IDENTIFICATION OF ENERGY CONSERVATION OPPORTUNITIES AT THE PORT DALHOUSIE WWTP, REGIONAL MUNICIPALITY OF NIAGARA

Andrea Dwight, BLUE SKY Energy Engineering & Consulting Inc.*, Melody Johnson, XCG Consultants Limited, Jason Oatley, Robin Young, Jim Grieve, Regional Municipality of Niagara

***BLUE SKY Energy Engineering & Consulting Inc., 4826 Derrydown Drive, Mississauga, Ontario L5M 7J7 andrea@bskyeng.com**

ABSTRACT

As part of Ontario's Green Energy Act, Regulation 397/11, all Municipal organizations must develop energy management plans which target reductions energy consumption and related green-house gas (GHG) emissions. The Regional Municipality of Niagara therefore undertook an ASHRAE Level II energy audit at the Port Dalhousie WWTP with the primary objective of identifying and evaluating measures that would improve the facility's environmental performance through energy and demand response savings.

The audit team used a systematic approach to discover process, facility and operational opportunities. A rigorous review of site operations and energy consumption data combined with benchmarking, detailed process, equipment and energy analysis, resulted in the recommendation of eighteen (18) energy conservation measures. The analysis included a detailed economic study of each opportunity and a measurement and verification plan.

This paper will review the approach, implementation and results of the detailed Energy Audit and Energy Management Plan undertaken at the Port Dalhousie WWTP. The following four energy conservation measures will be discussed in detail:

- Conversion from mechanical aeration in the bioreactors to a diffused air system;
- Optimization of the grit removal system operation;
- Operational changes to ventilation systems in a Bypass Screen building; and
- Optimization of the return activated sludge pumping.

INTRODUCTION AND BACKGROUND

The Port Dalhousie Wastewater Treatment Plant (WWTP), located in the City of St. Catharines, is owned and operated by the Regional Municipality of Niagara. The plant serves a population of approximately 75,000, has a rated average day flow (ADF) design capacity of 61,350 m^3/d and a peak flow capacity of 100,000m^3/d. In 2013, the site consumed over 4,500 MWh of electricity and over 70,000 m^3 of natural gas, with monthly peak electrical demand ranging from approximately 430 to 610 kilowatts.

The WWTP is a conventional activated sludge process (CAS), with treatment consisting of screening, de-gritting, primary settling, aeration, chemical phosphorus removal, secondary clarification, and seasonal disinfection via chlorination/de-chlorination. Waste sludge is stabilized via anaerobic digestion, and the digested sludge is hauled offsite for disposal. A storm water treatment facility, consisting of coagulant addition, flocculation, and sedimentation, operates in parallel with the Primary Clarifiers during normal operation, but also gives additional storm water capacity. A By-Pass Treatment Process operates with screening and chlorination for exceedances above peak flow capacity of 100,000 m^3/d.

The plant was first built in the 1960's and has been upgraded on a regular basis. The most recent upgrades included the installation of a grit removal system, improved returned activated sludge system (2007) and improved chlorination/dechlorination system in 2009.

The Port Dalhousie WWTP CAS plant consists of the following key processing systems and equipment:

- Influent Sewer and Screening Building – Overflow chamber, inlet gate, 2 mechanical screening systems
- Grit Building – 2 aerated grit removal packages with biofilter system
- Primary Clarifiers – 2 main primary clarifiers with the storm tank operating in parallel. The storm tank serves as an additional primary clarifier which enables the plant to meet the peak flow rate of 100 ML/D
- Aeration Tanks – 2 conventional tanks containing 4 cells each, with 8 surface mechanical aerators
- Secondary Clarifiers – 4 rectangular and 1 circular clarifiers
- Chemical Injection – seasonal chlorination/dechlorination system (April to October) and phosphorus removal system as needed
- Anaerobic Digestion System – 2 circular and 1 egg primary digesters and 1 circular secondary digester
- Sludge Removal System – 2 holding tanks and 1 truck loading station
- By-Pass Treatment System - 2 mechanical screening systems and chlorine contact tank

For CAS systems, the most energy intensive processes is typically aeration, followed by anaerobic digestion, process pumping, and building lighting / HVAC systems. Interestingly, at the Port Dalhousie WWTP, the energy use breakdown indicated that the degritting process and the storm water bypass building were relatively high consumers of electricity and therefore potential candidates for energy efficiency improvements.

