Doug Mitchell Thunderbird Sports Centre Energy Consumption Analysis

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Introduction

The University of British Columbia strives to meet society's needs without compromising economic, social and environmental sustainability; the carbon footprint of the university is one measure of sustainability of UBC. This is the measurement of the total greenhouse gas emissions caused directly and indirectly by a person, organization, event or product.

In 2010, UBC adopted the most aggressive greenhouse gas (GHG) emission reduction targets amongst the world's top 40 universities. The University aims to:

- Reduce GHG emissions to 33 per cent below 2007 levels by 2015;
- Reduce GHG emissions to 67 per cent below 2007 levels by 2020;
- Reduce GHG emissions to 100 per cent below 2007 levels by 2050, at which point UBC will be a net positive energy producer.

The most significant opportunities to meet these targets and demonstrate climate action leadership are in energy use, business travel, commuting, paper use and food. Evaluating the amount of energy used in individual buildings on campus, and constantly looking for ways to decrease usage, is one step towards reducing our carbon footprint.

About the Doug Mitchell Thunderbird Sports Centre

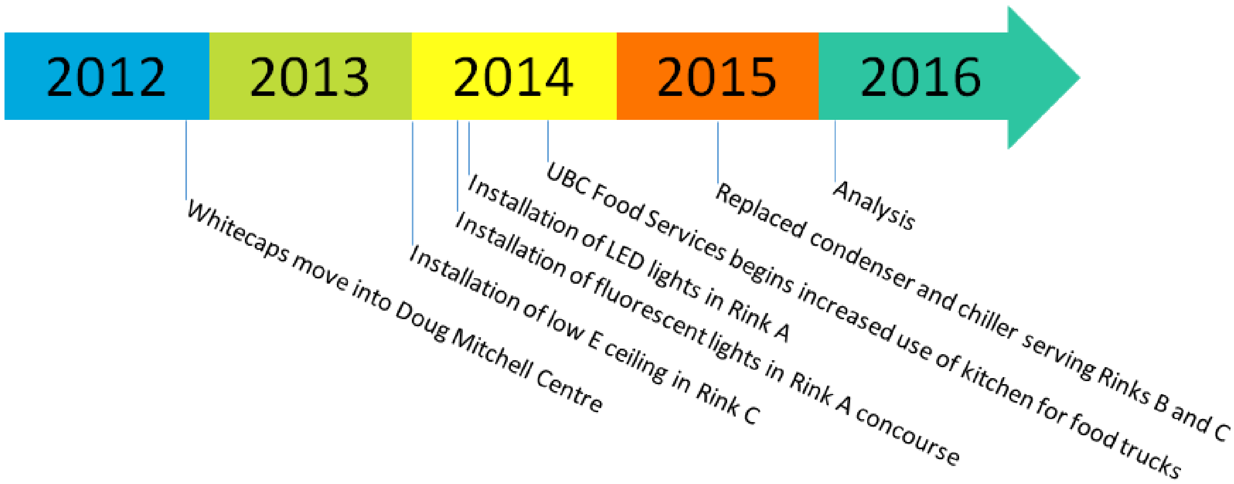
The Doug Mitchell Thunderbird Sports Centre (DMTSC) was a host venue for the Vancouver 2010 Olympic and Paralympic Winter Games. The centre, comprised of the 5,033-seat arena, a practice arena and the refurbished Father David Bauer arena, was the venue for some ice hockey and all sledge hockey events during the 2010 Games. The DMTSC also contains a 6,000-square-foot multi-purpose room, a 5,000-square-foot physiotherapy or fitness centre, 13 public dressing rooms, six referees / coaches rooms, two varsity rooms and one alumni room, and is home of the UBC Sports Hall of Fame. The centre can hold up to 7,000 people for special events including: concerts, sporting events, conventions, speakers, film shoots and hockey related programs. In addition, it is the Vancouver Whitecaps FC Training Facility.

Scope

Since 2013, UBC Athletics has invested in numerous power-saving capital improvements for the DMTSC. At the same time, it has increased its community programming, and tied in with other campus units (including Food Services) to increase the utilization of its facilities. In this report we will examine these capital improvements, and increases in facility usage to determine the overall change in power consumption by the DMTSC.

Timeline

The capital improvements, and changes to the utilization of the DMTSC occurred between November 2012 to July 2015.



The dates of the changes are:

- November 2012 – Whitecaps move into the DMTSC
- January 2014 – Installation of low emissivity ceiling in Rink C
- March 2014 – Installation of fluorescent lights in Rink A concourse
- April 2014 – Installation of LED lights in Rink A
- August 2014 – UBC Food Services begins using kitchen facilities to service food trucks
- July 2015 – Replaced condenser and chiller serving Rinks B and C

The Whitecaps

The Vancouver Whitecaps FC are a Canadian professional soccer team, which competes in Major League Soccer. The Whitecaps play their home matches in BC Place; however they use facilities at the DMTSC arena for training. The Whitecap facilities at the DMTSC include a fully equipped dressing room, office and meeting space, showers, a large medical room, and a 4,100 square foot high performance training facility. In addition, the Whitecaps use the laundry facilities at the Arena. The Whitecaps moved into the arena in November 2012.

Analysis

An analysis of the historical energy use data found that in the year before the Whitecaps moved into the DMTSC (November 1, 2011 to October 31, 2012), 4,664,478 kWh of energy was consumed. In the year after the Whitecaps' move (December 1, 2012 to November 31, 2013), the energy use was 5,176,986 kWh[1]. This is an 11% increase in the consumption of electricity recorded.

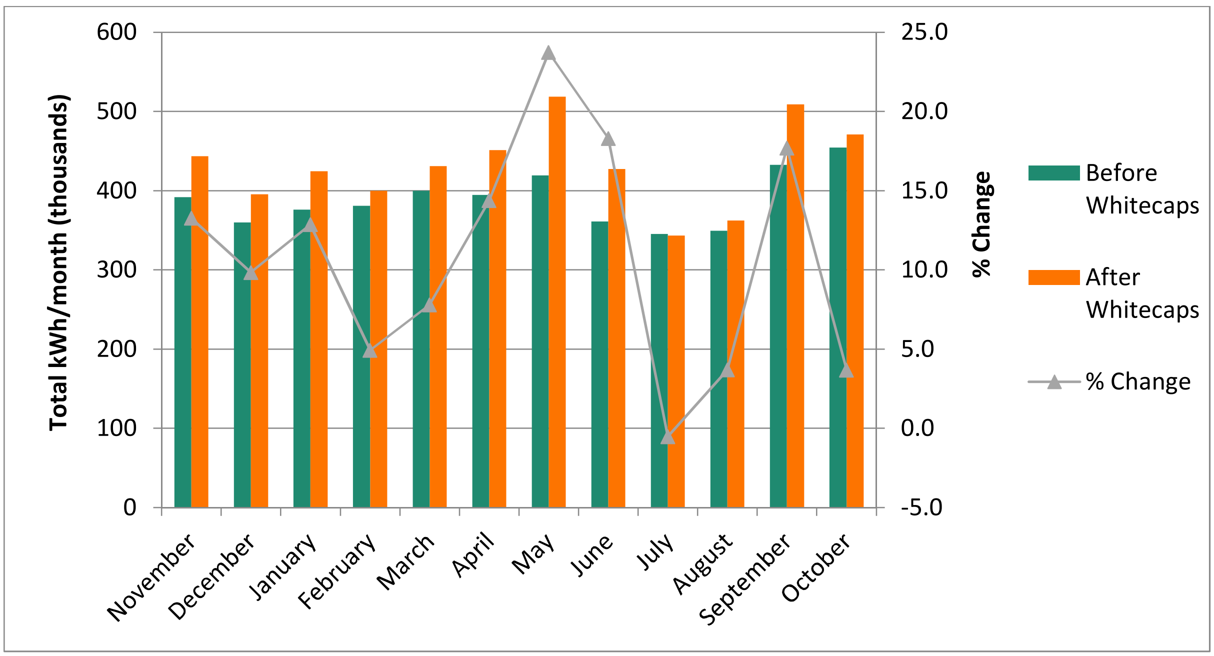


Figure 1 DMTSC Energy Consumption Before and After Whitecaps

It was hypothesised that outside temperature can impact the electrical consumption of the DMTSC; if so, annual temperature must be taken into account. Heating degree days (HDD) are a measurement designed to reflect the demand for energy needed to heat a building. It is derived from measurements of outside air temperatures. Cooling degree days (CDD) are a similar measurement, which reflect the amount of energy used to cool a building. Heating and cooling degree days are defined relative to a base temperature, which for this purpose we have

[1] In the year after the Whitecaps' move, there were five hours when energy consumption was not recorded. For the purposes of this analysis, those five hours were considered to be statistically insignificant.

selected 14ºC because that is the ambient temperature in the DMTSC. In the year before the Whitecaps moved in, there were a total of 2,076 total degree days (TDD, HDD plus CDD). The year after the Whitecaps move there was 2,051 TDD, which is a 1.2% decrease in TDD.

