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# Assessing the Integration of Sustainable Cooling Technologies in Southern California Ice Arenas

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## Abstract

Ice rinks use massive amounts of energy, much of which is derived from conventional power sources like coal, oil, and natural gas [1]. This energy use contributes to greenhouse gas emissions, further accelerating climate change. To address this issue, this study aims to find ways to integrate more efficient–and thus more sustainable–cooling technologies in ice rinks. A key focus of this work is redirecting wasted energy from the ice cooling process back into the cycle, lowering the energy from outside sources and potentially producing a self-sustaining cycle. Not only does this energy redirection decrease emissions of harmful gasses; it also lowers the operational costs of cooling the ice rink [2]. This paper compares three promising sustainable cooling technologies: waste heat recovery, atmospheric water harvest, and low-emissivity glass. Each technique was assessed using criteria including upfront and operational costs, feasibility based on current technology, amount of energy produced or recycled, amount of energy needed to run the technology, and distinguishing factors unique to the cooling technique itself. Based on findings, the recommended technology to install out of those investigated is the plate heat exchanger due to cheaper upfront cost, relatively higher energy efficiency, and flexibility in changes and maintenance during operation.

## Introduction

Climate change continues to increase the frequency and strength of natural disasters each year, costing governments around the world billions of dollars in attempts to remedy the situation [3]. According to the International Monetary Fund, direct damages caused by climate change total to $1.3 trillion over the past decade, approximately 0.2% of the world GDP [3]. Improving energy efficiency in industrial cooling has been a major goal for many scientists and climate activists, as energy usage and waste heat emissions directly contribute to climate change by enhancing global warming effects. A combination of energy efficiency improvements and a transition away from polluting refrigerants used for cooling could reduce between 210 to 460 billion tons of greenhouse gasses in the next four decades [4].

One way to reduce energy use is to optimize energy consumption in ice rinks. Ice rinks, on average, use 1,500,000 kWh/year, equal to 141 households' average annual electricity consumption [5]. Much of this energy use comes from the cooling systems integrated in the rink. Traditional cooling systems use a fluid with a lower freezing point than water to remove and divert heat from the ice rink. Typically, this involves running liquid refrigerant (brine) at -9℃ through pipes laid underneath the surface of the ice [6]. The liquid draws heat from the ice and is fed to a chiller, which allows the liquid to remain at a cool temperature using outside air and water [7]. Another cooling liquid with a lower freezing point than the refrigerant, typically ammonia, removes the refrigerant's energy. That ammonia is boiled and vaporized, taking the excess heat out of the system, while the brine is recycled back to use on the ice.

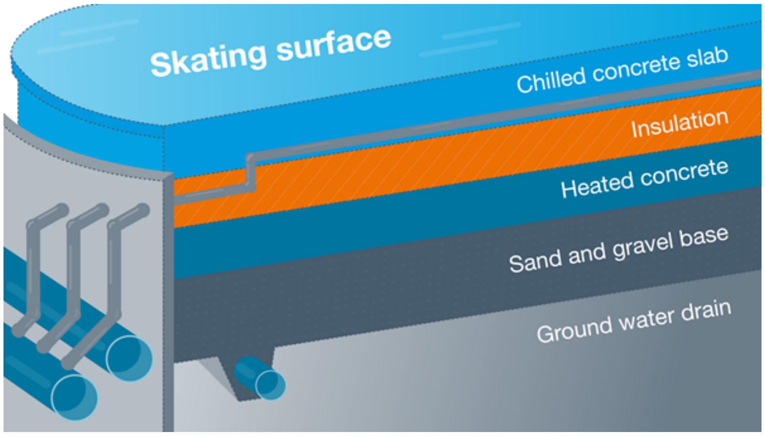

**Figure 1**. Schematic of traditional rink cooling system [8]

Prior research has conducted both qualitative and quantitative analysis and calculations; yet, this research focused on minor adjustments to the ice rink structure, such as insulation and lighting, rather than changing the cooling system of rinks, which could result in the development of more energy-efficient systems. For example, Zhou *et al*. [9] reviewed the material and structural designs of atmospheric water harvesters. They concluded that relatively small energy input can release concentrated moisture, but additional energy is needed to power the heat pump at the Carnot limit for heat dissipation. This set a foundation for the research conducted in this paper as Zhou *et al* demonstrated the promise of atmospheric water harvesting through its limited energy input usage while illustrating further development is needed.