APPROACH TO THE ENERGY AUDIT

The energy audit of the Port Dalhousie WWTP was delivered using a systematic and multifaceted approach involving historical data reviews, on site observations and inventories, interviews with staff, energy monitoring, detailed analysis and benchmarking.

A historical billing analysis was carried out on each of the energy sources (electricity, natural gas and domestic water). Monthly facility electricity and natural gas consumption information from January 2010 to October 2013, was provided by the Region. Electrical interval data was also provided by the local utility for the period from September 2012 to October 2013 and was used for the electrical demand analysis.

The on-site assessment was completed over a series of days in which the team executed the energy monitoring plan, performed a detailed inventory of energy consumers and audited the facility. Available single line drawings, maintenance system lists and interviews with staff ensured the compiled equipment inventory was complete.

Field instrumentation and SCADA data provided equipment operating conditions so that theoretical energy consumption could be compared to the actual consumption as recorded by the power monitoring. Operations logs at the plant provided additional sampling and quality data. The Region extracted equipment specifications and work order records from the maintenance management system.

A detailed process review was an integral component of this project. It provided an operational benchmark against which potential future energy saving opportunities could be evaluated not only in terms of economics but also to effluent quality. Qualitative assessments of the building envelope of each of fourteen (14) facilities (roof, walls, fenestrations etc.) were also conducted. At the same time, a lighting, HVAC and plug load inventory was completed with detailed observations.

Power measurement program

A total of 32 of the plant's largest energy consuming equipment were monitored for a seven or two-day period from October 23rd to November 2nd, 2013 to support the site energy use breakdown and baseline analysis. In addition, five (5) MCCs were monitored and four additional pumps were fitted with data loggers.

Power consumption, KVa, KW, KVAR, Power Factor and harmonics were measured at each location. Dranetz PX5, EP1, 4300, PQube and Hioki power meters were used.

In addition to being used in the site energy breakdown, this information was analyzed for demand, power factor and operating anomalies to determine equipment specific energy savings opportunities.

Historical energy analysis

The annual breakdown of energy use by type, electricity vs. natural gas, is shown below in Figure 1.

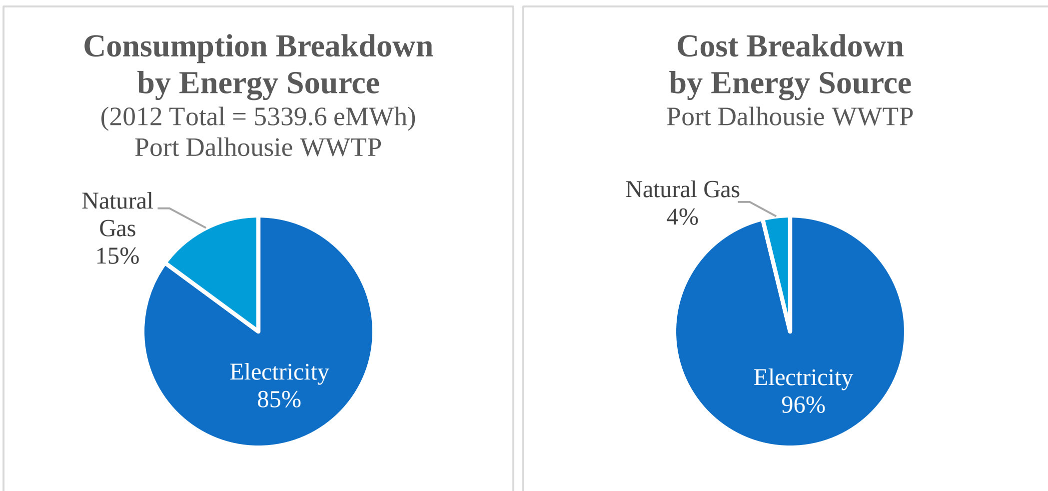

Figure 1: COST BREAKDOWN AND CONSUMPTION BREAKDOWN BY ENERGY SOURCE

Although natural gas makes up approximately 15% of the energy used on site, it only comprises 4% of the total cost.