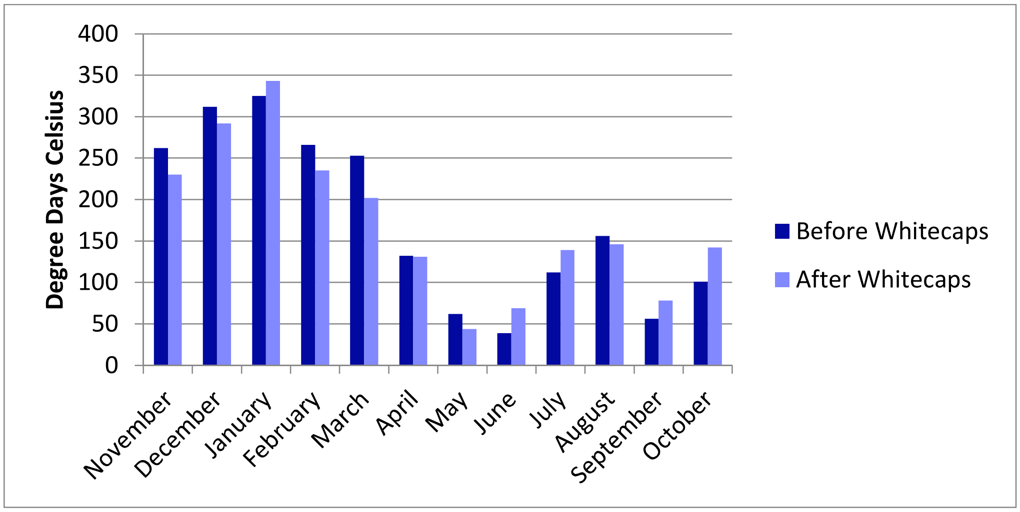


Figure 2 TDD Before and After Whitecaps

Total number of hours of rink usage can have an effect on energy consumed at the DMTSC. Hours of rink usage has been provided as total quarterly usage. In the year prior to the Whitecaps move there was a total of 9,991 hours of rink usage, while in the year after, there was 10,411 hours of rink usage. This is an increase of rink usage of 4.2%.

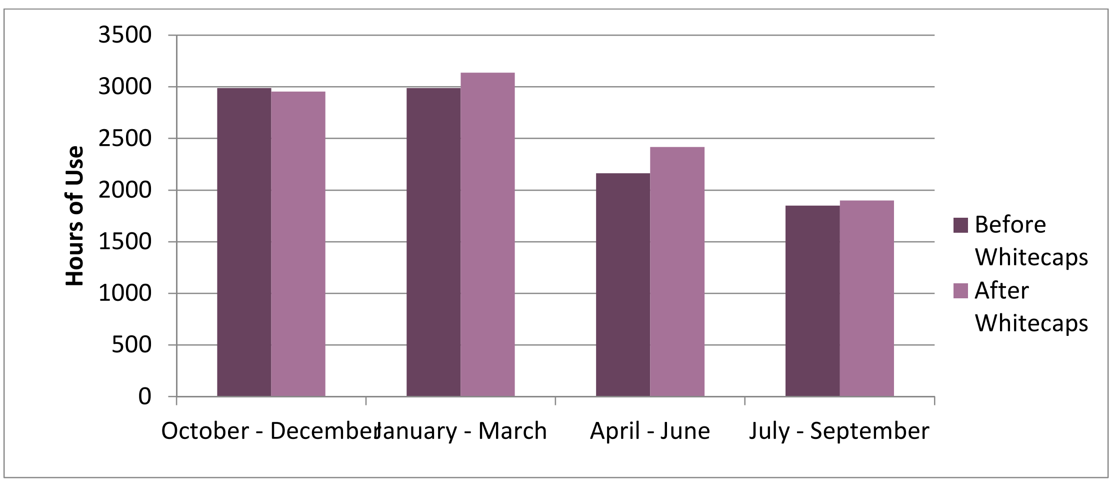


Figure 3 DMTSC Quarterly Hours of Rink Usage before and after Whitecaps

The Whitecaps consume energy in a variety of ways including:

- lighting in the Whitecaps facilities;
- laundry facility use;
- hot tub;
- multiple refrigerators and kitchen facilities; and
- ice makers.

The Whitecaps produce, on average, 25 loads of laundry per week from mid-January until the end of October. The water for the laundry is heated by a gas boiler, which does not impact the electrical power used by the DMTSC. In addition, the dryers are also gas heated. The electrical power required to clean a load of laundry goes to powering the motors and drives of the machines for spinning, rather than heating. Although 25 loads of laundry would be significant with regular washers and dryers, as the heat is all provided by gas, it would not significantly contribute electrical consumption.

The Whitecaps also have two hot tubs which are used for treating sports injuries. One hot tub is used for ice baths, while the other is used as a traditional hot tub. The hot tubs are Softub brand. According to information available on the Softub website, the tubs can be used for 20 minutes a day for a total of 83 kWh per month[2]. It is likely that Whitecaps use the tubs for more than 20 minutes per day. If the data provided by Softub can be correctly extrapolated, using a tub for 2 hours per day would be approximately 500 kWh per month, or 6,000 kWh if used constantly. If the tubs were used constantly the year after the Whitecaps moved in, it would account for 1.4% of the electrical usage at the DMTSC. This however, is very unlikely.

Whitecaps Conclusions

The 11% increase in electrical power consumption at the DMTSC likely came from a number of factors, including the Whitecaps. The 4.2% increase of rink usage likely contributed to the increase of power consumption, as did the Whitecaps facilities and laundry usage. Further analysis would be recommended to determine the actual amount of power used by the Whitecaps, including installing an electrical meter in the Whitecap facilities. If laundry use continues to be a concern, a future SEEDS project could be to use an ammeter to measure power usage during a Whitecaps laundry session.

[2] http://montanasoftubs.com/softub-energy-efficient

This calculation is based upon CEC protocol, using a model 220 Softub every day for 20 minutes, with the jets on. The water temperature was maintained at 102° Fahrenheit at all times, with an ambient temperature of 60° Fahrenheit or lower. Using the national average cost of energy of $0.1097 per kWh, the monthly cost calculates to $9.12 per month.

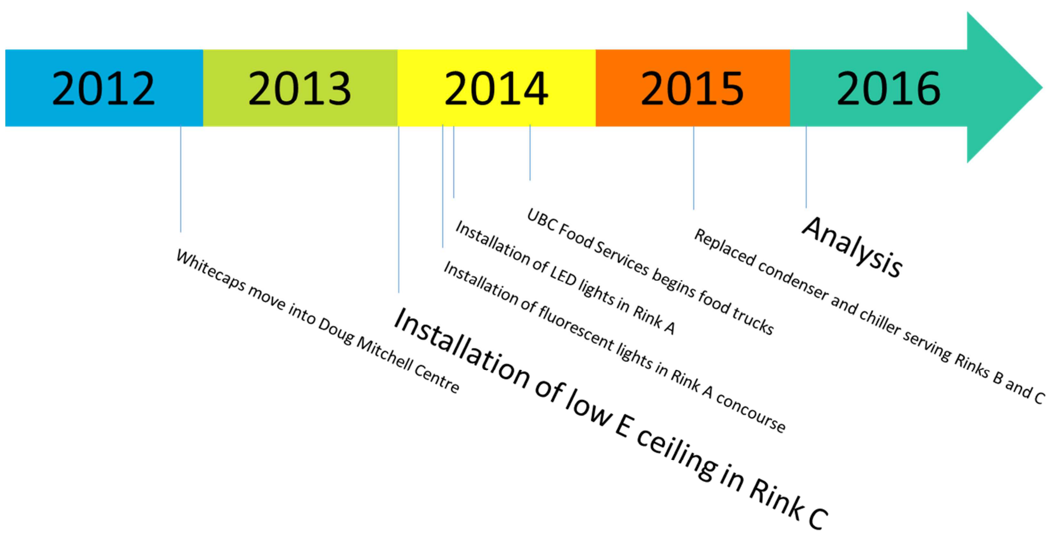
Low Emissivity Ceilings

Low emissivity ceilings, or low-e ceilings, were installed in Rink C, also known as the Protrans Arena, in January 2014, with the objective to reduce heat loading on the arena due to the ceiling. This resulted in a reduction in energy consumption to cool the arena, and maintain the ice surface.

Emissivity is the total radiation emitted, divided by the total radiation that would be emitted by a blackbody at the same temperature. Emissivity is a value between 0 and 1, where a value of 1 would equal the emissivity of a black body. A blackbody emits the theoretical maximum amount of radiation possible at a given temperature and can also be referred to as an ideal radiator. (Kreithm & Bohn, 2000)

Low emissivity materials were mounted to the ceiling of the Protrans Arena to prevent the ceiling from heating the ice surface. In previous reports, an emissivity of 0.9 was given as an appropriate value for the original ceiling. The vendor of the low emissivity ceiling stated that the ceiling material has a 0.032 emissivity, which significantly reduced the thermal radiation emitted by the ceiling.

The low emissivity ceiling was installed in the Protrans Arena in January 2014. However, it should be noted that energy saving lighting upgrades were also completed in March and April 2014, further reducing energy consumption of the building.



