receptacle usage would often not be enough to comply with the standard. Not only do these systems account for less than 90% of the end energy usage, metering all HVAC (or all lighting or receptacle) loads together does not allow building owners to analyze how the energy is being used. From the regulations:

> "Reasonable provision of sub-metering would be to provide sub-metering such that the following consumptions can be directly metered or reliably estimated:
>
> - Motor control centers for fans and pumps with a total load of 10 kW or more
> - Boiler installations of 50 kW or more
> - Chillers of 20 kW or more
> - Electric humidifiers of 10 kW
> - Final electrical distribution boards with a total load of 50 kW or more"

Interestingly, the standard does not require direct measurement for each of these end uses, perhaps due to the potential high initial costs to install meters for each end use category. Direct metering is the preferred method, however it is permissible to estimate end use using a variety of methods including: indirect metering, monitoring run hours in combination with known constant loads, and simply estimating small power uses[28]. As an example, a constant volume supply fan could measure run hours rather than energy usage. The energy use could be calculated by multiplying the kW of the fan by the run hours.

Again, it should be noted that simply measuring and/or calculating the total energy usage will have no impact on reducing energy consumption. The key to reducing energy usage stems

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[28] "General Information Leaflet 65."

from the use of data gleaned from metering, measurements and calculations. Returning to the afore mentioned example, a building owner who has access to see the run hours of a supply fan may be able to identify and troubleshoot potential problems. For example, the owner may see that the fan is running almost continuously on weekends when the building is unoccupied. The solution may be a simple change to the controls sequence for the fan. The owner could make the change and quickly identify if the problem was solved.

Although at first glance it appears that the metering requirements of L2 are significantly stricter than those in ASHRAE 90.1, the flexibility that the standard allows for in measuring and calculating energy usage has perhaps been a key to its successfully implementation. Rather than requiring additional sub-meters to directly measure all loads of a certain end use, the L2 standard allows several options to minimize the initial cost impact. Many building energy management systems already include monitoring of run times and indirect metering for HVAC equipment. Using data from the energy management system may allow electrical designers to eliminate one or more sub-meters that would be required in an ASHRAE 90.1 compliant design. The downside to this approach, however, is that the building owners are put into a position where they must run calculations and make estimates in order to determine actual energy use. The added work involved may dissuade building owners from evaluating systems that are not directly metered. Further research is needed in this area to determine if, and how often, building owners are utilizing data from their direct and indirect measurements to inform their operation and maintenance decisions.

Chapter 7 - Case Study

This paper has thus far identified methods of sub-metering as well as benefits and potential issues. One major concern that should be addressed is the question of cost. Although multiple options exist to allow sub-metering, it is apparent that additional equipment will be required regardless of the method used. In an attempt to provide a rough estimate of the costs associated with the additional sub-metering equipment, a case study for a fictitious building has been performed. The following assumptions describe the proposed building, located in the Kansas City, KS area:

- The proposed building is a 4-story office space, with a floorplate of 200’x100’.
- The facility will be served with 480/277V, 3-phase, 4-wire.
- There will be (2) 15HP elevators in the building.
- Natural gas boilers will provide heating hot water needs.
- An air-cooled chiller will supply chilled water needs.
- (2) 10HP chilled water pumps and (2) 10 HP hot water pumps will be installed in the building.
- Fan powered boxes will be used throughout the building to distribute air.
- (2) 12kW electric water heaters will provide domestic hot water needs.
- Building is intended to be occupied by either a single owner or 1 tenant per floor.

The building has been designed and priced for three different design solutions. The first method (Baseline) is a design that does not allow sub-metering of mechanical, lighting and receptacle loads. The design could be applicable in a jurisdiction that has adopted the International Energy Conservation Code in lieu of the ASHRAE 90.1 standard. This method is considered the baseline case for pricing purposes. In order to minimize oversizing branch circuits due to voltage drop, 2 electrical rooms are assumed to be provided per floor. A main electrical room houses the 2000A main switchboard as well as a 225A 480/277V high voltage panelboard, a 45kVA 480V-208/120V transformer and a 150A 208/120V panelboard. Each secondary electrical room will contain the same size 480/277V panel, 480V-208/120V transformer and

208/120V panelboard. A portion of the one-line diagram showing the main switchboard, high voltage panels, transformers and low voltage panels for the first floor is shown in Figure 7.1 for reference. The complete one-line diagram of the system is provided in Appendix A - .

