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Refrigeration System Assessment

TCorp, Inc. was contracted to audit the ice making refrigeration system at the Gordon Paquette Arena at Leddy Park located in Burlington, Vermont. The purpose of the audit was to provide an overview of the existing ice making equipment and its supporting systems. Based upon our review of the systems and interviews with the Owner, Sweeney Refrigeration and Temperature Controls of Vermont, we present a number of Energy Conservation Measures.

Ten Energy Conservation Measures were assessed for applicability and cost-effectiveness:

1. Reducing or adjusting air temperature in the rink
    a. Sensible temperature and Relative Humidity are primary factors in energy use management for ice arenas.
        i. Assuming an ice temperature of 21 degrees F and 80% relative humidity, convective heat transfer costs 5.7 B.T.U.'s/hr-SF. [1]
        ii. 17000 SF of ice will require approximately 96,900 B.T.U.'s per hour per degree difference between the ice temperature and the ambient air temperature, depending upon the relative humidity of the ambient air (latent heat of fusion.)
        iii. The Munters desiccant de-humidifier is designed to minimize the energy required to overcome the latent heat stored in the ambient air.
            1. Note: The Automated Logic interface shows only outdoor Relative Humidity, it is the indoor RH that effects the energy used by the compressors.
                a. Install an indoor RH sensor and use it to compare to the de humidifier supply air RH setting as a continuous commissioning tool.
    b. Maintain the smallest temperature difference between ice surface and room temperature that is tolerable to occupants.

[1] 2010 ASHRAE Handbook - Refrigeration

i. As room air warms it increases its capacity to hold moisture which, in turn increases relative humidity that must be removed by the de-humidification system and refrigeration compressors.

2. Ice temperature control is critical to both ice quality and energy conservation. When unoccupied, the ice temperature can be allowed to rise as much as 4 to 6 degrees F.
   a. Accurate sensing of ice surface temperatures with Infra-Red technology combined with sensors monitoring the supply and return temperature of the brine can ensure the ice is maintained at optimum consistency for the users. Additionally, setting up the temperature of the ice during long periods of vacancy can significantly reduce costs; studies have shown that by adjusting the ice temperature just 1 degree F can save 6% of the annual refrigeration costs without affecting the amount of energy extracted for sub-floor heating. [2]
   b. Six percent of the annual cost of electricity for the Leddy Arena would amount to approximately $7600. If a new building automation system such as the Automated Logic were installed at a cost of $35,000, the simple payback would be 4.65 years. The net present value of such an investment would provide a Savings to Investment Ratio of 2.5.
3. Ice thickness should be maintained between ¾ and 1 ½ inches.
   a. Ice thicker than necessary acts as an insulator and causes the compressors to run more often and for longer durations. Neither of these indicators is evident in the electrical usage history.
   b. The Leddy Arena main skating surface was rebuilt from the subfloor up in 1997. It is assumed to be level and the ice thickness is kept at approximately 1 inch.
4. Improved Water Quality
   a. Consider a reverse osmosis process to provide demineralized water for the ice making floodwater.
   b. Water with low mineral content freezes with less refrigeration
      i. Depending on the purity of the supply water, demineralized water can reduce electricity requirements of the compressor system and reduce the required resurfacing water temperature.
      ii. The need for demineralized water is water-condition-dependent and therefore requires water quality testing before the economics can be estimated.
         1. Typical cost for a system is $20,000.
         2. An example of a reverse osmosis system can be seen at the University of Vermont, Gutterson Arena.
5. Head pressure controls on reciprocating compressors

[2] Smart Energy Design Assistance Center (http://smartenergy.illinois.edu/publications.html), University of Illinois at Urbana-Champaign, IL.