The peak power in the winter months was determined to be approximately 610kW, and 430kW in the summer. The difference was primarily due to a large number of resistive space heaters used throughout the facility in cold weather. It should be noted that in 5 of the 12 months studied, the peak load was measured during a significant rain event in which the By-pass screen building was in use.

By analyzing the consumption and demand data trends with weather data using statistical analysis a consumption baseline was developed. The current consumption baseline of the plant, calculated using the most recent energy consumption data, was determined to be 287MWh/month plus an additional 205 kWh for every heating or cooling degree (HDD / CDD) in the month.

Energy end use breakdown

The on-site audit of equipment inventory, energy monitoring data, drawing and SCADA review, and staff interviews have been the basis of the following breakdown. Referring to Figure 2 below, the largest energy consumer for the plant was found to be the aerators with 36% of the consumed electrical energy, followed closely by the pumps (22%) and the electric heating and cooling systems (19%). Fans and blowers (process not HVAC) and the miscellaneous motors (collectors, screen drives etc.) categories were at the 13% and 8% level respectively.

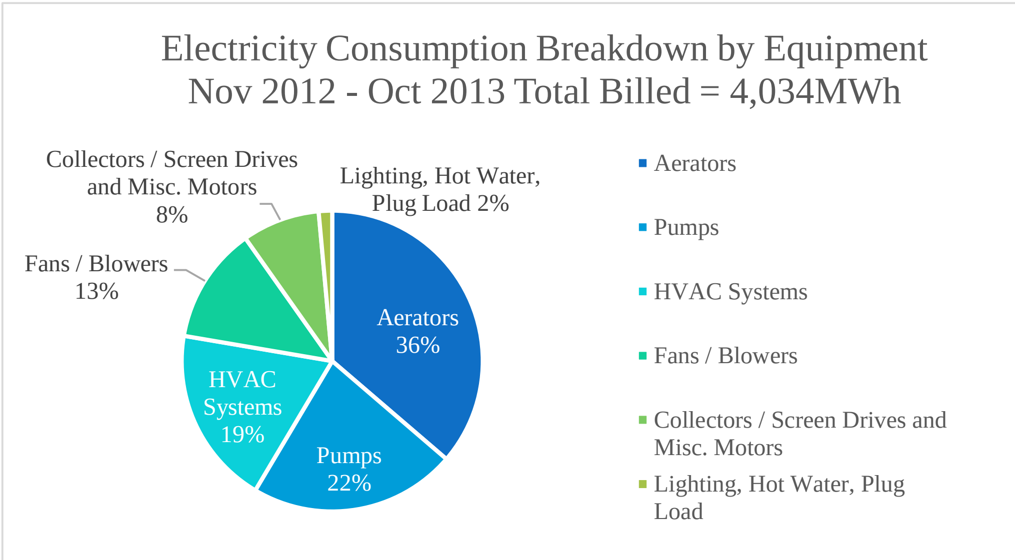

Figure 2: ELECTRICITY CONSUMPTION BREAKDOWN BY EQUIPMENT TYPE

The building HVAC systems account for 19% of the total plant electrical load and there is a strong correlation between ambient temperature and electrical consumption. Several unoccupied buildings are heated to the same level as the occupied administration building which helps explain why the HVAC consumption is high, relative to the total plant consumption. Substantial energy savings could be realized be lowering the set point temperature to 13°C (55°F) for unoccupied spaces in the winter months. Figure 3 below, illustrates the consumption of electricity by process step in which the aeration process is clearly the largest consumer.