In a report for "PHASE 1", it was expected that a reduction of 15% energy consumption would be achievable by installing low emissivity ceilings in the two smaller ice rinks. Expected installation cost would be $1.5/ft^2$. Following that, a report produced by a student of the University of British Columbia reviewed the results from the installation of the low emissivity ceiling in Rink B. (Russell-Jones, n.d.) Ceiling radiation was stated to be the highest heat load on the ice rinks, as well as the greatest potential for heat load reduction, according to (Blades, 1992). The heat load due to the ceiling of Rink C was theoretically calculated to be 46.64 kW on average. The installation of a low emissivity ceiling was expected to reduce that heat load to 6.12 kW. The expected simple payback was calculated to be within 3.25 to 5 years with a capital cost of approximately \$100,000 and \$30,924 annual savings. In addition, various incentive programs from BC Hydro's Produce Incentive Program, was mentioned to potentially improve the payback period with a \$10,000 incentive per installed sheet of low emissivity ceilings from a range of suppliers. Lastly, it was recommended that continuous measurement of ice and ceiling temperature be performed prior to and following the installation of the low emissivity ceiling.

A second report produced by a professional engineer further analyzed the potential savings of installing a low-e ceiling on Rink C (Protrans Arena). Using the typical emissivity values of steel and grey paint, an emissivity of 0.9 was used to develop energy savings estimates. The engineer also collected data on ceiling temperature and outdoor temperature, and found a significant correlation between the two temperatures. The ceiling vs. outdoor temperature regression coefficient was 0.65 and 0.71 for sunny and cloudy conditions, respectively. The correlations indicated that the ceiling temperature would be 5.2^{o}F lower than the outdoor air temperature on average. The report concluded that the low-e ceiling should be installed and expected to result in \$7,431 in annual savings and have a simple payback of 1.5 years

Verifying Low Emissivity Ceiling Performance

The performance of the low-e ceiling was verified using a Raytek Raynger ST60 non-contact thermometer. Measurements were made between bare sections of the ceiling vs areas covered with the low emissivity material.

Figure 4 Reading 36.5^{o}F (2.5 ^{o}C) of the low emissivity ceiling.

All measurements were taken during cloudy days, reducing the overall direct solar radiation heating of the ceiling. This was due to predominantly cloudy weather during the measurement window.

The average difference over three separate measurement recordings was 10.2^{o}C. The actual temperature measurement of the low emissivity ceiling is expected to reflect the ice rink's temperature due to the material's high reflectivity, rather than a true indication of the emitted radiation of the low-e ceiling.

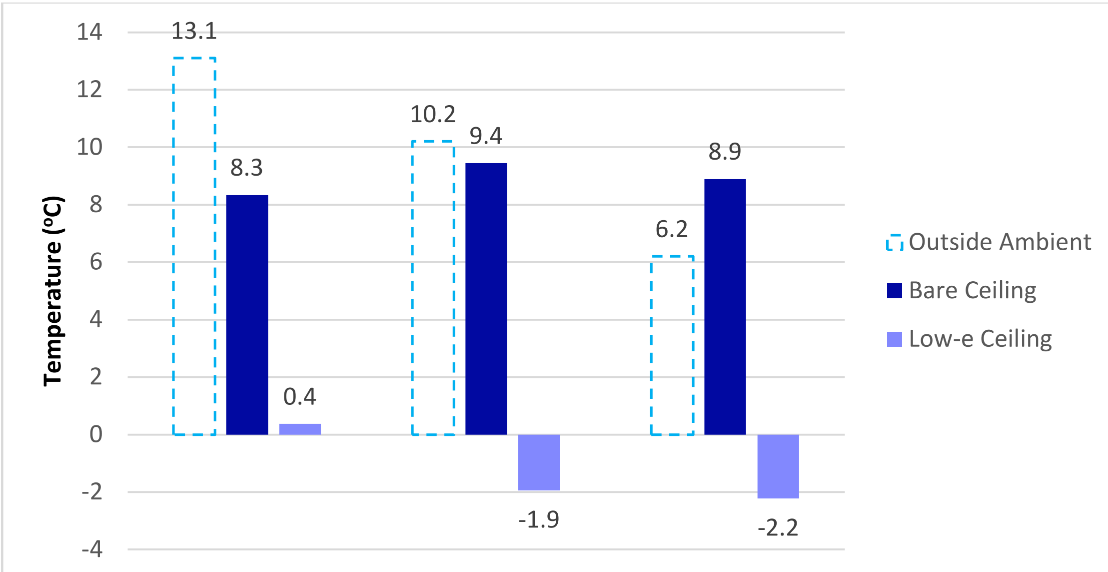


Figure 5 Low Emissivity Ceiling Performance

We can conclude that the material is performing as expected, significantly reducing the energy emitted from the ceiling.

Analysis

Leading up to the installation of the low emissivity ceiling in 2014, the energy consumption trend of the DMTSC had a strong linear correlation for the three years prior, which we can expect from the increase use of the DMTSC. Forecasting into 2014, the electrical consumption was expected to be 5,601,937 kWh for the calendar year.

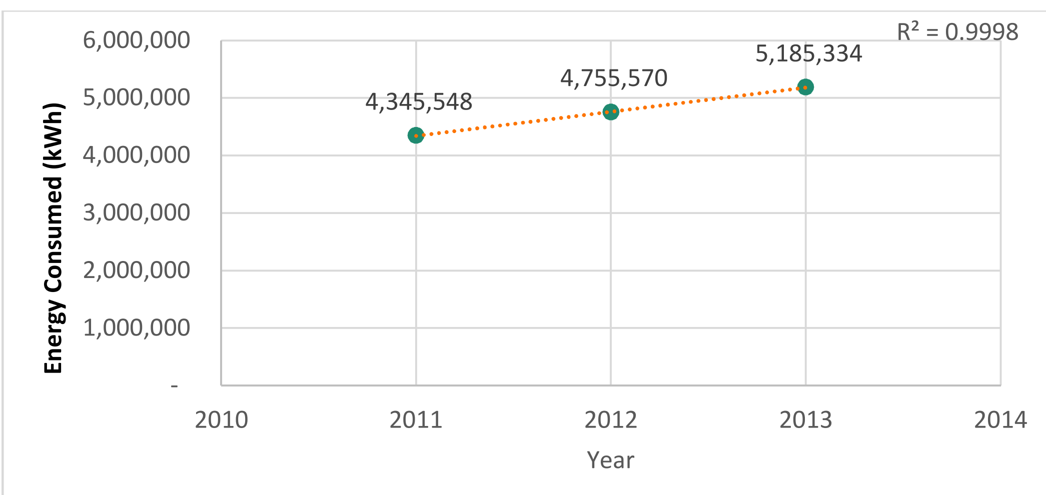


Figure 6 DMTSC Energy Consumption Prior to Low Emissivity Ceiling Installation (2011-2013)

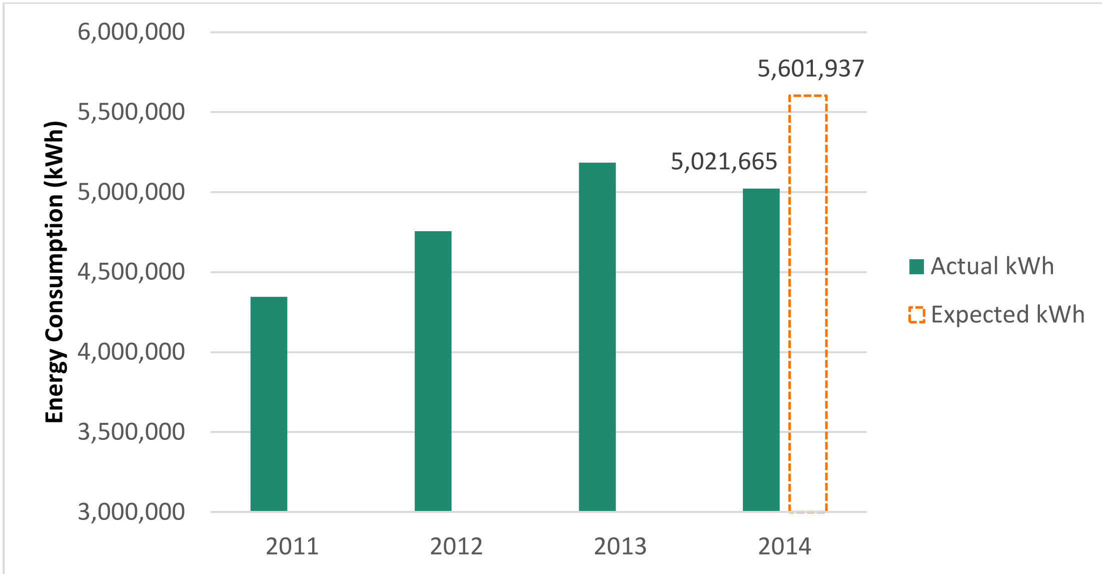


Figure 7 DMTSC Energy Consumption, Expected and Actual 2014

The actual energy consumption for the 2014 calendar year was 5,021,665 kWh. This represents a 580,272 kWh savings when compared to the projected energy use. This suggests a 580,272 kWh savings in annual energy between 2013 and 2014. A previous engineering report suggested that 390,000 kWh in savings was possible for the year, following the installation of low emissivity ceilings. The large energy savings suggests that the low emissivity ceiling was a major contributor to this savings. However, lighting upgrades also occurred in March and April 2014, and to properly verify that the low emissivity ceilings resulted in energy savings, a comparison was limited to the months of January and February over the previous three years and 2014.