    a. According to Sweeney Refrigeration, the existing compressors do not come to full load until the oil pressure meets its design threshold; in essence, it acts as a soft-start but there are no head pressure controls.
    b. Head pressure controls typically modulate the water flow rates and cooling tower fans to keep head pressures within the most efficient operating thresholds.
        i. Reducing condenser capacity through reduced water flow and fan speed increases efficiency by maintaining a larger temperature difference between the refrigerant saturation condenser temperature (SCT) and the ambient wet bulb temperature (WBT).
        ii. Possible operating efficiency improvements of approximately 23 %.
        iii. Savings are limited by the expansion valve's pressure requirement [3]
6. Installation of VFD's
    a. Similar to the existing cooling tower, the new cooling tower should have VFD's for fans and pumps.
    b. The new brine pump should be equipped with a VFD.
    c. If compressors were changed to newer screw type compressors, then a VFD would be used to more closely match the tonnage delivered to the load. This method can improve the part-load efficiency of the system dramatically.
7. High Efficiency Motors
    a. The compressor motors are high efficiency motors (95.4%).
    b. The New Brine Pump should be coupled to an Induction Rated, High E motor.
8. Dual Drive Brine Pump
    a. The existing brine pump has two speed controls, a new Brine Pump should be fully variable to match the sub-floor heating requirements.
9. Subcooling / Snow-melt pit
    a. Could be done but more cost-effective in new construction.
    b. If demineralized water an option, then recovery of water worth consideration.
        i. Snow melt pits are less cost-effective than waste heat recovery to provide heat for domestic hot water, ice resurface water heating, building heat and ventilation air preheat.
10. Titanium plate chiller
    a. Titanium is used for flat plate heat exchangers when used with calcium Chloride as secondary cooling medium; Titanium is more corrosion resistant than metals typically used in heat exchangers.
    b. Presently using shell and tube heat exchanger.

In an article written for the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) titled Improving Efficiency in Ice Hockey Arenas, a general survey of ice arenas in northern climates (mostly Ontario), an average ice skating facility has a gross size of 34,000 square feet and uses between 1,500,000 and 800,000 kilowatt hours per year.

[3] Fixed and Floating Head Pressure Comparison for Madison Ice Arena, July 1998; Kyle A. Brownell, Brownell Engineering

The Leddy Arena is approximately 250 feet by 150 feet or 37,500 gross square feet and the two - year average annual electrical consumption was 834,814 kWh; an exemplary number for a rink with equipment 15 years old or more. Some of the attributes of the rink that contribute to the low energy use of this rink are the desiccant dehumidification system, the Low E Ceiling, variable speed drives for the cooling tower fan motors, high efficiency electric motors and the two-speed pump for the secondary cooling system.

The Low Emissivity ceiling has reduced the radiant energy of the sun, new lighting has reduced the wattage (1 watt of lighting is equal to 3.412 BTU's of energy that must be removed from the ice as the heat energy is absorbed.), and the dehumidification system reduces the latent heat of vaporization from the moisture in the air and the two-speed brine pump reduces electricity use of the pump.

Provided all these systems are managed optimally, and the refrigeration system is working as well as it can, making any significant "low-cost" reductions in energy use will be difficult.

Major rink renovation every 25 years: ~$700,000

- Minor rink renovations for energy efficiency every 10 years: ~ $200,000
  - Typical simple payback of 5 to 8 years or less
    - Process integration of heating and refrigeration typically has 5 to 8 years in retrofit

Opportunities:

Minor Investment	Moderate Investment	Major Investment
Nighttime Ice Temp. Control	Snow Pit w/ water recovery	Cold Climate Adaptation
Improved Lighting	Waste Heat Recovery	Major Equipment upgrade*
Improved Systems Controls		

* New Screw Compressor with Variable Frequency Drive: ~$515,000[4]

The least expensive and potentially most cost-effective method of electrical energy reduction is the lighting. Better control of the lighting, so that when no one is occupying the space(s), no lights are on and replacing the fluorescent lighting with LED fixtures will reduce the use of electricity from the operation of the lighting and reduce the radiant load on the ice surface. Additionally, LED lighting is proving to last longer with less maintenance required over the life of the fixture compared to any other type of illumination other than daylight and perhaps induction lighting.

The refrigeration system has Ammonia as the primary and calcium chloride as the secondary cooling medium. Based upon the information provided by the existing monitoring system, the existing refrigeration compressors are operating within manufacturer's parameters. The high E motors, pump and fan controls (variable frequency drives) and desiccant dehumidification are doing an adequate job and the use of electrical energy is comparable with some of the more energy efficient rinks throughout the Northeast.

[4] L.N. Consulting Inc. August 6, 2010 Simple Economic Analysis – Revised.

What is suspect is the control system. The Automated Logic electronic monitoring and controls system has the capability of performing at a much more effective level but as it is, built on a much older platform, the system can do no more than show what the end-points are reading. Note, some of those sensors sending information to the control software are reaching a reasonable end of useful life and may not be accurate.

