This paper has been developed to outline a suburban office complex power monitoring system that was implemented by BLDG Services Group Inc (BSG) in 2011. The power monitoring systems configuration, operation and use at the facility is discussed herein.

Introduction

The implementation of power monitoring in an office building environment provides the users of these systems with a unique insight into the performance of many aspects of an office building. Such systems provide the ability to troubleshoot building operations issues on many levels and specific to multiple systems. The ability to correlate between electrical distribution, mechanical systems and devices, lighting systems and controls, along with consumption patterns of the base building systems and tenant suites allows for a deeper understanding of today's modern building systems and controls and the benefit of seeing optimization opportunities that are not visible when the building systems and tenant activities cannot be seen together as a larger system or in a holistic manner.

This paper attempts to provide both a description of the power monitoring system in terms of implementation and use, as well as to provide some examples of the benefits and savings that have been achieved through its use.

The Facility

The facility in which this power monitoring system was implemented is the Steppes Business Campus. The Steppes is located in Edmonton Alberta, Canada and incorporates approximately 75,000 square feet of office space in 2 buildings. The Steppes construction was completed in 2008 was based upon a sustainable building design. The Steppes is also operated with a focus on environmental friendly and sustainable principles that have resulted in its receiving the BOMABest - Level 4 green building operational award in 2011 and the BOMA Earth Award in 2012. Additionally, the Steppes, has been found to have the lowest potable water consumptions of any surveyed office building in Canada based on the Realpac 2010 study of office building water consumption.

The result of the building management company's efforts toward sustainable operation has resulted in some of the lowest operating cost per unit area of any building in the region while maintaining an A class standard in terms of comfort, quality and amenities.

The office campus buildings share a common base heating and cooling system, but have independent fresh air supply systems. The buildings above grade areas are heated and cooled with water-to-air zone based heat pumps that use a hybrid geothermal and low temperature boiler source water supply. The fresh air supply is provided via make up air handling units that produce the entire make up air volume with fresh air controlled based on variable air volumes and indoor air quality (through carbon dioxide measurement).

A rain water collection and treatment plant provides supply for non potable application including, water supply to toilets, irrigation and wash water supply.

A facility performance audit is performed by the building management and operations company each year with the first study being performed in 2009. Due to the availability of the data through the power monitoring system implemented in 2011, this year, 2012 will be the first year that the performance audit will be based in a large part on empirical data specific to electrical consumption patterns within the facility.

The Design

The system design was developed to provide flexibility for viewing, isolating distribution and consumption by location or groups, consolidating and developing complex data types, and correlation of data with other building systems. To achieve this it was decided to develop the database and display in the existing building management system (BMS) which is based on the Tridium supervisory controller. As well, it was decided to pursue a power monitoring hardware platform that provided the data for both diagnostics and revenue metering and that could be integrated quickly and inexpensively into the exiting BMS. Additionally it was decided to segregate the HVAC control network from the power monitoring network and as such a dedicated Modbus network was chosen for the power monitoring system as it represented the widest support in the industry for power monitoring devices and was available as a supported protocol of the BMS.

The deployment of the power monitoring hardware data acquisition devices and transducers required that they be installed in immediate proximity to the power source being monitored. As such, and to minimize the cost of deployment and installation all base building distribution panels were monitored at the primary distribution points to the panel rather than at the panel locations resulting in the requirement for only 2 power monitoring device boxes to be installed. This design both reduced the time to deploy and allowed for consolidated circuit protection and distribution terminal strips and therefore reduced capital cost for support equipment. Additional device boxes were required to isolate sub circuits within distribution panels to allow for independent power monitoring of tenant suites were those suites shared a primary distribution panel.

The facilities primary distribution system is based on a 600 volt 3 phase supply with localized transformation to 110/208 volt. All primary distribution panels (13 in total) were included for monitoring. An additional 3 sub circuits were also required to be monitored to allow for tenant specific sub metering. With the addition of the primary service the total number of metering points was 17.