The energy consumption over the previous three years for January and February, show a strong linear correlation and was used to project the January and February energy consumption.

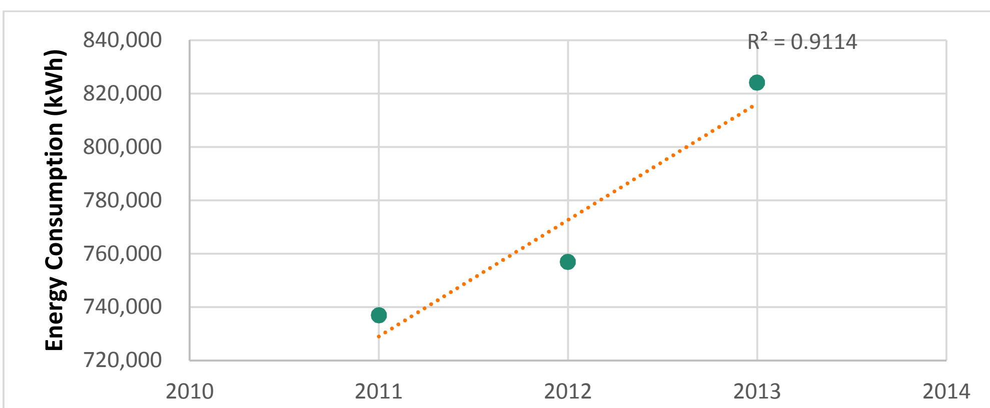


Figure 8 Energy Consumption (January to February for Each Year)

Projecting the energy consumption into 2014, the expected kWh is 859,856 kWh, while the actual consumption recorded was 830,845 kWh. This represents a savings of 29,011 kWh compared to projected.

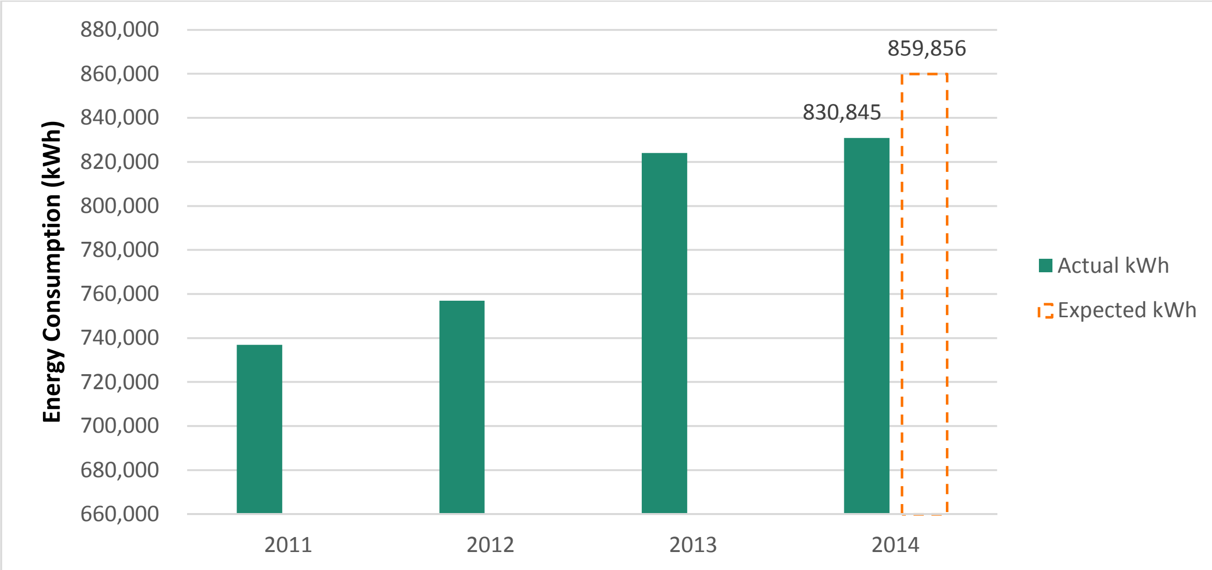


Figure 9 Observed Energy Savings after Low Emissivity Ceiling Installation (January to February)

The total rink usage hours between April and September, from years 2011 to 2015 was compared with total DMTSC energy consumption to see if there was a relationship between these parameters. This analysis was to ensure that changes in rink usage did not contribute to the energy savings. The expectation is that greater usage would increase energy demand due to greater heat loading from users in the space, and more frequent resurfacing of the ice.

However, it was found that overall DMTSC energy consumption decreased as the Protrans Arena use increased, showing that the usage does not contribute to greater energy use, and that energy consumption has been dropping rapidly as usage has been increasing rapidly.

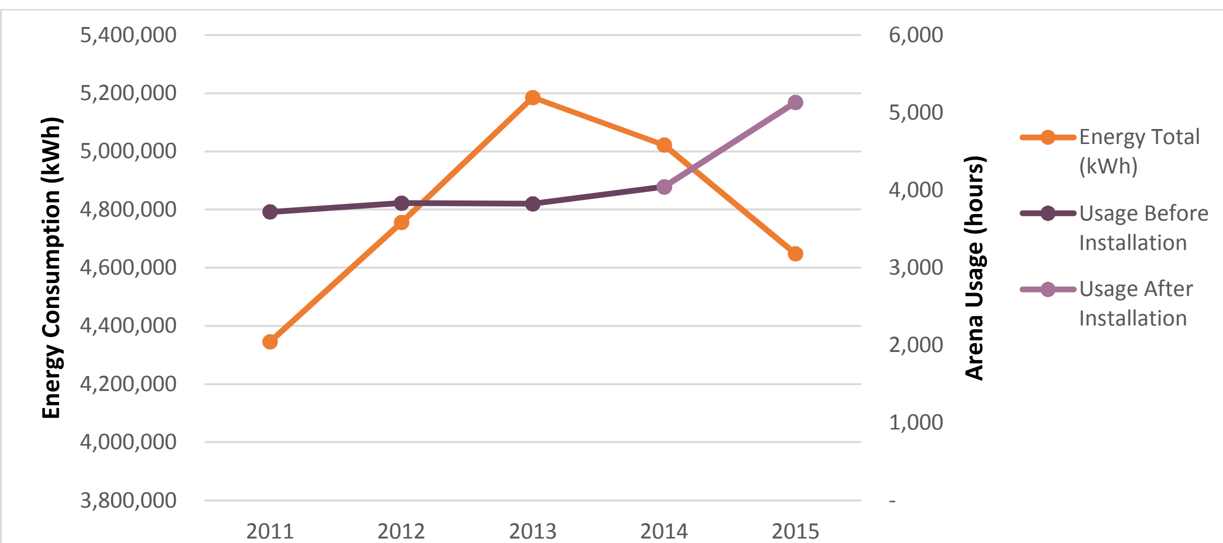


Figure 10 Protrans Arena Usage vs. DMTSC Energy Consumption

Challenges in Determining Energy Savings Due to Low Emissivity Ceiling

Typically, for thermal performance of buildings the degree-days method can be used as a simple method determine a building's energy consumption. The degree day method assumes that energy consumption is related to the difference between indoor building balance temperature and the outdoor temperature. (De Rosa, Bianco, Scarpa, & Tagliafico, 2014)

Unfortunately, the facility does not display a significant correlation between the indoor and outdoor temperatures, which reduces the ability to determine the effectiveness of the low emissivity ceilings beyond projections of energy use, and without direct energy consumption measurements for the ice cooling equipment.

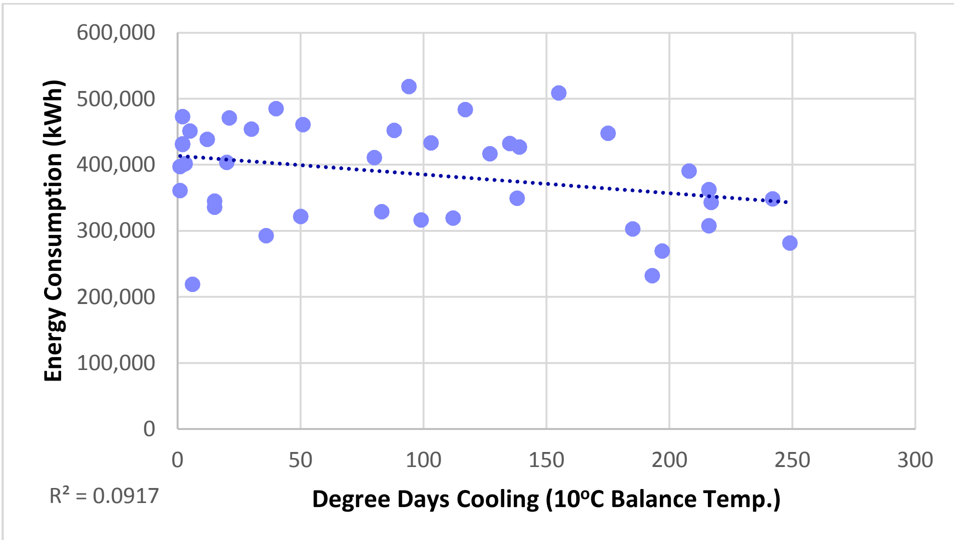


Figure 11 Degree Days Cooling vs. kWh

Low Emissivity Conclusions

After validating the performance of the low emissivity roof and comparing the DMTSC energy consumption before and after the ceiling's installation, the data suggests that the roof greatly contributed to the 580,272 kWh in savings seen in 2014. This is in line with the expected 390,000 kWh from a previous engineering study.