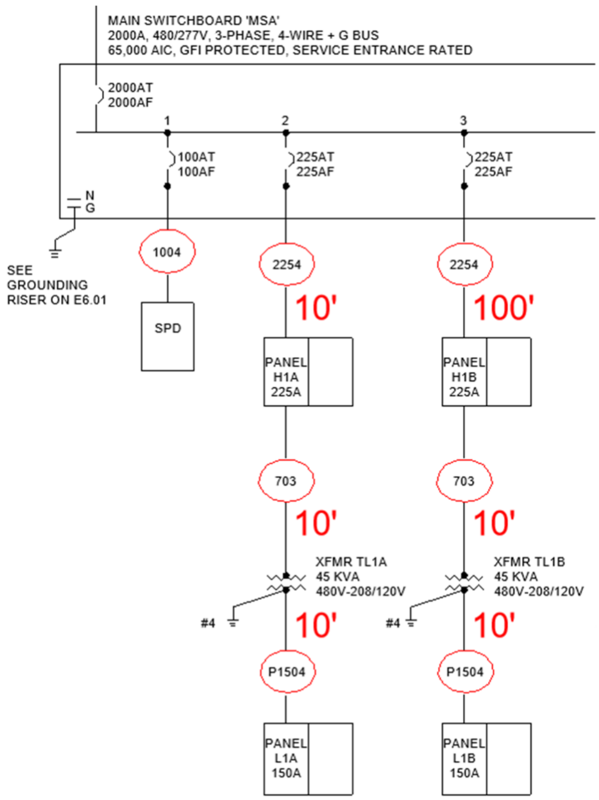

Figure 7.1. One-line Diagram Excerpt for IECC Compliant Design (Baseline Design)

The second design (Option 1) evaluated allows mechanical, lighting and receptacle loads to be sub-metered by providing a separate panel for each. This requires an additional 480/277V panel to be provided within each electrical room to separate the mechanical loads from the lighting loads. The 480/277V panels are, however, rated for a smaller ampacity. Rather than a single 225A panel, a 150A panel will serve the mechanical loads and 480-208/120V transformer and a 100A panel serves the lighting. In this instance, each panel is provided with a single-point meter to measure the entire load on the panel. These meters are not capable of measuring the load on individual circuits within the panel, however since the mechanical loads will all tie to the mechanical panel (H1A, H1B), lighting loads to the lighting panel (H1B, H1D), and receptacle loads to the receptacle panel (L1A, L1B), the design meets the sub-metering requirements of ASHRAE 90.1. A portion of the one-line diagram is shown in Figure 7.2 for reference.

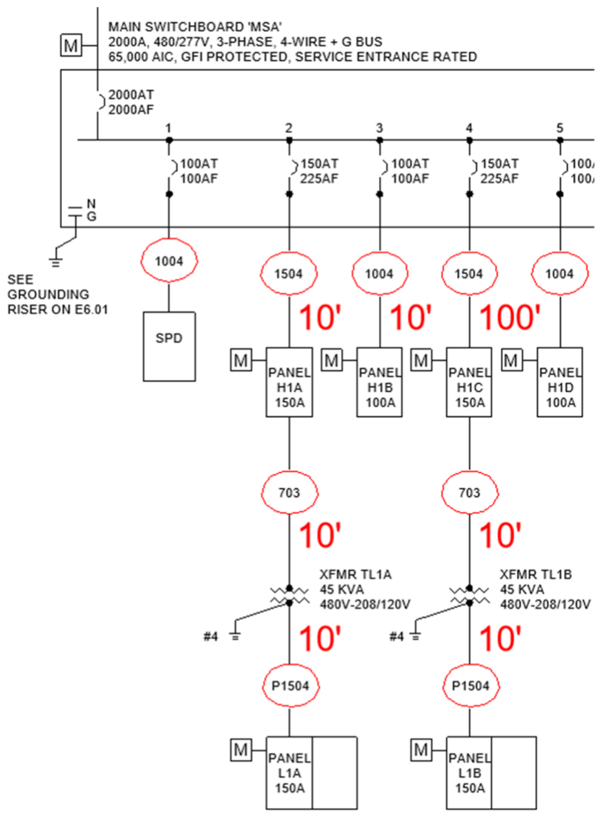

Figure 7.2. One-line Diagram Excerpt for Sub-Metering Using Separate Mechanical, Lighting and Receptacle Panels (Option 1)

The final design solution (Option 2) utilizes multi-point meters to monitor each circuit independently. These meters can be installed either integral to the panel or externally mounted. The only difference between this solution and the baseline design is the addition of the multi-point meter and associated current transformers to allow each circuit to be metered. A portion of the one-line diagram is shown in Figure 7.3 for reference.

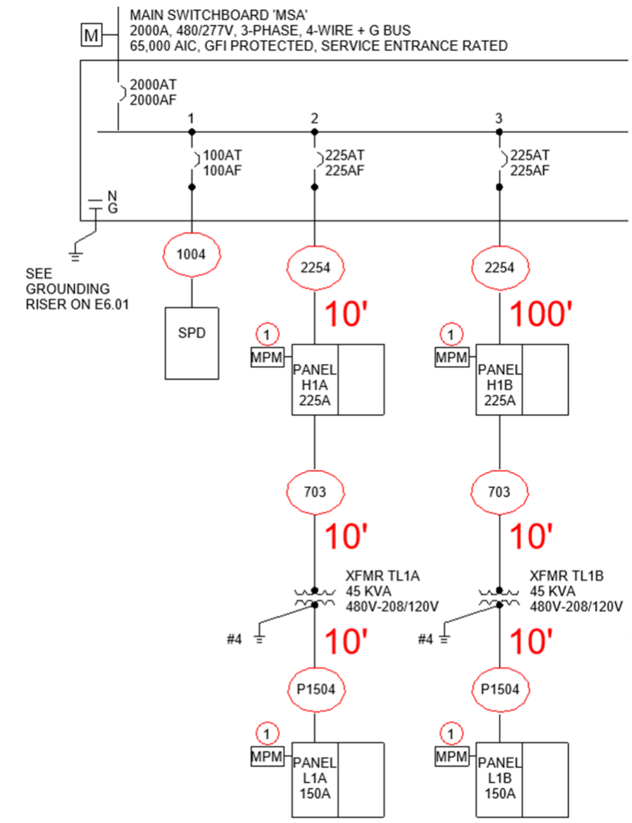

Figure 7.3. One-line Diagram Excerpt for Sub-Metering Using Multi-Point Meters (Option 2)