With several energy efficiency enhancing systems already installed at the Leddy Arena, it is critical to have an automated control system that enables Management to optimize and minimize energy use while providing the highest quality product (ICE) possible. Computerized controls must be updated and re-commissioned periodically due to the rapid advancement of technology. At this time, the existing computer upon which the Automated Logic system resides, has failed and a decision has been made to replace it with a newer but used computer. Without a new platform and programming, there will still be no trending studies, system change scheduling or occupancy scheduling. Replacement of the existing software and graphic interface with an up-to-date controls package from Automated Logic would provide the ability to optimize the operation of existing and new equipment which, in turn, will reduce operating costs.

Chart 1: Electricity Demand and Usage History

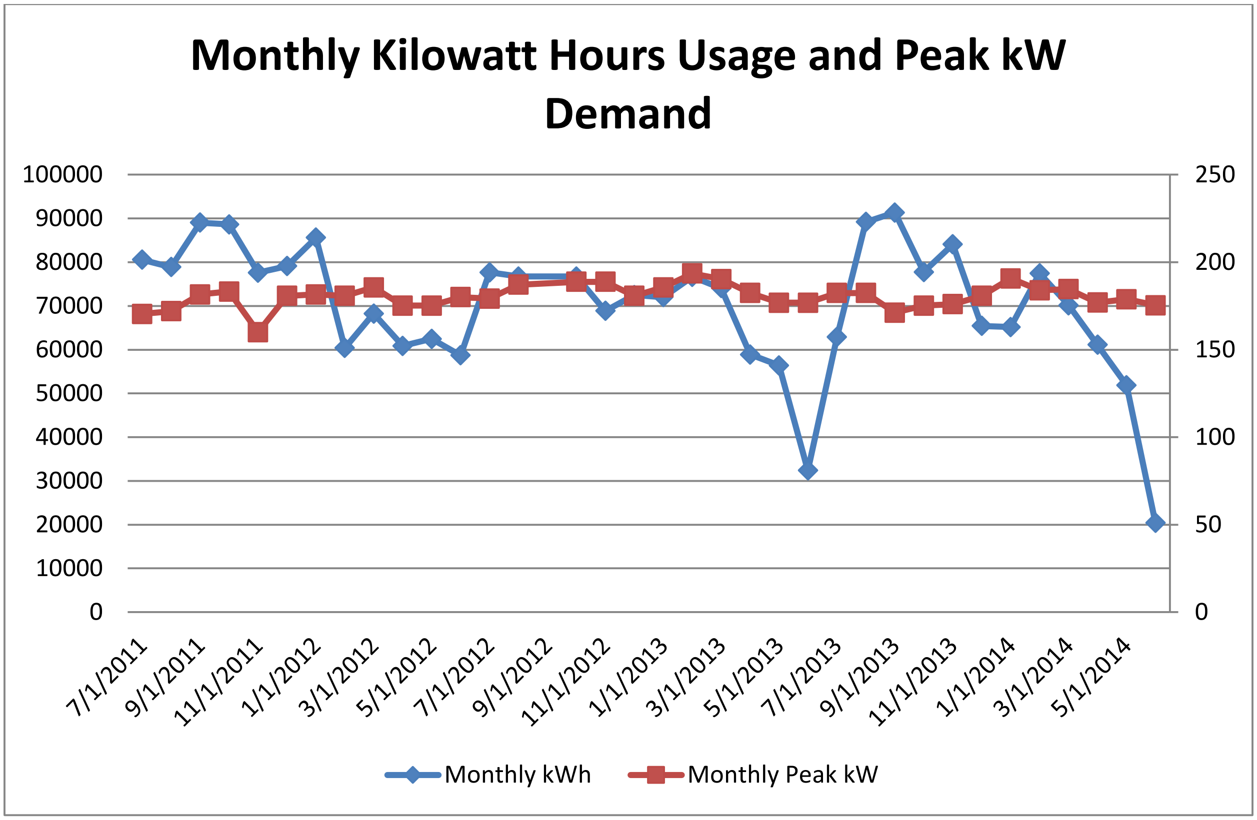

Chart 1 shows the monthly Peak kilowatt (kW) demand and kilowatt hours (kWH) of energy used each month from June 2011 to June 2014. The kW demand peak is the highest average demand for power over a 15 minute period each month and as shown in the chart, remains fairly constant. Kilowatt hours, the energy used each month to produce and maintain the ice sheet, operate lights, run the concession and offices and pump hot water for heating and showers, fluctuates with climate and hours of operation. Your monthly electric bill is affected