Lighting

Lighting is a significant source of energy consumption in some facilities; According to The U.S. Department of Energy, Buildings Energy Data Book consumption ranges from 14% in residential homes to 26% in some commercial facilities. Ice hockey facilities, however, consume a significant amount of energy to maintain ice surfaces; as a result, lighting becomes a smaller proportion of energy consumption. From *The Technical Guidelines of an Ice Rink*, published by the International Ice Hockey Federation, lighting typically accounts for 2% of overall energy consumption in a training facility, as shown in the figure below.

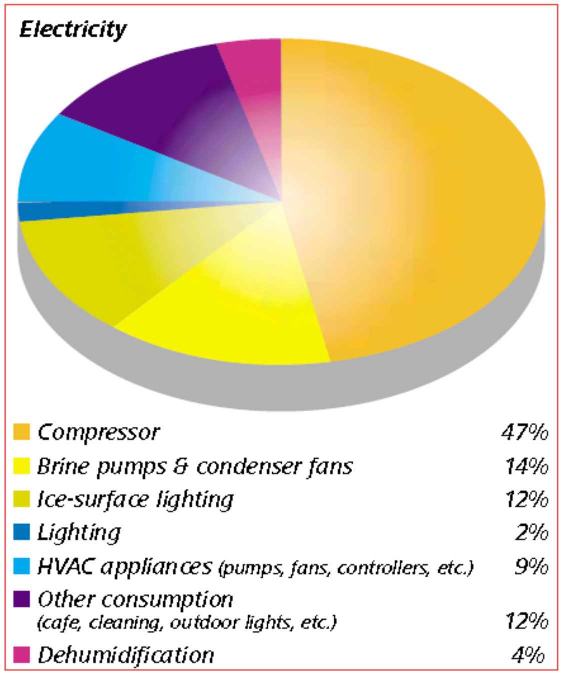
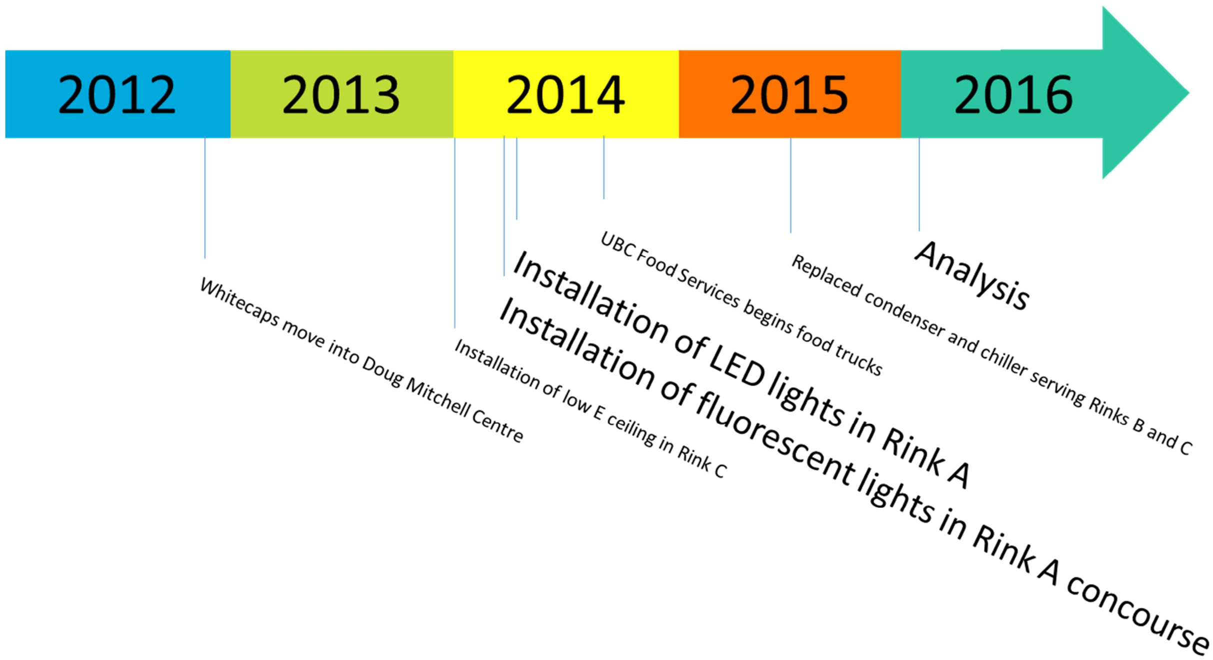


Figure 12 Main Electricity Consumption Components of a Typical Training Facility

Lighting retrofits in the concourse and mezzanine areas of Rink A took place in March 2014, replacing metal halides with high output fluorescents. In April 2014, LED lights replaced the metal halide lights in Rink A. For analysis purposes, the energy savings of these two retrofits has been considered in conjunction, as they occurred in consecutive months. An assessment of energy consumption before and after the lighting retrofits was deemed to be not possible due to the installation of the low emissivity ceiling in Rink C occurring in January 2014, and UBC Food Services beginning to service the food trucks out of the DMTSC in August 2014. These events prevented a comparison of energy consumption before and after the retrofits while avoiding seasonality issues. Due to these factors, it is only possible to calculate projected savings, not changes in observed energy consumption.



Rink A

In 2014, DMTSC undertook a retrofit of the lighting for Rink A. Two reports, commissioned in 2012 and 2013, were used to determine effectiveness estimates for this retrofit.

Traditionally, arenas have used high intensity discharge (HID) fixtures for lighting; metal halide being the most common, and the version of HID used in the DMTSC. Several options were available when the lighting system retrofit was undertaken. The table below outlines some options available for lighting in ice hockey facilities. LED was selected, which has greater initial costs, but lower energy and maintenance costs, so significant savings are expected from this upgrade.

Table 1 Comparison of Lighting Sources taken from various manufacturer spec sheets[3]

	Metal Halide (400W)	High Pressure Sodium	Fluorescent T8	Fluorescent T5	Induction	LED[4]
Average Lifespan (hrs)	12,000-20,000	15,000-25,000	20,000-40,000	20,000-40,000	60,000-100,000	50,000-200,000*
Instant-On	No	No	Yes	Yes	Yes	Yes
Lumen Depreciation	35-45%	40-50%	10-15%	5-10%	25-30%	5-30% at 100,000 hrs
Efficiency (lm/W)	65-125	60-150	80-100	85-105	70-90	80-120
Dimmable	No	No	Yes	Yes	No	Yes

3 Ranges show variability based on installation, brand differences, and service conditions.
4 LED fixtures typically fade out, as opposed to burn out. “End of useful life” is generally considered to be when they reach 70% of the initial lumen output.

Relative Installation Costs	Low	Low	Medium	Medium	Medium	Medium-High
Relative Maintenance Costs	High	High	Medium	Medium	Low	Low
Relative Energy Costs	High	High	Medium	Medium	Low	Low

Based on specifications, the total power demand of the previous fixtures was 118.38kW. This can be broken down into 12.6kW for the mezzanine, 7.2kW for the concourse, and 98.58 for the ice surface. The new installation of fixtures is specified to be 45.73 kW in total; 36.89 kW for the ice surface, and the mezzanine and concourse requiring 6.44 kW and 2.4 kW respectively.

A portion of the original metal halides were left in place, to be used to increase lighting levels during televised events; remaining off at other times. As these events tend to be infrequent, the power consumed for the extra lighting is considered negligible on an annual scale.

The BC Hydro Power Smart Lighting Redesign, commissioned for the DMTSC, assumed 2,000 hours per year of "on-time" to develop estimates. This is approximately 5.6 hours per day, which is less than the typical daily operating period of the DMTSC. A 2013 SEEDS report contains readings from light loggers placed around the DMTSC, and reports that lights were on between 12 to 24 hours per day during the reporting period. This confirms that the illuminated or "on-time" assumptions of the Power Smart report are low, and that lighting use is irregular and difficult to accurately estimate.

Since no accurate estimates of illumination "on-time" are available, energy savings due to the lighting retrofits was calculated using an "on-time" range of 2,000 hours to 5,500 hours, as shown in the figure below.