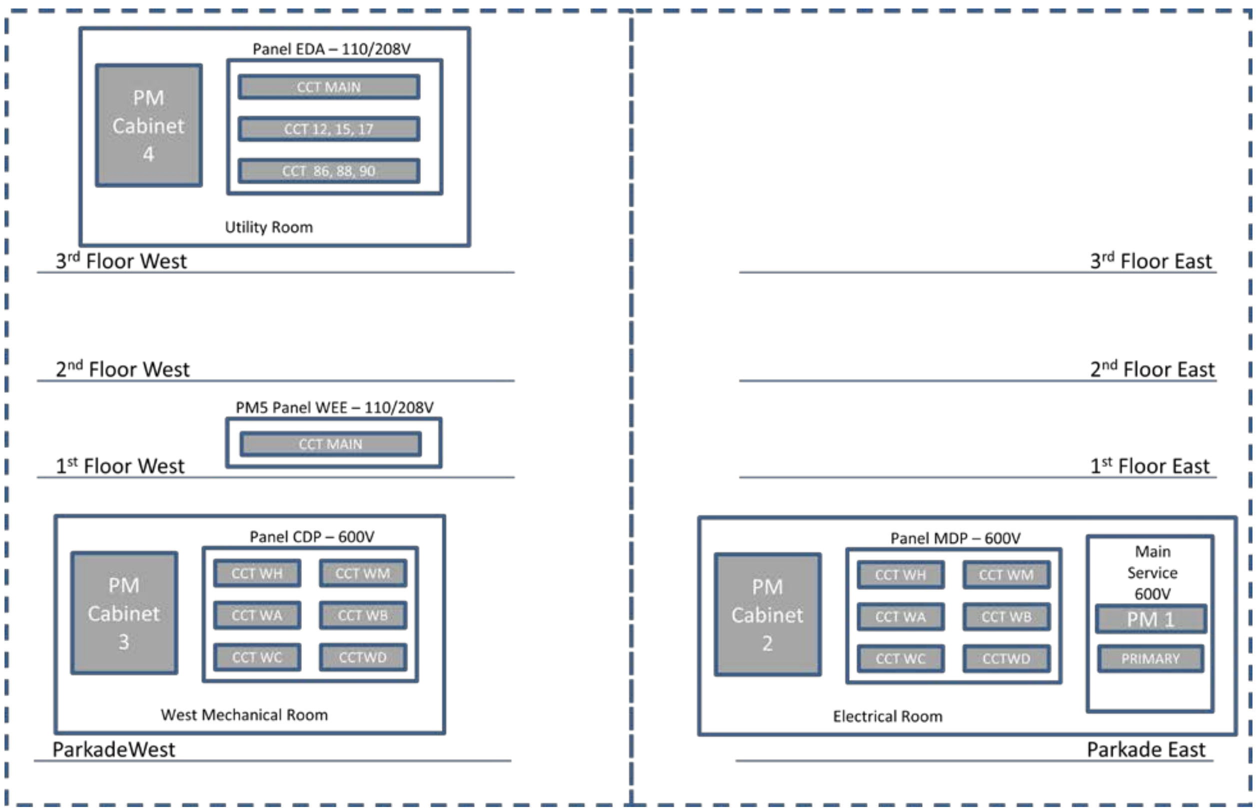

Figure 1 - System Design Schematic

Implementation

The power monitoring systems was implemented in stages from April of 2011 and through July of 2011. The first stage was a pilot project involving the primary services. The intent of the pilot project was to test the communications interface and to gain experience with the system specific to registers, the behavior of the system hardware, and to test custom controls that were developed to perform such functions as reset cumulative power measurements on timed intervals as well as to develop the user interface.

The next phase of installation included the primary distribution panels monitoring hardware was installed in each of the 2 buildings. This hardware was interfaced with the power monitoring network and integrated in to the BMS. Commissioning of this phase was completed at the end of June 2011. The final phase of power monitoring included tenant sub metering on individual floors. Commissioning of this phase was completed at the end of August of 2011.

Measured Parameters

At the main service panel the following parameters are measured;

- Line voltage and phase A, B, and C
- Line to line voltage and phases AB, BC, and CC
- Average voltage
- Current on each phase A, B, and C
- Average current
- Line frequency
- Real power
- Apparent power
- Energy consumption
- Voltage imbalance
- Current imbalance
- Power Factor

At each 600 volt distribution panels the following parameters are measured;

- Line voltage and phase A, B, and C
- Current on each phase A, B, and C
- Real power
- Energy consumption month to date

Tenant areas measured parameters are aggregated when more than one distribution panel provides power to a single tenant. In the case of multiple tenants on a single panel individual circuit metering is used to derive the individual tenant power use.

Calculated Values

Calculated values were developed to provide complex data types that can provide a “dash board’ view of different distribution points and tenant consumption patterns. These calculated values included:

- percent power use is calculated for each distribution panel and for each tenant,
- tenant estimated energy cost month to date,
- estimated CO_2 emissions month to date and,
- power use per unit area (watts per square foot)

Graphic Interface

The graphic interface to the power monitoring system is provided through the building management system which is a web based graphic display. Screen shots of the graphic interface are included in the end of this report.