by the relationship of the monthly Peak kW (power) and the number of kilowatt hours used; the greater number of kilowatt hours used for each kW of demand the lower your bill. Therefore, it is important that the kW be as low as possible and the average number of kilowatt hours used per kW of demand be as high as possible. In this case the average efficiency of the operations is approximately 53% which is quite good considering the size of the equipment being used.

Demand is dictated mostly by the ice resurfacing operation. It takes a specific tonnage to set up the newly resurfaced ice sheet, based upon the indoor environmental conditions; latent energy in the indoor atmosphere, the radiant energy from the ceiling and lighting and the temperature of the resurfacing water all contribute to the number of Tons of refrigeration required to produce an acceptable product. A more efficient chiller plant would reduce the kW per Ton of refrigeration required as described in the 2010 L&N Engineering report.

Chart 2, Natural Gas Usage History

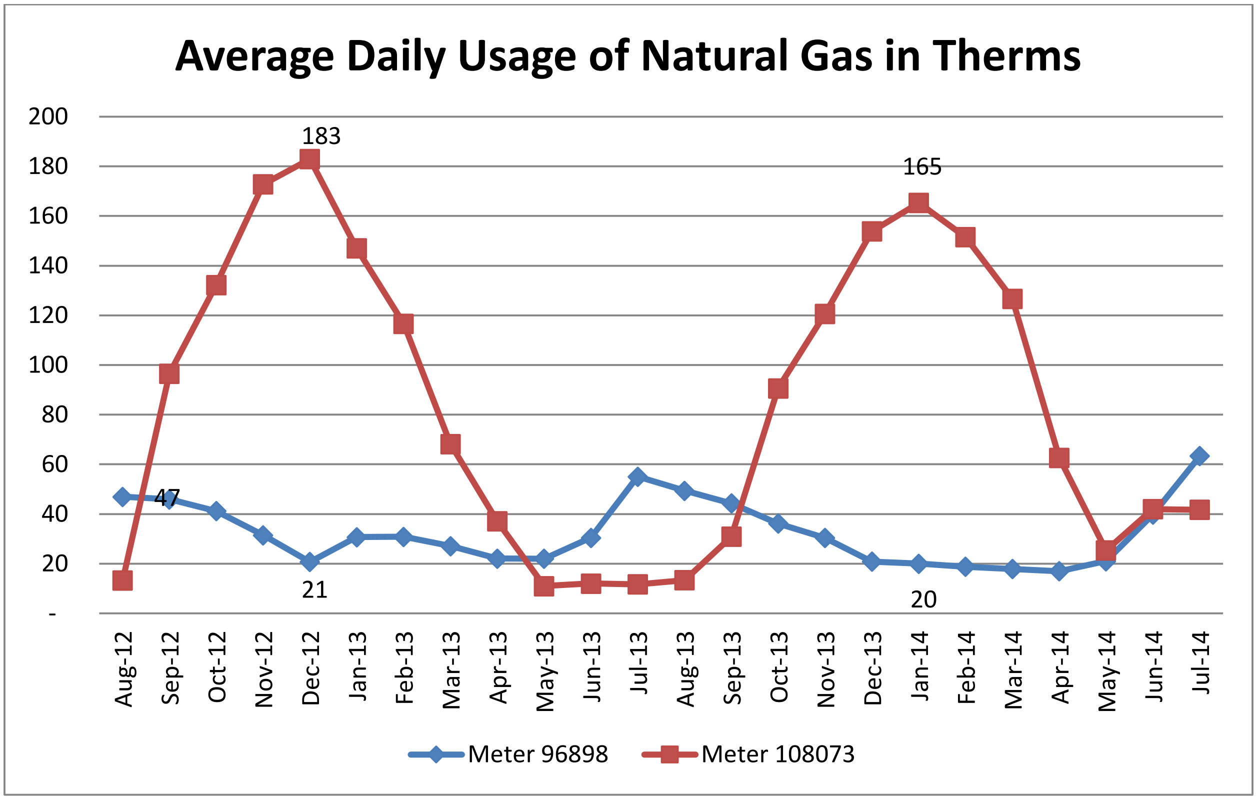

Chart 2 shows the usage of the two Natural Gas meters. Meter 108073 shows the usage profile for heating and 96898 for humidity control. Essentially, usage goes up during the heating season or when the relative humidity of the outside air being brought into the rink is high. When the outside air temperature is cold, it holds less moisture and therefore, the two meters will naturally consume greater amounts of gas during different times of the year.

