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Benchmarking model for the ongoing commissioning of the refrigeration system of an indoor ice rink

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ABSTRACT

This paper proposes the development of the benchmarking model for the ongoing commissioning of the operation of the refrigeration system of an indoor ice rink. The paper presents (1) the development of models for chillers, ice-concrete slab and controller, (2) the training phase in which the parameters of the benchmarking model are identified based on measurements under normal operating conditions, and (3) the comparison between measured and predicted energy performances. The proposed approach for the development of a benchmarking model can be implemented as application software in the Building Energy Monitoring System of any ice skating rink, if measurements of relevant independent variables are available.

1. Introduction

In Canada, indoor ice rinks are an integral part of community life and activities. Ice rinks are used for sports (hockey, free skating, speed skating or figure skating) and on occasion as auditoriums. They are often used 18 h per day, seven days a week during eleven months each year [1]. Since indoor ice rinks use significant quantities of energy due to their simultaneous refrigerating and heating needs, the continuous monitoring and analysis of energy performance of refrigeration system is essential for the optimum operation and maintenance.

At our best knowledge most papers published so far have used the forward modeling techniques on the estimation of ice cooling load and energy use by refrigeration systems. Such models are developed for the comparison of different design or retrofit alternatives. Zmeureanu et al. [2] simulated the cooling loads of the ice sheet and the energy performance of the refrigeration system by integrating new routines in the DOE-2.1E program. Bellache et al. [3,4] have investigated the airflow, and the heat and humidity transfer in indoor ice rinks by using a computational fluid dynamics model. Daoud and Galanis [5] developed the Above Ice Model (AIM) that couples a zonal model with an energy analysis program to simulate the transient thermal behavior of an ice rink. Ouzzane et al. [6] have presented measurements performed in an indoor ice rink located in Montréal. Seghouani et al. [7] developed the Below Ice Model (BIM) that simulates the transient heat exchange between the pipes inserted in the concrete slab, used to circulate the brine at, and the surrounding soil. Mun and Krarti [8] developed a thermal model of the ice rink load and brine temperature integrated with EnergyPlus program.

In the case of an existing facility, the ongoing commissioning could help to maintain optimum operation by performing constant monitoring of HVAC systems, data analysis, and comparison of measured data with benchmarking data to detect abnormal operation conditions or performance deterioration [9].

2. Ongoing commissioning

This paper proposes the development of the benchmarking model for normal operating conditions of the refrigeration system of an indoor ice rink, which is an essential element of the ongoing commissioning. The paper presents [10] (1) the development of models for chillers, ice-concrete slab and controller, (2) the training phase in which the parameters of the benchmarking model are identified based on measurements under normal operating conditions, and (3) the comparison between the energy performance predicted by the calibrated benchmarking model and measurements.

Once the benchmarking model is calibrated, it can be used for the ongoing commissioning phase, in which the model is used along with new measurements to predict the performance of refrigeration system, as expected under normal operating conditions. The measured and predicted energy performances are then compared, and if abnormal differences are noticed, warnings are sent to the building operating team. The ongoing commissioning phase is not presented in this paper.

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The proposed approach has the following advantages:

(1) the models of chillers (including compressors and heat exchangers) and of thermal response of the ice-concrete slab are extracted from measurements in an existing facility, rather than from design specifications; hence they are representative of as-operated conditions;
(2) the approach can be applied to any other ice rink refrigeration system for the identification of parameters provided that measurements of relevant independent variables are available; and
(3) the proposed ongoing commissioning approach can be implemented in the Building Energy Monitoring System, and used for the detection of abnormal changes of energy performance.

This paper presents in Section 3 the existing refrigeration system used as a case study, the available measurements (Section 4), the flowchart of benchmarking model (Section 5), the mathematical models of three main components of the refrigeration system, chillers, ice-concrete slab and controller, and the identification of model parameters from measurements (Section 6), and the comparison of predictions with measurements (Section 7). The measurements collected by CanmetENERGY [11,12] in Camillien-Houde indoor ice rink, located in Montreal, are used in this study.

