Energy consumption and heat recovery of refrigeration system in modern Arena

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Introduction

In a world with constant growing energy prices and with growing concerns about the global climate changes too much energy consumption can cause it is becoming more interesting to save energy wherever possible. In a competitive world it also of interest to create the product as cheap as possible and in this case the product is to maintain an ice rink with a good quality of ice all over the surface and keep it as uniform as possible.

A number of factors have to be taken in to consideration and are not so easy to avoid. It is possible to find some guidelines on how to calculate an ice rink from different sources but only by experience and hard work it is possible to gain sufficient knowledge to do an effective and competitive system.

In the ASHRAE Journal cover June 2009 you will find an article "Improving Efficiency in Ice Hockey Arenas". In the reference list you will find a reference to a survey mapping the North American ice rink market and their energy consumption. Some data is collected from this source to give some values for the estimations done.

Challenges

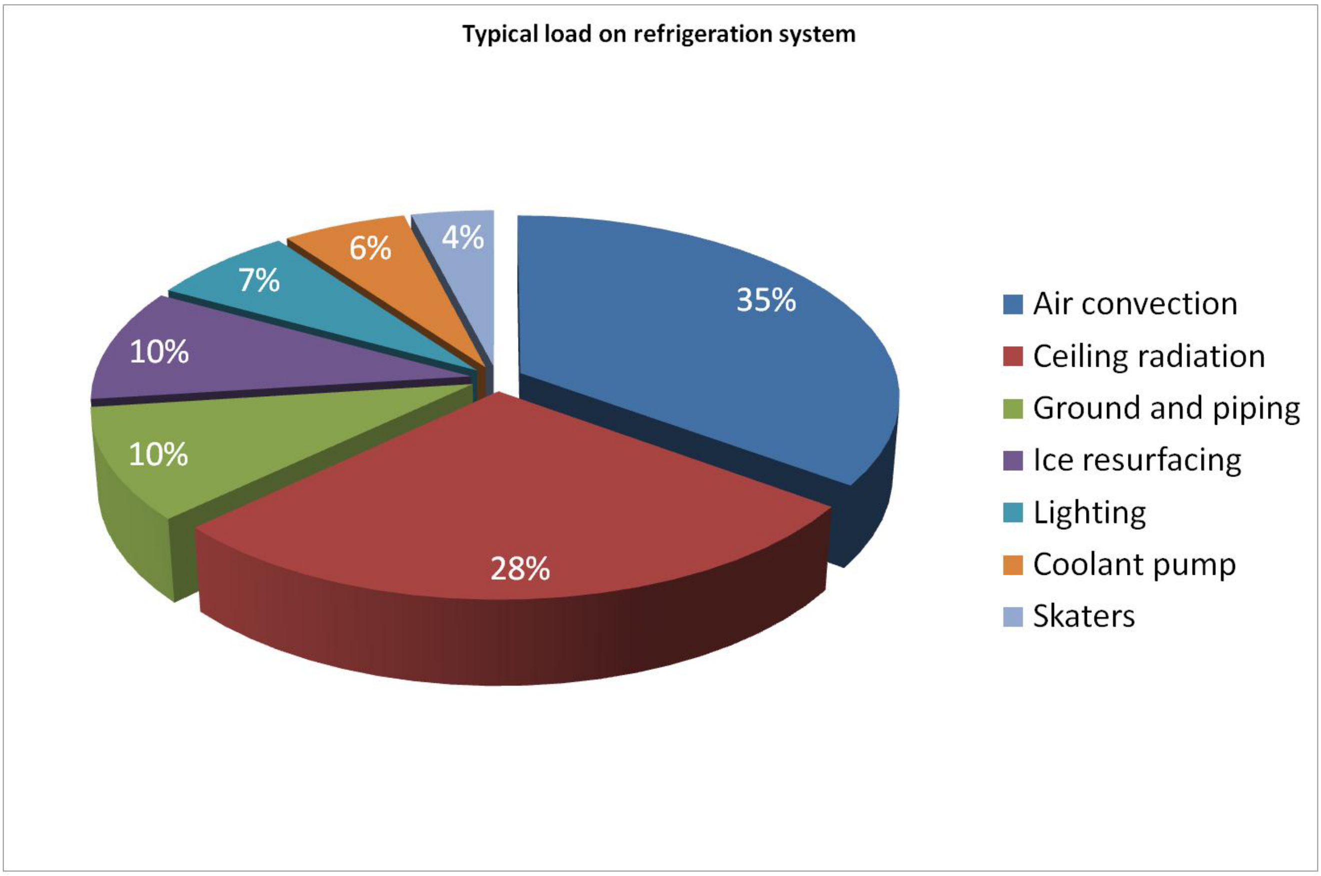
The challenge is to create the cooling capacity using the lowest possible amount of energy. The opportunity is to save energy for warming water using heat recovery or heat pumps. There are two different philosophies, and there is quite a big difference in the technologies. Heat pumps are one of the buzz words at the moment. This technology is used in some ice rink systems but the suggestion is here to exploit the opportunities more.