Waste Heat Recovery

Estimating the annual run hours of the compressors to be 3700 and an average load requirement of 50 Tons, the annual energy (heat) removed from the ice is approximately 2,785,680,000 B.T.U.'s per year or the equivalent of 27,860 therms of natural gas. Of this waste heat potential, only under slab heating is being employed at present. Listed below is a breakdown of potential applications for waste heat recovery and their estimated cost savings potential.

For the past two years, the average annual natural gas usage for meter 108073 was 30815 Therms and cost $27,650. Meter 108073 is assumed to provide fuel for boilers, water heaters, and the concession appliances.

Uses for Waste Heat:

1. Ice Resurfacing Hot Water
    a. Based upon an average of 10 resurfacings per day Monday through Friday and 16 resurfacings per day Saturday and Sunday, 46 weeks per year with a water temperature of 110 degrees F and 60 gallons per resurfacing and a natural gas hot water heater efficiency of 75%, total savings of approximately 1400 therms of natural gas could be saved. Cost savings would amount to $2100 annually.
2. Building Thermal Requirements (Heat)
    a. Estimated energy required to heat the building, including reheating ½ air changes per hour, is approximately 2,000,000,000 BTU's or the equivalent of 20,000 Therms.
3. Under Slab Freeze Protection
    a. Assuming a heat exchange efficiency of 60%, the estimated BTU's required to maintain ground temperature of 55 degrees F. under the ice slab is 850,000,000 per year or the equivalent of 8500 Therms ($12,750).

Note: Although waste heat is "free", the cost to recover it is not. A detailed cost / benefit analysis should be done to determine its cost-effectiveness. Included in this study should be the cost to replace the existing boiler(s) and water heaters with more efficient systems. Replacement of the boilers is highly recommended in any case because, based on the usage of meter 108073, not all heating needs would be covered by waste heat recovery.

Ammonia (R-717) is used to make ice in many industrial applications and has several benefits including the fact that it has no global warming potential and will not be phased out like CFC and HCFC refrigerants. It is, however, toxic and has an unpleasant odor when released and should only be handled by trained experts. That being said, it is the most energy efficient of all common refrigerants.

I thank you for this opportunity to have input into the energy efficiency efforts of the City of Burlington, Parks and Recreation Department.

Sincerely

Peter C. Tousley

Peter C. Tousley, President.

Glossary

B.T.U. or a British Thermal Unit – The amount of heat required to raise the temperature of one pound of water between 32 degrees F and 212 degrees F.

Latent Heat – The amount of heat required to change the state of a substance without changing its temperature.

For example, when we apply heat to a pound of ice at 32 degrees F. it requires 144 B.T.U's to change it to water at 32 degrees F. When changing ice to water, the amount of heat is called the Latent Heat of Fusion.

Sensible Heat – The heat required to produce a change in temperature.

Latent Heat of Vaporization – The amount of heat required to change a liquid to a gas without changing its temperature. Latent Heat of Ammonia at atmospheric pressure (14.7 pounds per square inch) is 565 B.T.U.'s. Water is 970 B.T.U.'s.

Latent Heat of Fusion – The amount of heat required to change a substance from a solid state to a liquid state. One pound of ice requires 144 B.T.U.'s to change it from a solid to a liquid without raising its temperature.

Atmospheric Pressure – The pressure at sea level is 14.7 pounds per square inch (PSI). 14.7 PSI reads as 0 on a pressure gage (PSIG).

Ton of Refrigeration – The method used to rate the size of a refrigeration machine. One ton of refrigeration is equivalent to 12,000 B.T.U.'s of cooling capacity per hour or the energy required to produce 2000 pounds of ice at 32 degrees F in 24 hours. (144 B.T.U's [latent heat of fusion] * 2000 pounds [on ton] water at 32 degrees F) / 24 hours = 12,000 B.T.U.'s.