UBC Social Ecological Economic Development Studies (SEEDS) Student Report

Evaluating Peak Demand Management Alternatives for the University of British Columbia

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CEEN 596 – Final Project Report

Evaluating Peak Demand Management Alternatives For the University of British Columbia

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Executive Summary

Recent UBC campus expansion has increased the demand for electricity and caused the existing transmission lines to frequently operate at their capacity during peak demand periods. BC Hydro estimates that the 100% redundant transmission capacity can be upgraded from 42 MVA to 62 MVA at a cost of $260k +/-30%. UBC estimates that it would need to invest approximately $10 million to upgrade the campus substations when the lines are upgraded beyond 62 MVA. The prospect of real-time pricing for electricity in British Columbia further in combination with the infrastructure limitations faced by UBC are keys reasons to evaluate the current potential for implementing peak demand management strategies at UBC. This report investigates peak demand management strategies and their potential usage at UBC. Successful peak demand management at large-scale institutions has been found to reduce peak demand by up to 15%.

A literature review was conducted to identify peak demand management strategies being implemented at other North American universities. The review indicated that peak demand management is generally limited to universities in areas with Time-of-Usage electricity pricing and/or universities with infrastructure limitations.

A qualitative assessment of UBC's ability to undertake peak demand management indicates that the university already has the infrastructure and knowledge to implement manual and simple semi-automated demand management strategies. Simple strategies such as adjusting temperature setpoints or lighting load reduction have the potential to make a meaningful contribution to reducing peak electricity demand at UBC; however care must be taken to design strategies that do not interfere with research needs. For the 16 buildings identified in phase 2 of this report, 2.3 MW or roughly 5% of the UBC peak could potentially be shifted or avoided. These are strategies that can be implemented immediately with little to no capital expenditures. The value of a peak demand management project that reduces the projected monthly peak by 5% in each month over the next 20 years is estimated to be $3,396,600.

Finally, simulations were conducted to evaluate the potential peak reduction of zone temperature adjustments and reductions in lighting loads at the Life Sciences Centre using the Demand Response Quick Assessment Tool (DRQAT). The results indicate that demand can be shifted away from the peak with minimal impact on building occupants; however additional field tests are needed to verify the simulations.

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Preface

The project satisfies the requirements for CEEN 596 – Masters of Engineering in Clean Energy Engineering Final project. In addition, this report has been written for a SEEDS (Social, Economic and Environmental Development Studies) project. The goal of the SEEDS program is to foster collaboration between students, faculty and staff while addressing real-life campus sustainability issues.

Acknowledgments

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Terminology

For the purposes of the report:

Electricity use refers generally to the electricity consumed by electricity consumers measured over any time period. This includes both annual consumption (energy) and instantaneous load (power).

Energy efficiency strategies refer to actions taken that reduce both peak and off-peak electricity demand.

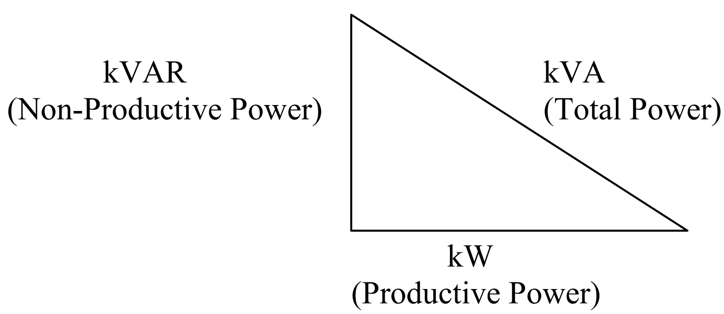
Load shedding refers to a temporary reduction of peak electric demand for maintaining system integrity or achieving economic savings. Activities can either be transparent or minimally intrusive demanding on the urgency of the need to shed the load.

Load shifting refers to consuming electricity at a different time to cause a flattening of the demand curve, and is typically used to avoid transmission capacity issues during peak demand or to benefit from time-of-use rates.

Peak load is the maximum simultaneous electricity demand for some portion of the electrical system, typically averaged over an hour. It typically is characterized as annual, daily, or seasonal

The terms *demand* and *load* are used interchangeably.

Power factor is the ratio of the productive power to the total power in an AC electric power system. It is a dimensionless number between 0 and 1 (e.g. 0.75 pf = 75% pf). The relationship is shown in the power triangle below.



The relationship between kVA, kW and kVAR is non-linear and is expressed as:

$$kVA^2 = kW^2 + kVAR^2$$

Real power is the capacity of the circuit for performing work in a particular time.

Apparent power is the product of the current and voltage of the circuit.

Introduction

The University of British Columbia's (UBC) annual utility expense is expected to increase significantly in the coming years due to a sustained increase in campus size and energy prices. UBC will need to invest significant capital to upgrade the transmission lines serving the campus in order to maintain 100 % redundancy in the electricity transmission capabilities. Electrical generation and transmission systems are generally sized to correspond with peak demand; lowering peak demand reduces overall capital cost requirements. UBC has the potential to delay capital expenditures associated with transmission system upgrades by pursuing peak demand management strategies.

Purpose

The purpose of this research project is to investigate the potential for implementing peak electricity demand management strategies at UBC. The project has been constrained to focus on electricity use data for the main campus, excluding south campus and UBC-Okanagan. The UBC campus has more than 400 buildings with a total building area in excess of 1.1 million m^2 that contribute to peak electricity demand. The buildings can be broadly categorized as multi-purpose academic (classrooms, labs, & offices), student & staff housing, libraries, maintenance facilities, athletic facilities, and commercial. For the purposes of this project, evaluation of peak demand management strategies was limited to multi-purpose academic buildings and parkades. The strategies investigated and modeled as potential strategies for UBC focused optimizing existing infrastructure on campus.

Project Objectives

This primary objective of this research was to answer two important questions:

1) What peak demand management strategies would be suitable for UBC?
2) What are the barriers to implementing peak demand management at UBC?

A secondary objective was to develop an understanding of building management systems software and to simulate potential peak electricity demand management strategies involving pre-heating, pre-cooling and zone temperature adjustment using the Demand Response Quick Assessment Tool (DRQAT) for a campus building.

Background

Due to their size and role in fostering innovation, university campuses are of vital importance to shaping how electricity is consumed and conserved. The constraints of existing infrastructure (ie. transmission lines) can physically limit the amount of electricity that can be delivered. Electricity consumption peaks at predictable times each day, varying in magnitude throughout the year. These spikes in energy demand increase the cost of electricity and place a strain the power grid. One mechanism for managing these spikes is to implement peak demand management strategies, such as load shedding and load shifting. Evaluating potential peak demand management strategies on university campuses is often difficult due to the complexities introduced by central heating and cooling, non-coincident and diverse building loads, and an inadequate number of electrical metering points on campus and in buildings that are needed to support an active monitoring & verification program [1].

Electrical Transmission and Distribution at UBC

The UBC campus is serviced by two transmission lines, one of which can handle a peak load of 62 MVA while the other is line is currently limited to a 42 MVA peak load in the summer and 55 MVA peak load in the winter [2]. The transmission lines are linked to two substations, and electricity is subsequently distributed throughout the campus using 69 KV and 12 KV overhead and buried lines. Electrical transformers and switchgear are typically located in electrical rooms in each building [3]. According to BC Hydro, the overall campus power factor is roughly 98% as measured at the substation. A simplistic illustration of the UBC transmission system is shown in Figure 1.

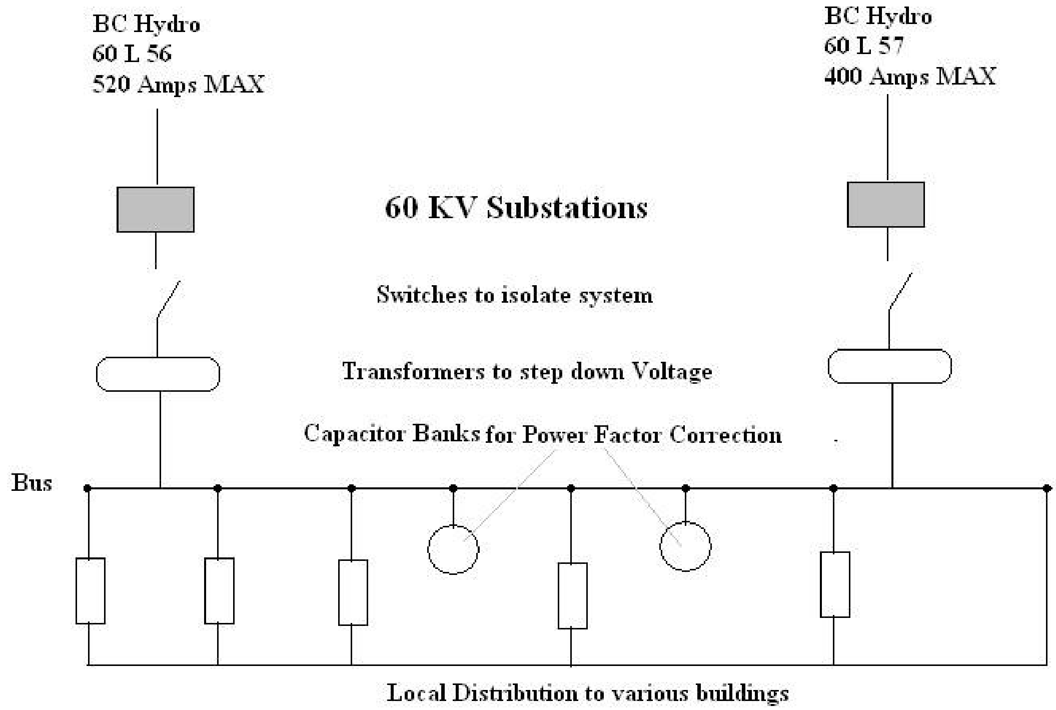


Figure 1 - Simplistic illustration of the UBC transmission system.

UBC purchases electricity from BC Hydro, spending $8.292 million in FY 2008/09. As of April 1st, 2010 the university pays a demand charge of $5.48/KVA and an energy charge of $32.12/MWh [4]. The university's steam plant and distribution network provides heating for the majority of campus buildings. Diesel generators provide emergency power for emergency medical systems and critical research equipment. UBC's annual utility expense is expected to continue to increase significantly due to a sustained increase in campus size as well as forecasted increases in natural gas and electricity prices. For billing purposes, the UBC campus electrical loads include all academic and tenant buildings, as well as student, staff and faculty housing. There are a number of recently developed private residential neighbourhoods in and around the UBC campus. These buildings are billed separately by BC Hydro.

UBC has a policy that mandates 100% redundancy in the transmission line capacity, implying that if one line were temporarily taken out of service, the other line would be capable of handling the campus's peak demand for electricity. On a number of occasions in the last two years the 15-minute peak demand at UBC has exceeded the maximum policy-mandated transmission capacity. In response, the University initiated an investigation to examine:

1. Infrastructural costs to increase redundant capacity to 62 MVA ((BC Hydro Project #60L57RC)
2. Infrastructural costs to increase redundant capacity above 62 MVA
3. Feasibility of implementing Demand Management to reduce peak demand

BC Hydro estimates that the upgrade of the south line to match the capacity of the other line (i.e. to increase the capacity from a summer peak load of 42 MVA to 62 MVA) will cost $260k +/-30% [2]. The investigation determined that the lines should ultimately be upgraded to 62 MVA and would require UBC to invest approximately $10 million to upgrade the campus substations, but the timing of the upgrade has yet to be determined [5]. The concerns outlined above make the investigation of peak demand management systems a high priority. Successful peak demand management at large-scale institutions has been found to reduce peak demand by up to 15% [6]. In 2009, UBC's electricity demand charges amounted to approximately $2.6 million, thus even a 10% reduction in peak demand (between 3.6 and 4.7 MW depending on the month) would result in savings of approximately $260,000 per year. Spees and Lave 2006 [6] suggest that peak load reductions are currently being achieved at $21/kW·y, or less than one fourth of the $94/kW·y it costs to build new capacity.

UBC Continuous Optimization Program

In partnership with BC Hydro, from 2010 to 2014 UBC will implement the Continuous Optimization program in 72 core academic buildings with the goal of optimizing energy use [7]. The program consists of four steps:

- *Step 1: Energy Audit* - A consultant will conduct an energy audit of a building and recommend energy efficiency measures along with identifying the expected savings.
- *Step 2: Implementation* - UBC Building Operations staff and contractors will make programming changes to the building management system software and conduct physical retrofits such as replacing lighting.
- *Step 3: Monitoring* - Electricity and steam meters for each building will be connected to Pulse Energy's energy management software for tracking and analysis by the energy manager. In addition, alerts will be set up so that Building Operations staff will quickly catch and rectify any abnormal energy use. Building occupants can view the energy consumption through the user-friendly dashboard interface and watch how the building's energy use changes in real-time
- *Step 4: Building operator training and coaching* - Building Operations personnel will be trained in using the tracking software and employing best management practices. Ongoing coaching will ensure that operators contribute to continuous energy savings.

For further information on this program please see the following webpage: http://www.sustain.ubc.ca/energy-optimization

Characterizing Peak Electricity Demand

There are a number of important factors to consider when designing peak demand management strategies [8]:

- **Climate**: Local climate is an important driver of peak electricity demand. In regions with warmer climates, the largest peak demand events tend to occur on the hottest days in the summer and are typically linked to air conditioning loads. In regions with cold climates, peak demand events occur on the coldest days in the winter and are typically linked to the demand for electric heating on the coldest days of the year. In regions of moderate climates, such as UBC, summer and winter peak electrical demand can be comparable in size. With the onset of climate change, scientists expect more frequent extreme weather days. This trend strengths the need to implement peak demand management strategies.
- **Building Usage**: The types of buildings and how they are operated are critical to characterizing the peak and understanding the elasticity of the demand for electricity. University campuses typically have complex electrical demand profiles caused by concentrated clusters of multi-purpose and specialty buildings where research occurs at all hours and classes continue late into the evening and on weekends.
- **Occupant comfort and productivity:** Strategies need to be mindful of the building occupants' comfort range. Acceptable lighting levels and temperature ranges should to be established in order to properly inform decision makers.
- **Behaviours and Habits of Building Occupants**: How people work and live on campus will have a direct impact on peak energy demand. For example, equipment and building ownership tends to affect peak demand.
- **Health and Safety**: energy management strategies should never compromise the health and safety of the building occupants.
- **Environmental impacts**: Strategies should be evaluated based on their impact on the local air quality, land use, water quality on other environmental indicators.
- **Security**: energy management strategies should never compromise the security of the building or its occupants.

What is Peak Demand Management?

Demand management activities are simply actions taken to manage the consumption of electricity. Peak demand management consists of actions intended to reduce electricity use in response to supply conditions or physical constraints in the electricity grid [9]. Peak demand management does not necessarily decrease total electricity consumption but can reduce the need for capital investments in transmission or generation system, and help avoid excessive costs in regions employing time of usage electricity pricing.

The rationale for peak electricity demand management falls under the follow two categories:

1) **Emergency** – Typically emergency peak demand management activities involve predefined loads being quickly removed from the grid in order to avoid an outage.

2) **Economic** – Peak demand management strategies for economic purposes are activities that can be initiated by either the customer or utility to help minimize costs in jurisdictions with time of day pricing and/or to help utilities manage daily system peaks.

Peak demand management activities can be categorized their implementation method:

- **Manual** demand management activities involve individuals manually turning off loads, such as lights or machinery, in response to a request to conserve power. .
- **Semi-automated** demand management activities involve the use of a pre-programmed response strategy initiated by a person via a centralized control system [10].
- **Fully automated** demand management activities involve the use of dedicated control systems that respond to electronic communications signals, such as electricity market prices or utility requests, and adjust loads according to a pre-planned load prioritization scheme [11]. Loads can actually be increased in off-peak times to make use of reduced pricing.

Peak Demand Management Strategies

Peak demand management strategies typically involve load shedding or load shifting. Load shedding refers to a temporary reduction of peak electric demand for maintaining system integrity or achieving economic savings. This is typically achieved through commercial building control strategies such as control strategies for HVAC, lighting and other miscellaneous building end-use systems [9]. Load shifting refers to consuming electricity at a different time to cause a flattening of the demand curve, and is typically used to avoid transmission capacity issues during peak demand or to benefit from time-of-use rates. This can be achieved through the utilization of thermal energy storage or building thermal mass [9]. Some other examples of peak demand management strategies include dimming or turning off non-critical lighting, adjusting build zone temperature set points and turning off non-critical equipment at times of peak electricity demand. Table 1 describes four broad strategies to be considered when developing strategies to reduce peak electricity demand.

When designing peak demand management strategies, or policies, many factors need to be considered including:

- Current electricity use profile,
- Climate
- Occupant comfort and productivity,
- Behaviours and habits of building occupants,
- Health and safety,
- Environmental impacts, and
- Security

Where feasible, peak demand management strategies should be considered as part of an integrated planning and operational framework, since the issues are often interconnected [8].

Table 1- Categorization of Peak Electricity Demand Management Strategies

Load Reducing and/or Shedding Strategies	These strategies seek to reduce service demands without impacting the economic benefit and maintaining satisfactory occupant comfort levels. Examples include the use of load controls for adjusting temperatures, and lighting, and design considerations such as the use of daylighting, shading and high albedo roofing materials [8].
Load Shifting Strategies	These strategies involve altering when the energy is consumed. Some examples of load shifting strategies include the use of energy storage and smart equipment controls. Thermal storage systems for cooling make ice or chilled water during off-peak times and then draw on that cooling reservoir during peak times to cool the building. Thermal storage systems for heating operate in a similar manner storing heat energy in molten salts or specially designed borehole thermal energy storage systems. Numerous appliances are now manufactured with smart controls with timers that direct the equipment to only operate during off-peak hours. Thermal storage can also be achieved by utilizing the building management software to cool down (or heat up) buildings in the early morning (off-peak), and then attempt to "ride out" the peak period using the existing building thermal mass and a higher (cooling) or lower (heating) thermostat set point.
High Efficiency Buildings & Equipment	All active demand contributes to the peak demand, so strategies that focus on utilizing high efficiency equipment serve the dual function of reducing the total energy consumed and reducing peak demand. Key areas where high efficiency equipment should be pursued include heating & cooling, lighting, refrigeration and building design.
On-site Combined Heat & Power	On-site electricity generation can be used as a peak demand management strategy and operated during times of peak demand. Alternatively, the equipment could be operated in a continuous mode to augment existing electricity supply. Through co-generation, waste heat from the electricity generation process can be used to supplement and/or avoid the generation of heat from other sources [12]. Other sources of on-site generation include solar PV, wind, fuel cells, biomass, and geothermal.

Demand Response Quick Assessment Tool

The Demand Response Quick Assessment Tool (DRQAT) is a software tool developed and maintained by the Demand Response Research Center at Lawrence Berkley National Labs in California. The software was developed to predict demand reduction, operating cost savings, and occupant thermal comfort impacts associated with peak demand management strategies focused on building thermal mass control. It utilizes prototypical buildings and equipment types and allows the user to specify just a few parameters in order to quickly assess the potential of the peak demand management strategy [13]. Users are able to compare peak power demand, operating costs, and comfort between the baseline and a customized strategy. Yin et al, 2010 [14] have shown that after refining and calibrating the initial DRQAT models with measured data, the accuracy of the model can be greatly improved. The authors were able to predict load reductions within ±5% of accuracy of measured for a variety of commercial and office buildings.