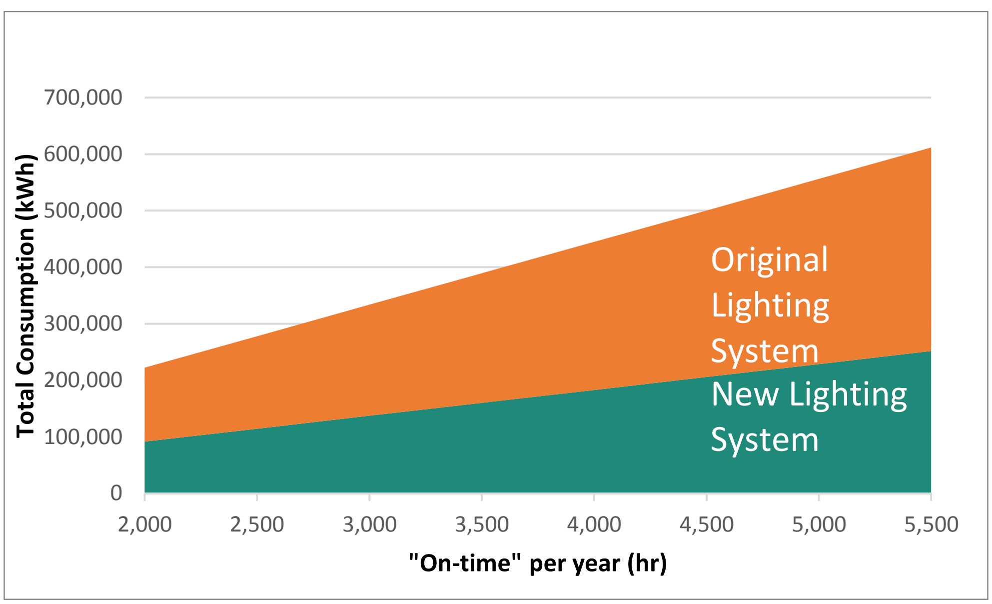


Figure 13 Original Lighting and Upgraded Lighting Annual Energy Consumption

Since the hours of illumination assumed vary from 6 to 15 hours per day, there is significant variation in potential total energy savings; 130,900 – 359,975 kWh.

Rink B

Rink B is currently using a metal halide lighting system, with 80-400W and 4-250W fixtures. Rink B is also similar to Rink C in size and configuration. Rink C currently is using 68-192W T5 florescent fixtures. Although the 2013 SEEDS report deemed this to be sufficient, to standardize the comparisons, a 1:1 replacement with the 220W fixtures quoted for the Rink A concourse was used in the calculations.

Without accurate estimates of illumination times the "on-time" range of 2,000 hours to 5,500 hours was used. Total energy demand in Rink B decreases from 36kW to 17.6kW with this proposed retrofit. The potential savings are shown to range from 36,800 – 101,200 kWh in the figure below.

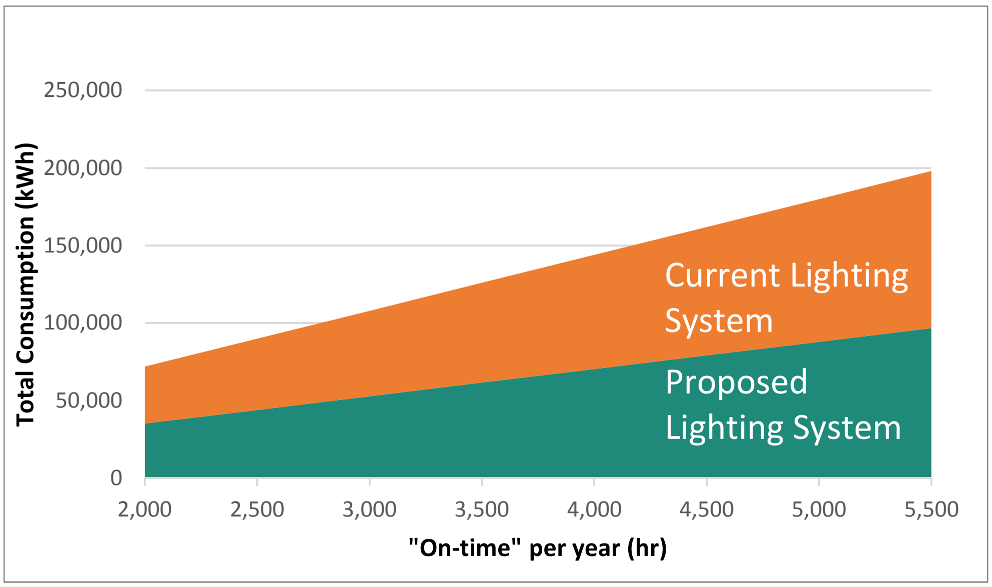


Figure 14 Rink B Potential Energy Savings after Retrofit to Rink C Fixtures

Lighting Conclusions

A significant savings in energy consumption has been achieved by the lighting retrofits in Rink A, and further retrofits in Rink B will generate further savings. Lighting, however, is estimated to comprise only 2% of the total energy consumption in a typical ice hockey training facility. This limits the effect that changes in lighting can have on overall energy consumption. The figure below illustrates the perspective energy savings due to lighting retrofits using the estimated "on-time" range of 2,000 and 5,500 hours, in comparison to the total energy consumption of the DMTSC.

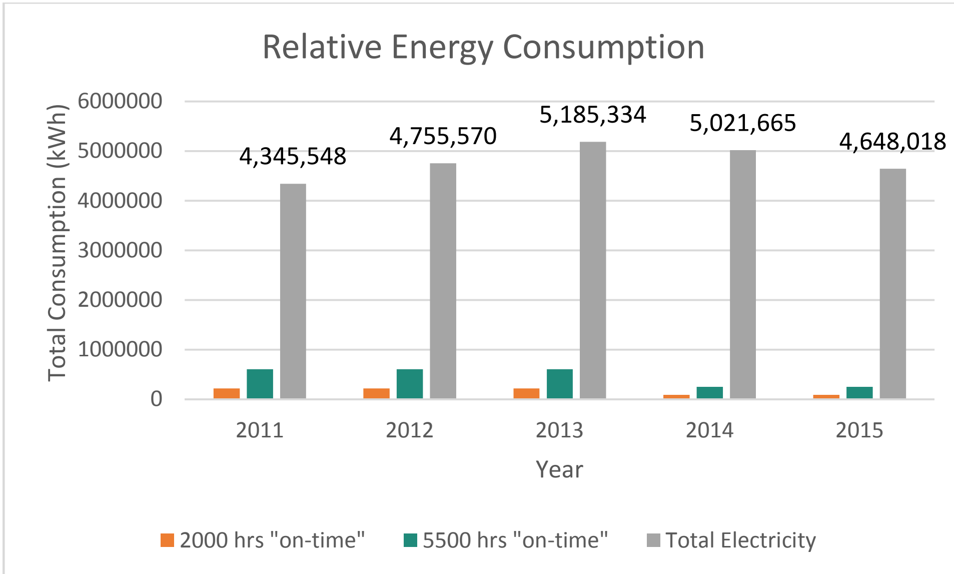
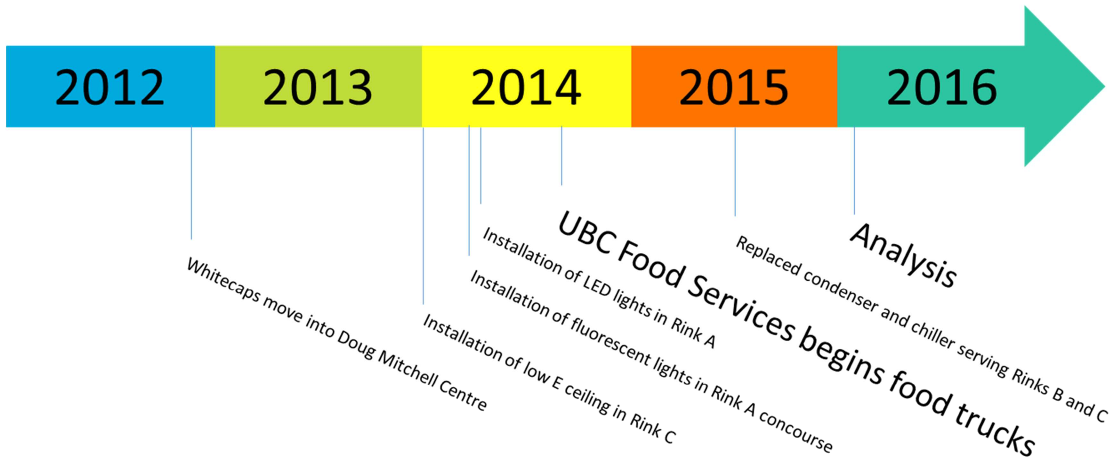


Figure 15 Potential Energy Savings vs. Total DMTSC Energy Consumption

Food Services

UBC Food Services began using the DMTSC to service and prepare food for their food trucks in August 2014. Food Services owns and operates five food trucks on the UBC campus; they use the DMTSC kitchen and facilities six days a week to store, prepare, and cook food for the food trucks. Additionally Food Services use the DMTSC to clean and wash dishes and towels, as well as "plug in" overnight to provide power to refrigerators in each truck. These activities have generated additional electrical load at the DMTSC.