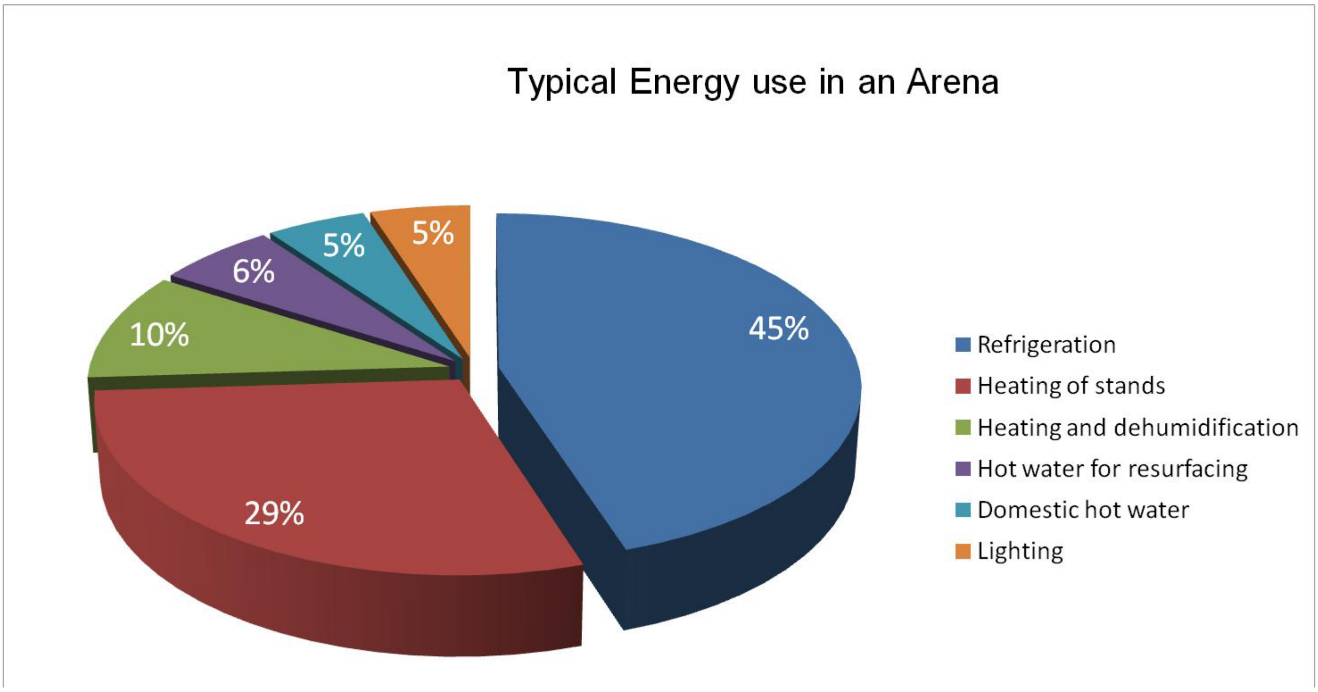
Another opportunity is to change the secondary refrigerant to carbon dioxide (CO_2 or R744). One of the big consumers of energy in the modern ice rink is the pump energy. The high power consumption is partly because the temperature difference between in and outlet has to be kept at about 2 to 3K. These pumps will be much larger than an equivalent CO_2 pump which has the same cooling capacity and working with a temperature difference of close to 0K. CO_2 in itself is also cheaper than the normally used secondary refrigerants.