Methodology

This project has been broken down into three components:

1. A *literature review* was conducted to develop an understanding of peak electricity demand management and the strategies currently being pursued on North American University campuses.
2. A *qualitative assessment* was conducted to develop an understanding of UBC's current capacity to undertake peak demand management strategies.
3. A *demand response experimental simulation* was conducted to estimate the load shedding potential of a variety of strategies for the Life Sciences Centre on the UBC campus.

Literature Review

To develop an understanding of peak electricity demand management and the strategies currently being pursued on North American University campuses, a number of peer-reviewed publications discussing peak demand management strategies were reviewed. An email questionnaire was sent to 15 North American universities with customized questions regarding the energy efficiency and peak demand management initiatives being implemented on their campus. To support the custom development of the questionnaire, numerous university websites and web-based sustainability report card submissions (http://www.greenreportcard.org/) were reviewed in order to discover the various energy management initiatives being undertaken.

Assessment of Peak Demand Management Capacity

The second phase of this project involved conducting a qualitative assessment of UBC's capacity to undertake peak demand management initiatives. A goal of this phase of the project is to inform future decision makers about UBC's capacity to undertake manual, semi-automated, and/or fully automated peak demand management strategies. The main activities were conducted to inform the qualitative assessment:

1. Building Infrastructure Assessment
2. Metering and Monitoring Assessment
3. Utility Bill Analysis and Historical Peak Identification

Using the results from these activities a qualitative assessment was made regarding UBC's capacity to undertake manual, semi-automated, and fully automated peak demand management strategies.

Building Infrastructure Assessment

Research buildings, parkades, and student housing were visited to in order to collect data needed to assess the potential for peak demand management. Building selection was limited to multi-purpose academic buildings with a floor area greater than 10,000 m2.

Facility staff guided some of the tours while others were self-guided and exploratory in nature. The knowledge gained through the literature review informed the data gathering process during this stage. To evaluate the capacity to conduct peak demand management strategies the following information was collected:

- Building characteristics (primary function, gross floor area, number of occupants)
- Existence of building management software
- Estimated occupancy trends
- Estimated level of control of HVAC equipment and lighting
- Estimate plug-load level
- Estimate of electricity demand elasticity

Metering and Monitoring Assessment

Electricity use at UBC is partially tracked and reported using the ION energy reporting system (or Remote Metering Site http://137.82.167.40/ion/) and the recently installed Pulse Energy Management dashboard (http://www.pulseenergy.com/). By analyzing the historical data available via these systems, the potential for peak demand management was assessed. In order to expedite querying and analyzing data a summary MS Access database was developed to store information extracted from the ION system. The information was used to determine individual building electricity consumption, power factors, load factors and to investigate the cause of the peak in electricity demand in July of 2009. Discussions with the BMS supervisor were conducted to develop an understanding of the capabilities of the BMS software.

Utility Bills Assessment

UBC's utility bills between 1994 and April 2010 were reviewed in order to determine whether or not a trend existed with regards to when electricity demand peaked. Electricity consumption and demand was simply plotted on a monthly basis and visual inspected.

Load Factor Analysis

Using UBC's utility data and information from the ION energy reporting system a load factor analysis was performed for selected buildings on the UBC campus using the following methodology:

- **Step 1**: Determine the total kilowatt-hours (kWh) of electricity use by the building for the year.
- **Step 2**: Determine the peak demand (kW) during the year.
- **Step 3**: Determine the average daily electricity usage by dividing the total kWh from Step 1, by the number of days in the year times 24 hours.
- **Step 4**: Calculate the load factor by dividing the answer from Step 3 by the peak demand from Step 2.

Weather Normalization

An attempt was made to normalize the electricity consumption and demand information using heating and cooling degree-day information for the Vancouver area.

- **Step 1**: Select a base year for the normalization process
- **Step 2**: Obtain the degree days (heating and cooling) for the billing periods
- **Step 3**: Base Year bills and Cooling Degree Days are normalized by number of days in the billing period.
- **Step 4**: Establish a relationship between electricity usage and the weather data by finding a line of best fit to all the utility bills.
- **Step 5:** Check to ensure that the best fit line is an acceptable fit ($R^2 > 0.75$)

Estimating the value of Peak Demand Management at UBC

The potential value of implementing a peak demand management program at UBC was estimated by considering the potential savings in demand charges and value of delaying the capital investment required to upgrade the transmission system beyond its 62 MVA capacity. The steps below outline the methodology used to determine this value.

1. A projection of future peak demand was made by making a linear extrapolation of the maximum peak demand and average monthly peak demand in each year since 2001.
2. The monthly savings in demand charges were estimated for a 5%, 10% and 15% reduction in the projected average peak demand and multiplying it by UBC's peak demand charge. The peak demand charge was assumed to increase by 1.5% per year.
3. For 5%, 10% and 15% peak demand reduction scenarios, the year in which the 62 MVA capacity was reached was identified and compared against the baseline projection.
4. Using the UBC estimate of $10 million for required sub-station upgrades when the upgrade beyond 62 MVA is required, the annual value associated with the delay in reaching the 62 MVA peak was calculated assuming that the value of the

delay was equivalent to allowing the investment to earn interest of 6%. The cost of the substation was assumed to inflate at a value of 1.5% per year.

5. The value of deferring the investment in upgrading the transmission system was discounted back to 2010 dollars using a 6% discount rate.

Demand Response Experimental Simulation

The final phase of the project involved designing and conducting a load shedding strategy for the Life Sciences Centre at UBC. This initial plan was to conduct a field test of the peak demand management strategy by programming the strategy into the BMS software. Unfortunately, due to time constraints the experiment was limited to conducting simulations of the strategy using the Demand Response Quick Assessment Tool (DRQAT). The DRQAT has traditionally been applied to office and retail type buildings. This is potentially the first application of DRQAT to a research facility.

Experimental Simulation Methodology

The methodology below outlines the procedure followed in setting up the experimental simulations.

1. **Select an appropriate building** – The UBC Life Sciences Centre (LSC) building was selected as the candidate building for the simulated peak demand management strategies. LSC is a relatively new building on campus and was certified LEED Gold when it was initially constructed. The building consumes a large amount of electricity and has a very well integrated BMS system.
2. A **building inspection** was conducted with the help of UBC staff member Peter Vickars. The data collected included building characteristics such as facility purpose, floor area, HVAC and lighting system profiles, and BMS. Historical electricity demand data obtained during phase two of the project was used to characterize the buildings energy consumption.
3. LSC measured **electricity consumption data** was assembled using information from phase 2 of this project. A baseline electricity consumption simulation model was constructed in the DRQAT.

4. The **peak demand management strategies were developed** as DRQAT simulation models were developed using knowledge and building information collected during the first and second phases of this project. The completeness and accuracy of the collected data have direct impact on the accuracy of the simulation results.
5. The **potential demand savings** of implementing each strategy was estimated.

<u>Methodology for Establishing a Baseline</u>

In order to establish the baseline electricity demand in the LSC the following steps were followed:

1. LSC building characteristics were obtained.
    a. Lighting load was determined from LSC documentation
    b. Occupancy & other loads were estimated through consultation with various building occupants
2. Plug load was estimated in an iterative fashion by comparing the measured load (Pulse) and the estimate load using the Baseline feature in the DRQAT
3. The Average Absolute Relative Deviation (AARD) between the simulated and the measured baseline for the month of July was calculated. When AARD was < 20% the simulated baseline was deemed to be a good fit of the measured data.

To determine AARD the following methodology was used:

- For each data point, the Absolute Relative Deviation (ARD) was calculated using

$$ARD = \frac{|S - M|}{M}$$

Where: S = Simulated data point

M= Measured data point

- Next, AARD was calculated using:

$$AARD = \frac{\sum_{i=1}^{n} ARD_i}{n}$$

Where: n = total number of data points collected

Results & Discussion

The key results obtained from the literature review are summarized below. The complete literature review is available for reference in Appendix A.

Literature Review

The design of load-shedding and load-shifting strategies must consider a variety of constraints. These constraints include various building characteristics, climate, rate structures, and building occupancy requirements. HVAC and lighting tend to be the two largest contributors to the electrical peaks on university campuses, and many demand reduction programs focus on HVAC due to its close integration with building energy management systems. In research facilities where fume-hoods are connected to the ventilation system, the fume-hood density is also an important parameter of building energy performance [15]. Traditionally, lighting systems are less automated and are thus make automated load shedding difficult. Considerable research has established a foundation for developing customized peak demand management strategies [16-19]. On university campuses, the occurrence of peak demand management strategies is linked strongly to the electricity rate structure that a given university is subject to. The majority of universities implementing peak demand management strategies are in areas where time-of-use (TOU) pricing is being implemented, providing a financial incentive to re-shape the campus electricity consumption profile.

<u>Peak Demand Management Strategies</u>

The literature review identified a number of ongoing or planned peak demand management strategies on North American campuses. These activities are categorized as follows:

- Load shifting strategies focusing on thermal storage for cooling
- Load reducing and/or shedding strategies focused on lighting
- Load reducing and/or shedding strategies focused on adjusting temperature set points
- Load replacing strategies implementing onsite electricity generation

Thermal Storage

Thermal storage for cooling is one of the most publicized peak demand management strategies on North American campuses. At the University of Maryland-Baltimore (UMB) and University of Arizona (UA), ice is produced for thermal storage during the off-peak hours to shift demand away from daytime on-peak hours, allowing the universities to participate in utility load management programs, and to hedge against increasing and variable electricity rates [22-23]. At the University of California-Irvine, the largest above ground thermal energy storage system in the western U.S. can shift up to 4.5 megawatts of electric load to off-peak hours [24]. At the University of California at Merced (UCM), a two million gallon chilled water storage system is used to flatten the campus load profile during peak periods. Approximately 1.2 MW, or over one quarter of the maximum campus load is shifted, impacting three academic buildings, the campus housing units, dining facilities, and auxiliary buildings. Research into demand response strategies at the UCM has revealed that recovery strategies, such as staggering the return from thermal storage to normal HVAC operations in a slow and methodical manner, should be considered to avoid a rebound peak. In addition, researchers have concluded that there is significant demand reduction possible by combining event-driven zone temperature set point changes with off peak thermal storage strategies [1].

Lighting Reduction

Lighting systems are good candidates for load shedding because the load is significant, the response time is quick and the reduction in demand is predictable. Rubinstein and Kiliccote have examined the lighting-related peak demand management strategies for commercial buildings and found that the size of load available for load-shedding is significant and that the lighting technologies currently available for providing load-shedding capabilities offer the added-benefit of improving energy efficiency through the finer control over the lighting system [25]. If dimmable lighting were implemented across a university campus, the demand response potential would be significant.

In Canada, Newsham and Brit [26], and Galasiu et al. 2007 [27] have investigated lighting energy savings and user acceptance of new demand responsive lighting technologies designed to provide highly efficient, customized lighting for cubicles in open-plan office areas. Galasiu et al found that occupancy sensors alone would offer savings in lighting energy use in the range of 30 to 40% compared to full lighting use. Newsham and Brit conducted demand responsive experiments using dimmable lighting on a college campus in southern Ontario where 2300 luminaires across several buildings were reduced by up to 40% over 1-30 minutes. The power reduction achieved ranged from 7.7-15.2 kW (14-18% of lighting load).

HVAC Operating Modes

A number of researchers have developed models to simulate the effect of different thermostat control strategies for reducing peak demand [18]. The simulated results indicate that thermostat control strategies can be surprisingly effective for reducing peak electricity demand. Morris et al. [19] conducted an experiment to evaluate two optimal dynamic building control strategies in a representative room in a large office building. The experimental results indicate that thermostat control strategies have the potential to reduce peak-cooling load by as much as 40%. Xu et al. [28] employed a strategy that involved maintaining zone temperatures at the cooler end (70 ^{o}F) of the comfort region until 2 pm, and then allowed the zone temperatures to rise to the high end of the comfort region (78 ^{o}F). This strategy reduced the buildings chiller power consumption by 80-100% (1 – 2.3 W/ft2) during normal peak hours from 2 – 5 pm, without causing any thermal comfort complaints. In Northern California, Xu and Haves [29] conducted a series of field tests to better understand the effects of various pre-cooling and demand shed strategies. The results indicate that a 25–50% reduction in cooling load is possible during peak hours and demonstrate the importance of calibrating strategies to avoid rebounds effects.

At the University of Maryland-Baltimore (UMB), building control systems periodically raise HVAC return-air set points for 30 minutes (or less) to reduce cooling demand, an effort that is unnoticed by occupants due to a buildings' thermal inertia [22]. At Fordham University, the HVAC system is ramped down during peak demand in order to reduce energy obtained from the grid.

Onsite Electricity Generation

A number of North American universities are capable of generating some or all of their electricity. This is an asset when it comes to developing peak demand management strategies. Fordham University is able to curtail energy obtained from the grid by shifting to on-campus generators and ramping down the HVAC system. If called upon to curtail power, Fordham will receive payments from the energy marketing company (Hess Inc.).

California State University Northridge (CSUN) has the world's largest university-based fuel cell power plant installation. The 1 MW system supplies 18% of the campus electricity needs and waste heat is recovered to provide space heating and hot water for several buildings [30]. The system is comprised of four DFC300MA natural gas reforming fuel cells produced by Fuel Cell Energy, Inc. This system allows CSUN to reduce its reliance on the electrical grid during peak demand periods. Over the power plant's 25-year life cycle the projected cost savings are estimated to be $14.5 million. In an effort to address the sustainability of the fuel cell power plant, CSUN is taking a novel approach to handling the carbon dioxide (CO_2) and water also produced by the fuel cell. A portion of the CO_2 and water will be used by the biology department in the development of an experimental microclimate for carbon enrichment testing.

UBC and Nexterra Systems Corp. have partnered to demonstrate a biomass-fuelled combined heat and power (CHP) solution developed by Nexterra and GE Power & Water's gas engine division. The CHP system will be located on the UBC campus, where it will provide heat and electricity for the campus, while offering a platform for bioenergy research. The CHP plant will produce 2 megawatts of electricity that can be used to offset UBC's existing power consumption. The system will also generate enough steam to displace up to 12 percent of the natural gas that UBC uses for campus heating, thereby reducing greenhouse gas emissions by up to 4500 t/yr. Construction is scheduled to start in the second quarter of 2010 and be completed in late 2011.

Assessment of Peak Demand Management Capacity

A survey of a sample set of UBC facilities and equipment was undertaken in order to inform the qualitative assessment of UBC's current ability to undertake peak electricity demand management. The following section summarizes the results of this survey.

Building Infrastructure Assessment

UBC has more than 400 buildings that contribute to the peak electricity demand. For the purposes of this study, site visits were focused on multi-purpose academic buildings with a footprint greater than 10,000 m^2. This limitation was put in place to help scope the project and due to the likelihood that these buildings have building management software installed; a requirement for semi-automated or fully automated peak demand management strategies. Site visits were conducted to 16 buildings and 5 parkades on the UBC campus. Tables 2 and 3 summarize the information collected, as well as recent electricity use and demand data. Building characteristics and usage information were obtained through site visits and the UBC library (www.library.ubc.ca/archives/pg.html). Electricity use data was retrieved from the ION energy reporting system. Table 2 also provides an optimistic estimate of curtailable load under ideal conditions. This estimate was determined by taking the difference between the peak demand on a weekday and on the weekend and suggests an optimistic peak demand reduction potential of 2.3 MW, or approximately 5 % of the current max peak experienced at UBC. An annual load factor (LF) was calculated for each building visited in order to gauge its potential for peak demand management and is shown in table 3. Buildings with high LF's (>0.75) have nearly constant loads. High load factors can be indicative of inefficient electricity use. For example, equipment might not be turned off at night. Alternatively, it can also indicate that the building is a poor candidate for peak demand management since the size of the peak demand relative to the average demand is small. Buildings with low LF's (<0.25) have very high peak power draws relative to the average load. Low LF's are typically indicative of buildings with large chillers or electric heating equipment that is turned off for much of the day. These buildings are potentially good candidates for thermal storage or HVAC temperate adjustment peak demand management strategies.

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Table 2 – Summary of data collected to aid the development of peak electricity demand management strategies for selected UBC buildings

Name	Construction Date	Trailing 12-month (ttm) Electricity use 07/09-07/10	Average Demand (ttm)	Peak Demand (ttm)	Optimistic Curtailable load	Notes
Buchanan (A/B/C/D)	1956-1960	569,443 kWh. (est. – see notes)	84.3 kW	168.6 kW (2:15 pm Apr 7th 2010)	40 kW	- Concrete, 5-winged building - ION data only available until May 2010
Buchanan Tower	1972	596,892 kWh	68 kW	229 kW (2:15 pm Sept 10th 2009)	100 kW	- Concrete frame and slab high-rise
Chemistry	1914-15, 1923-25, 1958-63 - S, N, E wings added 1989 - Annex	6,664,582 kWh	759.6 kW	1017.2 kW (3:15 pm Sept 23rd 2009)	200 kW	- Reinforced concrete, brick and glass
Hennings	1946-47 1962-63 - Teaching addition	849,388 kWh	131 kW	220.9 kW (3:00 pm Dec 10th 2009)	45 kW	- Concrete structure
ICICS/CS	1991-93, Addition 2005	2,425,124 kWh (Est. see notes)	293.4 kW	464.8 kW (5:30 pm July 30th, 2009)	120 kW	- Labs feature over-height ceilings and state-of-the-art IT equipment - Construction Type: Concrete frame - ION data only available until Jan 2010

Leonard S Klinck	1947-48	3,951,721 kWh	446.2 kW	523.3 kW (12:30 PM, July 8th, 2010)	50 kW	- 4-storey and basement, reinforced concrete frame
Michael Smith Laboratories	1987 2004 - expansion and renovation	5,552,849 kWh	633.1 kW	1119.8 kW (2:45 PM, July 30th, 2009)	300 kW	- Two-storey research facility that Includes a teaching lab and a 100-seat lecture theatre. - There are ~17 full-time and associate faculty members and almost 100 post-doctoral fellows, research associates and graduate students.
Civil & Mechanical Engineering	1974-76	975,758 kWh	111.3 kW	206.9 kW (12:00 PM, March 18th, 2010)	70 kW	- 2-floor building, structure is precast concrete beams and steel frame.
Chemical & Biological Engineering	2006	3,046,924 kWh	347.4 kW	742.6 kW (2:15 PM, July 30th, 2009)	200 kW	- Designed with state-of-the-art computer laboratories and lecture theatres and small-group design project spaces, as well as engineering laboratories.
Forest Sciences Centre	1998	4,762,867 kWh	543 kW	868.9 kW (12:30 PM, August 4th, 2009)	200 kW	- Construction demonstrates structural wood products - Facility accommodates teaching, laboratory and office space and includes the new Centre for Advanced Wood Processing (CAWP).
H.R. MacMillan	1966-1967	1,505,816 kWh	171.7 kW	299.6 (12:00 PM, March 25th, 2010)	100 kW	- Concrete and brick structure

Fred Kaiser	2005	N/A	N/A	N/A	N/A	- Features "Solar-protectant" ceramic window coating, automatic lighting system, passive ventilation, and low-flow plumbing fixtures.
Neville Scarfe	1962 1965 - Addition	1,425,397 kWh	162.1 kW	410.9 kW (1:30 PM, July 30th, 2009)	150 kW	- Concrete with steel seismic reinforcing structure - The addition was to serve as office space for faculty and teaching areas.
Life Sciences Centre	2005	10,618,466 kWh	2344.5 kW	3409.5 kW (3:00 PM, July 27th, 2010)	600 kW	- Photoelectric sensors automatically adjust interior lighting based on the amount of natural light coming in through windows and atrium skylights. - Building earned a LEED Gold Certification
Koerner Pavilion	1980	N/A	N/A	N/A	N/A	- Concrete structure, a 240-bed facility serves as a teaching and research care unit with 90 beds reserved for programs in clinical investigation
Instructional Resource Centre – IRC	1972 1978 - Addition	1,695,624 kWh	108.5 kW	245.9 kW (3:15 PM, Sept 23rd, 2009)	130 kW	- Five-storey concrete - Heavily used for conferences and evening public lectures - Centre contains a 500-seat auditorium, several 100 to 125-seat lecture halls, thirty seminar rooms and administrative offices