The analysis periods for determining the change in energy use caused by Food Services at the DMTSC was selected to be May – June 2014, and May – June 2015. The food trucks have seasonal peaks, which are between August and October annually, when more food is sold. The "Before Food Services" analysis period was selected as the LED lights in Rink A were installed in April 2014, rendering any data before that time ineligible for comparison. July 2014 was also not eligible for comparison, as the chiller and condenser for Rinks B and C were replaced in July 2015. Therefore only two months were used for comparison, to avoid seasonal complications, and to ensure capital investments did not affect the results.

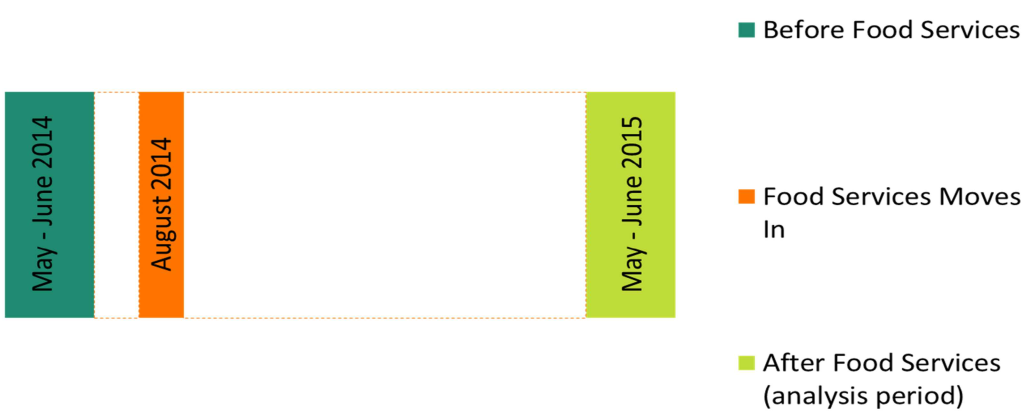


Figure 16 Analysis Periods for Food Services

In the May – June 2014 period the DMTSC consumed 869,277 kWh, while in the May – June 2015 period the DMTSC consumed 716,183 kWh. This represents a 17.6% decrease in energy consumption.

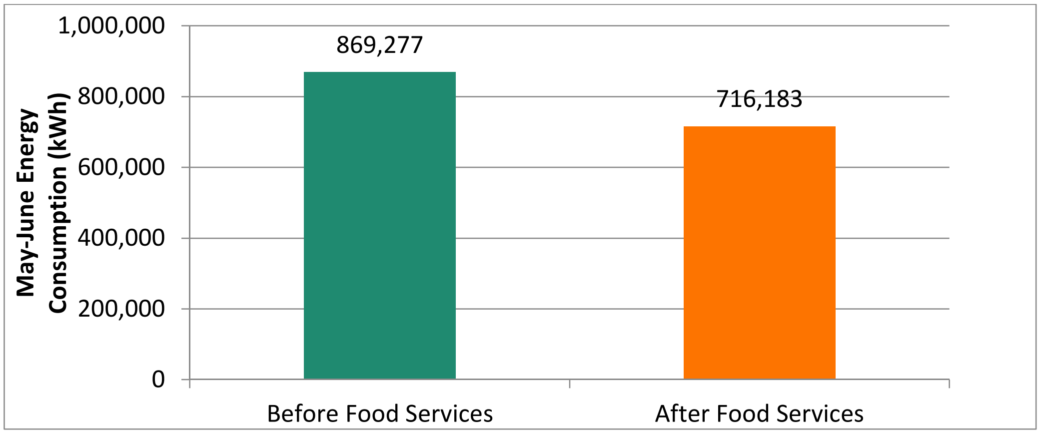


Figure 17 DMTSC Energy Consumption Before and After Food Services

Further investigation into the significant decrease in energy consumption between the two time periods revealed a 6.9% increase in energy use in the months of May 2014, and May 2015. In comparison, energy consumption between June 2014 and June 2015 decreased by 44.2%. The reasons for this significant decrease in energy consumption in June 2015 are unclear, however it has been hypothesised that the chiller that was replaced in July 2015 was shut down earlier than the provided records state. The total monthly energy consumption of the DMTSC is shown in the figure below.

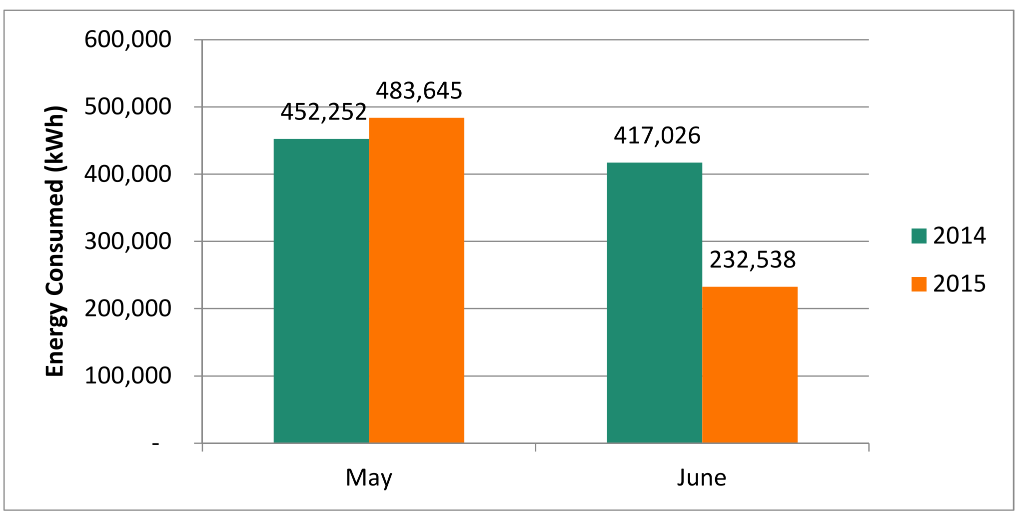


Figure 18 Monthly Energy Consumption in May and June, 2014 and 2015

It was also seen that the total degree days rose over the comparison period from 105 to 179 degree days, which represents a 71% increase.

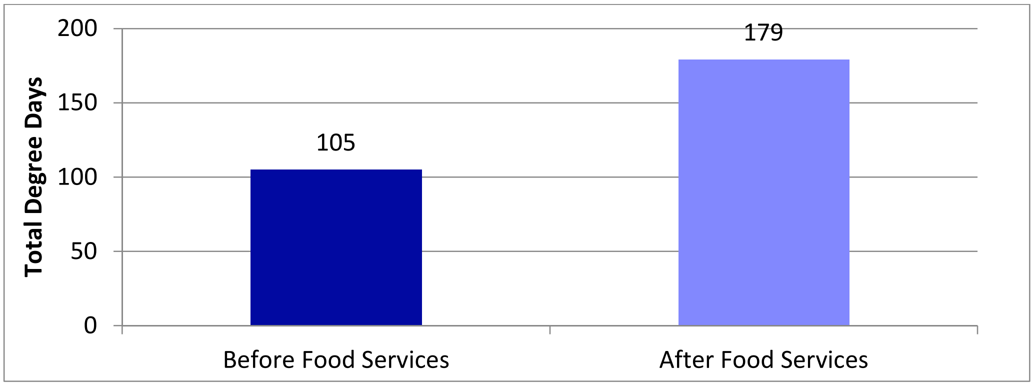


Figure 19 Total Temperature Degree Days May-June

When the total rink usage hours were examined over the comparison period, total usage hours increased from 2,635 hours to 3,577 hours over the comparison period. This is a 36% increase in rink usage.