Each of the following is represented by an individual graphic. All points on the graphic, including bar charts, are hyperlinked to their associate trend. Trends are 30 days in duration, with the exception of tenant power consumption, which has a one year duration but shown in monthly intervals.

- The main service
- 600V Distribution panels

Each distribution panel has a drill down screen that identifies individual power parameters

- Tenant power use
- Tenant relative power use

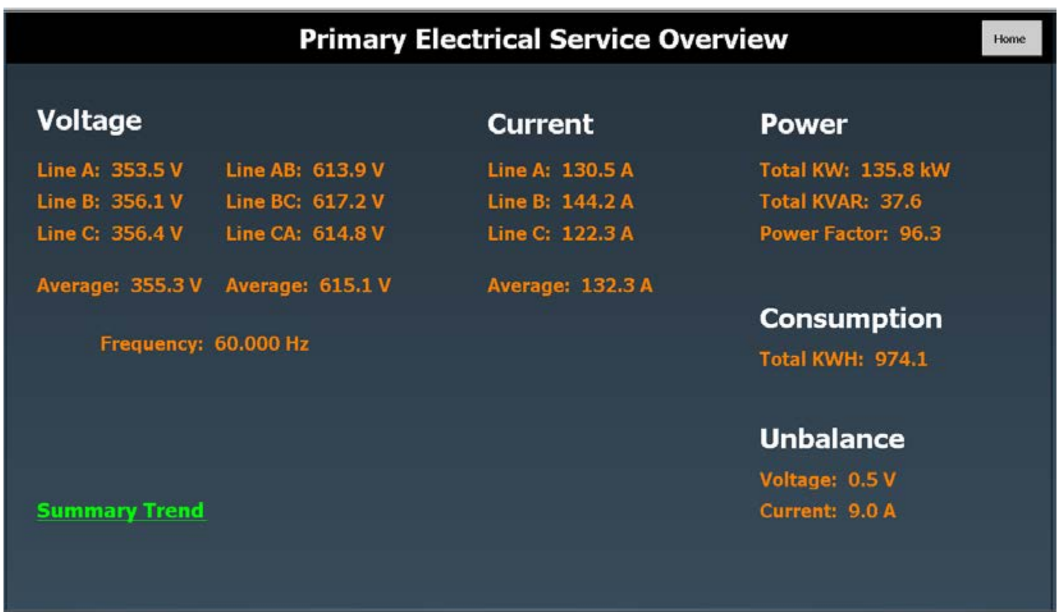

Figure 2 – Typical Individual Panel BMS Interface

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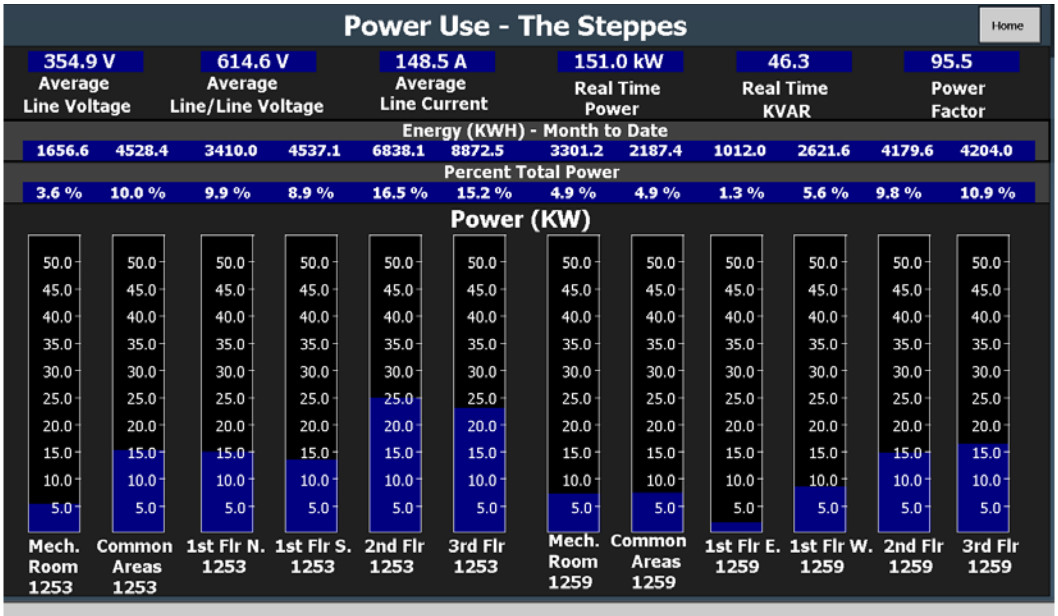