Table 3 – Summary of gross floor area, estimated occupancy, and estimated electricity loads for selected UBC buildings

Building Name	Primary Function	Gross Floor Area (m^2)	Estimated Max Occupancy (# people)[a]	Annual Load Factor	Power Factor Range (Min/Max/Avg)	Estimated Plug Load (W/m^2)[b]	Estimated Lighting Load (W/m^2)[c]
Buchanan (A/B/C/D)	Classrooms/Offices	15,720	437	0.506	Not available	8.1	17.2
Buchanan Tower	Offices	10,292	286	0.297	0.27 / 0.98 / 0.77	8.1	17.2
Chemistry	Lab/Research	19,166	532	0.747	0.4 / 0.95 / 0.84	24.75	17.2
Hennings	Lab	11,231	312	0.439	Not available	8.1	17.2
ICICS/CS	Lab/Research	10,066	280	0.733	0.79 / 0.93 / 0.87	8.1	17.2
Leonard S Klinck	Computers/Classrooms	11,264	313	0.854	0.66 / 1.00 / 0.96	8.1	17.2
Michael Smith Laboratories	Lab/Research	8546	237	0.566	0.59 / 0.92 / 0.80	24.75	17.2
Civil & Mechanical Engineering	Lab/Research	10,327	287	0.538	0.50 / 0.96 / 0.91	24.75	17.2
Chemical & Biological Engineering	Lab/Research	14,468	402	0.468	0.52 / 0.92 / 0.87	24.75	17.2
Forest Sciences Centre	Lab/Offices	22,718	631	0.623	0.44 / 0.92 / 0.83	8.1	17.2
H.R. MacMillan	Classroom Offices	14,537	404	0.574	0.77 / 0.96 / 0.90	8.1	17.2
Fred Kaiser	Lab/Offices	12,663	352	N/A	Not available	8.1	17.2
Neville Scarfe	Classrooms/Offices	19,945	554	0.396	0.29 / 0.94 / 0.64	8.1	17.2
Life Sciences Centre	Labs/Research	53,916	2600	0.355	0.63 / 0.93 / 0.86	24.75	9.79
Koerner Pavilion	Hospital	39,001	1083	N/A	Not available	24.75	17.2
Instructional Resource Centre – IRC	Classrooms/Labs/ Offices	11,687	325	0.787	0.43 / 0.99 / 0.96	8.1	17.2

Notes: a = In all cases except Life Sciences (LSC), the occupancy was estimated as 36 m^2 per person as used in Yin et al 2010 [14]. LSC occupancy was published in Coady et al. 2006 [32]

b = Plug loads were estimated at 8.1 W/m^2 for non-research facilities as used in Yin et al 2010 [14]. Research facilities were estimated to be 24.75 W/m^2 that was the value calibrated for LSC during phase 3 of the project.

c = Lighting loads were estimated at 17.2 W/m^2 as used in Yin et al 2010 [14], except for LSC where it was published in Coady et al. 2006 [32]

Metering and Monitoring Assessment

The UBC ION energy reporting system was reviewed and used while assessing the potential for peak demand management strategies at UBC. The system currently contains meters (electricity, steam, water) for approximately 70 buildings on campus. Data is measured on a 15-minute interval and historic date from March 2006 onward is available. After conducting site visits, the ION system was used to extract electricity related information for the selected buildings.

A key energy related challenge for research laboratories is the requirement to condition large volumes of ventilation air in order to meet health & safety requirements. Research labs typically have a designed ventilation standard of between 6 and 10 air change per hour (120-200 cfm) to meet the exhaust requirements of fume hoods [28]. Figure 2 illustrates the electricity demand profile for the Chemistry building. This is a research facility with a high annual LF (~0.75). The high base-demand is likely due to the heavy use of research equipment (fumehoods, centrifuges, fridges, freezers, etc.). Figure 3 illustrates the electricity demand profile for Buchanan Tower. The building features 12 floors and houses private academic offices as well as student study centres. This building has a low LF (~0.297) and the figure illustrates the key summer periods when cooling is required and effectively doubles the demand (peaks).

The range of power factors (PF's) for each building was also extracted from the ion system. Although the UBC campus PF is approximately 0.97 (97%), a number of the buildings have much lower PF's. This is difference is explained by the fact that power factor correction is performed at the substation; very few buildings are equipped for power factor correction. These lower PF's represent a potential opportunity for an improvement in energy efficiency and cost savings. Figure 4 illustrates the hourly power factor experienced by the Michael Smith Laboratories building.

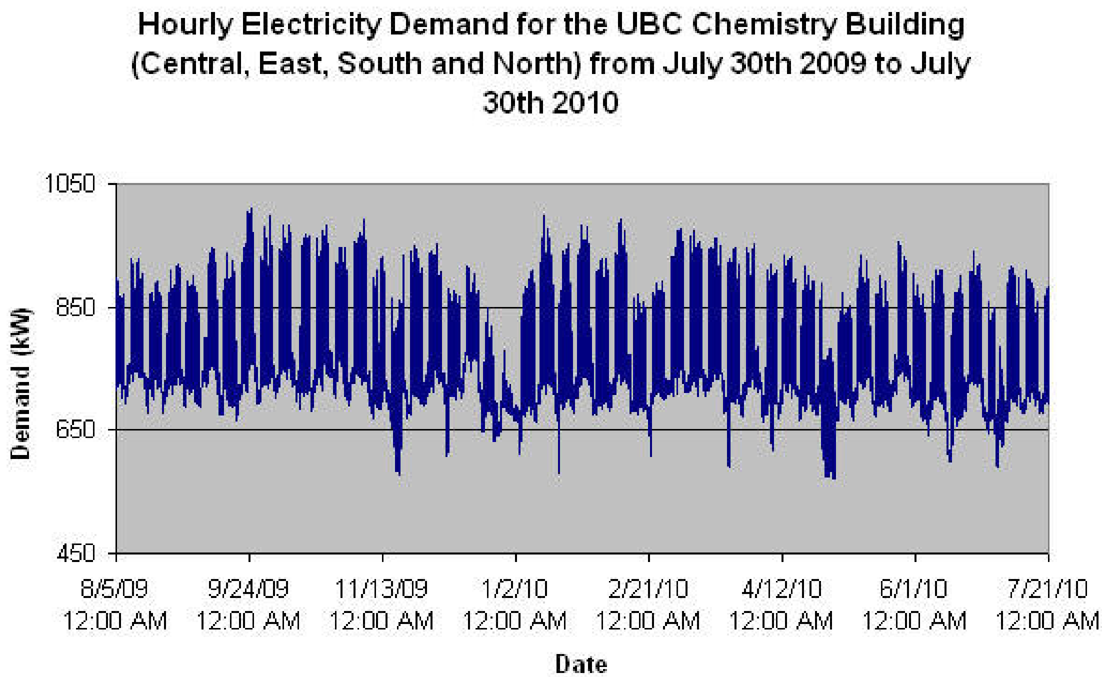

Figure 2 - Hourly electricity demand for the UBC chemistry building for the July 30th 2009 to July 30th 2010 period.

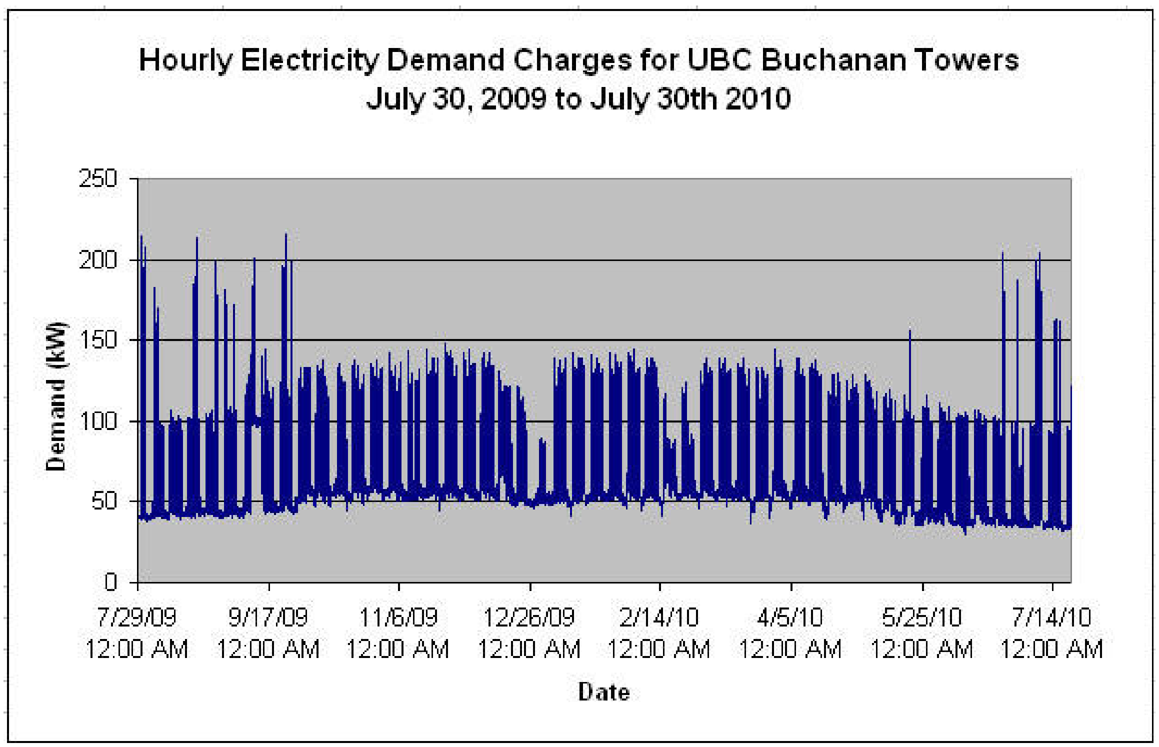

Figure 3 - Hourly electricity demand for the Buchanan Towers during the July 30th, 2009 to July 30th 2010

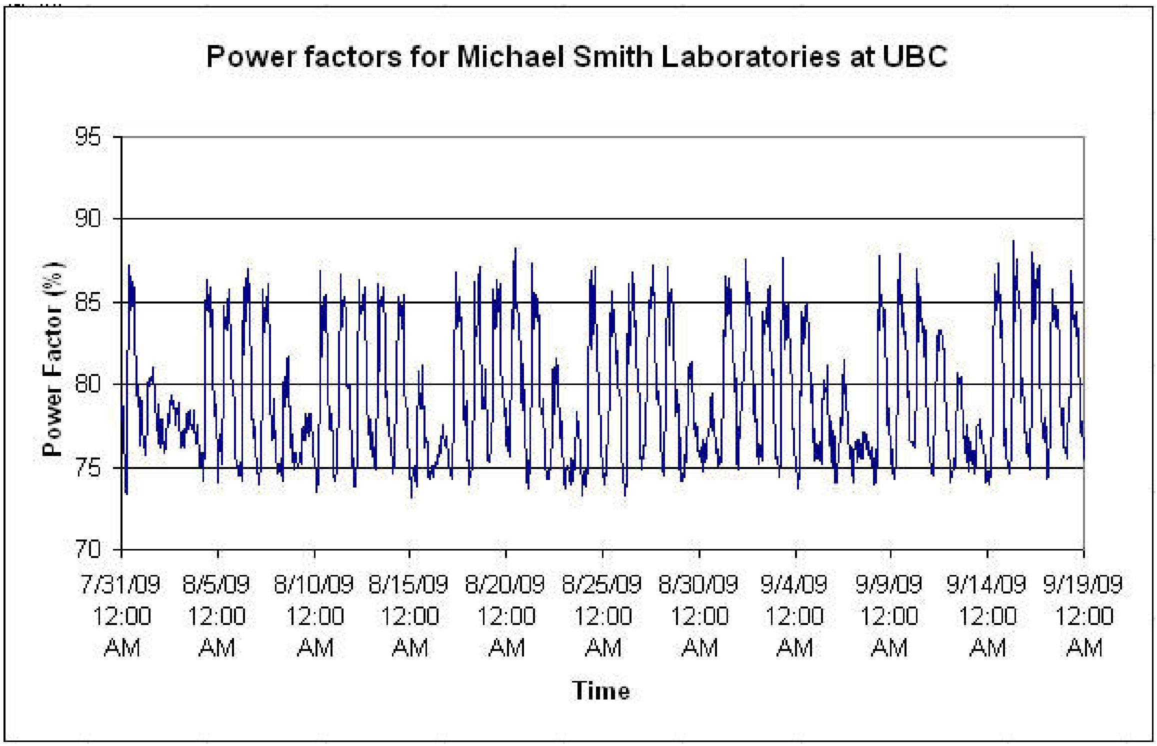

Figure 4 - Hourly power factor Michael Smith Laboratories

There are currently very few sub-meters within buildings at UBC that allow loads within the building to be better characterized. The current metering technology only indicates how much energy the building consumes and not how the electricity is consumed within the building. Energy costs are reported to account for 20-30 percent of total building operation budgets and good energy management programs have been repeatedly proven to save 15-30 percent savings in energy usage directly related to sub-metering programs [31]. Future infrastructure retrofits should consider the installation of additional sub-meters as this information would prove valuable to both energy efficiency and peak demand management strategies.

Utility Bills Assessment

Utility bill data dating back to 1994 for UBC was reviewed to develop an understanding of when peak demand was occurring. Figure 5 illustrates the historical monthly electricity demand for the campus.

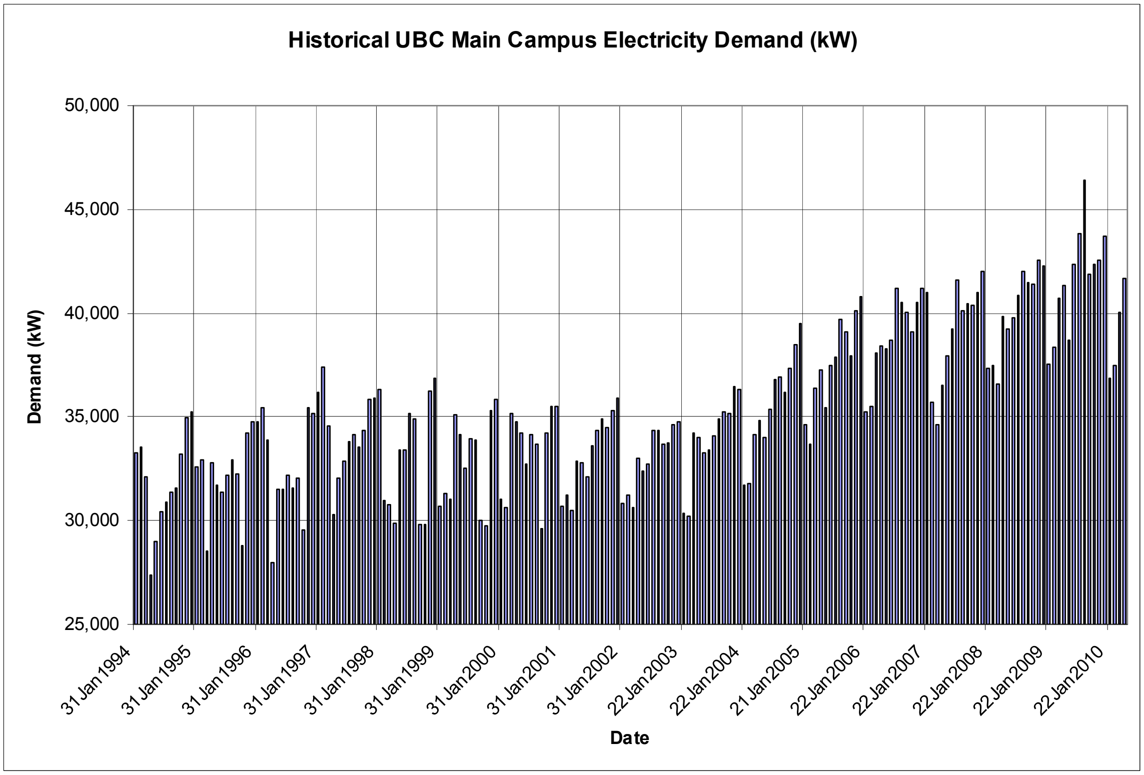

Figure 5 - Historical (1994-2010) monthly electricity demand for the UBC campus. The data was obtained from UBC utility bills supplied by BC Hydro.

In the mid to late 1990's, the UBC peak monthly electricity demand occurred in the winter months. However, the campus has recently started to produce two major peaks; one during the summer (July/August) and a second during the winter (December/January/February) as shown in figure 6. The summer peak is getting progressively larger with the recent campus growth and increased number of year round facilities. This is an important trend with direct implications for peak demand management. Above average temperatures in recent summers have also contributed significantly to peak demand. The temperature in Vancouver was 34 ^{o}C on July 29th, 2009 and the highest temperature ever recorded (34.4 ^{o}C or 93.9 ^{o}F) in Vancouver occurred on July 30th, 2009. According to BC Hydro utility bill records for UBC, peak electricity demand (30-min) occurred at 2 pm on July 30th, 2009. The winter peak is likely caused by electric heating baseboard loads in student housing and tends to peak during the December exam period when students are out of classes, but still in the dormitories. The January billing period (December 22nd – January 22nd) would likely be larger if not for the Christmas break causing a reduction in campus electricity demand.

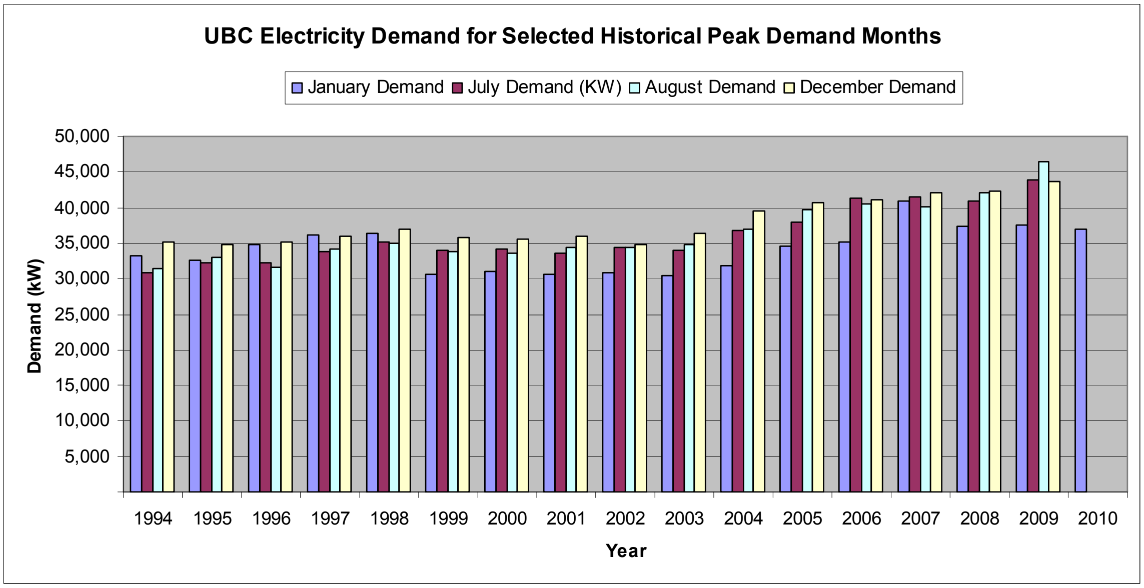

Figure 6 -UBC Electricity Demand for Selected Historical Peak Demand Months. Campus expansion has seen demand increase significantly since 2004 and caused a change to the timing of the expected peak demand month.

