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# Energy usage prediction model comparing outdoor vs. indoor ice rinks

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ABSTRACT

The overall aim of the project was to reduce energy usage in ice rinks. The specific scope of this study is to develop a comparison tool for indoor and outdoor ice rinks based on an energy usage prediction model. The refrigeration system cooling capacity, heat loads on ice surface and their correlation is studied in detail for an outdoor bandy (Bandy is a team winter sport played on ice, in which skaters use sticks to direct a ball into the opposing team's goal) ice rink for season 2010–2011. Climate data input has been validated along with performance analysis of refrigeration system. The cooling capacity and heat loads on ice surface are calculated, compared and analysed considering energy usage affecting parameters and weather parameters like temperature, wind speed, relative humidity and solar load. The deviation between total cooling energy produced and total heat load energy is found 19% and 27% for four warm days and season. The developed model provides a decision tool to choose between alternatives.


## 1. Introduction

### 1.1. Background

Energy usage varies a lot in Swedish ice rinks and could be explained by many factors like length of season, number of activity hours in the ice rink and building characteristics. Since the refrigeration system is a major energy consumer with average of 43% [1] of total energy consumption. So it is essential to decrease the heat load on ice rink which will ultimately result in lower energy consumption due to refrigeration system.

The climate change and usage pattern of ice rinks promotes development towards indoor ice rinks rather than classical outdoor arenas. Furthermore local clubs of many municipalities want to go indoor due to extended season. The operating cost of the system depends on seasonal differences of weather and many other energy usage affecting parameters. Labour cost for building up the ice and extra maintenance due to weather conditions is also one of the parameters which has to be considered. The complex interaction of all these factors makes accurate prediction a tough task.

### 1.2. Objectives and methodology of study

The overall objectives and procedure of this study is shown in Fig. 1. The aim is to develop a comparison tool for indoor and outdoor ice rinks based on an energy usage prediction model. The objectives are met by compiling field measurement data from outdoor ice rink refrigeration system and closest weather station. And then by comparing input climate data with closest official weather station and applying correlations to interpret effect of weather data on ice sheet. The perform analysis of refrigeration machinery like cooling capacity has been done. The heat transfer correlations are being evaluated and compared with relevant mechanisms for outdoor ice sheet. The heat load mechanisms are estimated with refrigeration system performance analysis. Finally model has been developed for predicting energy usage of indoor and outdoor ice rinks.

## 2. Weather data validation

The climate data for field measurements is obtained by ClimaCheck (CC) and compared with closest weather station of Swedish Meteorological Hydrological Institute (SMHI). The SMHI weather station is located at Svanberga; 11.8 km north of Norrtälje Sports Complex, Sweden. The measurements for outdoor temperature, wind speed and relative humidity are recorded whereas global radiation is extracted by STRÅNG – a mesoscale SMHI model [2].

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**Nomenclature**

| | |
|---|---|
| $k$ | thermal conductivity coefficient (W/mK) |
| $t$ | temperature (°C) |
| $v$ | air velocity (m/s) |
| $x$ | thickness of ice (m) |
| $Q$ | heat load or heat loss (W) |
| $q$ | heat load (W/m$^2$) |
| $h$ | enthalpy (kJ/kg) |
| $P$ | electric power (W) |
| $E$ | energy consumed (W) |

*Subscripts*

| | |
|---|---|
| comp.in | compressor in |
| comp.out | compressor out |
| sensor | sensor location |
| surf | surface |
| ref | reference |

### 2.1. Corrections for parameters

The correction of some field measurements is being done to estimate the actual heat loads on ice sheet.

#### 2.1.1. Ice surface temperature correction

As probe is located 3 cm below the ice surface so the recorded temperature is not the ice surface temperature and has to be corrected. The real ice surface temperature is calculated from the change in temperature $\Delta t = t_{surf} - t_{sensor}$ from sensor to surface. The sum of convective, diffusion, radiation and ice resurfacing heat loads on ice in W/m$^2$ ($q$), thermal conductivity ($k = 2.25$ W/mK, value of water at −5 °C, thickness ($x = 0.03$ m) of ice and ice temperature at sensor location are taken into consideration for it. The expression used to find out ice surface temperature is shown:

$$q = \frac{k}{x}(t_{surf} - t_{sensor}) \quad (1)$$

Finally +1 °C is added to sensor temperature ($t_{sensor}$) to get real ice surface temperature ($t_{surf}$). The negative radiations in nights (ice to sky) are considered when ice surface is warmer than ambient air which ultimately reduces the daily radiation heat load and outdoor temperature.