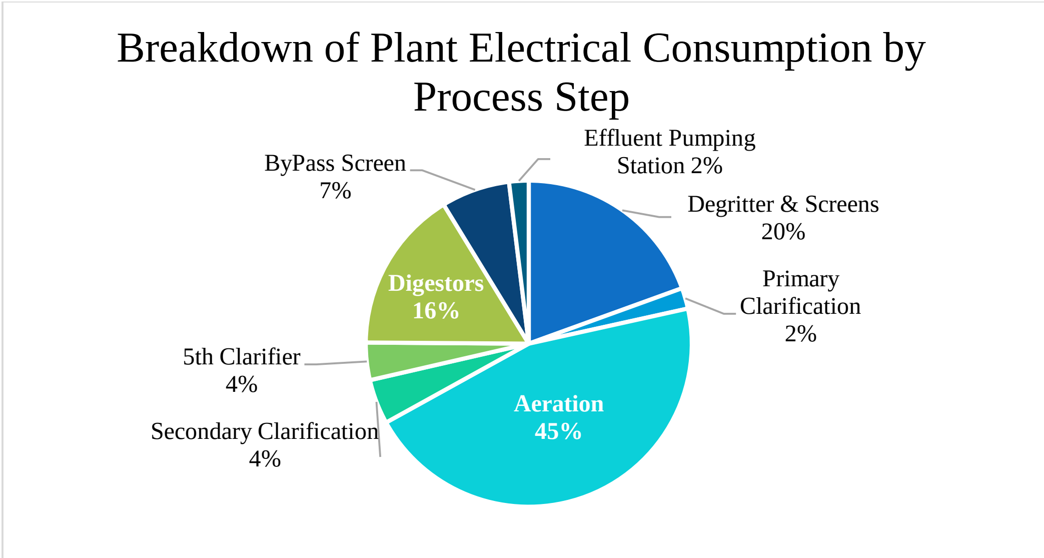

Figure 3: Electricity Consumption Breakdown By Process Step

ENERGY CONSERVATION OPPORTUNITIES

Four energy conservation measures of the eighteen (18) identified in the audit are discussed in the sections below.

Conversion from Mechanical Aeration in the Bioreactors to a Diffused Air System

The existing mechanical aerators consume 36% of the Port Dalhousie WWTP's annual electrical supply. The power monitoring exercise completed as part of the energy audit also highlighted that the aerators motors are, on average, only 50% loaded due to worn aerator impellers. The aerators have been in service for over 20 years and are due for replacement.

Because of the worn impellers, the oxygen transfer capacity of the existing aerators is less than the original design value. It was estimated that the existing aerators could meet the peak oxygen demands associated with an equivalent average day flow (ADF) of 24,000 m3/d, which is well below the CofA rated capacity of 61,350 m3/d and below the historic ADF of 35,200 m3/d. This finding is consistent with the reported periods of zero dissolved oxygen (DO) in the bioreactors.

In addition, the existing mechanical aerators are nearing the end of their useful life and will need to be replaced in the near future. Based on the results of the power monitoring and the age of the aerators, it is suspected that they are in poor condition, resulting in lower power demand and limiting the oxygenation capacity of the system. If the existing aerators are replaced with units of the same size and capacity, and the existing motors are reused, it is estimated that the total oxygen transfer capacity would increase to provide an equivalent ADF capacity without nitrification of 43,090 m^3/d, which is still below the CofA rated capacity of 61,350 m^3/d.

Because the existing mechanical aerators require replacement, this study included an evaluation of the options available to address the oxygen transfer capacity limitations and the age of the equipment, namely:

1. Option 1 – install a new diffused air system to meet oxygen demand requirements associated with operation at the C of A design ADF.
2. Option 2 – replace the existing mechanical aerators with a new mechanical aeration system with the same capacity as Option 1.

Although the existing CofA effluent requirements do not specify effluent total ammonia nitrogen (TAN) limits, there is the potential that the WWTP will be required to nitrify in the future. In addition, to meet the non-toxic effluent requirement under the Wastewater Systems Effluents Regulations (WSER), at a minimum partial nitrification will likely be required. As a result, analyses were conducted based on both non-nitrifying and nitrifying design oxygen demand requirements.

Table 1: POTENTIAL ENERGY SAVINGS – REPLACEMENT OF MECHANICAL AERATION WITH A DIFFUSED AIR SYSTEM.