Figure 7 illustrates the correlation between the extreme temperatures experienced during the summer of 2009 and the peak electricity demand. Data was only available for a portion of the campus buildings, thus the graph illustrates a 15-min demand graph for a portion of the campus with the corresponding hourly average temperature. The correlation is important to understand when designing peak demand management strategies.

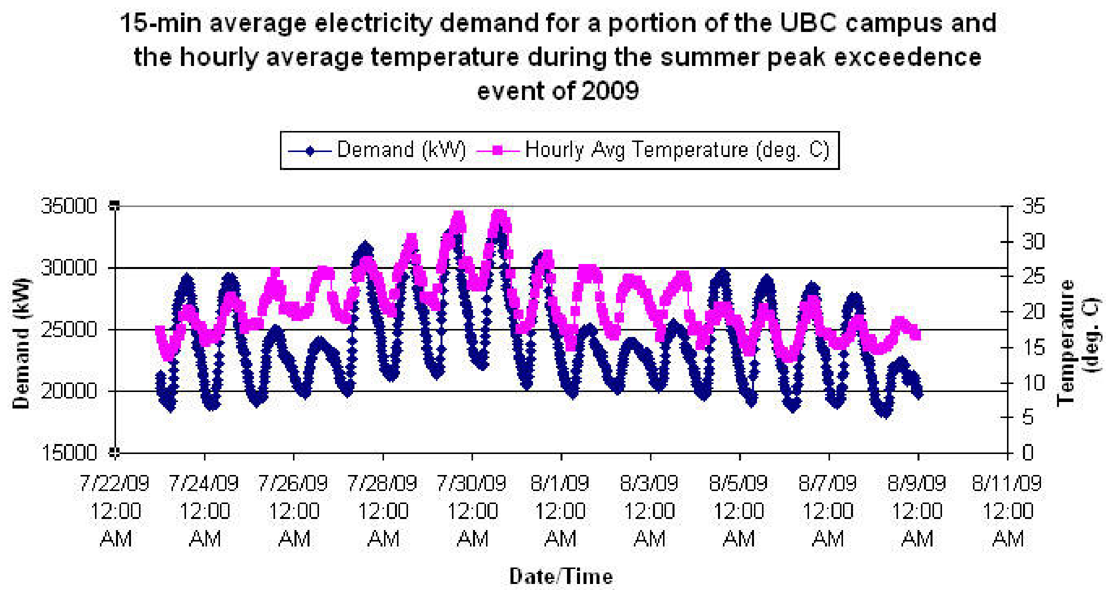

Figure 7 - Comparing hourly average temperature with electricity demand for a portion of the UBC campus during the summer of 2009.

Weather Normalization

Unfortunately, the recent campus expansion combined with the seasonal nature of university programs have resulted in HDD and CDD being poor predictors of electricity consumption on the UBC campus.

Estimating the value of Peak Demand Management at UBC

The potential value of implementing a peak demand management program at UBC was estimated by considering the potential savings in demand charges and value of delaying the capital investment required to upgrade the transmission system beyond its 62 MVA capacity. Figure 8 illustrates the projected peak demand for the campus using the growth in peak demand over the 2000-2009 time frame to parameterize the linear fit equation. It illustrates the peak demand under peak demand management strategies that reduce demand by 5, 10 and 15% and highlights the key thresholds in transmission capacity where capital investments are required. Based on the current trend UBC will need to upgrade transmission capacity beyond 62 MVA by 2022 if it wants to maintain its policy for 100% redundancy. Peak demand management strategies that reduce demand by 5, 10 and 15% will delay the requirement for the estimated $10 million capital investment in substation upgrades by 3, 6 and 9 years respectively.

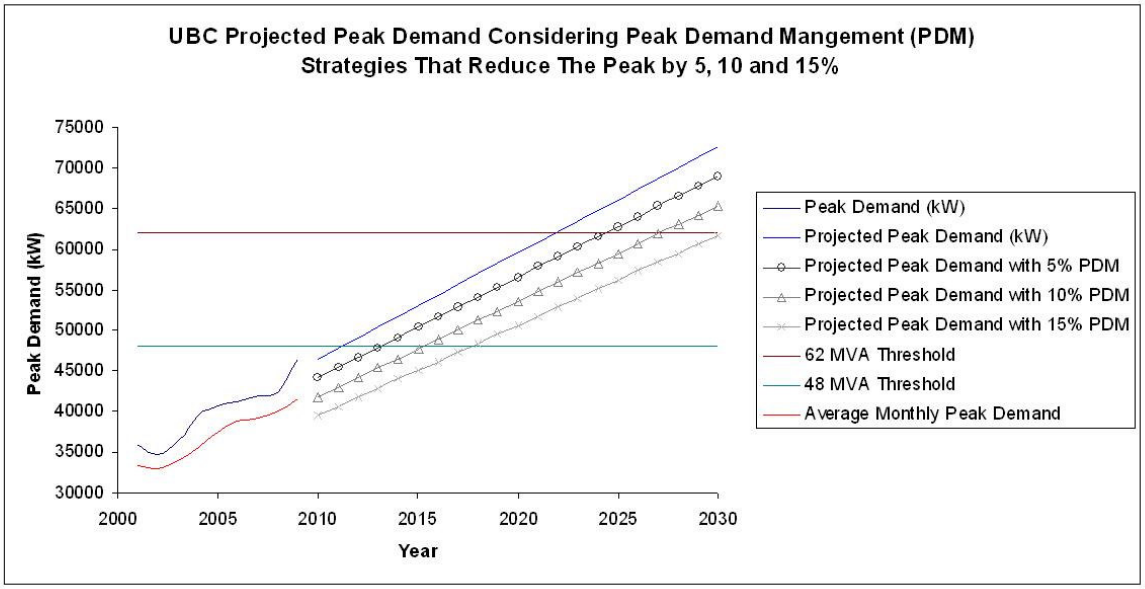

Figure 8 - Projected peak electricity demand for UBC as well as the peak demand for strategies that reduce the peak by 5, 10 and 15% annually.

Table 4 illustrates the anticipated savings associated with the three peak demand management strategies. In 2010 the annual savings associated with avoid demand charges ranges from $136,735 to $410,206. This savings climbs to a range of $285,380 to $856,139. In addition, the value deferring the capital expenditure associated with upgrading the transmission capacity beyond 62 MVA ranges from $1,024,722 to $2,714,422 in 2010 dollars for the 3 scenarios considered. The total value of a peak demand management program in 2010, lasting until 2030, that reduced 5% of the peak demand and delays the capital investment associated with upgrading the transmission capacity by three years is estimated to be $3,396,600.

The last decade has been a period of above average growth on the UBC campus. To better understand the potential variability in the estimate of the value of a peak demand management program, the slope of the project was reduced by 20% and the value recalculated. Figure 9 illustrates the original projected peak demand and the projected peak demand with a 20% reduction in the slope of the projection.

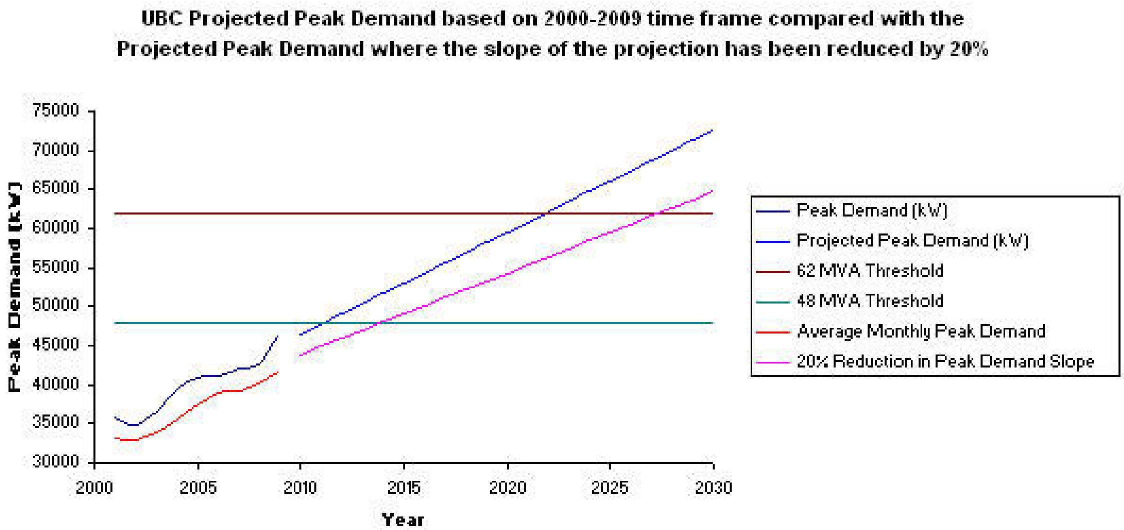

Figure 9 - Comparison of the projected peak demand using the original projection based on the 2000-2009 timeframe and a projection with a 20% decrease in slope.

Table 5 illustrates the impact in anticipated savings associated with the three peak demand management strategies for the scenario where the slope of the projected peak demand is reduced by 20%. In 2010 the annual savings associated with avoid demand charges ranges from \$132,978 to \$398,934. This savings climbs to a range of \$260,075 to \$780,226 in 2030. In this scenario, the timing of the baseline requirement to purchase the substation is pushed to 2028, and the 5%, 10% and 15% peak reduction programs delay the capital investment in the substation requirement for 3, 6 and 10 years respectively. In addition, the value deferring the capital expenditure associated with upgrading the transmission capacity beyond 62 MVA ranges from \$824,951 to \$2,379,365 in 2010 dollars for the three scenarios considered. The total value of a peak demand management program in 2010, lasting until 2030, that reduced 5% of the peak demand and delays the capital investment associated with upgrading the transmission capacity by three years is estimated to be \$3,054,630 (versus \$3,396,600 in the original projection).

Table 4 - Summary of forecasted annual demand charge savings and deferral value offered by implementing peak demand management strategies that achieve 5, 10 and 15% peak demand reduction based on the original projected demand scenario using the 2000-2009 time frame to characterize peak demand growth on the UBC campus.

									2010 Dollars (using 6% discount factor)					
Demand Charge	Year	Peak Demand Charge Savings 5%	10%	15%	Deferred Capital Investment 5%	10%	15%	Value of Sub-station	Peak Demand Charge Savings 5%	10%	15%	Deferred Capital Investment 5%	10%	15%
5.48	2010	$ 136,735	$ 273,471	$ 410,206	$ -	$ -	$ -	$ 10,000,000	$ 136,735	$ 273,471	$ 410,206	$ -	$ -	$ -
5.56	2011	$ 142,600	$ 285,201	$ 427,801	$ -	$ -	$ -	$ 10,150,000	$ 134,529	$ 269,057	$ 403,586	$ -	$ -	$ -
5.65	2012	$ 148,610	$ 297,221	$ 445,831	$ -	$ -	$ -	$ 10,302,250	$ 132,263	$ 264,526	$ 396,788	$ -	$ -	$ -
5.73	2013	$ 154,769	$ 309,538	$ 464,306	$ -	$ -	$ -	$ 10,456,784	$ 129,947	$ 259,894	$ 389,841	$ -	$ -	$ -
5.82	2014	$ 161,078	$ 322,157	$ 483,235	$ -	$ -	$ -	$ 10,613,636	$ 127,589	$ 255,178	$ 382,768	$ -	$ -	$ -
5.90	2015	$ 167,543	$ 335,085	$ 502,628	$ -	$ -	$ -	$ 10,772,840	$ 125,198	$ 250,395	$ 375,593	$ -	$ -	$ -
5.99	2016	$ 174,164	$ 348,329	$ 522,493	$ -	$ -	$ -	$ 10,934,433	$ 122,779	$ 245,558	$ 368,337	$ -	$ -	$ -
6.08	2017	$ 180,947	$ 361,894	$ 542,841	$ -	$ -	$ -	$ 11,098,449	$ 120,340	$ 240,680	$ 361,020	$ -	$ -	$ -
6.17	2018	$ 187,894	$ 375,788	$ 563,682	$ -	$ -	$ -	$ 11,264,926	$ 117,887	$ 235,774	$ 353,661	$ -	$ -	$ -
6.27	2019	$ 195,009	$ 390,018	$ 585,026	$ -	$ -	$ -	$ 11,433,900	$ 115,425	$ 230,851	$ 346,276	$ -	$ -	$ -
6.36	2020	$ 202,295	$ 404,589	$ 606,884	$ -	$ -	$ -	$ 11,605,408	$ 112,960	$ 225,921	$ 338,881	$ -	$ -	$ -
6.46	2021	$ 209,755	$ 419,511	$ 629,266	$ -	$ -	$ -	$ 11,779,489	$ 110,496	$ 220,993	$ 331,489	$ -	$ -	$ -
6.55	2022	$ 217,394	$ 434,788	$ 652,182	$717,371	$717,371	$717,371	$ 11,956,182	$ 108,038	$ 216,076	$ 324,115	$ 356,511	$ 356,511	$ 356,511
6.65	2023	$ 225,215	$ 450,430	$ 675,645	$728,131	$728,131	$728,131	$ 12,135,524	$ 105,590	$ 211,179	$ 316,769	$ 341,376	$ 341,376	$ 341,376
6.75	2024	$ 233,222	$ 466,443	$ 699,665	$739,053	$739,053	$739,053	$ 12,317,557	$ 103,154	$ 206,308	$ 309,462	$ 326,884	$ 326,884	$ 326,884
6.85	2025	$ 241,418	$ 482,835	$ 724,253	$ -	$750,139	$750,139	$ 12,502,321	$ 100,735	$ 201,470	$ 302,206	$ -	$ 313,007	$ 313,007
6.95	2026	$ 249,807	$ 499,614	$ 749,422	$ -	$761,391	$761,391	$ 12,689,855	$ 98,336	$ 196,671	$ 295,007	$ -	$ 299,719	$ 299,719
7.06	2027	$ 258,394	$ 516,788	$ 775,182	$ -	$772,812	$772,812	$ 12,880,203	$ 95,958	$ 191,917	$ 287,875	$ -	$ 286,995	$ 286,995
7.16	2028	$ 267,182	$ 534,365	$ 801,547	$ -	$ -	$784,404	$ 13,073,406	$ 93,606	$ 187,211	$ 280,817	$ -	$ -	$ 274,811
7.27	2029	$ 276,176	$ 552,352	$ 828,529	$ -	$ -	$796,170	$ 13,269,507	$ 91,280	$ 182,560	$ 273,839	$ -	$ -	$ 263,145
7.38	2030	$ 285,380	$ 570,759	$ 856,139	$ -	$ -	$808,113	$ 13,468,550	$ 88,983	$ 177,965	$ 266,948	$ -	$ -	$ 251,973
		Notes:	* Demand charges increase 1.5% per year (1994-2010 avg increase)											
			* A 6% discount rate is used to bring savings to 2010 dollars						Total Deferred Value (2010 $):			$1,024,772	$1,924,493	$2,714,422

Table 5 - Summary of forecasted annual demand charge savings and deferral value offered by implementing peak demand management strategies that achieve 5, 10 and 15% peak demand reduction based on the scenario using a 20% reduction in projected peak demand slope.

									2010 Dollars (using 6% discount factor)					
Demand Charge	Year	Peak Demand Charge Savings 5%	10%	15%	Deferred Capital Investment 5%	10%	15%	Value of Sub-station	Peak Demand Charge Savings 5%	10%	15%	Deferred Capital Investment 5%	10%	15%
5.48	2010	$ 132,978	$ 265,956	$ 398,934	$ -	$ -	$ -	$ 10,000,000	$ 132,978	$ 265,956	$ 398,934	$ -	$ -	$ -
5.56	2011	$ 138,024	$ 276,047	$ 414,071	$ -	$ -	$ -	$ 10,150,000	$ 130,211	$ 260,422	$ 390,633	$ -	$ -	$ -
5.65	2012	$ 143,191	$ 286,382	$ 429,573	$ -	$ -	$ -	$ 10,302,250	$ 127,439	$ 254,879	$ 382,318	$ -	$ -	$ -
5.73	2013	$ 148,482	$ 296,964	$ 445,446	$ -	$ -	$ -	$ 10,456,784	$ 124,668	$ 249,337	$ 374,005	$ -	$ -	$ -
5.82	2014	$ 153,900	$ 307,800	$ 461,699	$ -	$ -	$ -	$ 10,613,636	$ 121,903	$ 243,806	$ 365,709	$ -	$ -	$ -
5.90	2015	$ 159,447	$ 318,893	$ 478,340	$ -	$ -	$ -	$ 10,772,840	$ 119,148	$ 238,296	$ 357,443	$ -	$ -	$ -
5.99	2016	$ 165,125	$ 330,251	$ 495,376	$ -	$ -	$ -	$ 10,934,433	$ 116,407	$ 232,814	$ 349,220	$ -	$ -	$ -
6.08	2017	$ 170,938	$ 341,877	$ 512,815	$ -	$ -	$ -	$ 11,098,449	$ 113,684	$ 227,368	$ 341,051	$ -	$ -	$ -
6.17	2018	$ 176,889	$ 353,777	$ 530,666	$ -	$ -	$ -	$ 11,264,926	$ 110,982	$ 221,964	$ 332,946	$ -	$ -	$ -
6.27	2019	$ 182,979	$ 365,958	$ 548,937	$ -	$ -	$ -	$ 11,433,900	$ 108,305	$ 216,610	$ 324,915	$ -	$ -	$ -
6.36	2020	$ 189,212	$ 378,425	$ 567,637	$ -	$ -	$ -	$ 11,605,408	$ 105,655	$ 211,310	$ 316,966	$ -	$ -	$ -
6.46	2021	$ 195,592	$ 391,183	$ 586,775	$ -	$ -	$ -	$ 11,779,489	$ 103,035	$ 206,070	$ 309,105	$ -	$ -	$ -
6.55	2022	$ 202,119	$ 404,239	$ 606,358	$ -	$ -	$ -	$ 11,956,182	$ 100,447	$ 200,894	$ 301,342	$ -	$ -	$ -
6.65	2023	$ 208,799	$ 417,598	$ 626,398	$ -	$ -	$ -	$ 12,135,524	$ 97,893	$ 195,786	$ 293,680	$ -	$ -	$ -
6.75	2024	$ 215,634	$ 431,268	$ 646,902	$ -	$ -	$ -	$ 12,317,557	$ 95,375	$ 190,750	$ 286,125	$ -	$ -	$ -
6.85	2025	$ 222,627	$ 445,253	$ 667,880	$ -	$ -	$ -	$ 12,502,321	$ 92,894	$ 185,789	$ 278,683	$ -	$ -	$ -
6.95	2026	$ 229,781	$ 459,561	$ 689,342	$ -	$ -	$ -	$ 12,689,855	$ 90,452	$ 180,905	$ 271,357	$ -	$ -	$ -
7.06	2027	$ 237,099	$ 474,198	$ 711,297	$ 772,812	$ 772,812	$ 772,812	$ 12,880,203	$ 88,050	$ 176,100	$ 264,151	$ 286,995	$ 286,995	$ 286,995
7.16	2028	$ 244,585	$ 489,171	$ 733,756	$ 784,404	$ 784,404	$ 784,404	$ 13,073,406	$ 85,689	$ 171,378	$ 257,067	$ 274,811	$ 274,811	$ 274,811
7.27	2029	$ 252,243	$ 504,486	$ 756,729	$ 796,170	$ 796,170	$ 796,170	$ 13,269,507	$ 83,370	$ 166,739	$ 250,109	$ 263,145	$ 263,145	$ 263,145
7.38	2030	$ 260,075	$ 520,151	$ 780,226	$ -	$ 808,113	$ 808,113	$ 13,468,550	$ 81,093	$ 162,186	$ 243,278	$ -	$ 251,973	$ 251,973
7.49	2031	$ 268,086	$ 536,172	$ 804,258	$ -	$ 820,235	$ 820,235	$ 13,670,578	$ 78,859	$ 157,718	$ 236,577	$ -	$ 241,276	$ 241,276
7.60	2032	$ 276,278	$ 552,557	$ 828,835	$ -	$ 832,538	$ 832,538	$ 13,875,637	$ 76,669	$ 153,337	$ 230,006	$ -	$ 231,034	$ 231,034
7.72	2033	$ 284,656	$ 569,312	$ 853,968	$ -	$ -	$ 845,026	$ 14,083,772	$ 74,522	$ 149,044	$ 223,567	$ -	$ -	$ 221,226
7.83	2034	$ 293,223	$ 586,446	$ 879,669	$ -	$ -	$ 857,702	$ 14,295,028	$ 72,420	$ 144,840	$ 217,259	$ -	$ -	$ 211,834
7.95	2035	$ 301,983	$ 603,966	$ 905,949	$ -	$ -	$ 870,567	$ 14,509,454	$ 70,362	$ 140,723	$ 211,085	$ -	$ -	$ 202,841
8.07	2036	$ 310,940	$ 621,879	$ 932,819	$ -	$ -	$ 883,626	$ 14,727,095	$ 68,348	$ 136,695	$ 205,043	$ -	$ -	$ 194,230
		Notes:	* Demand charges increase 1.5% per year (1994-2010 avg increase)											
			* A 6% discount rate is used to bring savings to 2010 dollars						Total Deferred Value (2010 $):			$ 824,951	$ 1,549,234	$ 2,379,365

Current Potential for Peak Demand Management Potential Strategies

Based on the information collected in the first two phases of this project both manual and semi-automated peak demand management are possible at UBC. Manual peak demand management could be implemented in the form of an email announcement requesting staff and student's power down any unnecessary equipment. The emails would only need to be sent during anticipated times of peak demand. These would typically occur during periods of above average temperatures in the summer and below average temperatures in the winter.