Heating

It is important to understand where the heat comes from and what it is used for. Many analyses have been made over the years so we can make a broad overview of the experience published in different materials. One of the biggest and most described investigations has been made in the Canadian market. We are aware that there are differences in the markets on how the arenas are built, but this report is quite detailed and describes well the amount of energy used for different purposes in a big market.

Let's look at the results of this





In terms of money the energy in kWh/year for the most efficient arenas can be shown as follows:

Refrigeration	360,000	kWh/year
Heating of stands	232,000	kWh/year
Heating and dehumidification	80,000	kWh/year
Hot water for resurfacing	48,000	kWh/year
Domestic hot water	40,000	kWh/year
Lighting	40,000	kWh/year
	800000	kWh/year

and if you want to use the Finnish market price of energy according to www.energy.eu you can calculate this in to money:

Finnish price of energy	0.0559	kWh
http://www.energy.eu/		
Refrigeration	20,124	€/year
Heating of stands	12,969	€/year
Heating and dehumidification	4,472	€/year
Hot water for resurfacing	2,683	€/year
Domestic hot water	2,236	€/year
Lighting	2,236	€/year
Total expenditure	44,720	€/year

The expenditure on hot water production can be reduced as shown in the calculation here under.

Heat recovery

Basically the heat recovery systems allow you to collect the heat from the refrigeration systems warm side. The primary function of the refrigeration system is to keep the ice cold and not to create how water. The cold side and the temperature required here are therefore determined by the ice rink and the purpose of it. The warm side is defined by what the refrigeration system can do for you. There is a limit to how high the condensing pressure can become because you lose capacity as the condensing temperature increases and due to mechanical stresses in the system.

In current ice rink systems part of the heat is recovered, but at a relative low level. If you are recovering the superheat of the compressed gas you can recover about 10% of the heat giving a temperature of about 60°C going a capacity of about 30 kW going to 0 kW at 90°C.

Alternatively you can use the condensing temperature between 20-40°C but with a capacity of 400 kW. The higher the condensing temperature becomes the lower the cooling capacity and the overall efficiency decreases.

A third possibility is to use a heat pump that can generate 70°C hot water using the warm side of the cooling system as heat source. Basically this is staging the compressor system and that has always been better for efficiency. This is the ultimate way to save money for space heating and for heating tap water also compared to oil burners.

We will demonstrate how it is possible to generate 70°C water at a competitive price using local prices for electricity and natural gas.

The assumptions

We will assume that the refrigeration plant has a condensing capacity around 400 kW at 30°C which is a pretty standard refrigeration unit for a refrigeration unit in an arena. We also assume that the boiler has an efficiency of 100% although it is only close for new and high class boilers.

The prices we use are taken from the EU price of gas and electricity which can be found on the Internet (http://www.energy.eu/). These prices are only average but good enough for our calculation. We have also compared the boiler with a comparable heat pump with the same heating capacity. This can be an advantage for the boiler.

We furthermore assume that the load is constant at full load although the price for the heat pump is including variable speed drive (VSD). The assumption also use 5040 hours or 7 months of operation at full load conditions. This is an advantage for the boiler because they are not as efficient as the heat pump at part load.

Heat pump price	Installation price
121,500.00	25,000.00
Cost of installation	Service/year (Apx)
146,500.00	5,860.00

We assume the cost of installation and the approximate cost of service on the unit. The price is based on a quotation from the sales department.

What is not taken in to consideration is if you cannot use the heat in your own premises. In some cases you can sell the surplus heat to neighbors provided the supply temperature is hot enough.

The size of the unit chosen for the purpose is only designed to keep the condensing temperature of the ice rink unit at standard conditions. This means that we have not considered the effect of lowering the condensing pressure of the ice rink unit. Therefore it is possible to speed up the heat pump a little and reduce the condensing pressure. This will increase the performance by 3% each degree the condensing pressure on the ice rink unit is lowered.