Figure 3 – Distribution Panels BMS Interface

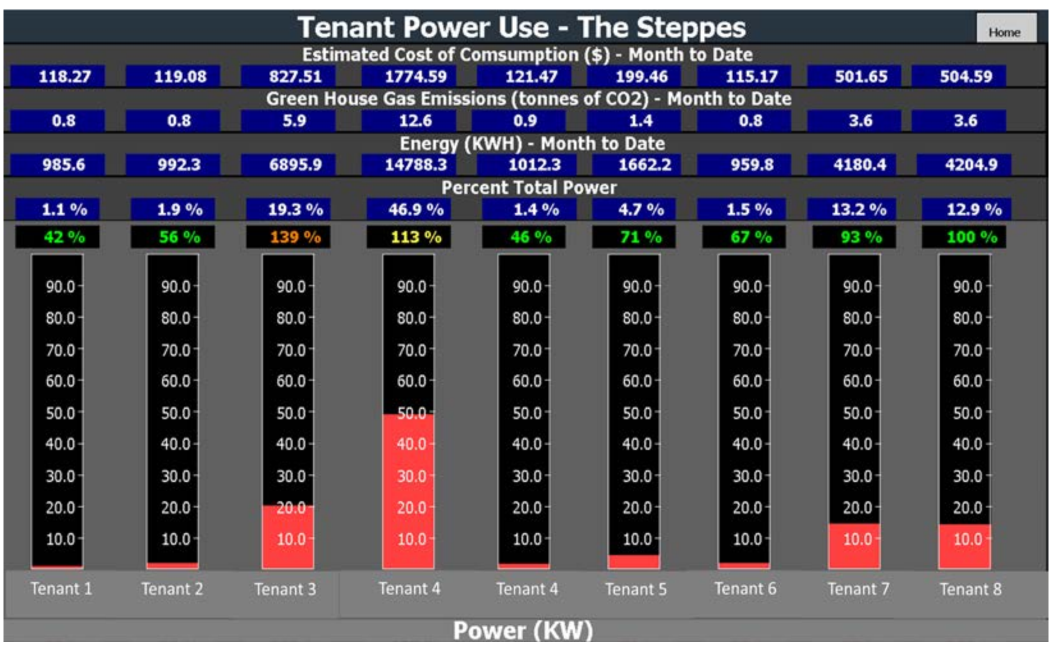

Figure 4 – Tenant Power Use BMS Interface

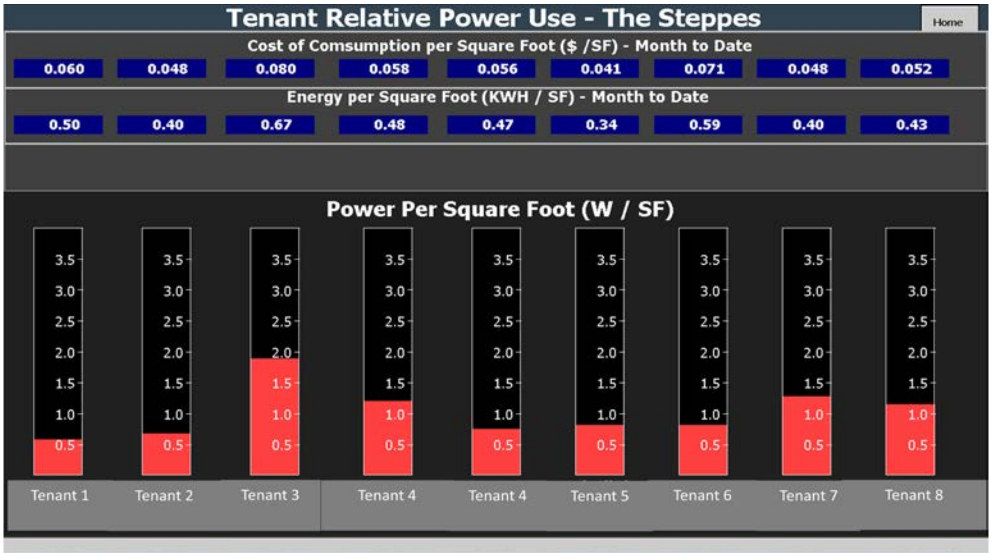

Figure 5 – Tenant Relative Power Use BMS Interface

System Success Stories

The power monitoring system has provided many insights into the consumption patterns of the base building and tenant suites as well as aided in troubleshooting and optimization of the electrical and mechanical systems. The system has also enabled building operations to quantify the benefits of energy use reduction programs and in particular those programs that are based on changes to operational procedures and that are the most difficult to measure.