In order to implement semi-automated peak demand management, scenarios would need to be programmed into multiple BMS systems. This would require an investment on the UBC's part to first validate the peak demand management strategy and then implement it in the BMS code. It would also help to install additional sub-meters to get a finer resolution on how electricity is being used within the selected buildings. Peak demand management strategies that have the best potential for success at UBC are ones that require low-capital investment and minimize the effects on occupants. These might include:

- Adjusting temperature set points for all buildings
- Allowing HVAC equipment to slowly ramp up
- Lighting strategies that reduce peak demand (dependant on electrical infrastructure)

It is unlikely that UBC could implement fully automated demand response at this time without additional capital expenditures. Current electricity prices and the absence of time of use pricing are likely to make any such investment ill-advisable at this time.

The EcoTrek program undertaken at UBC illustrates the university's history of implementing successful energy efficiency campaigns. The campus billing data also indicates the co-benefits of peak demand management and energy efficiency programs. Programs that seek to reduce kWh consumption can also have an impact on peak demand (or kW) and vice versa. However, it is difficult to quantify the size of the co-benefit as it is a function of the duration of the use of equipment or strategy being upgraded.

Kaizen – Change for the Better

The collective knowledge and ideas of UBC employees is impressive. However, during the site visits it was apparent that tension existed between senior management and building staff with a general sense of communication being top-down. In order to effectively leverage the skills and knowledge of staff, UBC should consider methods for improving communication between different function groups working and operating the university. In the spirit of the Continuous Optimization process that UBC is undertaking to improve the overall energy use in buildings, the university should consider a management strategy with same philosophy. Kaizen, which refers to the philosophy of focusing on continuous improvement, has been successfully applied in healthcare, government, auto making and other industries. The author has had personal experience working in an environment where the Kaizen approach has been successfully implemented (Honda of Canada Manufacturing) and believes that the approach deserves consideration at UBC as a way to nurture, praise, and encourage UBC's human resources to create and continually improve operations.

Potential Energy Efficiency Improvements

Lighting

The survey and site visits also revealed a number of lighting inefficiencies that should be reviewed in future lighting retrofits and/or BMS system updates. Appendix B illustrates various outdoor lighting that has been left on during the daytime, unnecessary hallway lighting in hallways/staircases and corridors with excellent natural lighting.

Parkades

The UBC campus has 5 major car parkades, all of which received an energy retrofit between 2006 and the summer of 2010. The parkades have certain qualities (significant lighting load, predictable occupancy schedule) that make them a potential candidate for peak demand management. Unfortunately, the energy retrofits did not consider peak demand management strategies. Parkades are rarely used to capacity during the summer and on weekends and offer an opportunity to reduce the campuses over energy use. One possible strategy would be to modify how the parkades are operated during low occupancy periods. This might include limiting access to certain levels, thereby allowing lighting to be turned off on the remaining levels. Alternatively, entire parkades could be closed during the summer.

Demand Response Simulation Experiment

The third and final phase of this project involved simulating a variety of peak demand management strategies using the Demand Response Quick Assessment Tool (DRQAT) for the Life Sciences Building on campus. Strategies involving temperature zone modifications and lighting load reductions were specifically simulated. For each of these strategies, it is possible that building occupants desired energy services may be temporarily compromised. There are a number of other potentially viable peak demand management strategies for UBC that have not been investigated in detail (see literature review). Research laboratories are an intriguing prospect when considering peak demand management strategies as they typically consume 5 to 10 times more energy per unit area than do office buildings [15]. Despite this fact, LSC architects expected that the LSC would perform 28% better than a similar building designed to the ASHRAE 90.1 standard resulting in an anticipated annual saving of approximately 6,400,000 kWh [32].

DRQAT Input Parameters

The initial DRQAT simulation models were parameterized using data collected during the second phase of this project. The input parameters include building type, gross floor area, location, occupancy schedule, utility rates, and lighting and plug loads and are shown in Table 6 & 7. These parameters are believed to have the greatest influence on demand reduction and cost savings.

Table 6 - DRQAT Simulation Model Inputs for the Life Sciences Centre at UBC

Gross Area (sq ft)	Length (ft)	Width (ft)	Floor Height (ft)	WWR_SN	WWR_EW	Building Orientation
	425	300	12	0.6	0.6	45

Notes: WWR_SN = window to wall ratio for south and north sides of the building
WWR_EW = window to wall ratio for east and west sides of the building
Building Orientation: Building north axis is specified relative to true north and the value is specified in degrees from “true north”

Table 7 - Life Sciences Centre Internal Loads for DRQAT Simulation Models

Lighting Load Density (W/SQ ft)	Plug and Misc Load Density (W/SQ ft)	Max Number of Occupants	HVAC System Type

0.85	2.00	2600	Water cooled

The building orientation, length, width, maximum occupancy and estimated lighting load were obtained from a case study on the LSC conducted by Coady et al 2006 [32]. Information related to occupancy schedules and demand intensities were not readily available. Therefore, initial estimates load densities were made using knowledge obtained during the site visit and later modified in order to get the baseline electricity demand profile in DRQAT match the electricity demand for the Life Sciences Center as reported by the Pulse Energy Management dashboard

LSC has packaged rooftop air handling units (AHU) with variable-air volume (VAV) distribution systems. Due to the nature of the building, the HVAC systems run almost continuously. Multiple zone temperatures are monitored throughout the building and controlled by a digital direct control (DDC) system. The system currently makes use of occupied and unoccupied modes and makes it possible to develop various global zone temperature reset strategies for peak demand management. Table 8 shows the current operating modes programmed into the system. Table 9 provides a list of the AHU's and laboratory exhaust fans (LEF) along with their default set points.

Table 8 - Life Sciences Centre default operating modes

Operating Mode	Description
Occupied	Building is in this mode between 7 am and 5 pm (adjustable by building zone)
Occupied-Vacant	Occurs whenever motion sensor is not active
Unoccupied	Building is in this mode between 5 pm and 7 am (adjustable by building zone)
Morning Warm up	Occurs when zone temperature falls below 65 degrees F within 2 hours before occupied mode
Morning Cool down	Occurs when zone temperature rises above 82 degrees F within 2 hours before occupied mode
Night Setback – heating	During unoccupied mode, if temperature falls below 65 degrees F, heating is initiated.
Night Setback - cooling	During unoccupied mode, if temperature rises above 82 degrees F, cooling is initiated.

Table 9 - Zone temperature set points and operating modes for AHU's and LEF's in the Life Sciences Building

Equipment Name	Operating Duration	Zone Temperature
AHU-27 a & b AHU 28 a & b AHU 29 a & b AHU 13 LEF 8	24x7	71 ^{o}F
LEF 1 a, b & c LEF 3 a, b & c LEF 4 a, b & c LEF 5 a, b & c LEF 6 a, b & c LEF 7 a, b & c	24x7 (But only 2 out of 3 are permitted to operate simultaneously)	73 ^{o}F (occupied) 78 ^{o}F (unoccupied cooling) 68 ^{o}F (unoccupied heating)
AHU 9, 10	24x7 (Occupied mode is 7 am to 7 pm)	73 ^{o}F
AHU 11, 12, 14, 15	24x7	73 ^{o}F
AHU 16, 18, 19, 20, 24	24x7	74 ^{o}F
AHU 17	24x7	70 ^{o}F
AHU 21, 26, 30, 31, 32, 33	24x7 (Occupied mode is 7 am to 5:30 pm)	73 ^{o}F
AHU 22, 23, 25	24x7 (occupied mode is 7 am to 6 pm)	71 ^{o}F
FCU (electrical room, freezer rooms)	24x7	70 ^{o}F
Elevator machine room	24x7	75 ^{o}F
Crystallization Room	24x7	64 ^{o}F

DRQAT Model Calibration

Using the information mentioned above, the DRQAT model for LSC was developed. The baseline electricity demand profile was calibrated with the measured electricity data reported in the Pulse Energy Management system. Figures 10 and 11 illustrate the baseline occupancy and demand schedules as well as the zone temperature set points. The weather data used in the model is TMY2 (typical meteorological year) weather files available within DRQAT for the Vancouver region.

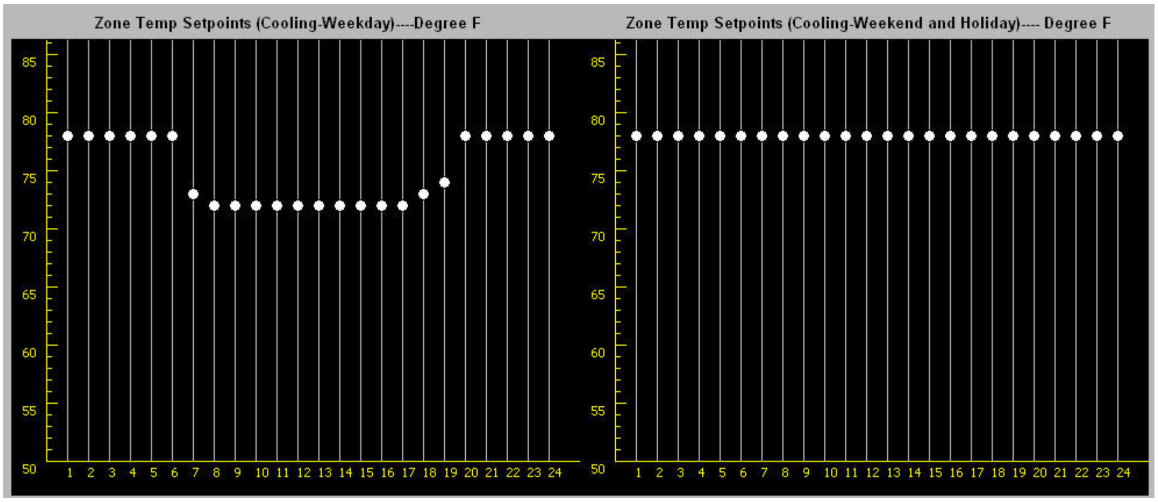

Figure 10 - Baseline weekday and weekend zone temperature setpoints for the LSC model in DRQAT.

In order to calibrate the baseline electricity demand, the absolute average relative deviation (AARD) was calculated between the measured and simulation results for hourly data. The AARD was calculated to be 9.84% for the simulated period of July 1st, 2010 to July 30th, 2010. The AARD exceeded 50% on three occasions. The first two were on the national holiday (July 1st) and on the Friday between the holiday and the weekend (July 2nd). It is currently not possible to identify holidays in the DRQAT. The third occurrence appears to be a power outage in the LSC when two-thirds of the power was lost for an hour on July 19th. Figure 12 illustrates the measured demand versus the calibrated simulation data.

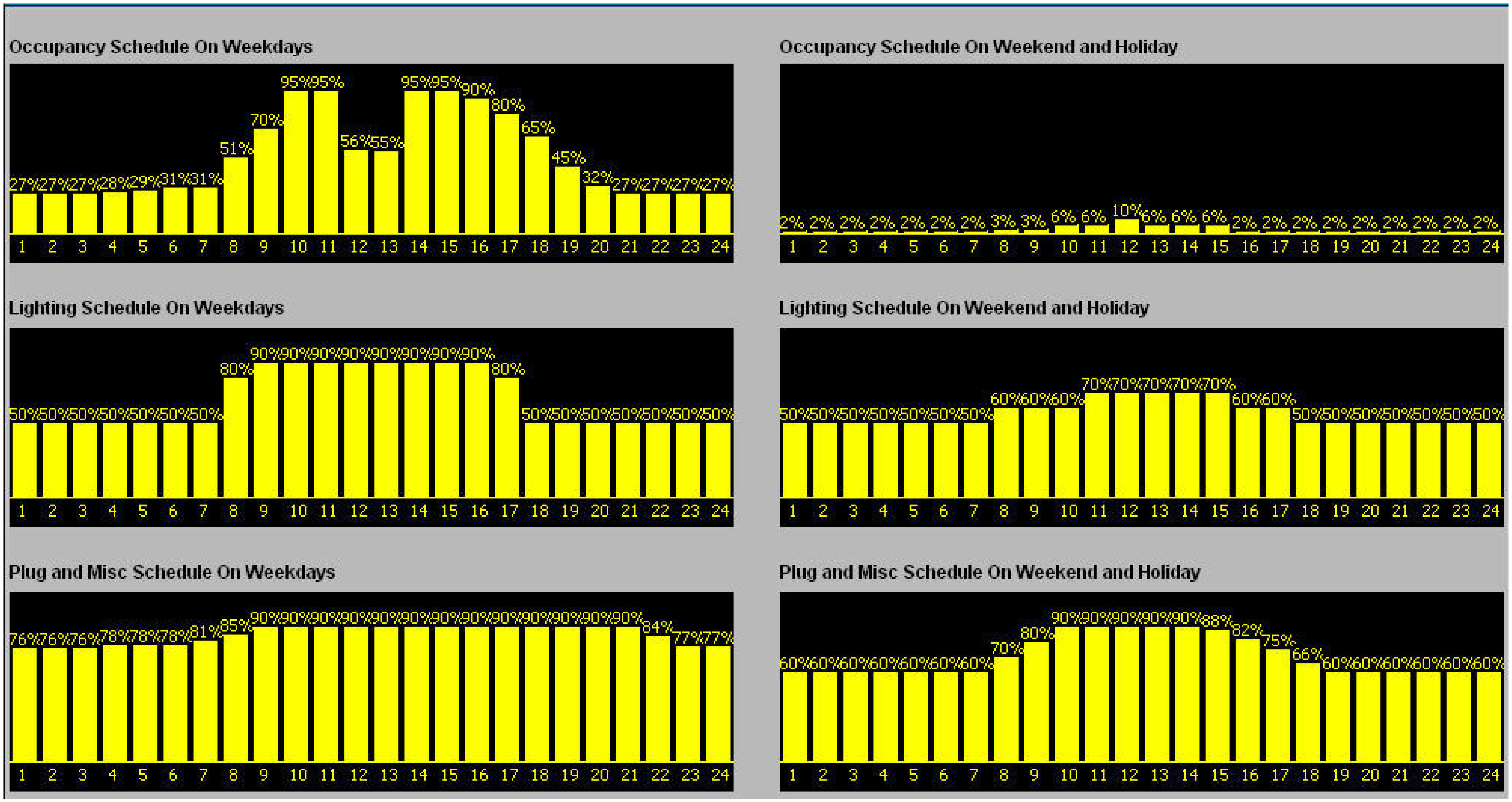

Figure 11 - Occupancy and Demand Load Schedule for Life Sciences Centre model in DRQAT

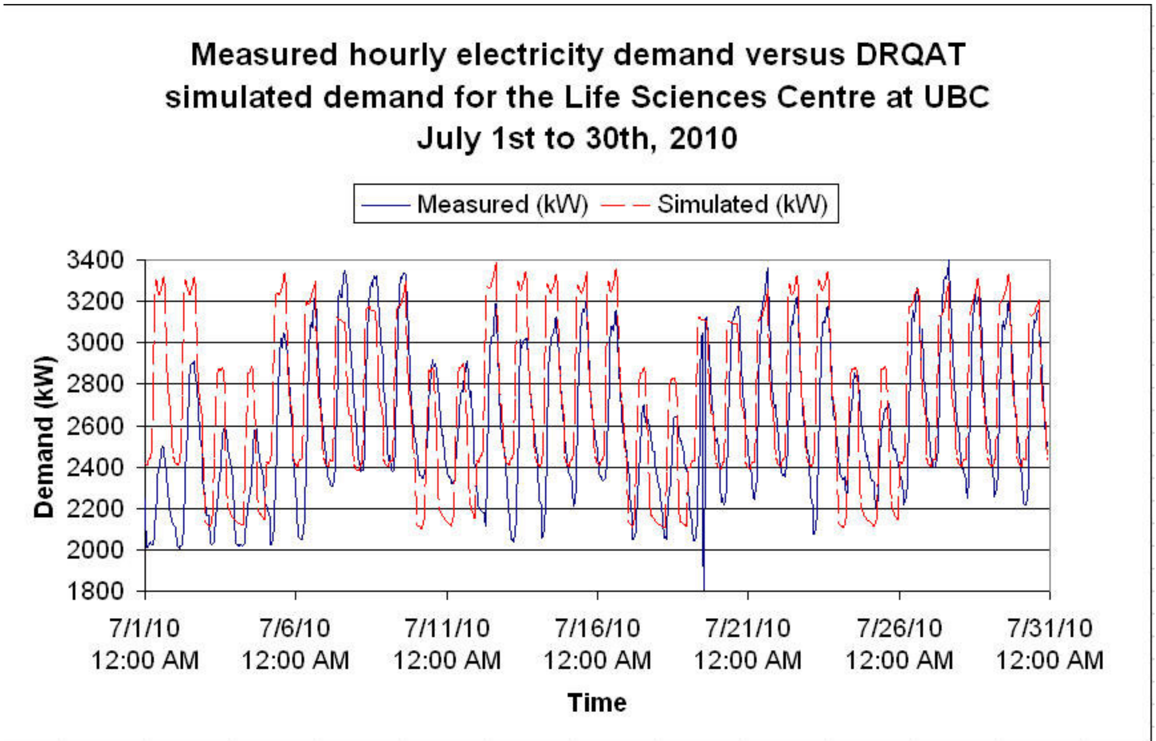

Figure 12 - Comparison of measured electricity demand for the Life Sciences Centre versus the simulated baseline in DRQAT for July 2010

DRQAT Simulation Results

Four strategies were created using the DRQAT in order to estimate the potential peak demand reduction. Table 10 describes the strategies simulated and the peak reduction estimated.