#### 2.1.2. Wind speed correction

The wind speed at field is measured at 4 m above ice surface shown by blue line in Fig. 2. But to estimate accurate convection and condensation heat load on ice sheet wind speed is needed very close to ice surface. So wind speed $V_w(h)$ at $h = 10$ cm above ice is found with wind speed $v_{ref}$ at reference height ($h_{ref}$) of 4 m. The Hellman exponent value ($\alpha$) for neutral air above water surface is taken as 0.10 [3]. The expression used is given [4]:

$$v_w(h) = v_{ref}\left(\frac{h}{h_{ref}}\right)^{\alpha} \quad (2)$$

The validation of weather data is really significant to calculate accurate heat loads to ice surface. The comparison of field and SMHI measurement for wind speed is presented as sample in Fig. 2. The red line shows SMHI weather station wind speed measured at 10 m above ground whereas purple line shows the corrected field wind speed at 10 cm above ice surface which is used for heat load calculations. The difference in red and blue trend lines is significant due to high wind speed at Lake Erken near Svanberga, buildings, hills, forests and local topography in between two stations.

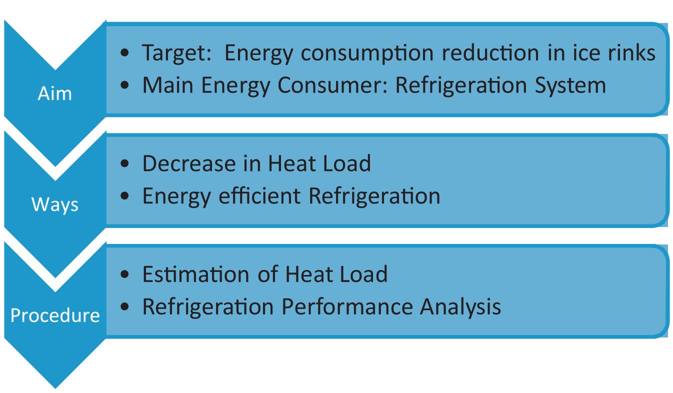


**Fig. 1.** Objectives and methodology.

## 3. Field measurements

In this study, measurements for cooling load have been obtained for outdoor bandy ice rink in Norrtälje, north of Stockholm. The measurement instrumentation is installed at machine room to analyse the performance of refrigeration system, inside the ice sheet and its surrounding air to study heat loads and their effect on ice.

### 3.1. Ice rink and refrigeration system

The outdoor bandy ice rink is big ice surface of 6000 m$^2$ which is divided in two sections each having separate circuits with twin compressors. The refrigeration system is indirect with ammonia as primary refrigerant, freezium 34% as secondary refrigerant and ethylene glycol 35%–water as coolant. The evaporator is direct expansion and condenser is Plate & Shell heat exchanger. The brine pumps are capacity controlled with frequency converter and speed is controlled according to brine temperature and heat load. The heat rejected from condenser is not used and desuperheater reduces the temperature of ammonia and then coolant. The views of Norrtälje outdoor bandy ice rink and machine room are shown in Figs. 3 and 4.

### 3.2. Refrigeration performance analyser method

ClimaCheck-method is an "internal method" used for analysing performance of ice rink refrigeration system. The internal method used is for performance analyses of refrigeration, air-conditioning and heat pump applications [5]. The compressor is used as *mass flow meter* so external mass flow meter is not needed. With help of energy balance over compressor and measurements of pressure and temperature before and after the compressor, the refrigerant mass flow rate is calculated by equation given below [6]:

$$m = \frac{\eta_{el} P_{el} - Q_{out}}{h_{comp.out} - h_{comp.in}} \quad (3)$$

where $m$ is the refrigerant mass flow rate; $\eta_{el}$, electric motor efficiency; $P_{el}$, electric power to the compressor motors; $Q_{out}$, compressor cooling by oil and water and or heat loss from compressor body; $h_{comp.out}$, enthalpy after compressor; $h_{comp.in}$, enthalpy before compressor.

The mass flow rate, the electrical motor efficiency and heat rejection from compressor body are two very essential parameters for accurate calculation. The type of motor, age and load on motor may have considerable effect on its electrical efficiency. The cooling capacity and COP of system are calculated with amount of compressor cooling, heat losses of 7% from compressor body [6], mass flow, refrigerant state of entering expansion valve, etc.