Both of the proposed options for metering HVAC, lighting and receptacle loads separately are viable options for most buildings. However, metering comes with a significant cost premium. Options 1 and 2, which include sub-metering, are roughly 30% more expensive than the baseline design, which does not include sub-meters (refer to Appendix A - for a complete cost estimate). Additionally, the added equipment will require additional space within each electrical room which may cause the electrical room dimensions to grow in size. Figure 7.4 below shows possible satellite electrical room layouts for each of the above mentioned options. Due to the additional panels and meters in Option 1, the room needed to increase roughly 10% in area to accommodate them. The addition of multi-point meters in Option 2 required a minor increase of approximately 2% in floor area.

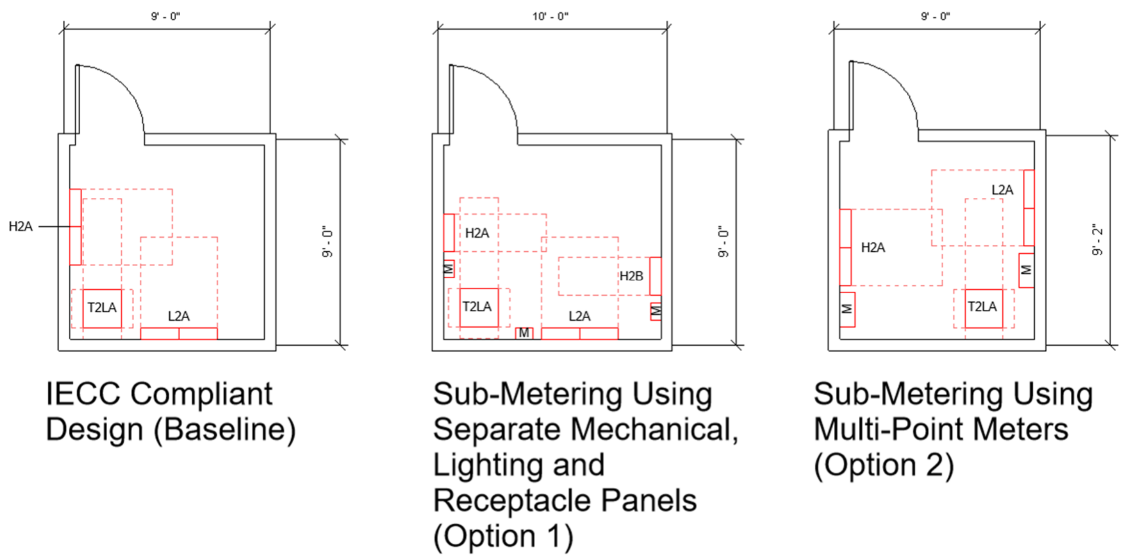

Figure 7.4. Electrical Room Layouts for Baseline Design and Options 1 and 2

The use of multi-point meters has additional benefits over providing separate panels for mechanical lighting and receptacles. If the building was ever changed from a single tenant per floor to multiple tenants per floor, the multi-point metering system could easily accommodate the change with no additional equipment required. Since each circuit is individually metered, tenants can utilize any circuit within the panels. The costs associated with the energy use for each circuit can easily be assigned to the tenant. Additionally, if there are any circuits that serve common areas, such as lobbies, corridors or exterior lighting, these loads can be separately metered and paid for by the building owner. The same is true for any shared equipment, such as elevators, chillers or domestic water heaters.

Changing from a single tenant per floor to multiple tenants would require additional costs and equipment if the building was originally designed following Option 1. Any new tenant would need to install a separate sub-fed panel and sub-meter for their HVAC loads, lighting loads and receptacle loads. These three additional panels and sub-meters could prove challenging to physically fit into the electrical room. Additionally, it would not be possible to separate out loads for shared spaces and equipment without adding another panel and sub-meter specifically for the house loads.

Although the multi-point meter offers additional flexibility, both offer significant benefits over the baseline design with no sub-metering. As has been mentioned in Chapter 2 - the implementation of metering will allow the building owner to better understand how and where energy is used within the building. The meters can help identify potential issues and energy efficiency measures that will help reduce overall energy costs. The meters will more readily allow for a Level 2 energy audit to be performed without requiring many, if any, additional temporary meters to be installed.

It is evident that for this case study, a multi-point meter solution is a better option than providing individual panels for mechanical, lighting and receptacle loads. A preliminary estimate of the two designs shows that the costs are essentially the same. Option 1 has increased cost due to the addition of the sub-meters, multiple panels and multiple feeders. Option 2 has increased costs due to the multi-point meters and the current transformers. Option 2 was priced with the ability to individually meter every circuit in the building for a total of 624 current transformers. In this case, the added flexibility of the multi-point system easily makes this the better option.