Table 10 - Summary of the 4 peak demand management strategies simulated for the Life Sciences Centre using the DRQAT.

Strategy Name	Potential peak reduction
Strategy 1 – Zone Temperature modification	100-300 kW (temperature sensitive)
Strategy 2 – Alternate Zone Temperature modification	150-250 kW (temperature sensitive)
Strategy 3 – Lighting Reduction	250 kW (temperature insensitive)
Strategy 4 – Combined Zone Temperature Modification and Lighting Reduction	350-450 kW (temperature sensitive)

Strategy 1 – Zone Temperature modification

The first peak demand management strategy simulated using DRQAT involved adjusting the zone temperature set points for the LSC model. Figure 13 shows a screen capture from the DRQAT model illustrating the baseline and modified zone temperature setpoints.

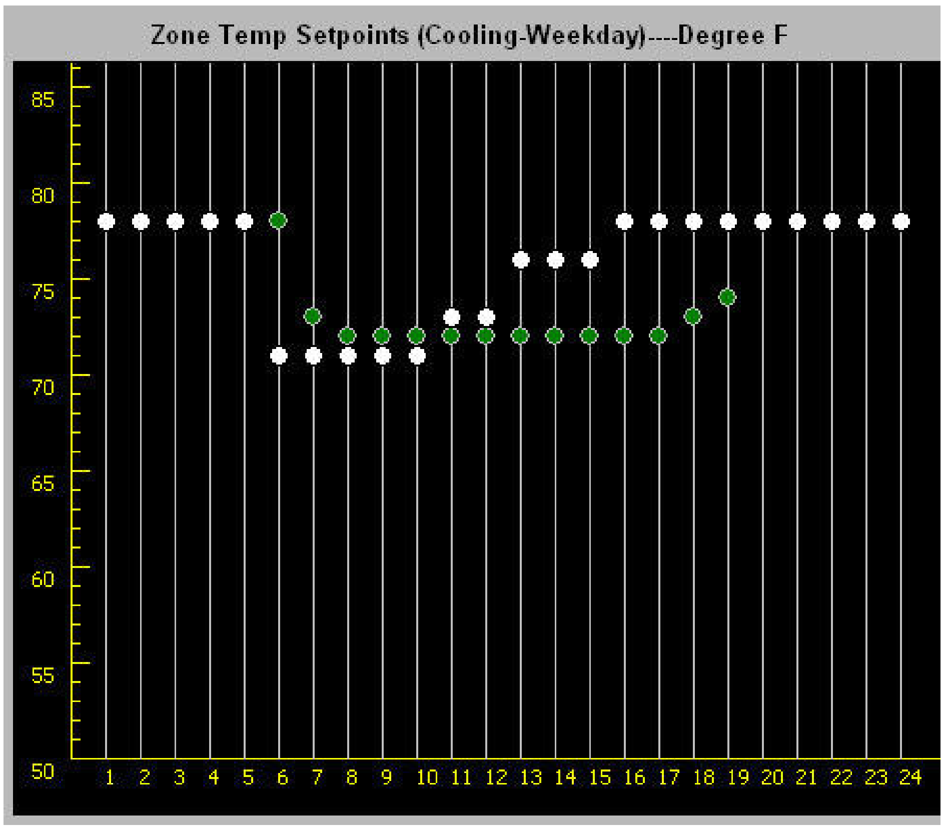

Figure 13 - Zone temperature setpoints for peak demand management strategy 1 versus the baseline for the Life Sciences Centre model in DRQAT.

The green dots represent the baseline setpoints while the white dots represent the new setpoints for strategy 1 (in some cases white overlaps green). This strategy seeks to establish a cool thermal mass early in the day and then gradually allow the building to warm towards its unoccupied temperature (78 ^{o}F). In this strategy the building could be warmer than the baseline four hours earlier. Figures 14 shows the comparison between the baseline demand and the demand predicted for strategy 1. Figure 15 shows the relative difference in demand between strategy 1 and the baseline. The results from strategy 1 indicate a relative increase in demand of approximately 250 kW because the HVAC cooling starts earlier than in the baseline scenario. However, during the afternoon peak demand period the strategy predicts a demand decrease ranging from 100 to 300 kW (weather sensitive). Over the month long period simulated, the gross reduction in demand relative to the baseline is predicted to be 12,837 kW.

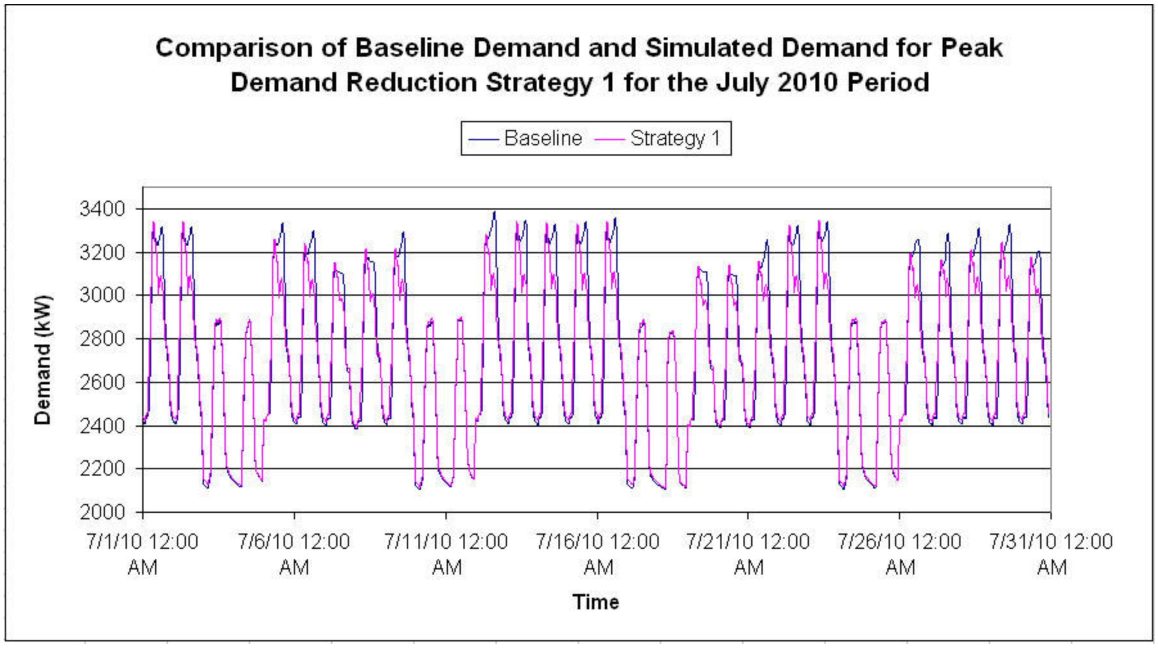

Figure 14 - Comparison of Baseline Demand and Simulated Demand for Peak Demand Reduction Strategy 1 for the July 2010 Period

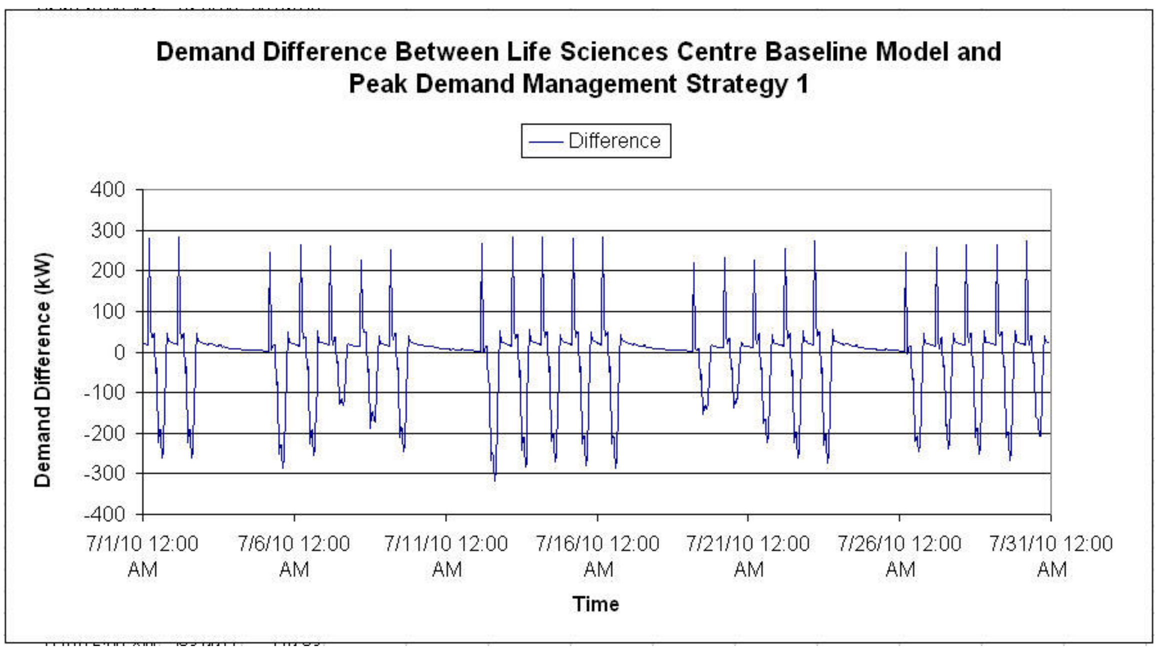

Figure 15 - Demand Difference between Life Sciences Centre Baseline Model and Peak Demand Management Strategy 1

Strategy 2 – Alternative Zone Temperature modification

The second peak demand management strategy simulated using DRQAT involved an alternate adjustment of the zone temperature set points for the LSC model. Figure 16 shows a screen capture from the DRQAT model illustrating the baseline and modified zone temperature setpoints. In this case cooling starts earlier than in the baseline, but is a more gradual decrease than simulated in the first strategy. In addition, this strategy only cools the building to a minimum of 75 ^{o}F and then allows the temperature to rise to 77 ^{o}F between noon and 3 pm.

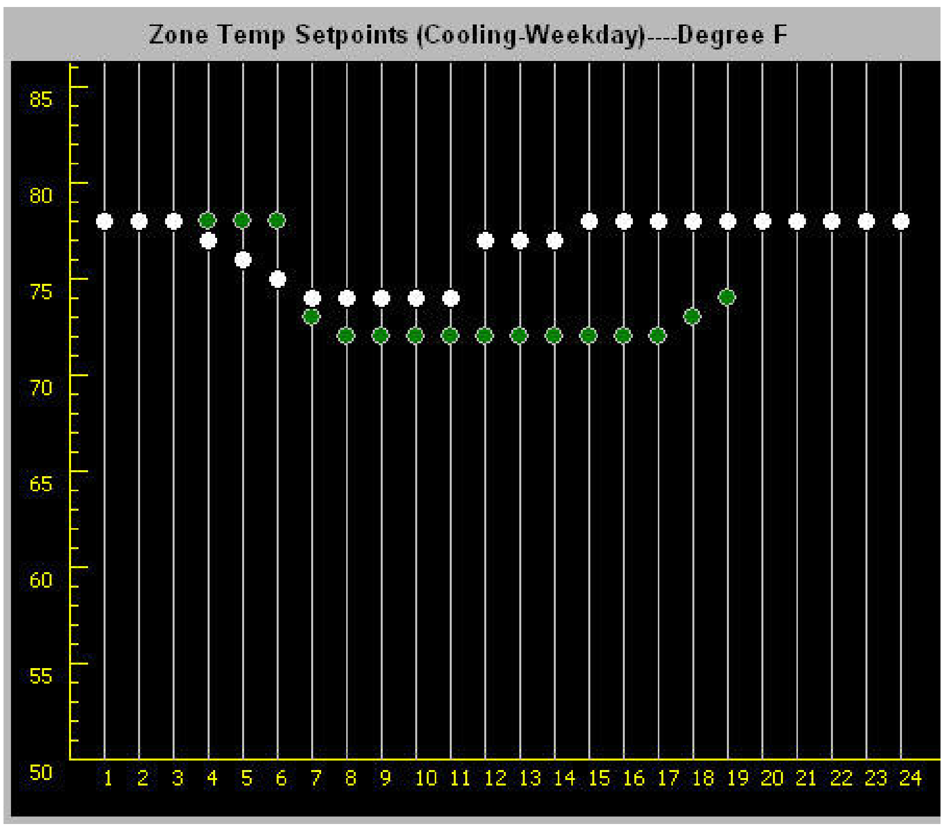

Figure 16 - Comparison of zone temperature setpoint for peak demand management strategy 2 versus the baseline for the Life Sciences Centre model in the DRQAT.

The green dots in figure 16 represent the baseline setpoints while the white dots represent the new setpoints for strategy 2 (in come cases white overlaps green). Figure 17 shows the comparison between the baseline demand and the demand predicted for strategy 2. Figure 18 shows the relative difference in demand between strategy 2 and the baseline. The results from strategy 2 indicate a relative increase in demand of approximately 100 kW because the HVAC cooling starts earlier than in the baseline scenario. However, during the afternoon peak demand period the strategy predicts a demand decrease ranging from 150 to 250 kW (weather sensitive). Over the month long period simulated, the gross reduction in demand relative to the baseline is predicted to be 20,881 kW.

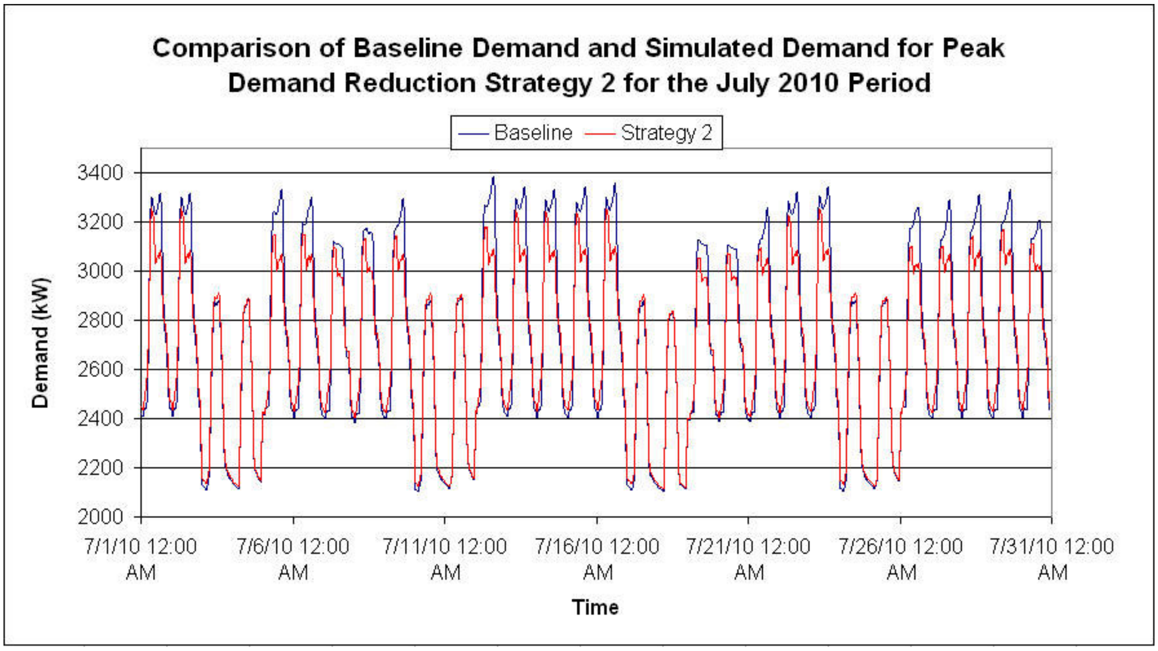

Figure 17 - Comparison of Baseline Demand and Simulated Demand for Peak Demand Reduction Strategy 2 for the July 2010 Period

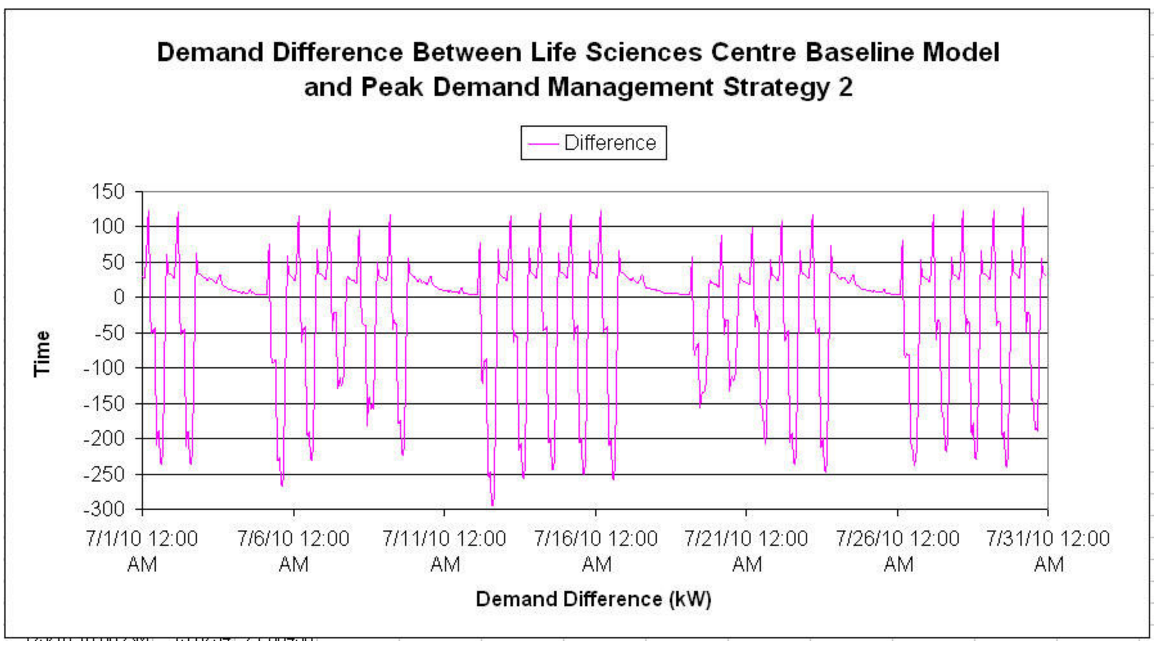

Figure 18 - Demand Difference between Life Sciences Centre Baseline Model and Peak Demand Management Strategy 2

Strategy 3 – Lighting Reduction

The third peak demand management strategy simulated using DRQAT involved reducing lighting loads by 33% between 12 pm until 5pm. This scenario has the most potential to adversely impact building occupants and it is not known how difficult it would be able to isolate and shed a lighting load of this size. Figure 19 shows the comparison between the baseline demand and the demand predicted for strategy 3.

