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Heat Recovery of the Refrigeration System in the Ice Arena

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Abstract
Maintaining good quality ice over the surface of an ice arena and keeping it as uniform as possible is a huge energy consumer. The ice arena also consists of many HVAC systems with differencing demands and specific technologies. To save energy is necessary wherever it is possible and the heat recovery from the refrigeration system offers interesting possibilities. The cooling in ice arenas in the Czech Republic is predominantly ensured by refrigeration compressor units. In the steam compressor cooling cycle, the waste heat rises in several temperature levels. According to the waste heat temperature, the options of its utilization in an ice arena are discussed and evaluated in the paper. Also, measured energy consumptions and experience with the operation of the ice hockey arena will be presented in the paper.
The most efficient and cheapest solution detected from the evaluation in the local ice arena is to recover the superheated vapor from the compressor displacement. The utilization is mainly for melting a snow pit, technological water heating, hot domestic water preheating and for subfloor heating. To cover the energy needs there is usually enough waste heat in the autumn and in the spring period of the season. Because of lower cooling demands of the ice sheet during winter, the amount of waste heat decreases and, as a consequence, primary energy sources must be used. In comparison with the utilization of superheated vapor of the compressor displacement, the utilization of condensation heat entails a lot of expensive equipment. This is caused by a huge amount of low temperature condensation heat. To make the heat usable its temperature has to be increased by a heat pump. Also, the requirements for the volume of accumulation, piping and pumping work are much higher and, therefore, more expensive. This solution has not often been used in the Czech Republic so far. The highest used amount of energy consumed by all the HVAC systems is the one used for cooling the ice sheet. Conveniently, the waste heat from the refrigeration system can be reused for practical purposes. The refrigeration heat utilization leads to energy savings in the hot water preparation system, in melting the snow pit and also in subfloor heating. If condensing heat is reused, the energy savings can also be extended in space heating, preheating ventilation air and in a dehumidification system.

Keywords – heat recovery; refrigeration system; ice arena

1. Introduction

Municipal ice arenas in the Czech Republic are mainly built for hockey games but they can also be used for concerts, cultural events, athletic events, etc. There are about 150 ice arenas in the Czech Republic and this means approximately 71 301 of citizens per one ice arena [1].

There have to be many zones with different demands in those arenas. There is a need for cloakrooms for players, referees, the first aid room and the rehabilitation and massage center, as well as a swimming pool, sauna and auditorium, a hall and sanitary facilities for spectators. In the complex of an ice arena, there are usually also an administrative building, a conference hall, meeting rooms, a hotel and restaurant and, finally, mechanical and electrical rooms, an ice resurfacer room and service rooms. The entire complex is a huge energy consumer with many high special energy needs which are changing according to the occupancy and use.

With high probability, ice arenas operate from 18 to 20 hours per day on weekdays and less during the weekends. The utilization on weekdays typically starts with the training of youth hockey teams and figure skaters, during the day are training sessions of adult professional players and in the late afternoon and evening the ice arena is occupied by recreational players.

About 60 % of ice arenas in the Czech Republic do not keep their ice sheet in operation from April to July. The ice sheet is used by 61 % of ice arenas from 181 to 270 days per season and only by 19 % for more than 270 days per season [1].

Two ice arenas in the Czech Republic will be compared in this paper. The arenas have approximately the same size and functions and also the ice sheet direct cooling system. On the other hand, the utilization of refrigeration heat is different and the ice arena Vlašim has a new construction and the second one in Třebíč is after reconstruction.

2. Cooling System in Ice Arena

There are usually compressor cooling units in the ice arenas in the Czech Republic. The main equipment of the steam compressor refrigerating cycle consists of the compressor, expansion valve, evaporator, condenser and pipes. These components could be enhanced by additional heat exchangers or aftercoolers. The components added into the cycle have different effects on the seasonal energy efficiency ratio.

The power input of the compressor cooling machine depends on the coolant's flow rate and on the coolant's pressure level. Both factors can vary according to the condensation temperature. When the condensation temperature decreases the condensation pressure decreases, too, and the specific refrigerating capacity increases at the same time. This phenomenon is showed on a left picture in Fig. 1.