As has been previously mentioned, the cost to install metering equipment for either option is significant compared to the baseline design. At a premium of approximately 30%, the added cost of implementing sub-metering must be justified if it is not a code requirement. In this design case, the added cost to provide sub-metering is approximately $58,000 for the building. It has been previously mentioned that tenants who pay for their own electricity usage typically consume 15-30% less energy than tenants who pay a flat rate based on the square footage they occupy. However, a tenant or owner who is already paying for their own electricity will see significantly less energy savings by installing sub-meters. It is estimated that a 5-10% energy savings is common as a result of addressing issues and implementing EEMs that are identified through the use of sub-meters[29]. Assuming this building is located in Kansas and matches the average Midwest energy use intensity of 15.3 kWh/SF[30] of an office space, the total annual energy usage would be 1,224,000 kWh/year. Using the average price of commercial electricity in 2018 of $0.1066/kWh[31], the total annual electricity cost for the building would be $130,478. If the addition of sub-metering results in a conservative 5% reduction in energy use, or $6,500/year, the building owner would see a simple payback period of just under 9 years. A savings of 10% would cut the time in half to 4.5 years.

The above example includes both the material costs involved with adding meters. Labor costs can vary widely, depending on where in the country the install takes place and who is installing the materials (apprentice, journeyman, foreman, or project manager.). Recognizing that each of the aforementioned workers will have a role in the procuring, pricing and installing the materials, an average rate of $90 per hour was used in the labor cost calculations. This accounts for the base hourly rate of the employees as well as profit and burden.

Actual results, costs and savings will inevitably vary from project to project, however in the example case study, it was found that the cost of implementing sub-meters was significant. However, sub-metering offers several benefits and flexibility in how the building is utilized in

[29] "General Information Leaflet 65."

[30] "2012 CBECS Electricity Consumption and Conditional Energy Intensity by Census Region."

[31] "2018 Average Monthly Bill-Commercial."

the future. The sub-meters will likely help reduce energy usage with the help from reviewing data gleaned from the meters or through an energy audit. The end result is a better performing building that will offset the initial cost of the sub-meters in an estimated 7 years or less.

Chapter 8 - Conclusions

In an attempt to reduce the overall energy consumption of buildings, several energy codes and standards have begun implementing requirements for sub-metering of various end-use equipment. The sub-meters alone will not change energy usage, but the data generated by them has the potential to reduce electrical consumption by an average of 5-10% for users already paying for their own electrical consumption, or 15-30% for tenants being billed on a square footage basis. Currently, including sub-metering in the electrical systems design comes with a significant cost premium. As more standards adopt sub-metering requirements, the demand for products that easily allow the design to meet the requirements will increase. With the increase in demand, it is hopeful that the initial costs for the necessary equipment will decrease. Additionally, the increased demand will put increased pressure on manufacturers to come up with new and innovative solutions.

Several manufacturers are currently working on new technologies that will change the way we think of breakers and meters. In the future, breakers will have built in metering capabilities and will be intelligent enough to automatically alert users to problems in the system or higher than normal energy usage. Future research in this area will be needed as manufacturers continue to develop and release these new pieces of equipment. Additional research is also needed to address potential security concerns with making energy use data widely available to building owners and occupants.

Until these new breakers arrive on the market, the current best technology is the use of multi-point meters for monitoring individual circuits. The added cost of a multi-point meter with associated current transformers provides building owners a much more thorough and in depth understanding of where and how energy is used, since each individual breaker is separately metered. The system also allows for more flexibility when leasing a space to multiple tenants while still allowing each tenant to track their individual energy consumption.

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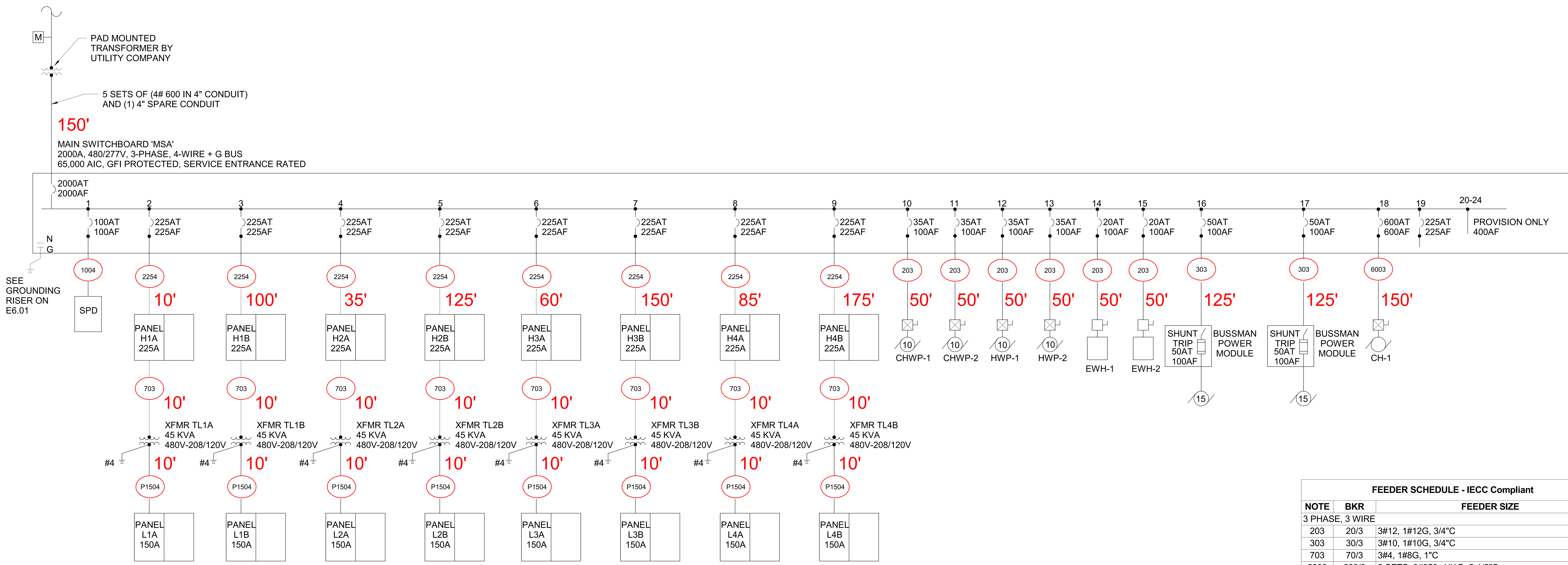
Appendix A - Case Study One-line Diagrams