Operating Condition	Estimated Average Power Input Requirement		Potential Savings Associated with Diffused Air	
	Option 1 - Mechanical Aeration	Option 2 - Diffused Air	kWh/yr (1,000's)	$/yr
Without Nitrification				
Existing Conditions	138 kW	96kW	368	$42K
At ECA Rated Capacity	281 kW	196 kW	745	$85K
With Nitrification				
Existing Conditions	336 kW	234 kW	894	$102K
At ECA Rated Capacity	679 kW	473 kW	1,805	$206K

Notes:

Costs estimated based on $0.114/kWh (Insyght, 2011).

Energy requirements estimated based on average oxygen demand values presented in Table 2.7, an oxygen transfer rate of 1.01 kg O_2/kWh for the mechanical aeration system (see Section 2.6), and 1.45 kg O_2/kWh for the diffused air system (based on a standard aeration efficiency of 4.25 kg O2/kWh (ITT, 2013), alpha of 0.45 (MOE, 2008) and beta of 0.95 (US EPA, 1989)).

As can be seen in Table 1, installation of a diffused air system would result in significant energy savings and an associated reduction in operating costs. In addition to energy savings, a diffused air system can be designed to easily expand to increase oxygen transfer capacity. Blanks can be provided within the aeration grid to accommodate additional diffusers in the future, and space can be provided to allow the installation of additional blower(s) in the future.

Based on the results of this study, it was recommended that the existing mechanical aerators be replaced with a diffused air system. The upgrades could be phased in as follows:

1. Install two, 300HP blowers and diffused air piping to provide a diffused air system to meet peak oxygen demands associated with non-nitrifying operation design for the CofA rated ADF capacity.
2. Prepare for the addition of two 300HP compressors and expansion of / addition of diffusers to the aeration grid so that the Port Dalhousie WWTP can meet oxygen demands associated with nitrification at the CofA rated capacity when required.

Grit removal system optimization

In the existing headworks, the grit screw conveyors, grit pumps, grit classifiers and screw grit collectors currently consume approximately 20% of the sites electrical energy. The two grit blowers and grit pumps are operated continuously and both were metered for over three days as part of the energy audit. The grit blower load curves are shown below in Figure 4.

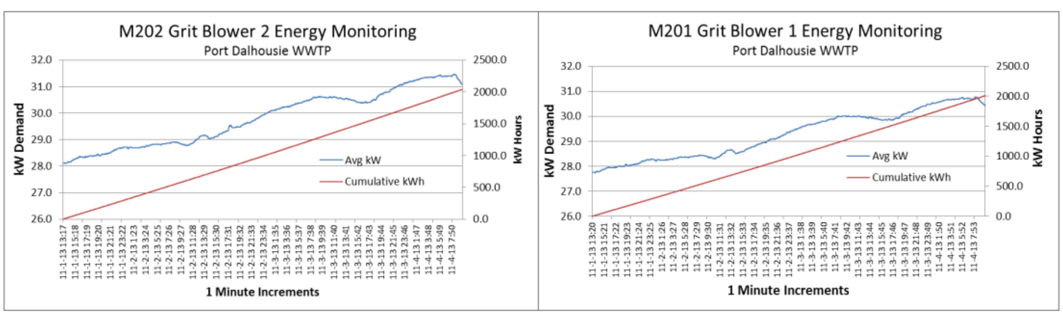

Figure 4 – GRIT BLOWER LOAD CURVES (1 MINUTE INCREMENTS)

A total of 4,044kWh was consumed by Grit Blowers M201 (2,038kWh) and M202 (2,006kWh) over the 68 hour monitoring period. Given the significant energy consumption of this system, the plant operating manual, design criteria from the original design firm, and previously published site condition assessments were reviewed to understand the original design parameters.

Grit Blowers:

According to grit chamber design parameters, the flow of air should be controlled to 420 scfm. Beyond this air flow, the air velocity in the chamber causes grit particles to be carried out of the chamber to the primary clarifiers.

Although two blowers were installed in the headworks, one was intended as primary with the second as a spare. Each of the blowers can deliver much higher than the 420 scfm required by the design. By reducing the number of blowers in operation from two to one, the site could save approximately 260,000 kWh of consumed energy per year ($28,600/yr at an energy price of $0.11/kWh) as well as the associated demand savings.