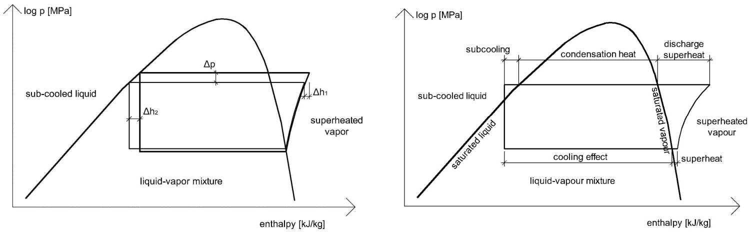

Fig.1 Compressor Cooling Cycle in the Pressure-Enthalpy Diagram

The heat in the compressor steam power cycle rises in several levels as we can see on a right picture in Fig. 1. The useful energy with different temperatures is available from the cooling of a compressor, superheated steam after compression, cooling of a condenser and from the aftercooler.

The highest temperature level of the heat from the refrigeration system is usually available from superheated steam after compression. The temperature at the compressor displacement depends on the condensation temperature of the coolant, coolant properties, evaporation temperature and superheated vapor temperature, and on the compressor type. The superheated steam of ammonia (NH_3) in a scroll compressor unit reaches temperatures of up to 130 °C, and in a screw compressor unit of up to 100 °C. After the heat transfer in the heat exchanger, the water reaches a temperature of approximately from 50 to 55 °C and this is a useful temperature level. By the utilization of superheated steam, the EER coefficient is not decreased because the condensation temperature is low enough under the temperature level in the heat exchanger.

The utilization of heat from the cooling of a condenser offers lower temperature levels than the superheated steam system. The ammonia is a mixture of liquid coolant and wet vapor there. By the utilization of the heat from the condenser cooling, the amount of heat discharged into the atmosphere decreases.

3. Heat Loads on Ice Sheet

The area of the ice sheet is about 1395 to 1788 m^2 depending on the dimensions of the arena. The higher energy consumer is the cooling of the ice sheet as can be seen in Fig. 2a. There are a variety of energy efficiency techniques known and available how to decrease the refrigeration system energy demand. According to them, it is important to analyze the heat loads on the ice sheet. The heat load on the ice sheet is approximately from 150 to 260 $W.m^{-2}$ and it is composed of three main parts [3]:

- air convection – 35 %,
- ceiling radiation – 28 %,
- ground and coolant piping – 10 %,
- ice resurfacing – 10 %,

- lighting – 7 %,
- coolant pump – 6%,
- skaters – 4%.

A great influence on the convection heat transfer is that of the temperature and velocity of the air moving above the ice sheet. A significant effect on the bulk of the heat load on the ice sheet is that of the temperature and volume of ice resurfacing water and the frequency of the ice treading process. The higher the temperature of the resurfacing water, the higher the quality of the ice sheet is.

The optimal temperature of an ice sheet depends on utilization, in other words, on the sport which will be held there. The lowest ice temperatures are needed for hockey and speed-skating, from -8 to -5 °C. For other sports such as figure skating and curling, the needed temperatures are from -4 to -2 °C. The temperature is measured by sensors approximately 1 centimeter under the surface of the ice sheet.

4. Heat Recovery of Refrigeration System

The heat which rises as a side product of the cooling process is often wasted but it could be reused as described below.

The energy efficiency of the refrigeration system can be improved in several steps. In the design stage, the influencing factors are the following; the type of a coolant and the type of a compressor and the efficiency of heat exchangers. During the lifetime of the equipment, the presence of oil in the system, clogging and dirt removing process have a significant effect.

The energy efficiency of a cooling system has an essential impact on the consumption and the level of operating costs. The energy consumption of the ice sheet cooling also depends on the cooling system (direct/indirect) and on the ice sheet thickness.

The direct cooling system is more energy efficient and has a simpler construction but is not acceptable for some coolants and has higher input costs. On the other hand, the indirect cooling system, NH_3 and glycol are usually used in the Czech Republic, has a lower coolant volume and any coolant can be used, but because of additional heat exchangers it is less energy efficient. The efficiency of the indirect system is lower in comparison with the direct system because of an additional temperature difference in the heat exchanger between the primary refrigerant and the glycol resulting in a necessary lower evaporation temperature, then a higher required pump power for secondary glycol. Moreover, additional pumping power for the brine circulation is needed.

The heat recovery system is designed to collect the heat from the refrigeration system warm side. The temperature requirements for the cold side are determined by the ice ring and the purpose of it.

In current ice rinks in the Czech Republic, part of the heat is recovered, but at a relatively low level. Usually, the superheat of compressed gas is used at a temperature of about 60 °C.