FEEDER SCHEDULE - IECC Compliant		
NOTE	BKR	FEEDER SIZE
3 PHASE, 3 WIRE		
203	20/3	3#12, 1#12G, 3/4"C
303	30/3	3#10, 1#10G, 3/4"C
703	70/3	3#4, 1#8G, 1"C
6003	600/3	2 SETS: 3#350, 1#1G, 2-1/2"C
3 PHASE, 4 WIRE		
1004	100/3	4#1, 1#8G, 1-1/2"C
2254	225/3	4#4/0, 1#4G, 2-1/2"C
3 PHASE, 4 WIRE, XFMR TO FIRST DISCONNECT		
P1504	150/3	4#1/0, 1#6G, 2"C

KSU

KSU ARE/CNS BUILDING

BASELINE DESIGN ONE LINE DIAGRAM

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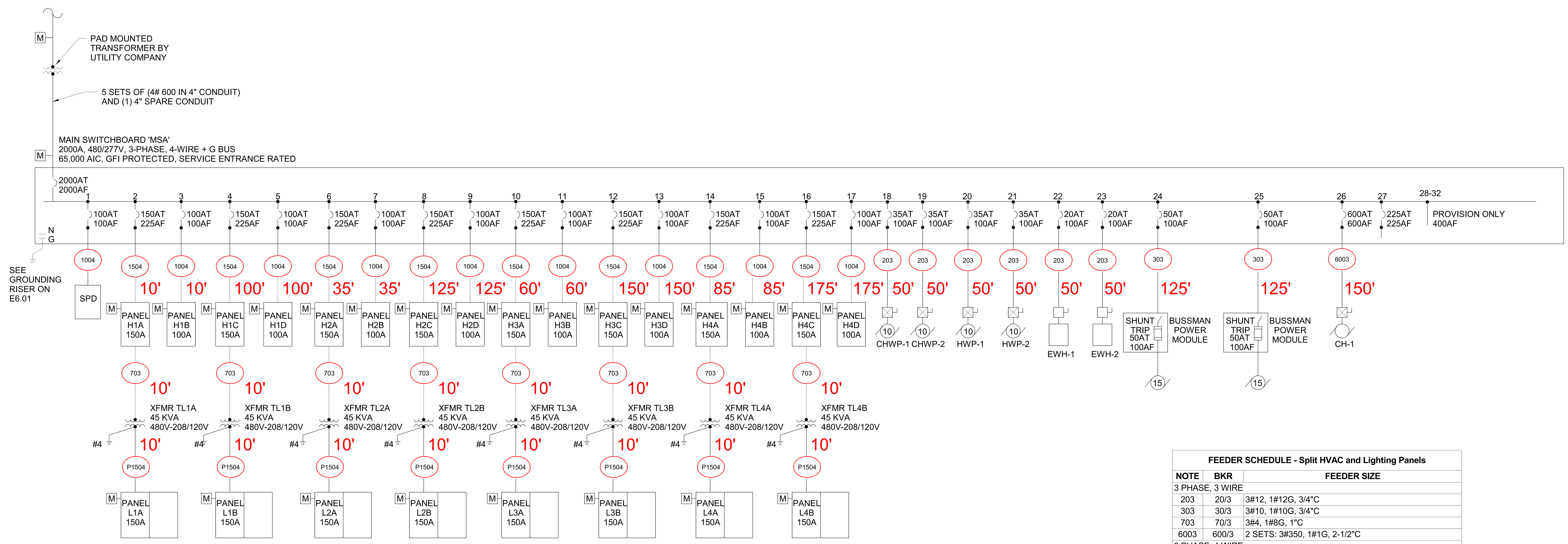