The blower discharge damper should also be adjusted to reduce the air flow to 420 scfm as read by a local gauge. This reduces the power required by the motor to approximately 20 kW (from 28kW measured during the audit – see Figure 4). This adjustment would save an additional 70,000 kWh/year (or approximately $8,300 at an energy price of $0.11/kWh) as well as the savings from an 8kW reduction in peak demand each month. Running the blowers at top velocity also causes the measured amps to exceed the full load rating on the motor. A reduction of velocity would therefore also reduce maintenance costs and increase equipment life by reducing the amps to the recommended design range.

Grit Pumps:

The grit pumping system was also reviewed. Grit pumps P201 and P202 run continuously as indicated during the power monitoring period. The plant's operating procedure explains that the grit removal, pumping and classification is a batch process that is sequenced to operate for five minutes every thirty minutes. The total energy used during power monitoring period for the two pumps was 1187 kWh over the 66 hour monitoring period. If the operation was sequenced as originally planned the energy used would have dropped significantly to approximately 187 kWh. This energy saving translates to 122,640 kWh per year or a potential annual saving of $14,600. There would not be a requirement for any additional equipment.

The current grit pumps were installed 1993 and have provided reliable service however they have a low mechanical efficiency (42%) and use potable water to flush seals. They are also V-belt drives, resulting in a system efficiency of approximately 34%. If these pumps were replaced with direct drive hidrostal pumps the system efficiency would increase to approximately 54%. This could save 26,5000kWh/yr (or approximately $2,900/yr). The energy savings are insufficient to justify replacing the XR3-8 grit pumps however the potable water savings (if a flushless seal design was available) could amount to over $23,000 per pump (potable water rate = $2.81/m^3).

Ventilation system optimization:

The By-Pass Screen building is operated during significant rain events to treat water when the plant's maximum volumes are exceeded. The facility is used approximately 10-20 times a year and the events typically last for less than a day. The remainder of the time, the facility sits idle.

Figure 5 below, illustrates the electrical load to the By-Pass Screen building and process. It was noted the load did not drop below approximately 50 kW when the building was left empty and idle. This indicates that energy conservation measures may be appropriate and therefore further investigation was conducted.