But the condensing capacity can also be used. The temperatures are lower, between 20-40 °C but with a higher energy capacity. The higher the condensing temperature becomes, the lower the cooling capacity and the overall efficiency decreases.

There are two options how to use condensing heat. At first, the low temperature utilization must be discovered, and the second option is to use the heat pump to increase the temperature of condensing waste heat on a usable level.

5. Refrigeration Heat Utilization for Technological Water Preparation and Ice Melting

In this paper, the term technological water means the water which is used for the ice sheet treading and for the heating of subsoil under the ice sheet.

To have a smooth ice sheet the resurfacing machine has to be used at least three times during one hockey game. Its approximate speed is 15 $km.h^{-1}$ and it uses hot water from 50 to 80 °C. Therefore, the ice resurfacing process involves high heat load. There is a consumption of 800 to 1000 liters of hot water for one maintenance cycle of the ice sheet.

Because of the permanent ice sheet cooling process, the subfloor could become frozen. Nowadays, the low temperature heating system is installed under the heat insulation of the ice sheet. The low temperature heating water heated by waste heat from the cooling system can be used for the subfloor heating to prevent the ice slab from cracking or upheaving.

While treading the ice sheet the resurfacing machine gathers the degraded layer of ice into a bin. The amount of crushed ice from one treading process is approximately 2.0 to 2.5 m^3. An opportunity to save energy in melting the snow pit is to use waste refrigeration heat and to circulate melted ice crush for next uses. The amount of heat to melt 2.5 m^3 (2017 kg) of crushed ice with a temperature difference of 10 °C is 23.5 kWh.

6. Refirigeration Heat Utilization for Space Heating and Hot Water Preparation

There are typically many rooms and areas with different space heating requirements in an ice arena. In the cloakrooms for players, the higher air temperature is needed. Other heated areas are the audience area, public areas and administrative areas, etc. To decrease the energy consumption it is advantageously possible to use the waste heat from the refrigeration system as a source of heat in a low temperature heating system.

The peak hot domestic water consumption is when all players take a shower after the sport performance at the same time. The potential for energy savings in the hot domestic water preparation system is the utilization of waste heat from the cooling system for the pre-heating of water.

7. Ventilation and Air Dehumidification in Ice Arena

One of the basic requirements for the air conditioning system in an ice arena is to deliver the minimal amount of fresh outside air because of its high humidity. The air conditioning system should also be able to reduce thermal loads on the ice sheet to protect constructions against dew activity caused by radiation from the ice surface and to ensure optimal microclimate conditions above the ice sheet.

The inside air of the ice ring has high humidity because of high sources of water vapor – moisture load of the occupants and the water evaporating during the ice resurfacing process. Too high air humidity leads to the degradation risk of structures, fog rising above the ice sheet and dew on a protective Perspex. Because of mixing the moist and the warm air from tribunes with the air over an ice sheet, the relative humidity and density of the mixture increases. Later, the air reaches the saturation point and fog rises over the ice sheet. Mainly the ceiling structures of an ice arena transfer heat onto the ice sheet which is heated up and conversely. The moisture condenses on the cold structures, which leads to their degradation but also water drops fall down on the ice which is, therefore, devaluated. These negative effects could be reduced by using ceiling materials with low emissivity, by increasing the air velocity around the cold surfaces or by air dehumidifying.

Low emissivity ceilings are designed to eliminate the refrigeration loads, to improve the lighting quality, to eliminate moisture and condensation problems and to improve acoustics. Ceiling radiation can account for 25 % to 35 % of the total refrigeration requirements [6]. The ceiling is warmed by solar radiation, outdoor air temperatures, and internal sources like people, lights, heaters, equipment and air stratification.

8. Case Study – Ice Arena Vlašim

The first ice arena is in the Vlašim district, Czech Republic. There is one ice sheet with dimensions of 28x 58 m. The ice arena was finished in September 2013. There is a tribune with seats for 700 people, there are locker rooms with 30 showers, fitness, management offices, a restaurant and technological rooms. Energy balance of the arena is showed in Fig. 2a. The ice sheet cooling performance has been calculated as 260 $W.m^{-2}$. The refrigeration system consists of two compressor units, their total peak performance is 510 kW. The cooling system of the ice sheet has been designed in the direct system because of the higher efficiency. The volume of the coolant (NH_3, R717) is 1000 kg. The total energy consumption for space heating is 143 $kWh.m^{-2}.year^{-1}$. The total amount of delivered energy is 2373 $GJ.year^{-1}$. The primary source of energy for heating is natural gas and its consumption measured every week in 2014 is showed in Fig. 2b. The air conditioning system in the ice arena is mainly used for the ventilation of locker rooms, the restaurant and fitness, the area of the tribune can be heated by hot air and, if necessary, the air above the ice sheet can be dehumidified. The heating of stands and air dehumidification is a huge energy consumer and is only used if it is needed. The total maximum amount of distributed air is 33 800 $m^3.h^{-1}$.