FEEDER SCHEDULE - Split HVAC and Lighting Panels

NOTE	BKR	FEEDER SIZE
3 PHASE, 3 WIRE		
203	20/3	3#12, 1#12G, 3/4"C
303	30/3	3#10, 1#10G, 3/4"C
703	70/3	3#4, 1#8G, 1"C
6003	600/3	2 SETS: 3#350, 1#1G, 2-1/2"C
3 PHASE, 4 WIRE		
1004	100/3	4#1, 1#8G, 1-1/2"C
1504	150/3	4#1/0, 1#6G, 2"C
3 PHASE, 4 WIRE, XFMR TO FIRST DISCONNECT		
P1504	150/3	4#1/0, 1#6G, 2"C

KSU

KSU ARE/CNS BUILDING

OPTION 1 ONE LINE DIAGRAM

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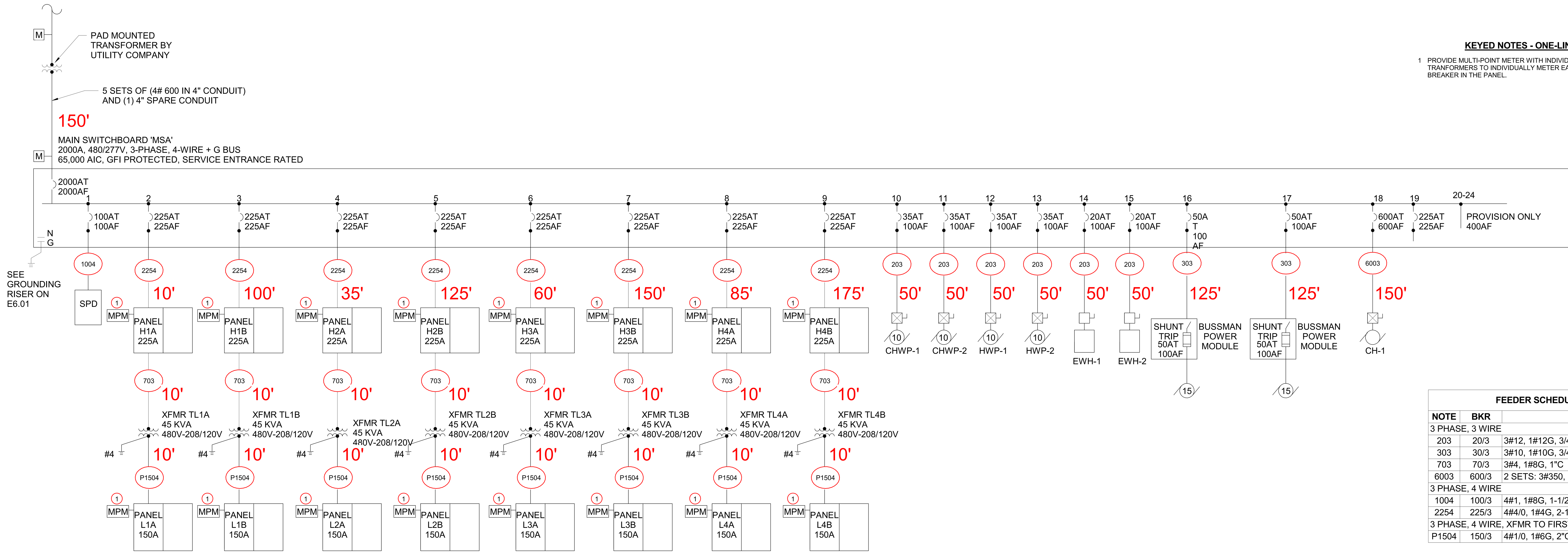

KEYED NOTES - ONE-LINE

1 PROVIDE MULTI-POINT METER WITH INDIVIDUAL CURRENT TRANFORMERS TO INDIVIDUALLY METER EACH CIRCUIT BREAKER IN THE PANEL.

FEEDER SCHEDULE - Multi-Point Meter

NOTE	BKR	FEEDER SIZE
3 PHASE, 3 WIRE		
203	20/3	3#12, 1#12G, 3/4"C
303	30/3	3#10, 1#10G, 3/4"C
703	70/3	3#4, 1#8G, 1"C
6003	600/3	2 SETS: 3#350, 1#1G, 2-1/2"C
3 PHASE, 4 WIRE		
1004	100/3	4#1, 1#8G, 1-1/2"C
2254	225/3	4#4/0, 1#4G, 2-1/2"C
3 PHASE, 4 WIRE, XFMR TO FIRST DISCONNECT		
P1504	150/3	4#1/0, 1#6G, 2"C

KSU

KSU ARE/CNS BUILDING

OPTION 2 ONE LINE DIAGRAM

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Appendix B - Case Study Cost Estimate