In contrast, Jouhara *et al*. [7] reviewed a different cooling method, waste heat recovery and its applications. They outlined that a key component in selecting the applicable technology is determining the source of the waste heat, and that the heat recovery equipments are largely categorized based on temperature range and fluid recovered. In a rink cooling system, dissipated heat from the condenser can be recycled through waste heat recovery and redirected elsewhere as heat energy.

Similarly, Hou *et al*. [10] also investigated waste heat recovery but in the form of waste heat refrigeration systems for dust collectors in monosilicon manufacture. They found that for temperatures lower than 76℃, the ejection cycle has better performance than the absorption cycle, which is more suitable for an industrial setting. The ice rink is ideal for this condition as the atmospheric temperature is less than 76℃ and the cooling system is similar to that of industrial settings.

Tutumlu *et al.* [11] extends the analysis of cooling technologies to an ice rink, with the addition of an underground thermal storage tank. They conclude that thermophysical properties of the earth surrounding the storage tank affect its performance. This research overcomes such barriers as the technologies are placed within the rink cooling system, unaffected by their environment.

This paper addresses the problem of excess energy usage in ice rinks and focuses on maximizing energy efficiency while noting costs and feasibility by comparing several sustainable cooling technologies. The four technologies compared are low emissivity paint/coating, plate heat exchangers, heat pipe system, and atmospheric water harvesting. These methods were downselected from an in-depth literature review of cooling techniques based on ability to remove heat and aptitude for application to an ice rink. They showed similar applications to the cooling systems and could be a feasible solution for ice rink cooling to be energy-efficient.

The methodology employed starts by building a knowledge foundation through a literature review. The paper first gives an overview of each technology and compares the four criterias: upfront cost, maintenance cost, energy efficiency, and feasibility based on current technology and the nature of ice rinks. These areas of comparison were chosen after literature review of the cooling methodologies. Upon gathering necessary information, each technology is analyzed and compared quantitatively through calculations of ability to carry heat load and unit sizing in the latter half of the paper. The advantages and disadvantages of each method were also noted in the qualitative analysis that follows.

## Methodology

### *Low emissivity paint/coating*

Low emissivity paint is typically used for glass but can also be applied onto other surfaces, achieving similar thermal insulation. This type of coating minimizes the passage of ultraviolet, infrared light, and heat energy by reflecting them while still allowing visible light to pass through [12]. The paint itself is made of layers of silver and dielectric materials. By manipulating the thickness and composition, visual and thermal properties of the coating can be controlled [13]. In the context of ice rinks, the low-emissivity coatings are to be applied on ceilings, walls, and other enclosures of the rinks.

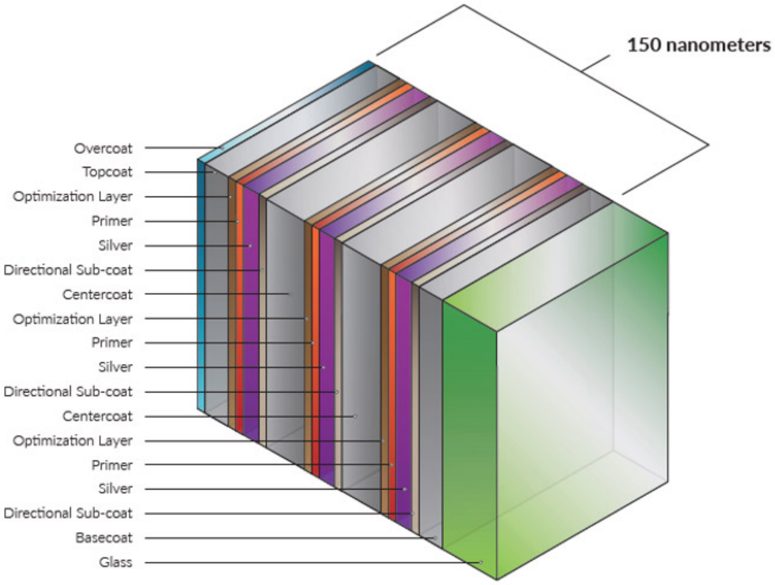

**Figure 2**. Layers of low-e coating [4]

### *Plate heat exchanger*

The objective of waste heat recovery techniques is to circulate waste heat developed during industrial processes or commercial processes back into the system. The plate heat exchanger is a type of waste heat recovery method that consists of metal plates stacked parallel to each other. Two liquids, one hotter and one colder, are pumped through the plates, and heat transfers from the hotter to the colder liquid. Patterns stamped onto the plates create turbulent flow, thus increasing the surface area and mixing for better heat exchange. Gaskets on the openings of the plates prevent leakage [14]. The fluids flow in counter flow direction to maximize the temperature difference, which is proportional to the heat transfer from Fourier's law, and hot and cold alternate throughout the plates, with heat conducted between through the metal [15]. The stream of liquid carrying the heat from the ice surface will become the hot stream for the plate heat exchanger.

