## CHAPTER 35

# ICE RINKS

ANY level sheet of ice made by refrigeration (the term **artificial ice** is sometimes used) is referred to in this chapter as an ice rink regardless of use and whether it is located indoors or outdoors. Bobsled-luge tracks are not referred to as rinks but are referenced under this chapter.

An ice sheet is usually frozen by circulation of a heat transfer fluid through a network of pipes or tubes located below the surface of the ice. The heat transfer fluid is predominantly a secondary coolant such as glycol, methanol, or calcium chloride (see Chapter 21 of the 2005 *ASHRAE Handbook—Fundamentals*).

R-22 and R-717 are most frequently used for chilling secondary coolants for ice rinks. R-12 and R-502 have also been used; however, because of the phaseout of the CFC refrigerants, they should no longer be considered for use. R-22 will also be phased out, so for new rink equipment selection, R-22 and CFC replacements should be evaluated according to status and availability.

In some rinks, R-22, and R-717 to a lesser degree, have been applied as a direct coolant for freezing ice. The direct-refrigerant rinks operate at higher compressor suction pressures and temperatures, thus achieving an increased COP, compared to secondary coolants. The primary refrigerant charge is greatly increased with this method of freezing. Because of emissions regulations, the projected R-22 phaseout, building codes, and fire regulations, R-22 and R-717 should not be used to freeze ice *directly* in indoor rinks.

## APPLICATIONS

Most ice surfaces are used for a variety of sports, although some are constructed for specific purposes and are of specific dimensions. Usual rink sizes include the following:

**Hockey.** The accepted North American hockey rink size is 26 by 61 m. Radius corners of 8.5 m are recommended by professional and amateur rules. The Olympic and international hockey rink size is 30 by 60 m, with 6 m radius corners. Many rinks are considered adequate with dimensions of 26 by 56.4 m, 24.4 by 54.9 m, and 21.3 by 51.8 m. In substandard size rinks, a corner radius of not less than 4.5 m should be provided to allow use of mechanical resurfacing equipment.

**Curling.** Regulation surface for this sport is 4.3 by 45 m; however, the width of the ice sheet is often increased to allow space for installation of dividers between the sheets, particularly at the circles. Most curling rinks are laid out with ice sheets measuring 4.5 by 46 m.

**Figure Skating.** School or compulsory figures are generally done on a “patch” measuring approximately 5 by 12 m. Freestyle and dance routines generally require an area of 18 by 36 m or more.

**Speed Skating.** Indoor speed skating has traditionally been performed on hockey-sized rinks. The Olympic-sized outdoor speed skating track is a 400 m oval, 10 m wide with 112 m straightaways and curves with an inner radius of 25 m. Most speed skating ovals were originally constructed outdoors; however, some have now been constructed indoors.

**Recreational Skating.** Recreational skating can be done on any size or shape rink, as long as it can be efficiently resurfaced. Generally, 2.3 to 2.8 $m^2$ is allowed for each person actually skating. This ratio may vary for large numbers of beginner skaters. A 26 by 61 m hockey rink with 8.5 m radius corners has an area of 1517 $m^2$ and will accommodate a mixed group of about 650 skaters.

**Public Arenas, Auditoriums, and Coliseums.** Public arenas, auditoriums, field houses, etc., are designed primarily for spectator events. They are used for ice sports, ice shows, and recreational skating, as well as for non-ice events, such as basketball, boxing, tennis, conventions, exhibits, circuses, rodeos, tractor events, and stock shows. The refrigeration system can be designed so that, with adequate personnel, the ice surface can be produced within 12 to 16 h. However, general practice is to leave the ice sheet in place and to hold other events on an insulated floor placed on the ice. This approach saves significant time, labor, and energy.

**Bobsled-Luge Tracks.** The bobsled-luge track usually incorporates steel piping embedded in the track and fed by an ammonia liquid recirculation system. Approximately 85 000 to 90 000 m of piping is required for an Olympic-sized track. The total refrigerated surface is 8000 to 9300 $m^2$. Refrigeration plant capacities in the range of 4000 to 5000 kW are required, depending on ambient design conditions, wind, and sun loads. The ammonia charge can exceed 90 000 kg. Because elevation changes are significant, care must be used in placing liquid recirculators, selecting ammonia pumps, and circuiting floor piping.