Option 1- IECC Compliant Design (Baseline Design)					
Gear:	**Qty**	**Unit Price**	**Total**	**Labor**	**Labor Total (hrs)**
MSA	1	$ 30,000.00	$ 30,000.00	17.5	17.5
MSA SPD	1	$ 2,250.00	$ 2,250.00	2	2
225a DT 480/277V	8	$ 1,600.00	$ 12,800.00	8	64
SPD Addition	8	$ 1,000.00	$ 8,000.00	0.5	4
45 KVA Transformer	8	$ 1,650.00	$ 13,200.00	12	96
150a DT 208/120V	8	$ 950.00	$ 7,600.00	7	56
SPD Addition	8	$ 650.00	$ 5,200.00	0.5	4
		Total Gear:	**$ 79,050.00**		**243.5**
Feeders:	**Length**	**Price/100'**	**Material $**	**Labor per 100'**	**Labor Total (hrs)**
UT to MSA	150	$ 23,334.00	$ 35,000.00	183.3	275
MSA to H1A	10	$ 3,250.00	$ 325.00	70.0	7
MSA to H1B	100	$ 1,025.00	$ 1,025.00	19.0	19
MSA to H2A	35	$ 1,500.00	$ 525.00	22.9	8
MSA to H2B	125	$ 1,080.00	$ 1,350.00	16.8	21
MSA to H3A	60	$ 1,292.00	$ 775.00	20.0	12
MSA to H3B	150	$ 1,100.00	$ 1,650.00	16.0	24
MSA to H4A	85	$ 1,206.00	$ 1,025.00	17.6	15
MSA to H4B	175	$ 1,086.00	$ 1,900.00	16.0	28
MSA to CHWP-1	50	$ 200.00	$ 100.00	10.0	5
MSA to CHWP-2	50	$ 200.00	$ 100.00	10.0	5
MSA to HWP-1	50	$ 200.00	$ 100.00	10.0	5
MSA to HWP-2	50	$ 200.00	$ 100.00	10.0	5
MSA to EWH-1	50	$ 200.00	$ 100.00	10.0	5
MSA to EWH-2	50	$ 200.00	$ 100.00	10.0	5
MSA to ELEV-1	125	$ 200.00	$ 250.00	7.6	9.5
MSA to ELEV-2	125	$ 200.00	$ 250.00	7.6	9.5
MSA to CH-1	150	$ 5,000.00	$ 7,500.00	46.7	70
	Total Feeder:		**$ 52,175.00**		528
	Total Material:		**$ 131,225.00**	Total Labor:	771.5
				Labor cost/Hr:	$90
				Labor Cost:	**$69,435.00**
	Total Cost (Material+Labor):		**$ 200,660.00**		

*Pricing and labor values come from Trimble Accubid and represent typical values in the Kansas City, Kansas Area

Option 1- Sub-Metering Using Separate Mechanical, Lighting and Receptacle Panels					
Gear:	**Qty**	**Unit Price**	**Total**	**Labor**	**Labor Total (hrs)**
MSA	1	$ 30,000.00	$ 30,000.00	17.5	17.5
Metering Addition	1	$ 5,000.00	$ 5,000.00	2	2
MSA SPD	1	$ 2,250.00	$ 2,250.00	2	2
150a 480/277V	8	$ 1,050.00	$ 8,400.00	4	32
Metering Addition	8	$ 1,250.00	$ 10,000.00	2	16
100a 480/277V	8	$ 950.00	$ 7,600.00	3	24
Metering Addition	8	$ 975.00	$ 7,800.00	2	16
SPD Addition	16	$ 650.00	$ 10,400.00	0.5	8
45 KVA Transformer	8	$ 1,650.00	$ 13,200.00	12	96
150a DT 208/120V	8	$ 950.00	$ 7,600.00	7	56
SPD Addition	8	$ 450.00	$ 3,600.00	0.5	4
Metering Addition	8	$ 1,125.00	$ 9,000.00	2	16
		Total Gear:	**$ 114,850.00**		**289.5**
Feeders:	**Length**	**Price/100'**	**Material $**	**Labor per 100'**	**Labor Total (hrs)**
UT to MSA	150	$ 23,334.00	$ 35,000.00	183.3	275
MSA to H1A	10	$ 3,250.00	$ 325.00	70.0	7
MSA to H1B	10	$ 2,800.00	$ 280.00	60.0	6
MSA to H1C	100	$ 1,025.00	$ 1,025.00	19.0	19
MSA to H1D	100	$ 925.00	$ 925.00	17.0	17
MSA to H2A	35	$ 1,500.00	$ 525.00	22.9	8
MSA to H2B	35	$ 1,143.00	$ 400.00	22.9	8
MSA to H2C	125	$ 1,080.00	$ 1,350.00	16.8	21
MSA to H2D	125	$ 940.00	$ 1,175.00	15.2	19
MSA to H3A	60	$ 1,292.00	$ 775.00	20.0	12
MSA to H3B	60	$ 1,000.00	$ 600.00	16.7	10
MSA to H3C	150	$ 1,100.00	$ 1,650.00	16.0	24
MSA to H3D	150	$ 917.00	$ 1,375.00	14.7	22
MSA to H4A	85	$ 1,206.00	$ 1,025.00	17.6	15
MSA to H4B	85	$ 971.00	$ 825.00	15.3	13
MSA to H4C	175	$ 1,086.00	$ 1,900.00	16.0	28
MSA to H4D	175	$ 929.00	$ 1,625.00	14.3	25
MSA to CHWP-1	50	$ 200.00	$ 100.00	10.0	5
MSA to CHWP-2	50	$ 200.00	$ 100.00	10.0	5
MSA to HWP-1	50	$ 200.00	$ 100.00	10.0	5
MSA to HWP-2	50	$ 200.00	$ 100.00	10.0	5
MSA to EWH-1	50	$ 200.00	$ 100.00	10.0	5
MSA to EWH-2	50	$ 200.00	$ 100.00	10.0	5
MSA to ELEV-1	125	$ 200.00	$ 250.00	7.6	9.5
MSA to ELEV-2	125	$ 200.00	$ 250.00	7.6	9.5
MSA to CH-1	150	$ 5,000.00	$ 7,500.00	46.7	70
	Total Feeder:		**$ 59,380.00**		648
	Total Material:		**$ 174,230.00**	Total Labor:	937.5
				Labor cost/Hr:	$90
				Labor Cost:	**$84,375.00**
	Total Cost (Material+Labor):		**$ 258,605.00**		
	Total Increase vs Baseline:		**$ 57,945.00**		
	% Increase vs Baseline:		**29%**		
	Total Increase vs Option 2:		**$ 269.00**		
	% Increase vs Option 1:		**0%**		