Your country	Finland	
Gas price	0.027	€/kWh
Heat capacity	10	kWh/m3
Price of Electric power	0.056	€/kWh
	Winter	
Capacity	100%	
Boiler capacity	483.3	kW
Gas concumption	48.33	m3/h
Running cost	13.19	€/h
Heat pump capacity	483.3	kW
Electricity consumption	83	kW
Running cost	4.64	€/h
Yearly activity	5760	Hours
Saving	49,273.29	€/year
Price of heat pump	146,500.00	€
Simple pay back	3.0	Years

Working with natural gas is not so straight forward as many might think. Some qualities fluctuate quite a lot and if the boiler is not looked after by a qualified engineer all the time it might stop from time to time or the efficiency will suffer substantially. Other suppliers have a very stable quality of gas which allows no-supervision plants. Using heat pumps you are out of these thoughts as long as you have a stable power supply.

Basically you can see that the boiler has a coefficient of performance (COP) equal to 1 and the heat pump has a COP = 483/83=5.82. Translated in to clear text it means for each amount of (gas/oil/coal) heating capacity in kWh gives one kWh as output (without considering age and lower efficiency) compared to the heat pump that delivers 5.82 kWh for each kWh put in to the motor. This is without considering the increased efficiency that comes with the lower condensing temperature of the refrigeration system.

A simple estimate:									
Savings on the "cold" side									
	Lower condensing temperature								
	5	°C					Coolinh load	350	kW
	Normal power input						Condensing load	420	kW
	420	kW	23.478	€/h	135,233	€/year			
	New power input								
	357	kW	19.9563	€/h	114,948	€/year			
					20,285	€/year			
	Total savings in runing cost per year			69,558.28	€				
	Payback time			2.1	Years				

If it is possible to lower the condensing temperature it will reduce the simple payback period for the system to about 2.1 years. On top of this we can add the longer service life of the system because of less wear and tear from working with less load. Less service requirements can also come in to question due to better running condition for the refrigeration system.

Low cost reduction measures

There are a number of possibilities of saving energy already widely used. Most of them are self evident but perhaps worthwhile mentioning:
Increase the ice temperature during unoccupied periods or when the users do not need the very hard ice sheet e.g. figure skating or free skating. One degree increased temperature on the ice sheet can result in 6% saving annually.
Infrared sensors mounted over the ice sheet give a better temperature control than an embedded sensor.
Reduce the ice thickness. Some ice rinks use very thick ice sheet but it has a penalty on the energy consumption
Avoid running at high than necessary condensing pressure/temperature. One bar higher condensing pressure gives 3% additional energy consumption. It is in many cases better to use a dedicated heat pump to produce hot water when needed.
Reduce the space temperature and ventilation when not needed
Consider other fluids e.g. CO_2 for new ice rinks. CO_2 pumps use about 10% of the energy for the same cooling capacity compared to glycol pumps.
Consider lower flow rates in coolant to reduce the pump power absorption
Reduce the lighting when possible and use motion sensors to switch off light when rooms are not used.
Heat pumps can be used to cool exhaust air and warm in coming air. Alternative is to use heat pipes using CO_2 as heat transfer media.
Space heating accounts for about 30% or more. A lot of possible solutions to conserve energy are available here. An important issue is to separate the air on stands from the air over the ice sheet. The warm air is a major contributor to heat load on the refrigeration system
Ventilation rates can be controlled using CO_2 room sensors

Conclusions

The desire for saving energy in the ice arena and the main areas of focus falls in to two categories
The refrigeration system and tasks for operating and maintenance of the ice sheet

Heating, ventilation and dehumidification of stands, rink, locker rooms and common areas.
Hot water and lighting play a minor role in the big picture (each about 5%) but hot water is easy to produce efficiently and cheap by recovering heat from the refrigeration system. Lightning is a topic often discus.

A low hanging fruit is to apply a heat pump that can provide high value hot water that can provide heating and hot water eliminating need of boilers.