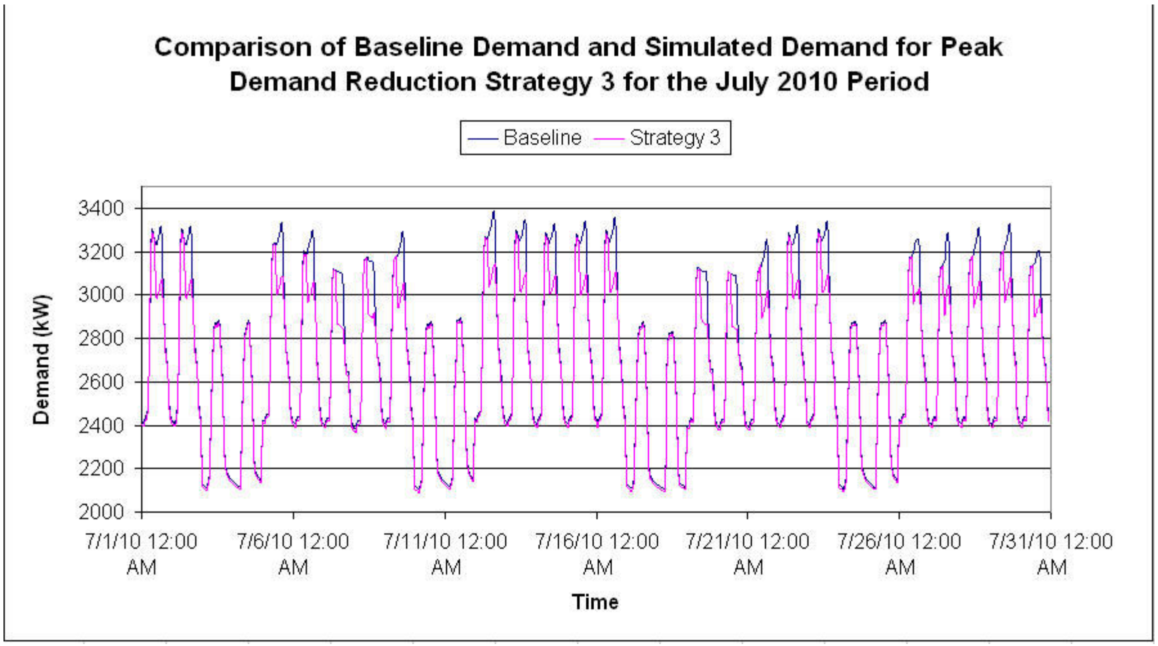

Figure 19 - Comparison of Baseline Demand and Simulated Demand for Peak Demand Reduction Strategy 3 for the July 2010 Period

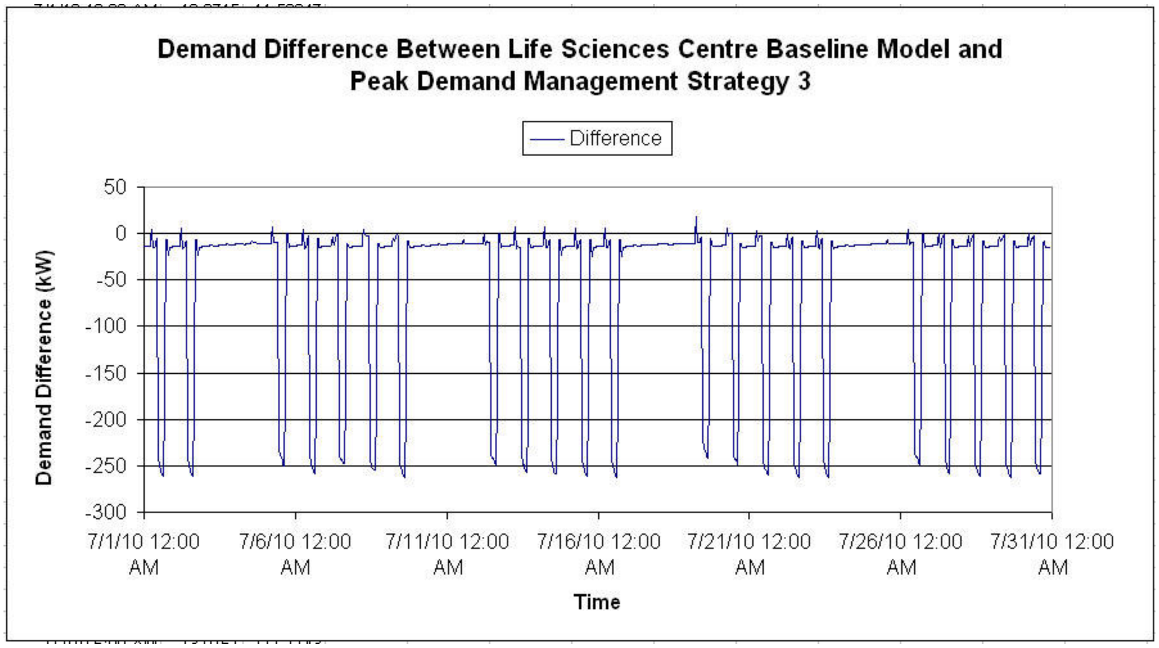

Figure 20 - Demand Difference between Life Sciences Centre Baseline Model and Peak Demand Management Strategy 3

Figure 20 shows the relative difference in demand between strategy 3 and the baseline. The results from strategy 3 indicate a peak demand reduction of approximately 250 kW (weather insensitive). Over the month long period simulated, the gross reduction in demand relative to the baseline is predicted to be 37,734 kW.

Strategy 4 – Combination of Strategy 2 and 3

The fourth and final peak demand management strategy simulated using DRQAT was a combination of strategy 2 and 3. Lighting loads were reduced by 33% between noon until 5pm in combination with a cooling period that begins earlier but only cools the building to 75 ^{o}F. Figure 21 shows the comparison between the baseline demand and the demand predicted for strategy 4. Figure 22 shows the relative difference in demand between strategy 4 and the baseline. The results from strategy 4 indicate a potential peak demand reduction range of approximately 350-450 kW (weather sensitive). Over the month long period simulated, the gross reduction in demand relative to the baseline is predicted to be 63,759 kW.

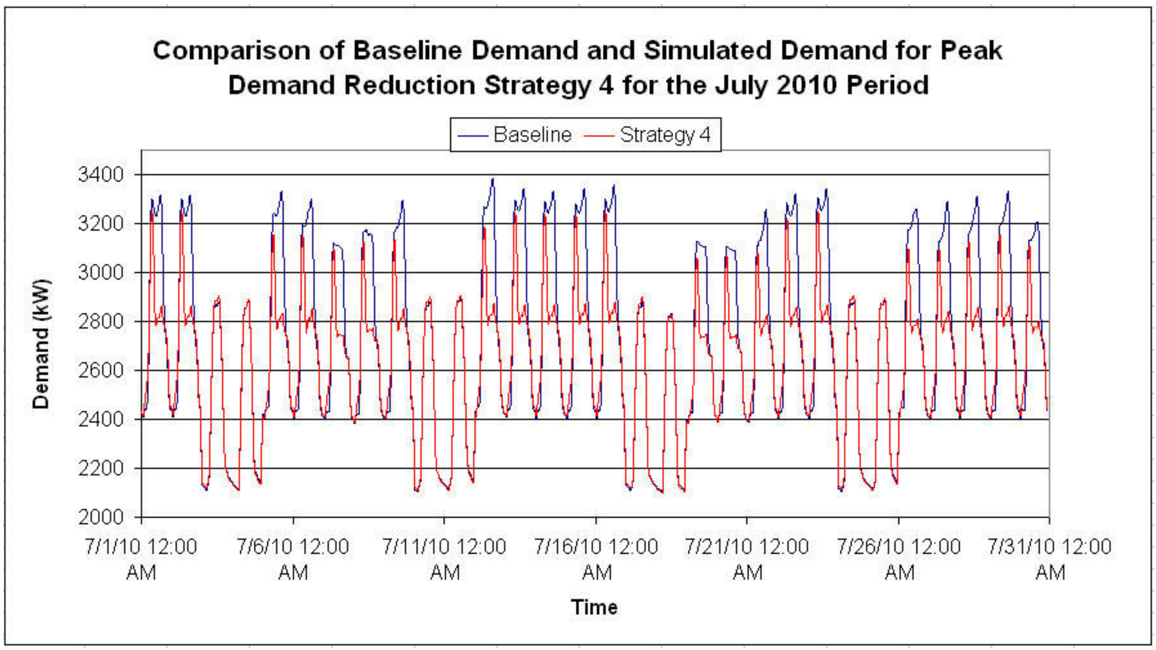

Figure 21 - Comparison of Baseline Demand and Simulated Demand for Peak Demand Reduction Strategy 4 for the July 2010 Period

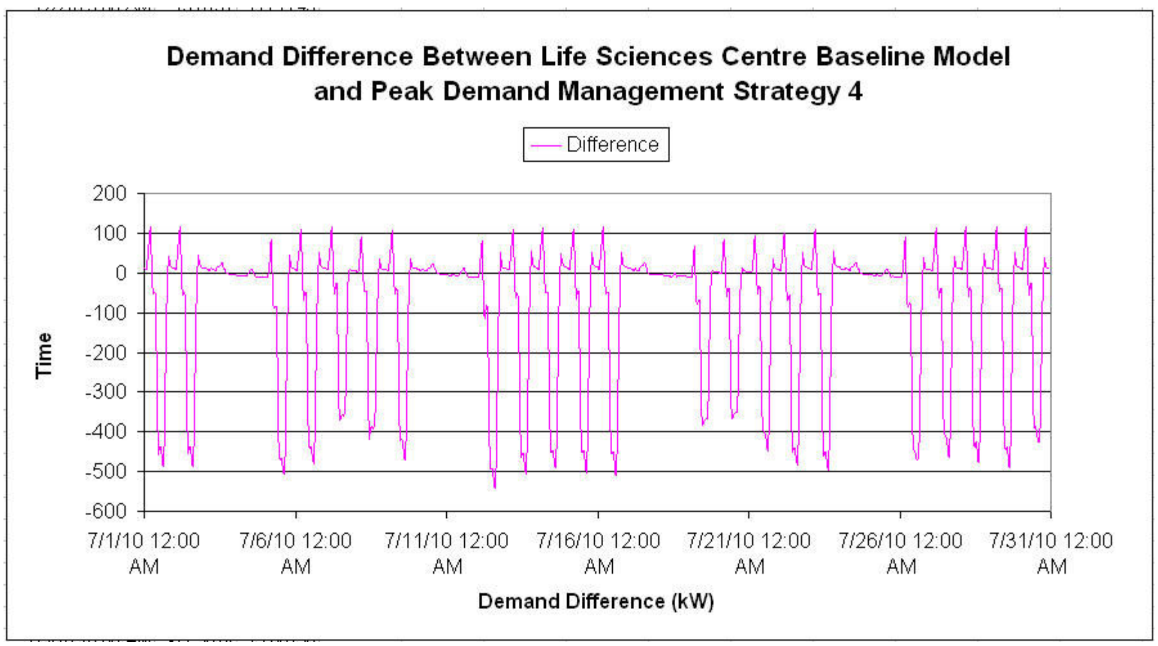

Figure 22 - Demand Difference between Life Sciences Centre Baseline Model and Peak Demand Management Strategy 4

Sources of Error

The potential sources of error for third phase of this project include:

- The strategies investigated do not explicitly consider the heating by-product of lighting.
- It is important to recognize the different buildings have different times when he peak demand occurs. Ultimately it is the coincidental peak across the campus that will be used to evaluate the effectiveness of a peak demand management program. The estimates for peak demand reduction provided are at the building level, and thus the potential reduction estimated is not likely to be completely additive when estimating a potential peak reduction.
- Difficulties arose while attempting to have DRQAT use actual meteorological data for Vancouver, so typical meteorological data was used. If actual data could be used, the model would probably achieve a better fit of the actual data.
- The cost of implementing the circuits and the feasibility for reducing the lighting loads by 33% is not known.
- Researchers at the Demand Response Research Centre indicate that science buildings are poor candidates for demand response due to their complexities [1]. The DRQAT model has been successfully applied to office and commercial buildings, but not to research facilities. Field tests are required to validate the potential demand reduction predicted by the model.

Conclusions

The two main incentives for implementing peak demand management are to reduce costs due to time-of-usage pricing and/or to delay costly infrastructure upgrades. Although the current reasoning behind pursuing peak demand management strategies at UBC is to delay the capital costs associated with upgrading the transmission system, consideration needs to be given to a future that involves real-time or time of usage electricity rates.

UBC has the infrastructure and knowledge to implement manual and simple semi-automated demand management strategies. Simple strategies such as adjusting temperature setpoints or lighting load reduction have the potential to make a meaningful contribution to reducing peak electricity demand at UBC; however care must be taken to design strategies that do not interfere with research needs. For the 16 buildings identified in phase 2 of this report, 2.3 MW or roughly 5% of the UBC peak could potentially be shifted or avoided. These are strategies that can be implemented immediately with little to no capital expenditures. A value of a peak demand management project that reduces the annual peak by 5% over the next 20 years is estimated to be \$3,396,600. To evaluate the uncertainty of the estimate and the potential impact of recent campus growth to biasing the projected peak demand, an alternate estimate was made using a 20% reduction in the slope of the projected peak demand. The corresponding value of the peak demand management program under this scenario was reduced by approximately 10% to \$3,054,630 (in 2010 \$'s).

Recommendations

- Conduct field tests to validate the DRQAT results for the Life Sciences Centre.
- Conduct additional DRQAT model simulations for the 15 buildings identified in phase 2 of this project. Conduct field-tests if the simulations indicate that that a reasonable peak demand reduction could be achieved.
- Develop a 'quick-start' information guide to UBC electricity use and demand illustrating:
    - Summer, winter and monthly peak kW (or kVA) demand loads by end use (lighting, plug loads, HVAC, other).
    - Summer, winter and monthly peak kW (or kVA) demands by major user groups such as core academic, research tenants, and housing.
- Establish a 10-year schedule for comprehensive energy audits and retrofit of campus buildings.
- New buildings should be required to implement infrastructure that permits loads to be adequately monitored and controlled.
- Perform additional analysis to develop a better understanding of costs (currently estimated at $10 million) associated with upgrading the transmission lines beyond 62 MVA.
- Investigate the feasibility of peak demand management strategies that were not simulated and that would require significant capital expenditure (on-site generation, HVAC re-commissioning, etc.)
- Investigate the feasibility of reducing fume hood face velocity to 80 cfm.
- Document UBC building temperature setpoints and adjust accordingly. The evidence presented by Simpson, 2003 [33] documenting the penalty of overheating and overcooling, along with the preliminary DRQAT results for the LSC indicate that simply adjusting temperatures can lead to significant savings.
- Conduct additional studies to better quantify the feasibility and cost of implementing lighting load reduction capabilities through retrofits.

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Appendix A – Literature Review

Peak Electricity Demand Management Initiatives at North American Universities

CEEN 596 – Literature Review Project

Peak Electricity Demand Management Initiatives at North American Universities

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Introduction

In North America, academia is a multi-billion dollar industry that consumes significant amounts of energy and resources [1]. Due to their size and role in fostering innovation, university campuses are of vital importance to shaping how electricity is consumed and conserved. University campuses typically have complex electrical demand profiles caused by concentrated clusters of multi-purpose and specialty buildings where research occurs at all hours and classes continue late into the evening and on weekends. To further complicate the issue; most campuses currently have very few electrical sub-metering points that are needed to support an active monitoring program [1].

The constraints of existing infrastructure (ie. transmission lines) can physically limit that amount of electricity that can be delivered, and provides an incentive to alter the pattern of daily energy consumption. In areas that permit time of usage (TOU) pricing, rate structures are providing an incentive for universities to reduce their peak demand.

The purpose of this literature review is to identify and review the various peak electricity demand management activities occurring on North American university campuses. Electricity consumption typically peaks at predictable times each day, and these peaks cause strain on the power grid resulting in increased electricity costs.

Background

A Brief History of Energy Management on Campus

The OPEC oil embargo in the 1970's caused a major shift in the way that universities managed energy. Up until this point, energy consumption had risen steadily on North American campuses. In response to the constraints imposed by the oil embargo, universities started to create permanent staffing positions to manage energy issues and conservation initiatives [2]. Across North America, various projects were undertaken that cumulatively resulted in a dramatic decrease in electrical consumption. These projects included the installation of computerized building management systems, the removal of excess lighting and replacing old equipment with equipment that was more efficient.

The 1990's brought growing concerns about global warming initiated and a new wave of campus building retrofits, equipment replacement and conservation initiatives. For example, in 1994, the University of Toronto undertook a campus wide retrofit of fluorescent lighting that led to an estimate 6 million kWh annual reduction in electricity consumed. This retrofit was soon followed by the installation of 80 variable speed drives resulting an estimated net reduction of 4 million kWh annually [3]. At the University of New Brunswick, a new automated energy management system was installed in 1991. This updated system permitted energy managers to program occupancy schedules and monitor over 50 heating, ventilation and air-conditioning systems in 11 facilities. Since its inception, the system is estimated to have avoided more than 43 million kWh of electricity consumption [4].

What is Peak Demand Management?

Demand management activities are simply actions taken to manage the consumption of electricity. Peak demand management consists of actions intended to reduce electricity use in response to supply conditions or physical constraints in the electricity grid [5]. Peak demand management does not necessarily decrease total electricity consumption but can reduce the need for capital investments in transmission networks or generation facilities, and help avoid excessive costs in regions employing time of usage electricity pricing.

Peak demand management activities typically involve load shedding or load shifting. The rationale for peak electricity demand management falls under the follow two categories:

1) **Emergency** – Typically emergency activities involve predefined loads being quickly removed from the grid in order to avoid an outage.
2) **Economic** – These activities can be initiated by either the customer or utility to help minimize costs in jurisdictions with time of day pricing and/or to help utilities manage daily system peaks.

Load Shedding

Load shedding refers to a temporary reduction of peak electric demand for maintaining system integrity or achieving economic savings. This is typically achieved through commercial building control strategies such as control strategies for HVAC, lighting and other miscellaneous building end-use systems [6].

Load Shifting

Load shifting refers to consuming electricity at a different time to cause a flattening of the demand curve, and is typically used to avoid transmission capacity issues during peak demand or to benefit from time-of-use rates. This can be achieved through the utilization of thermal energy storage or building thermal mass [6].

Implementing Peak Demand Management Activities

Implementing peak demand management activities occurs in one of three ways:

1) **Manual** demand management activities involve individuals manually turning off loads, such as lights or machinery, in response to a request to conserve power. Email broadcasts at some universities have proven surprisingly effective at reducing peak loads.

2) **Semi-automated** demand management activities involve the use of a pre-programmed response strategy initiated by a person via a centralized control system [7].
3) **Fully automated** demand management activities involve the use of dedicated control systems that respond to electronic communications signals, such as electricity market prices or utility requests, and adjust loads according to a pre-planned load prioritization scheme [8]. Loads can actually be increased in off-peak times to make use of reduced pricing.

Open Automated Demand Response

The Open Automated Demand Response (OpenADR) protocol is a communication standard developed at the Lawrence Berkeley National Laboratory Demand Response Research Centre (DRRC) that allows facilities with building automation systems to participate in demand response programs. The initial goal of OpenADR was to develop a low cost communications infrastructure to improve the reliability, repeatability, robustness, and cost-effectiveness of demand response (DR) in commercial buildings [9]. Six years of successful research culminated in the protocol being selected by the US National Institute of Standards and Technology as the national standard for demand response signalling for integrating building automation systems with a smart utility grid in 2010 [10].