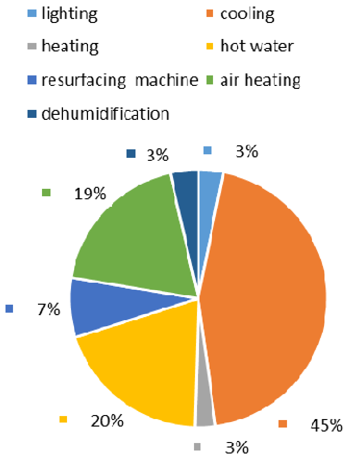

Fig. 2a Energy Balace

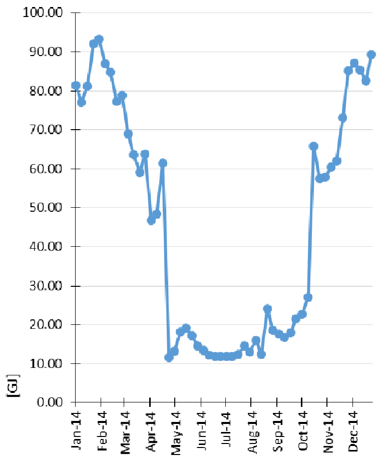

Fig. 2b Natural Gas Consumption

Fig. 2 The Ice Arena in Vlašim

The refrigeration heat system recovery uses only superheated steam after compression. The energy is then used for the ice resurfacing machine, the snow melting pit and for subsoil heating. A detailed connection is showed in Fig 3. There is also a hot domestic water tank with a volume of 1 m^3 heated by gas boiler.

The amount of refrigeration heat is high enough to cover all requirements in the months when the outside air temperature is higher, usually in August and in September. During winter when the cooling requirement is lower and, therefore, the amount of refrigeration heat is also lower, the demands which can be covered by refrigeration heat are not satisfied and gas boilers are used on these days. The energy saving reached by the utilization of refrigeration heat is 400 $MWh.year^{-1}$ and, therefore, 43 010 m^3 of natural gas.

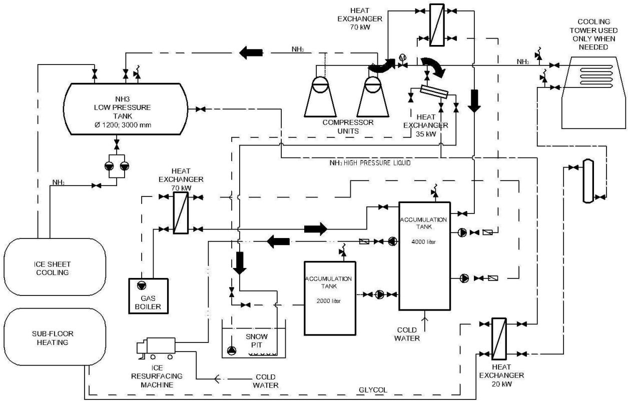

Fig. 3 Connection Scheme in the Ice Arena in Vlašim

9. Case Study – Ice Arena Třebíč

The second ice arena is in the Třebíč district, Czech Republic. The ice arena has had its cooling and heating system reconstructed since 2007. There is one sheet with dimensions of 59.2x 28.1 m. The total area of the arena is 11263 m^3, the heated area is 3041 m^3 and the total heat loss is 231 kW. There are gas boilers with a total heat output of 580 kW and there is also a cogeneration unit. There is a tribune with 840 seats. The refrigeration system consists of two compressor units, the coolant in the system is ammonia (NH_3, R717), direct ice sheet cooling system and the volume of the coolant is 1100 kg. The cooling capacity of the units is 310 and 255 kW (temperatures of -10/+30 °C). At the compressor's displacement, the ammonia's vapor pressure is approximately 1.03 MPa, this corresponds with its temperature from 108 to 110 °C. The refrigeration heat system recovery uses superheated steam after compression and via heat pumps also condensing heat. The available heat power from superheat is 122 kW and from condensation 608 kW. The refrigeration heat dissolution during one year is showed in Fig. 4.