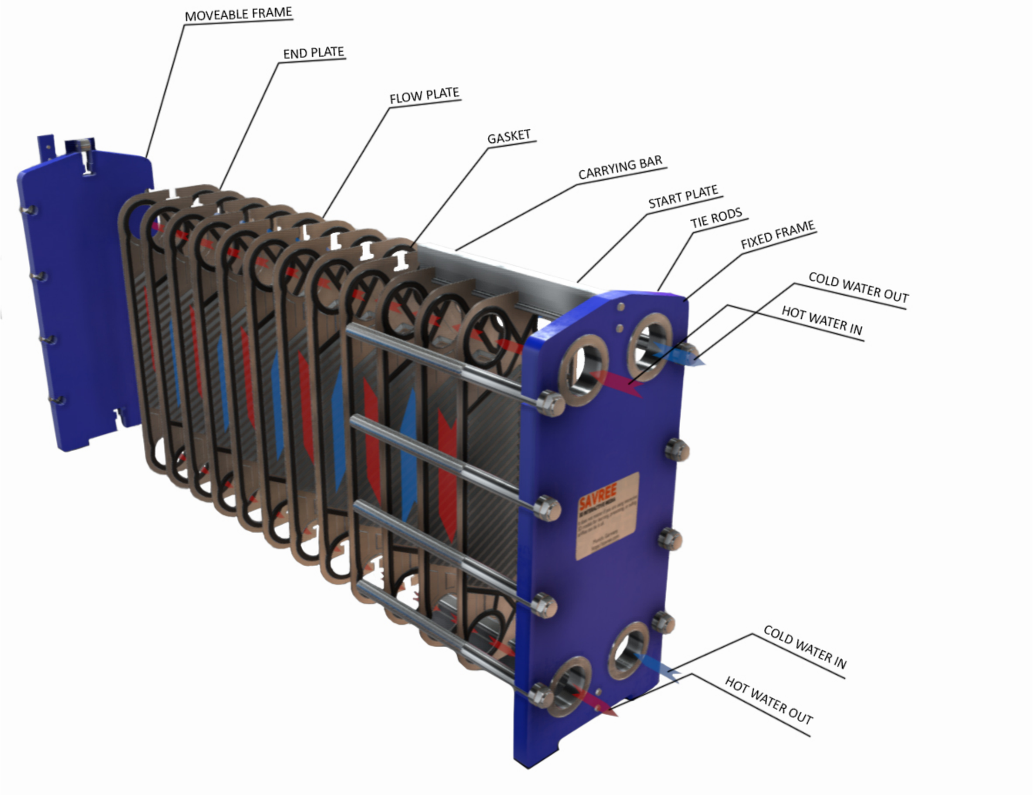

**Figure 3**. Components of a plate heat exchanger [15]

*Heat pipe system*

A heat pipe system contains a pipe, wick structure, and fluid that facilitates the heat transfer process. Heat enters the system through one end of the pipe, vaporizing the fluid. Then, the generated vapor pressure drives the vapor through the pipe, where the temperature is lower. The vapor loses its heat to a heat sink and condenses back to liquid form. Capillary pressure caused by the wick structure drives the liquid back to the hot end of the pipe [14]. The heated liquid for the heat pipe system will come from the liquid refrigerant that already absorbed heat from the ice surface.