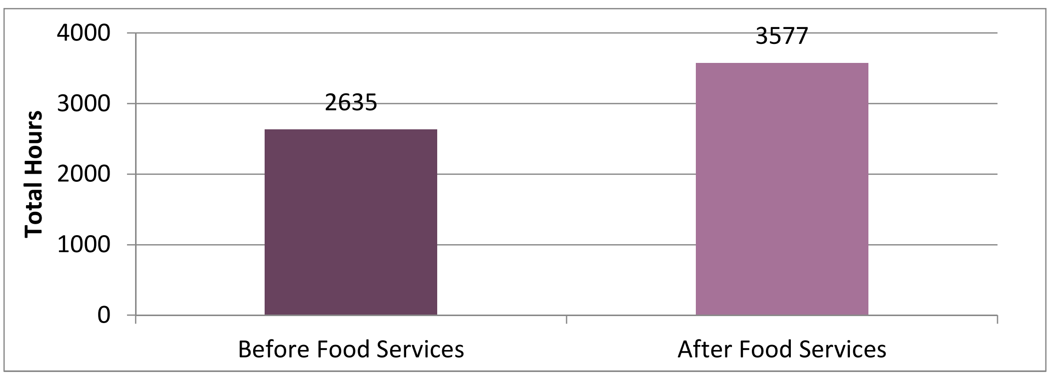


Figure 20 DMTSC Rink Usage (hours) April - June

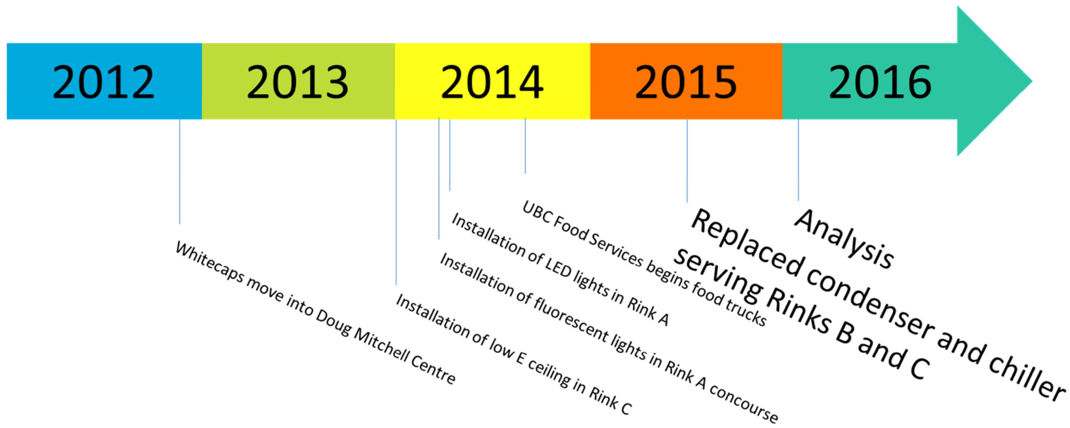
Food Services Conclusions

Although there was a decrease in energy consumption in the total May-June periods compared, there was a significant increase in TDD and rink usage. There was an observed 6.9% increase in energy consumption when May 2014 was compared to May 2015, while June 2014 and June 2015 had a decrease of 44.2%. It is likely that the decrease observed in the month of June was caused by an abnormal event, and should be discounted from the analysis. One month of data, however, is not sufficient to draw conclusions from, besides it is likely that UBC Food Services does increase the amount of energy consumption at the DMTSC.

If there is further interest in the amount of energy consumed by Food Services it would be advisable to install a meter on the kitchen facilities.

Chiller Replacement

In July 2015 the chiller serving Rinks B and C was replaced. To measure the impact of this replacement, rink usage, total degree days, and corresponding change in energy consumption was measured.



To best utilize the available data, the periods of comparison chosen were the months of September to December 2014 and September to December 2015. These comparison periods avoid including the impact of the lighting upgrades in March and April 2014, and low emissivity ceiling upgrades in January 2014. Using the same time periods in 2014 and 2015 reduces the impact of seasonality of facility use. The month of August was not included in the analysis to avoid the impact of UBC Food Services moving into the DMTSC in August 2014.

Figure 21 Analysis Periods for Chiller Replacement

Between the two comparison periods, there was a total energy consumption decrease of 9% from 1,751,199 kWh to 1,600,173 kWh.

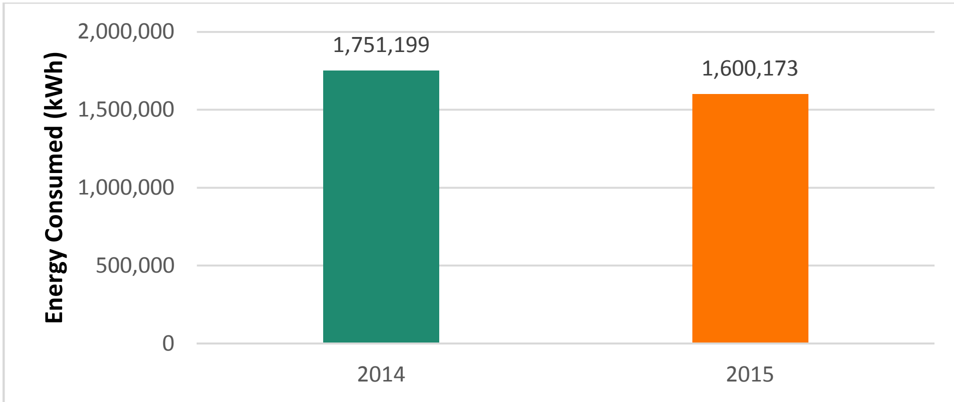


Figure 22 DMTSC Energy Consumption (September - December)

It was also found that the total degree days increased between the comparison periods from 521 to 538 degree days; this represents a 3% increase.

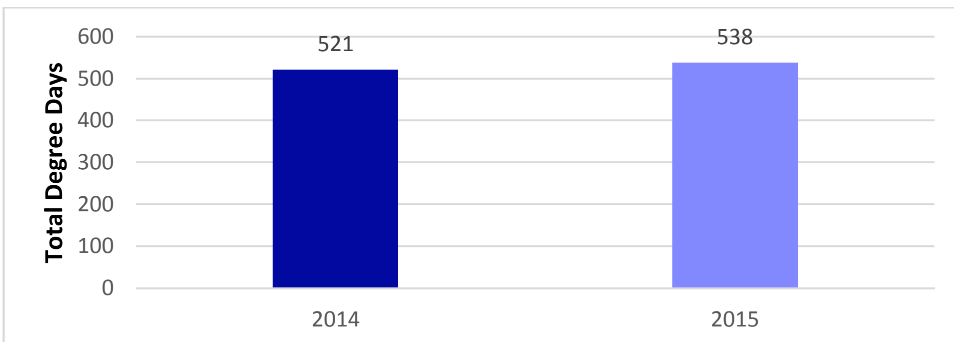


Figure 23 Total Temperature Degree Days from September - December

The total rink usage hours were examined over the comparison periods; total usage hours reduced from 3,280 hours to 3,232 hours during those periods. This represents a 1% reduction in usage.

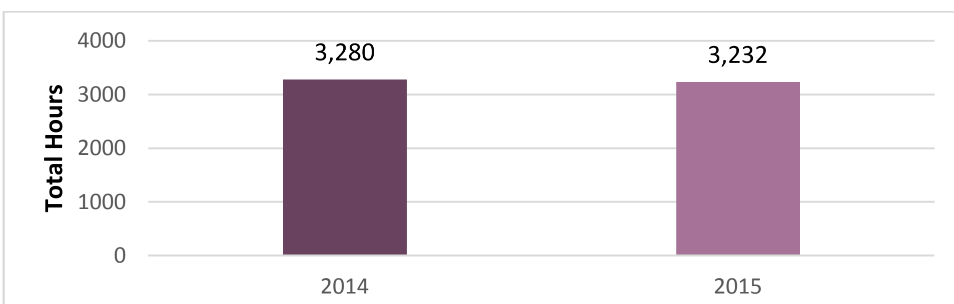


Figure 24 DMTSC Rink Usage (hours) from September - December

Chiller Conclusions

The data suggests that the chiller replacement contributed to an energy reduction of 9% between the comparison periods, given that ambient temperature and rink usage did not change greatly between the same time periods in 2014 and 2015.

Recommendations

The energy consumption of the Whitecaps could be more accurately monitored by the installation of a meter on their facilities. Although it is unlikely that their laundry use is a significant contributor to energy consumption at the DMTSC, if it continues to be a concern, conducting a further SEEDS investigation using an ammeter to monitor the exact energy use would be recommended.

A feasibility study on installing a low emissivity ceiling in Rink A should be conducted. The performance of the upgrades for Rinks B and C have contributed to a large portion of the energy conservation efforts of the DMTSC. The initial student study for installing low emissivity ceilings in Rink A indicated 257,000 kWh savings. View factors define how much energy that is emitted from one surface and reaches another. Previous studies assumed that the ceiling and ice surface were parallel and equal in size to reduce the complexity of view factor calculations. Rink A, however, has a ceiling that is significantly larger, concave and elevated higher from the ice surface, which requires a study that correctly calculates the view factor to determine the feasibility of the installation.

The DMTSC could realize further energy savings in the lighting systems by automating the number of hours that the lights are on, coinciding with when the facilities are not being used.

- Low use areas, such as change rooms, washrooms, utility and maintenance areas, could have motion sensors for lighting, to reduce unused lighting.
- Install a programmable lighting control system capable of timing and dimming control for all rinks. The programming could be synched with scheduling, so when surfaces are not in use, lighting is at emergency levels, and adjusted during booked times.

The DMTSC could achieve further energy savings by investing in further capital improvements. Recommended capital improvements include:

- Further lighting retrofits to upgrade Rink B to match lighting in Rink C;
- Upgrading the lighting retrofits to upgrade other areas of the facility to LED lighting systems.

The current method for reporting energy use in the DMTSC is as one aggregate number for all uses within the facility. Installing meters within the DMTSC to determine the contribution of segments of the facility, such as the kitchens, laundry, and the Whitecaps to the total energy use would allow for a better understanding of changes in use or facility upgrades. At this time, the aggregate energy use reporting does not provide the ability to understand the energy costs when use levels change or capital improvements are made.

"If you can't measure it, you can't improve it" – Lord Kelvin

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