3. Description of refrigeration system

The indoor ice rink was constructed in the early 1980's with the ice surface of 61 m long by 26 m wide. The refrigeration system is composed of two chillers using R-22 refrigerant that are connected in series on the brine side. Chiller no.1 has two open-drive 4-cylinder semi-hermetic reciprocating compressors Carrier 5H40 driven by 22 kW electric motors, while chiller no.2 has only three such compressors Carrier 5H40. Compressors are connected in parallel on the direct expansion evaporators. The compressor suction pressure is approximately of 260 kPa, while the discharge pressure is of 1550 kPa. Each compressor has a capacity of about 53 kW of refrigeration (15 t of refrigeration) and an electric input of 22 kW; each compressor is connected to an air-cooled condenser installed on the roof of the building. Each condenser has six 1.6 kW fans that draw air through the coil. The maximum number of compressors in operation is five to limit the electric demand of the system. The brine, a solution of calcium chloride ($CaCl_2$), makes four passes through the 32 mm polyethylene pipes installed in the concrete slab before returning to the circulating pump. An 11.2 kW constant flow pump circulates the brine through the evaporator and pipe network. The system operates approximately from 3:00 to 24:00, eleven months per year.

4. Measurements

The long-term measurements of the following variables related to this study were collected at one-minute intervals during several days of different months by permanently installed sensors [6]: (1) the brine temperature entering and leaving the evaporator (both chillers) was measured with 4 W-RTD's (accuracy of ±0.1 °C) inserted into existing brine piping thermowells, (2) refrigerant temperature leaving the evaporator, (3) refrigerant temperature entering the expansion valve, (4) the electric power input was measured with power meters (accuracy of 5%). Temperature measurements on the refrigerant side have been conducted by measuring the temperature on the surface of the pipe. Short-term measurements were also collected: (1) Suction and discharge pressures at the compressor using manometers; and (2) the refrigerant and brine flow rates were measured with an ultrasonic meter (accuracy of ±2%)[13]. The saturation pressure at the condenser was controlled and maintained constant. The return brine temperature was controlled and maintained constant, and therefore the saturation pressure at the evaporator was also constant regardless of the thermal load.

The cooling capacity of the refrigeration system was obtained based on measured data (see reference [6] for a comparison of three methods used for this purpose). In addition, the municipality has provided operational data of the HVAC&R equipment from their own Building Monitoring System: (1) the operation mode (On/Off) of compressors, circulating pump, dehumidifiers, lighting system, heating system under the slab, and infrared heaters installed over stands, (2) the temperature of the concrete slab, (3) the ice temperature measured with an infrared sensor above the blue line of the ice rink, and (4) the return brine temperature.

Tables 1 and 2 present a summary of the measured operating conditions on March 16th and May 14th 2006, respectively, which are expressed as daily mean and standard deviation.

5. Flowchart of benchmarking model

The benchmarking model is developed in TRNSYS program [14]. In the training phase the parameters of mathematical models of main components (chillers, ice-concrete slab and controller) are identified from measurements in the existing refrigeration system. The flowchart of information between inputs, components and outputs is presented in Fig. 1.

The temperature is estimated in key points of the refrigerant and brine circuits. The brine temperature is written as *Tb*, and the number of compressors in operation is represented by *n*. The input values are in bold, while internal variables exchanged between the components are written inside dashed boxes. The components used to simulate the refrigeration system are in solid boxes. The ice temperature and brine mass flow rate along with the brine temperature leaving the evaporator of chiller #2 and entering the concrete slab (*Tb4*) are input in the slab model, which calculates the brine temperature entering the pump, equal to the brine temperature leaving the concrete slab (*Tb1*). This temperature is then used by the pump model, along with the pump efficiency and the brine mass flow rate, to calculate the brine temperature leaving the pump and entering the evaporator of chiller #1 (*Tb2*). The model of chillers no.1 and no.2 uses the inlet brine temperatures (*Tb2* and *Tb3*), the outdoor air temperature and the air mass flow rate to obtain the exit brine temperatures (*Tb3* and *Tb4*) and the electric demand ($\dot{W}_1$ and $\dot{W}_2$) of chillers #1 and #2, respectively. The chillers are connected in series on the brine side. The controller determines the number of compressors in

Table 1
Measured operating conditions of the refrigeration system on March 16th, 2006.

Parameter	Units	Daily mean	Standard deviation	Minimum	Maximum
Ice sheet cooling load	kW	136.8	34.6	74.7	312.2
Load on the refrigerant side per compressor	kW	56.0	0.2	55.7	56.7
Ice temperature	°C	−6.1	0.8	−7.5	−4.8
Exterior air temperature	°C	−0.9	1.0	−2.8	2.1
Return brine temperature	°C	−8.0	0.8	−9.2	−4.9
Electric demand	kW	111.5	16.2	40.2	146.1
Coefficient of Performance (COP)	–	2.2	–	1.9	2.3