Time of Usage Electricity Rates

Time of Usage (TOU) metering refers to the practice of charging seasonally adjusted higher rates at peak load periods during the day and lower rates during off-peak load periods. The peak period typically occurs during the day, however the times of peak demand/cost will vary in different markets around the world. Depending on the elasticity of the demand for electricity and the peak rate, TOU pricing can serve as an incentive to undertake peal demand management initiatives.

In the United States, utilities in eight states have real-time pricing (RTP) as a default service for commercial and industrial (C&I) customers. In the Pennsylvania-New Jersey-

Maryland (PJM) Interconnection region, Curtailment Service Provider (CSPs) companies are being formed to act as an interface party between the independent system operator (ISO's) and end-use customers to deliver demand response capacity [11]. A number of universities in the United States have already started working with these companies to help plan and manage their peak demand management initiatives [12]. In Canada, TOU pricing is currently (or soon to be) an option in both Ontario and Alberta [13].

Discussion

Over the last decade many North American universities have undertaken numerous energy efficiency & conservation initiatives in an effort to reduce energy use, GHG emissions and costs. Recently, demand management programs, such as load-shedding and load-shifting, have been successfully implemented at select universities. For the purposes of this paper, a number of peer-reviewed publications discussing peak demand management strategies were reviewed. In addition, 15 North American universities responded to an email questionnaire about campus-related energy efficiency and peak demand management initiatives. In addition, university websites and submissions to sustainability report card (insert website name) for over 50 other schools were reviewed in order to discover the various energy management initiatives being undertaken.

Because energy efficiency & conservation measures ultimately contribute to reducing peak energy use, the discussion below highlights both peak demand and energy efficiency strategies that are occurring on North American campuses.

Peak Demand Management Strategies

Overview

The design of load-shedding and load-shifting strategies must consider a variety of constraints. These constraints include various building characteristics, climate, rate structures, and building occupancy requirements. HVAC and lighting tend to be the two largest contributors to the electrical peaks on university campuses, and many demand reduction programs focus on HVAC due to its close integration with building energy management systems. Traditionally, lighting systems are less automated and are thus make automated load shedding difficult. Considerable research has established a foundation for developing customized peak demand management strategies [14-17]. On university campuses, the occurrence of peak demand management strategies is linked strongly to the electricity rate structure that a given university is subject to. The majority of universities implementing peak demand management strategies are in areas where time-of-use (TOU) pricing is being implemented, providing a financial incentive to re-shape the campus electricity consumption profile. Energy marketing companies in TOU pricing states typically pay universities a monthly fee to commit to reducing electricity usage during times of peak demand. The company is then paid by regional power pools for preparing its customers to reduce electricity consumption during peak periods. An example of this would the arrangement forged between Fordham University and Hess Corp.'s Energy Marketing division in New York. Hess provided the Fordham with an energy audit, advanced metering equipment and an online energy monitoring system, at no out-of-pocket cost to Fordham. Hess then worked with Fordham to develop an electricity curtailment plan in the event the power grid operator requests a short-term reduction in electricity consumption. As a result, Fordham is able to shed 768 kilowatts of power on short notice [18].

Thermal Storage

A number of researchers have published peer-reviewed literature illustrating the potential for utilizing thermal storage and a buildings' thermal mass in load shifting and peak demand reduction strategies. Using simulations and field experiments, Braun [14] outlines the potential for building thermal mass strategies aimed at shifting and reducing peak cooling loads in commercial buildings, while Keeney and Braun [19] found that pre-cooling strategies could reduce peak cooling load by up to 25%. A number of universities have been early adopters of this research, making thermal storage strategies one of the most significant peak demand management strategies employed on North American campuses to date. At the University of Maryland-Baltimore (UMB) and University of Arizona (UA), ice is produced for thermal storage during the off-peak hours to shift demand away from daytime on-peak hours, allowing the universities to participate in utility load management programs, and to hedge against increasing and variable electricity rates [20-21]. At the University of California-Irvine, the largest above ground thermal energy storage system in the western U.S. can shift up to 4.5 megawatts of electric load to off-peak hours [22].

At the University of California at Merced (UCM), a two million gallon chilled water storage system is used to flatten the campus load profile during peak periods. Approximately 1.2 MW, or over one quarter of the maximum campus load is shifted, impacting three academic buildings, the campus housing units, dining facilities, and auxiliary buildings. Research into demand response strategies at the UCM has revealed that recovery strategies, such as staggering the return from thermal storage to normal HVAC operations in a slow and methodical manner, should be considered to avoid the rebound peak. In addition, researchers also concluded that there is significant demand reduction possible by combining event-driven zone temperature set point changes with off peak thermal storage strategies [23].

Lighting Reduction

Lighting systems are good candidates for load shedding because the load is significant, the response time is quick and the reduction in demand is predictable. Rubinstein and Kiliccote have examined the lighting-related peak demand management strategies for commercial buildings and found that the size of load available for load-shedding is significant and that the lighting technologies currently available for providing load-shedding capabilities offer the added-benefit of improving energy efficiency through the finer control over the lighting system [24]. If dimmable lighting were implemented across a university campus, the demand response potential would be significant.

In Canada, Newsham and Brit [25], and Galasiu et al. 2007 [26] have investigated lighting energy savings and user acceptance of new demand responsive lighting technologies (WS luminaries) designed to provide highly efficient, customized lighting for cubicles in open-plan office areas. Galasiu et al found that occupancy senors alone would offer savings in lighting energy use in the range of 30 to 40% compared to full lighting use. Newsham and Brit conducted demand responsive experiments using dimmable lighting on a college campus in southern Ontario where 2300 luminaires across several buildings were reduced by up to 40% over 1-30 minutes. The power reduction achieved ranged from 7.7-15.2 kW (14-18% of lighting load).

HVAC Operating Modes

A number of researchers have developed models to simulate the effect of different thermostat control strategies for reducing peak demand [16], and the simulated results indicate that thermostat control strategies can be surprisingly effective for reducing peak electricity demand. Morris et al. [17] studied conducted an experiment in order to evaluate two optimal dynamic building control strategies in a representative room in a large office building. The experimental results indicate that thermostat control strategies have the potential to reduce peak-cooling load by as much as 40%. Xu et al. [27] employed a strategy that involved maintaining zone temperatures at the cooler end (70 ^{o}F) of the comfort region until 2 pm, and then allowed the zone temperatures to rise to the high end of the comfort region (78 ^{o}F). This strategy reduced the buildings chiller power consumption by 80-100% (1 – 2.3 W/ft2) during normal peak hours from 2 – 5 pm, without causing any thermal comfort complaints. In Northern California, Xu and Haves [28] conducted a series of field tests to better understand the effects of various pre-cooling and demand shed strategies. The results indicate that a 25–50% reduction in cooling load is possible during peak hours and demonstrate the importance of calibrating strategies to avoid rebounds effects.

At the UMB, building control systems periodically raise HVAC return-air set points for 30 minutes (or less) to reduce cooling demand, an effort that is transparent to occupants because of the buildings' typical level of 45-minute "thermal inertia." [20]. While at Fordham University, the HVAC system is ramped down during peak demand in order to reduce energy obtained from the grid.

Switchover to Onsite Generators

A number of North American universities are capable of generating some or all of their electricity. This is an asset when it comes to developing peak demand management strategies. Fordham University is able to curtail energy obtained from the grid by shifting to on-campus generators and ramping down the HVAC system, which controls heating, ventilation and air conditioning. If called upon to curtail power, Fordham will receive payments from the energy marketing company (Hess Inc.).

California State University Northridge (CSUN) has the world's largest university-based fuel cell power plant installation. The 1 MW system supplies 18% of the campus electricity needs and waste heat is recovered to provide space heating and hot water for several buildings [29]. The system is comprised of four DFC300MA natural gas reforming fuel cells produced by Fuel Cell Energy, Inc. This system allows CSUN to reduce its reliance on the electrical grid during peak demand periods. Over the power plant's 25-year life cycle the projected cost savings are estimated to be $14.5 million. In an effort to address the sustainability of the fuel cell power plant, CSUN is taking a novel approach to handling the carbon dioxide (CO_2) and water also produced by the fuel cell. A portion of the CO_2 and water will be used by the biology department in the development of an experimental microclimate for carbon enrichment testing.

UBC and Nexterra Systems Corp. have partnered to demonstrate a biomass-fuelled combined heat and power (CHP) solution developed by Nexterra and GE Power & Water's gas engine division. The CHP system will be located on the UBC campus, where it will provide heat and electricity for the campus, while offering a platform for bioenergy research. The CHP plant will produce 2 megawatts of electricity that can be used to offset UBC's existing power consumption. The system will also generate enough steam to displace up to 12 percent of the natural gas that UBC uses for campus heating, thereby reducing greenhouse gas emissions by up to 4500 t/yr. Construction is scheduled to start in the second quarter of 2010 and be completed in late 2011.

Energy Efficiency & Conservation Initiatives

Overview

The way in which buildings are operated has a significant impact on energy use. Energy managers at the State University of New York (SUNY) at Buffalo estimate that each degree of overheating or overcooling cost the university $100,000 per year in unnecessary campus energy use [2].

Improving energy efficiency on campus can go a long way to reducing energy bills and improving campus sustainability. There are a number of areas where North American campuses have strived for improvement including:

- Lighting
- HVAC

- Building Automation
- Integration of Renewable energy generation
- Steam System Upgrades
- Heat Recovery
- Plug loads
- Fume hoods
- Other equipment
- Operations, Monitoring and Maintenance Programs

<u>Lighting</u>

There are two general trending in lighting improvements:

- Replacing incandescent and T12 lighting with more efficient lighting technology (T8, T5 and LED's)
- Installing lighting control systems to add finer control to the operation of lighting.

The University of Saskatchewan (U of S) is an excellent example of the type of lighting related energy efficiency programs that North American universities have been undertaking for the last 15 years. At the U of S an ongoing lighting retrofit project has replaced over 26,000 magnetic ballast fluorescent fixtures with more energy efficient electronic ballasts and fluorescent bulbs. In addition about 3,000 incandescent bulbs are being replaced with compact fluorescents and almost 700 exits signs retrofitted with light emitting diodes (LED's) [32]. Energy managers at the University of Maryland-Baltimore suggest the following guidelines for lighting [12]:

- *During periods of high demand* limit the use of non-essential public area lighting such as corridors, conference rooms, and large meeting rooms and control this function remotely
- Use occupancy sensors to regulate lighting and HVAC loads via remote control.

Recent research studies indicate that electrical use can be substantially reduced by using lighting control systems such as daylight-linked dimming and occupancy sensors [31-33]. Researchers have found that in private offices occupancy sensors worked best for low occupancy offices and dimmable lighting worked best for high-occupancy offices. Occupancy sensors that turned the lights off after a 15-20 minute period of no-occupancy saved 20-26% in electricity costs when compared to the baseline usage. Daylight-linked dimming provided additional savings of about 20%.

HVAC

Heating, ventilation and air conditioning makes up a significant portion of the energy use on North American college campuses, making it an important area for designing energy efficient strategies. Examples of strategies being pursued include:

- Using variable air volume (VAV) HVAC controls with variable frequency drive pumps and fans
- Interconnecting building-chilled water plants to optimize chilled water production
- Installing more efficient chillers
- Utilizing novel cooling technologies

The University of Maryland-Baltimore (UMB) uses a distributed chiller loop system encompassing several buildings, to make the best use of the energy from the chilled water. Since integrating this system, energy load across the campus's 62 buildings has fallen by 20 million kWh in two years [12].

At the Massachusetts Institute of Technology (MIT) MIT's chiller plant expansion has added two 2,500-ton electric driven chillers in otherwise unusable space over the railroad right-of-way. Numerous features have been incorporated into the design, which will make these chillers among the most efficient on campus and save an estimated 2.8 million kWh per year, plus additional thermal and water savings. In addition, MIT is demonstrating an innovative cooling system known as "chilled beams". MIT researchers estimate the potential energy reduction of using chilled beams ranges from 20 percent to 50 percent when compared to traditional AC's.

Building automation

By improving building automation, energy managers have finer control over energy use. Finer control over a buildings system allows managers to develop customized building strategies. Building automation tends to focus on automating lighting or HVAC. Some examples of typical building automation strategies being employed at North American campuses include:

- At Arizona State –Tempe, buildings may be cooled to no lower than 78 degrees and heated to no more than 68 degrees
- At the University of British Columbia (UBC), night time set back and system scheduling based on classroom occupancy schedules are used to regulate temperature (http://www.greenreportcard.org/report-card-2010/schools/university-of-british-columbia/surveys/campus-survey#climate).
- At the University of California-Merced (UCM) an automated energy management and control system (EMCS) monitors over 10,000 points across 800,000 ft2 of building space. A variety of historic trends are stored ranging from whole-building meters, to electric panels, zone temperatures, thermostat overrides and fan power. From: (http://drrc.lbl.gov/pubs/lbnl-2753e.pdf)
- At UMB, more than 66,000 points around the campus are tracked and available for remote viewing. This allows for real time adjustments and enables facilities managers to support energy and maintenance activities without having to be physically on site. (http://www.mcmorrowreport.com/sfm/articles/energycon.asp)
- At Amherst College, buildings are set to 68 degrees (+/- 2 degrees) for heating purposes during occupied hours. During unoccupied hours, the temperature is set back to 60 F in academic and administrative buildings and 64 F in dormitories. For cooling, during occupied hours buildings are set at 76 F.

Integration of Renewable Energy Generation

A number of North American universities benefit from the ability to generate electricity on-site. The electricity can be used to augment electricity purchased from a utility or as a load-shifting mechanism during peak demand periods. Some examples of renewable energy generation occurring on campuses include:

- The University of Calgary's Child Development Centre has a building based array of solar panels that produce 65,649kWh annually
- Allegheny College uses geo-exchange heating and cooling system in various residence office buildings and passive solar heating in the Arts centre
- The University of Arizona is in the process of developing a roof-top mounted solar PV system that will provide approximately 2-3% of the University's typical winter month peak electrical demand (see http://www.uanews.org/node/26690). In addition, the feasibility of a concentrated solar power generation system for providing the majority of the electrical energy needs of the campus is currently being investigated (see http://www.uanews.org/node/26690)

Steam System Upgrades

A number of university campuses use steam for heating. One of the common energy efficiency improvements identified in the survey of campuses were upgrades to the steam system. The steam trap renewal project at MIT offers a typical example of steam system upgrades occurring on North American campuses. A steam trap holds steam in a radiator until the steam releases its energy and condenses. The trap then opens to allow condensate to flow into the return system. When it fails, steam and energy are wasted. The project focused on older heating systems throughout the campus, had a payback of less than one year and saved the campus more than $800,000 a year.

Fume hoods

The fume hoods used by research facilities on North American campus contribute significantly to campus electricity use. Fume hoods can use as much energy as several single-family homes – primarily due to the requirement for large volumes of heated and/or cooled air for ventilation purposes. MIT researchers conducted a research project and concluded that the face velocity of a fume hood could be safely reduced 20% (to 80 feet per minute) without a reduction of hood performance. These findings have been implemented at MIT in 130 fume hoods. The project is expected to save $162,000 per year and have a payback of 2.65 years.

Other Equipment

The variety of equipment on North American equipment is staggering. However, universities are focusing on one of the most common, the vending machine, as a source of energy savings. Universities throughout North America are using "Vending Misers," a product designed to save energy in vending machines by adjusting the compressor cycle and turning off machine lighting, as a mechanism for reducing energy use.

At the University of Manitoba, elevators are being switched from constant speed drive to more energy efficient variable speed drive. Arizona State has undertaken a motor replacement project where 379 premium efficiency motors, ranging in size from 2 to 60 HP, in fifty-seven buildings were installed.

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Appendix B – Images of Lighting Inefficiencies

This appendix contains a select set of images taken on the holiday Monday of the May long weekend in 2010. The images highlight some of the lighting inefficiencies that remain on campus including outdoor lighting left on during the day and unnecessary hallway/corridor lighting in areas with excellent day-lighting.

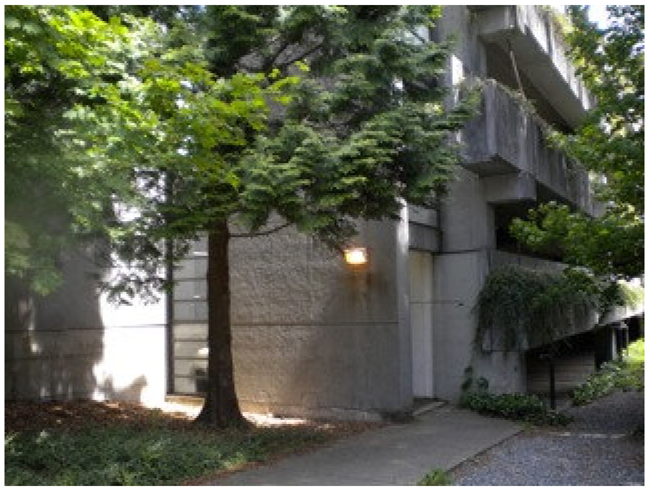

Figure A-1: Exterior light – appears to operate continuously

Figure A-2 – Exterior light and interior staircase light at West Parkade operating throughout the day

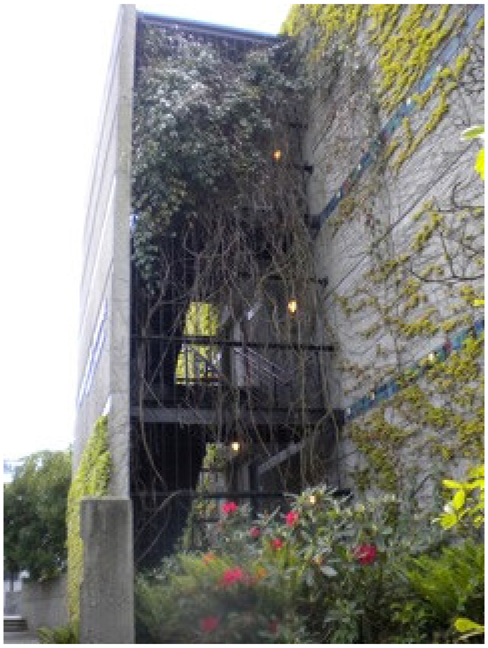

Figure A-3 – Exterior lighting operating during day time hours.

Figure A-4 – Pole lighting operating during day time hours.

Figure A-5 – Multiple exterior lights operating during midday at recently renovated Sauder School of Business building

Figure A-6 – Interior lighting operating during daylight hours in a staircase with excellent day-lighting

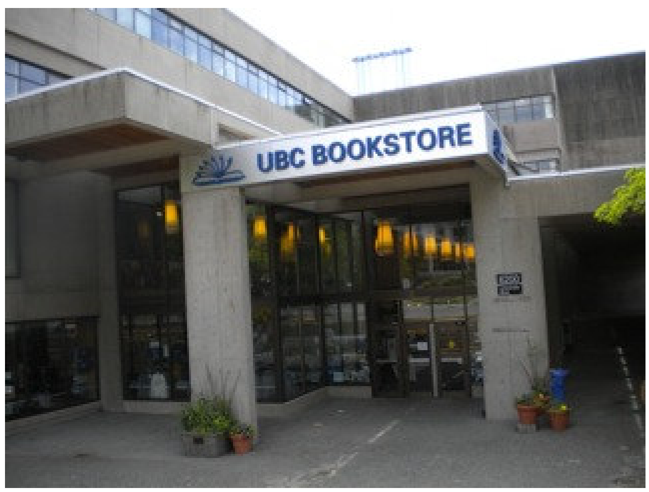

Figure A-7 – Interior lights operating at the UBC Bookstore. It's a holiday and the bookstore is closed.