*Pricing and labor values come from Trimble Accubid and represent typical values in the Kansas City, Kansas Area

Option 2- Sub-Metering Using Multi-Point Meters					
Gear:	**Qty**	**Unit Price**	**Total**	**Labor**	**Labor Total (hrs)**
MSA	1	$ 30,000.00	$ 30,000.00	17.5	17.5
Metering Addition	1	$ 5,000.00	$ 5,000.00	2	2
MSA SPD	1	$ 2,250.00	$ 2,250.00	2	2
225a DT 480/277V	8	$ 1,450.00	$ 11,600.00	8	64
Multi-Point Meter	8	$ 2,250.00	$ 18,000.00	5	40
SPD Addition	8	$ 650.00	$ 5,200.00	0.5	4
45 KVA Transformer	8	$ 1,650.00	$ 13,200.00	12	96
150a DT 208/120V	8	$ 950.00	$ 7,600.00	7	56
SPD Addition	8	$ 450.00	$ 3,600.00	0.5	4
Multi-Point Meter	8	$ 1,850.00	$ 14,800.00	5	40
Current Transformers	624	$ 20.00	$ 12,480.00	0.1	62.4
		Total Gear:	**$ 123,730.00**		**387.9**
Feeders:	**Length**	**Price/100'**	**Material $**	**Labor per 100'**	**Labor Total (hrs)**
UT to MSA	150	$ 23,334.00	$ 35,000.00	183.3	275
MSA to H1A	10	$ 3,250.00	$ 325.00	70.0	7
MSA to H1B	100	$ 1,025.00	$ 1,025.00	19.0	19
MSA to H2A	35	$ 1,500.00	$ 525.00	22.9	8
MSA to H2B	125	$ 1,080.00	$ 1,350.00	16.8	21
MSA to H3A	60	$ 1,292.00	$ 775.00	20.0	12
MSA to H3B	150	$ 1,100.00	$ 1,650.00	16.0	24
MSA to H4A	85	$ 1,206.00	$ 1,025.00	17.6	15
MSA to H4B	175	$ 1,086.00	$ 1,900.00	16.0	28
MSA to CHWP-1	50	$ 200.00	$ 100.00	10.0	5
MSA to CHWP-2	50	$ 200.00	$ 100.00	10.0	5
MSA to HWP-1	50	$ 200.00	$ 100.00	10.0	5
MSA to HWP-2	50	$ 200.00	$ 100.00	10.0	5
MSA to EWH-1	50	$ 200.00	$ 100.00	10.0	5
MSA to EWH-2	50	$ 200.00	$ 100.00	10.0	5
MSA to ELEV-1	125	$ 200.00	$ 250.00	7.6	9.5
MSA to ELEV-2	125	$ 200.00	$ 250.00	7.6	9.5
MSA to CH-1	150	$ 5,000.00	$ 7,500.00	46.7	70
	Total Feeder:		**$ 52,175.00**		528
	Total Material:		**$ 175,905.00**	Total Labor:	915.9
				Labor cost/Hr:	$90
				Labor Cost:	**$82,431.00**
	Total Cost (Material+Labor):		**$ 258,336.00**		
	Total Increase vs Baseline:		**$ 57,676.00**		
	% Increase vs Baseline:		**29%**		

*Pricing and labor values come from Trimble Accubid and represent typical values in the Kansas City, Kansas Area

Appendix C - Energy Efficiency Measures

The following are common low or no cost energy efficiency measures (EEMs) that can be implemented for commercial buildings:

- Increase thermostat setpoint by 1° during summer months and decrease by 1° in winter months
- Install vacancy sensors to turn off lighting when spaces are unoccupied
- Tie variable air volume boxes and fan powered boxes to vacancy sensors to damper down when spaces are unoccupied
- Set computers to sleep or hibernation mode when not in use
- Install timers for coffee machines
- Utilize power strips that shut off power to devices not in use, eliminating vampire draw
- Utilize laptops instead of desktop computers
- Decrease water heater output temperatures to 120°
- Change air filters in HVAC systems
- Clean refrigerator coils
- Perform regular maintenance on pumps, motors and HVAC equipment
- Utilize shades or blinds to decrease heat gain
- Seal penetrations in the building envelope
- Replace outdated incandescent and fluorescent lamps with LEDs
- Use task lighting in lieu of room lighting
- Install dimming controls for lighting
- Establish "high-end trim" settings for dimming controls to reduce typical light output from 100% to 90%