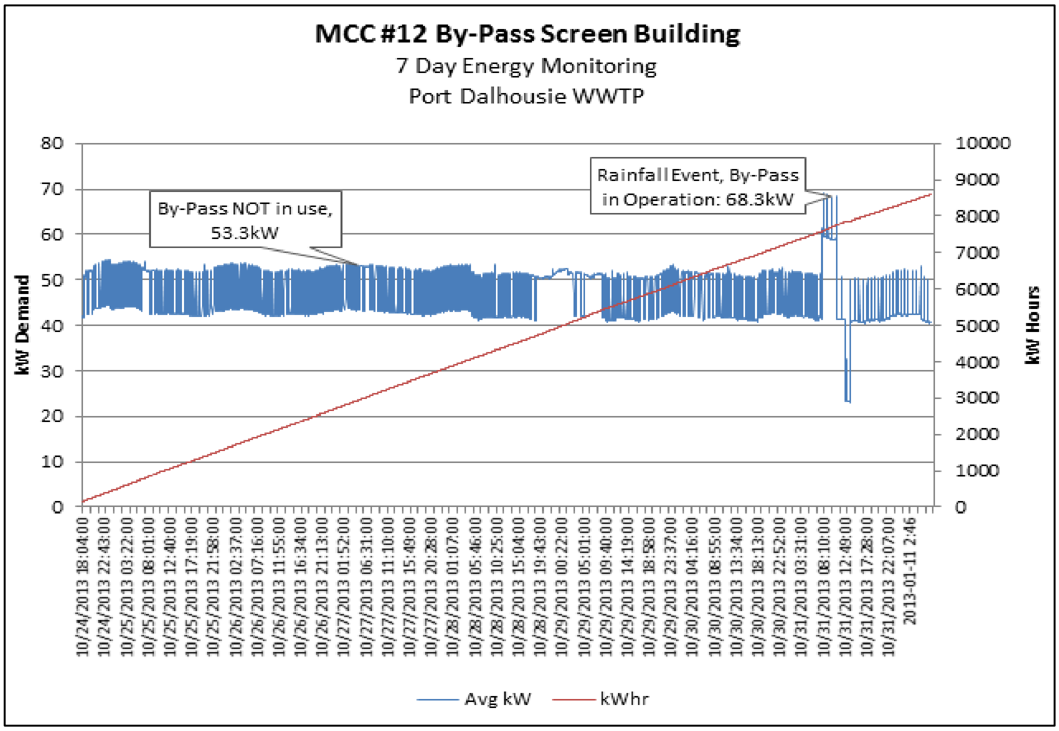

Figure 5: BY-PASS SCREEN BUILDING ENERGY LOAD PROFILE

It was determined that the primary contributors to the high baseline load were a large odour control fan (B-232, 18.6kW) which runs continuously, and two large unit heaters (rated at 20kW each). It was separately recommended that the electric unit heaters be reduced to a minimal temperature setpoint of 13°C (55°F), as the setpoint during the audit was 21°C , high for an unoccupied space.

It was determined that the odour control fan not only provided odour control during the operation of the By-Pass facility but it also was the primary exhaust fan for the first floor of the building. Given that the building is only in use for less than 20 days a year, the process needed to be changed such that the blower was only engaged during operating periods.

In order to reduce the use of the blower but still protect the safety of the operators, it was recommended that the building be locked when not in use, and the main entrance be interlocked with the odour control fan. It was also recommended that four gas detectors be installed in the screen section of the building so that hydrogen sulphide or methane can be properly detected.

If the odour control fan was turned on only when required, (on average the building is used 20 days per year), the annual energy savings would be approximately 149,000 kWh or $16,400.

Return activated sludge pumping optimization:

In 2013 there was a significant change made to the RAS pumping rates from Clarifier 5 to the bioreactors. The maximum flow was lowered from 465l/s to 310l/s and the average flow lowered from 350l/s to 250l/s. These adjustments resulted in the existing 75HP pump motors operating at approximately 20% load. This presents a significant opportunity for improvements to the energy efficiency of the system by down-sizing the pumps and motors.

In addition, the existing waste activated sludge (WAS) pumps associated with Clarifiers 1 to 4 are not currently used. Rather, the RAS pumps associated with these clarifiers are used to pump WAS to the primary clarifiers for co-thickening. WAS flow is controlled by throttling valves on the RAS / WAS piping connection. Because they are not currently in use, there is the potential to relocate these WAS pumps to Clarifier 5, potentially reducing capital costs associated with modifications to the Clarifier 5 RAS pumping system.

Based on the current configuration of the RAS and WAS pumping systems, it was recommended that the two 75HP Clarifier 5 RAS pumps be replaced as soon as possible with three 20HP pumps. To reduce capital costs associated with recommendation, the two 20HP WAS pumps from Clarifiers 1 to 4 could be repurposed as Clarifier 5 RAS pumps. Clarifier 5 would have to be taken offline to complete piping and electrical tie-ins (possibly for two weeks). This could be mitigated by completing the work during the typically drier summer months.

With these changes, immediate savings associated with potable water and energy savings would amount to $33,140 each year. In addition, operations staff would have improved process control of Clarifier 5.

CONCLUSIONS

The audit revealed 18 key conservation findings, four of which were discussed in this paper. In total, approximately 1350MWh/yr ($153,000) could be saved in electrical consumption if the following four projects were delivered:

- Conversion from mechanical aeration in the bioreactors to a diffused air system;
- Optimization of the grit removal system operation;
- Operational changes to ventilation systems in a Bypass Screen building; and
- Optimization of the return activated sludge pumping.

In addition, water savings of $33,000/yr could also be realized with the delivery of the RAS pumping optimization options. An additional $23,000/yr. of Potable water could also be conserved (approximately $23,000/yr) if the Grit pumps in the headworks were replaced with pumps with flushless seals.

Although several of the identified opportunities are large capital projects, a significant portion of the savings could be realized through low cost operational changes. With proper sub-metering and benchmarking, conservation measures typically hidden from view can be identified and critically evaluated. This was found throughout the site and reaffirms the value of conducting a thorough site wide energy audit.