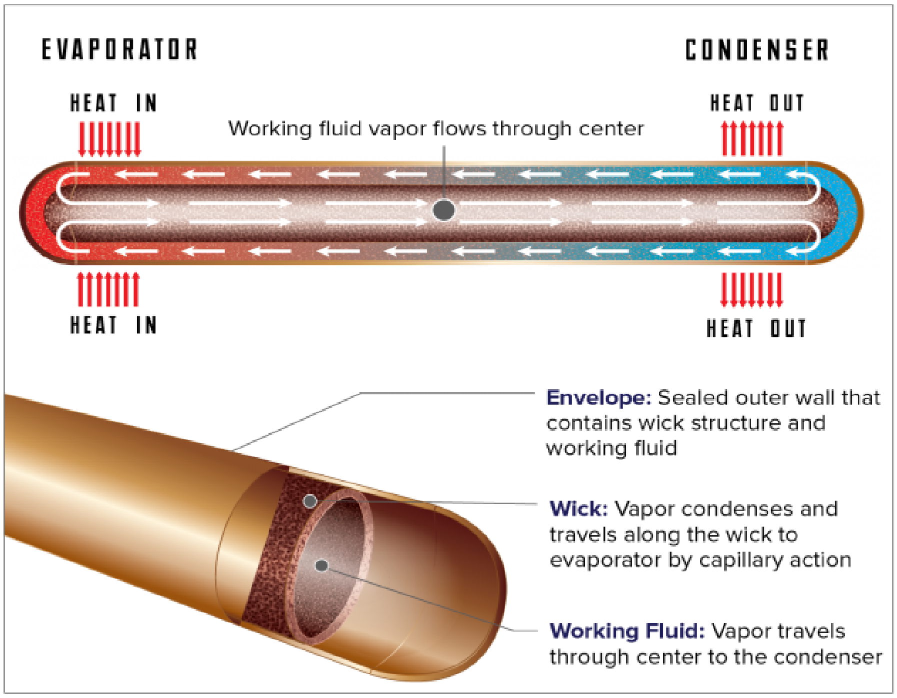

**Figure 4**. Schematic of heat pipe system [16]

*Atmospheric water harvesting*

The most common method of atmospheric water harvesting is the use of condensing systems. A compressor circulates the refrigerant to the condenser, which the evaporator coil uses to cool the surrounding air [17]. Once the temperature of the air has been cooled to or below the dew point, water condenses out and is “harvested” for use in other applications [9]. The atmospheric water harvester can not only supply the cooling system with liquids, but it can also remove water vapor from the air to prevent it from condensing onto the ice surface.

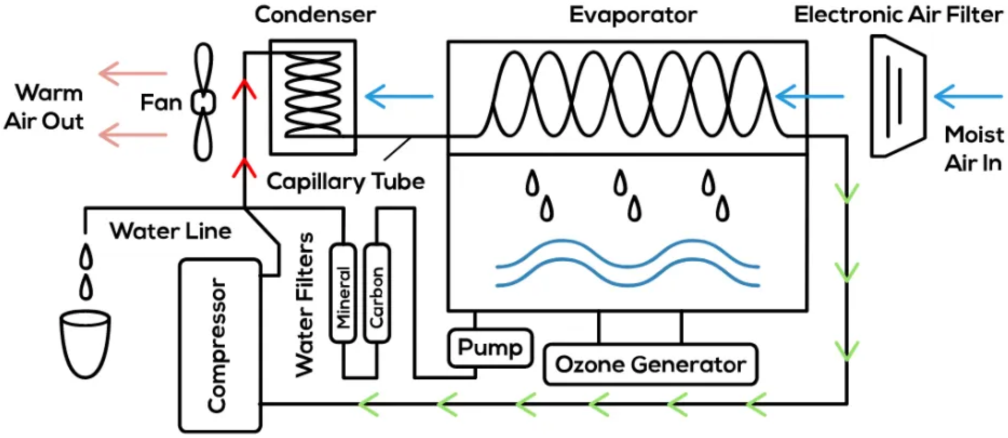

**Figure 5**. Diagram of atmospheric water harvester [18]

*Heat Load Calculations*

The heat dissipation and unit sizing was calculated to ensure the feasibility of each technology and compare the energy efficiency of each method. First, the amount of ice was determined using the density of water. The heat gain through convection was calculated using the difference in temperature between the air above the ice surface and indoor temperature of the rink. Next, the radiative gain was obtained and the total heat gain computed, giving a value of 1255.19 kW. Therefore, a cooling system would need to remove 1255.19 kW to keep the ice at the same temperature and state.

For the plate heat exchangers, the inlet and outlet temperatures of both hot and cold streams were determined using the known temperature of refrigerant exiting the cooling cycle. Then, the log mean temperature difference and surface area of the plate heat exchanger was calculated to estimate the cost and sizing of the technology.