HVAC Optimization

The power monitoring system is used to identify and prioritize HVAC optimization programs as well as to assess and quantity the effects of controls changes on energy consumption.

In this facility there are multiple cooling systems and the cost to operate those systems is relative to the buildings operating mode and outdoor conditions. By correlation of energy consumption to outdoor air temperature a cooling control schema was developed that stages and switches between cooling systems to minimize power consumption based on operational and environmental conditions. The result of this controls change based on power monitoring has lead to a more stable and more efficient cooling system.

Another case in which the power monitoring system was used to aid in optimization was the measurement of energy consumption of the water to air heat pumps that are used to condition the above grade spaces. An opportunity to access free cooling under certain outdoor conditions required that the supply temperature of the heat pump water loop be lowered by 2 degrees C when the building was in a primarily heating mode and increased by 2 C when the building was in a primarily cooling mode. Without the power monitoring system data the effects on power consumption of the heat pumps relative to this change would be very difficult to measure empirically. However, with the power monitoring data available it was quite simple to quantify the implications of this changes and it was found to be a viable method of accessing free cooling in shoulder season and warmer winter days.

HVAC Trouble Shooting

The power monitoring systems has aided in HVAC system trouble shooting on several occasions. During a period of very cold weather over night it was found the heat pumps in some the tenant suites were not able to maintain the heating set point although the sizing of the system was confirmed to be adequate to do so. This circumstance lead to a diagnostic focus on individual heat pump operation performance and questioning of heat pump supply water flow rates that lead to no resolution of the issue. Upon review of the power consumption trends for the affected areas it was found that there was no power consumption attributable to the heat pumps under questions and as such they were simply not running even though they were confirmed to operate the day following the incident. After correlation with the outdoor air temperature and the consumption patterns it was found that the heat pumps would fail to operate below -28 C. This lead to review of the controls and it was found that a number of the controllers had not been configured from the factory default value to stop operation below -28C to the building specification of -40C to accommodate the cold climate operating condition.

Tenant Sub-Metering

After the implementation of the power monitoring system the individual tenant power consumption patterns and levels were available for review and comparison. In review of these tenant specific consumption patterns and levels a number of issues were discovered.

The most significant of these issues was the existence of a large server array in a tenant suite that was found to represents over 8% of the total yearly power consumption for the project as a whole. As of 2012 the sub circuit supply the server array in question was retrofit with a revenue meter and the cost and allocation of that consumption is now borne exclusively by that tenant which will result in an 8% decrease in the energy consumption cost allocated to tenant operating cost.

Another issue that was found during this review was the quantity of waste that occurs due to both lighting intensity in tenant suites and lights left on during unoccupied periods. Lighting intensities were found to be 2.2 times the recommended levels of 1.0 watts per square foot of tenant suite floor area. A light audit was performed following this discovery and it has resulted in a re-lamping program for 2012 and the plans for in suite lighting controls program in 2013.

To deal with unoccupied lighting use building operations developed automated lights left on email alarms that are sent to tenant representative of lights left on during unoccupied hours. As well, the development of an automated lighting control system project occurred to deal eliminate the issue after its deployment in 2012.

Tenant Communications

Since the installation of the power monitoring system, and with the intent of engaging tenants in the process of energy conservation with an objective of effecting tenant behavior specific to energy consumption, the tenants receive a monthly score card. This score card lets them know their relative ranking in relation to other tenants of power consumption levels on a unitized basis. As well, it provides them with their green house gas emissions, approximate cost of consumption, and the number of occasion that their lights have been left on overnight. The reception by tenants to this communications has been mixed, but the performance of tenants relative to conservation has improved overall. It is intended in 2012 to provide this information in the form of a "tenant dashboard" via a web browser so that it will be available to any employee of the tenant to access and review. This will automate the dissemination of the information and hopefully provide a larger audience for it and therefore have a greater effect on consumption.

As a Training Tool

The power monitoring system has proven to be an effective training tool for facility managers, building operators, HVAC technicians and engineers. With the ability to have real time feedback and historical trends that can be correlated with ambient conditions and the other content of the BMS, concepts relating to building design and operation are easily illustrated and shown empirically rather than explained theoretically which has been found to better engage the individual being trained.

Results

System installation cost was $13,300.00. Although, the exact saving that can be directly attributable to this system are difficult to compute, the single example of the discovery tenant over consumption specific to the large server array results in simple return on capital, through reduced operating cost of the facility, of approximately 20 months.