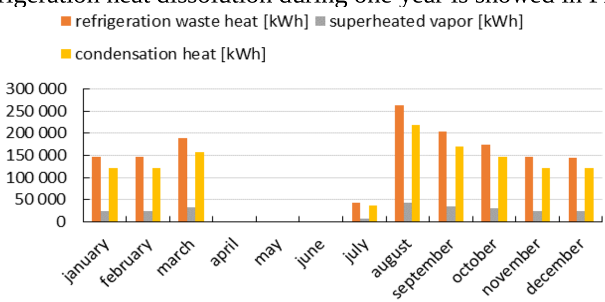

Fig. 4 Refrigeration Heat Dissolution during One Year

The refrigeration heat is used for the hot domestic water preparation, the ice resurfacing machine, the snow melting pit and for subsoil heating and it covers a part of the heating load. There is an accumulation tank with a volume of 8 m^3 and two hot domestic water tanks with a volume of 4.5 m^3 each. There are three heat pumps characterized by a power output of 63 kW and a power input of 9.5 kW according to temperatures W20W35. A detailed connection is showed in Fig 5.

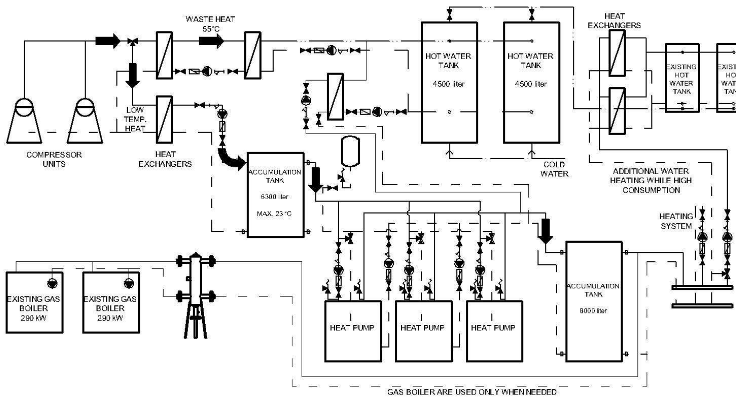

Fig. 5 Connection Scheme in the Ice Arena in Třebíč

The average energy consumption of the old cooling and heating system (before reconstruction) was 556 MWh.year^{-1} of electricity and 93 000 m^3 of natural gas. Nowadays, the system with the heat pump covers all energy needs named above. The total electric energy delivered into the refrigeration heat recovery system is 59 600 kWh and the total gained heat energy is 224 855 kWh. To produce this amount of heat energy by a boiler with an efficiency of 89 % it would be necessary to deliver 24 060 m^3 of natural gas. The heat pump’s electric energy consumption is 93 MWh.year^{-1} and the amount of produced heat is 353 MWh.year^{-1}. The amount of exhaled emissions has decreased, mainly the production of CO_2 has been reduced by 15 tons.year^{-1}.

10. Conclusion

The paper deals with the refrigeration heat utilization in ice arenas in the Czech Republic. In the first place, the compressor cooling system is described because this is the main local system used. The possibilities of the waste refrigeration heat utilization are described according to temperatures on both sides – the source and sink side. The main requirements for technologies in an ice arena are defined. Relating to the refrigeration heat utilization, mainly the subsoil heating, ice resurfacing machine technological water, snow melting pit, hot domestic water preheating and low temperature heating are important.

Two case studies have been described, namely the ice arena in Třebíč and in Vlašim. These two arenas both have the compressor cooling system and the size of them is comparable. On the other hand, the refrigeration heat utilization system is different. The ice arena in Vlašim was built in 2013 and uses superheated vapor from the cooling cycle. The heat is used for the ice resurfacing machine, snow melting pit and for subsoil heating. The ice arena in Třebíč has a cooling and heating system after its reconstruction in 2007 and uses not only superheated vapor but also low temperature condensing heat via heat pumps. The heat is used for the hot domestic water preparation, ice resurfacing machine, snow melting pit and for subsoil heating and covers a part of the heating load.

Both compared systems work reliably and have reached inconsiderable energy savings. In Vlašim, the primary energy saving is lower and low temperature condensing heat has to be destroyed in the cooling tower. But the investment costs have been lower and the space needed for accumulation tanks and related equipment is lower, too. In Třebíč, the refrigeration heat utilization system is more complex and, therefore, more complicated. The investment costs have been much higher as space for heat pumps and accumulation tanks was required.

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