When sizing the heat pipe system, combinations of the various heat pipe metrics were tested and optimized, and the variables included heat pipe length, diameter, angle, evaporator and condenser lengths, and the operating temperature. The lengths of the evaporator and condenser were maximized, taking up 90% of the total length of the heat pipe to produce the largest energy output, ensuring that at least 10% of the length is left for the wick to conduct capillary action, driving the fluid.

## Results

### *Unit Sizing*

This information was used to calculate the heat duty of each plate heat exchanger, and the optimal combination was calculated to have a heat duty of 163 kW, requiring 8 exchangers integrated in the cooling system. Each heat exchanger is estimated to be about 0.207 $m^3$, a total of 1.656 $m^3$. The optimal combination for a heat pipe produced a power of 443.6 W, requiring 2830 individual heat pipes each 100 mm in length and with a total volume of 0.0222 $m^3$.

### *Water in Air*

For the atmospheric water harvester, a relative humidity of 60% inside the rink is converted to the mass fraction of water in the air. Utilizing the typical building dimensions of an indoor ice rink, 51.2 meters by 86 meters by 11.6 meters [19], the amount of water in the air is calculated to be $1.22 \times 10^7$ kg of water. This process ensures that the humidity level is high enough to meet the threshold for gathering water used for rink cooling.

### *Methods Comparison*

The results from this study are grouped into the following table for better comparison of the technologies.

**Table 1**. Ice rink cooling technology side-by-side comparison

| Technology | Cost | Energy efficiency | Feasibility |
|---|---|---|---|
| Low-e paint/coating | \$0.0319 - \$0.0406/sq ft [20]; \$2060.21 to \$2622.09 total | About 20-25% less energy consumed in building for cooling/heating [21] | More established technology; no sizing restrictions; roof need to be painted; |

| | | | |
|---|---|---|---|
| | | | indirect, cooling environment |
| Heat pipe system | $20,080.26 total | More suited for low power situations; not suitable for high power & high coolings demands; highest effectiveness of 54.4% [22] | More design flexibility (pipes); smaller units inefficient to install |
| Plate heat exchanger | Each unit costs $2589.46 to $2966.92 on average; $15,627.69 to $18,123 total | Most efficient of all heat exchangers; efficiency rates of ~90% [23]; large surface area & turbulent flow contribute to heat efficiency | Incompatible with high fluid temperatures (gasket cannot handle); Increase potential for leakage as gaskets age; compact design; able to move relatively large amounts of heat |
| Atmospheric water harvesting | $28,000 per unit [25] | Between 40-68% saving in energy consumption per unit volume of water harvested [24]; producing 100 gallons of water [25] | Humidity level meet basic threshold for employment of atmospheric water harvesting; established technology used commercially; indirect, cooling environment and air |

*Optimal Method*

The choice between the waste heat recovery methods was the plate heat exchanger. Its upfront cost was approximately 25% less than the cost for the heat pipes. A single unit of heat exchanger has a high heat duty in comparison to the heat pipe system and allows for addition or removal of plates, which makes the installation of the device and adjustment of the heat duty extremely flexible. Furthermore, it is the most energy efficient out of all waste heat recovery technologies, with an efficiency rate of approximately 90%. Although the heat pipe system is more compact, the sizing of the two technologies is not a determining factor as both are relatively small.

Between the two supplemental methods, the better-suited option is the low-emissivity coating. It costs less and contains a relatively easier implementation process. Rather than having to relink the entire cooling system and supply of liquids, the coating simply needed to be applied to the surfaces.

## Conclusion

This paper proposes four different sustainable cooling methods that can be integrated into Southern California ice rinks: low-emissivity coating, atmospheric water harvesting, plate heat exchanger, and heat pipe. The technologies are compared based on standards that include costs, energy efficiency, and feasibility, all of which are modeled to suit the ice rink cooling structure. The heat capacity of each technology was calculated and used to estimate the sizing and costs of one unit. Having conducted quantitative and qualitative analysis on the data gathered, plate heat exchanger is determined to be the most optimal technology used as an adjunct to the rink cooling system because of its low costs and high energy efficiency. The results from this study can be used in further research and development in the field of cooling technologies and integration into already-existing building structures to lower the cost of circulating cooling water systems such as power plants and food processing plants. Future constructions of rinks can also model designs based on the results of the study.

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