## REFRIGERATION REQUIREMENTS

The heat load factors considered in the following section include type of service, length of season, use, type of enclosure, radiant load from roof and lights, and geographic location of the rink with associated wet- and dry-bulb temperatures. For outdoor rinks, the sun effect and weather conditions (wind velocity and rain) must also be considered.

Refrigeration requirements can be estimated fairly accurately based on data from a number of rink installations with the pipes covered by not more than 25 mm of sand or concrete and not more than 40 mm of ice (a total of 65 mm sand or concrete and ice).

Refrigeration load may be estimated by considering the larger of (1) the refrigeration necessary to freeze the ice to required conditions in a specified time, or (2) the refrigeration necessary to maintain the ice surface and temperature during the most severe usage and operating conditions that coincide with the maximum ambient environmental conditions.

In the time-to-freeze method, determine the (1) quantity of ice required (rink surface area multiplied by thickness); (2) heat load to reduce the water from application temperature to 0°C, freeze the water to ice, and reduce the ice to the required temperature; and (3) heat loads and system losses during the freezing period. The total requirement is divided by system efficiency and freezing period to determine the required refrigeration load or rate of heat removal.

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**Example 1.** Calculate the refrigeration required to build 25 mm thick ice on a 1500 $m^2$ rink in 24 hours.

Assume the following material properties and conditions:

| Material | Specific Heat, kJ/(kg·K) | Temperature, °C | | Density or Mass |
|---|---|---|---|---|
| | | Initial | Final | |
| 150 mm concrete slab | 0.67 | 2 | –6 | 2400 $kg/m^3$ |
| Supply water | 4.18 | 11 | 0 | 1000 $kg/m^3$ |
| Ice | 2.04 | 0 | –4 | — |
| Ethylene glycol, 35% | 3.5 | 5 | –9 | 14 000 kg |

Latent heat of freezing water = 334 kJ/kg
Building and pumping heat load = 170 kW of refrigeration
System losses = 15%
Mass of water = $1500\ m^2 \times 0.025\ m \times 1000\ kg/m^3 = 37\,500\ kg$
Mass of concrete = $1500\ m^2 \times 0.150\ m \times 2400\ kg/m^3 = 540\,000\ kg$

Then,

$$q_R = (\text{Sys. losses})(q_F + q_C + q_{SR} + q_{HL})$$

*where*

$q_R$ = refrigeration requirement
$q_F$ = water chilling and freezing
$q_C$ = concrete chilling load
$q_{SR}$ = refrigeration to cool secondary coolant
$q_{HL}$ = building and pumping heat load

$$q_F = \frac{37\,500\ \text{kg}\{4.18(11 - 0) + 344\ \text{kJ/kg} + 2.04[0 - (-4)]\}}{24\ \text{h} \times 3600\ \text{s/h}}$$

$$= 172.8\ \text{kW}$$

$$q_C = \frac{540\,000 \times 0.67[2 - (-6)]}{24 \times 3600} = 33.5\ \text{kW}$$

$$q_{SR} = \frac{14\,000 \times 3.5[5 - (-9)]}{24 \times 3600} = 7.9\ \text{kW}$$

$$q_R = 1.15(172.8 + 33.5 + 7.9 + 170) = 442\ \text{kW}$$

When no time restrictions for making ice apply, the estimated refrigeration load is the amount of heat removal needed to offset the usage loads plus the coincidental heat loads during the most severe operating conditions. Table 1 lists approximate refrigeration requirements for various rinks with controlled and uncontrolled atmospheric conditions. Table 1 should only be used to check the calculated refrigeration requirements. Table 2 shows the distribution of various load components for basic construction and the estimated potential load reductions that may be obtained when energy-conserving design and operating techniques are used.

## Heat Loads

Energy and operating costs for ice rinks are very significant, and these costs should be analyzed during design. A good estimate of required refrigeration can be calculated by summing the heat load components at design operating conditions. Heat loads for ice rinks consist of conductive, convective, and radiant components. Connelly (1976) collected the performance data summarized in Tables 2 and 3. The amount of control over each load source is indicated as an approximate percentage of the maximum reduction possible through effective design and operation.

**Table 1 Range of Refrigeration Capacities for Ice Rinks**

| Type of Facility | Up to 7 months (spring, fall, winter), $m^2/kW$ | 8 months to year-round, $m^2/kW$ |
|---|---|---|
| Outdoors, unshaded | 2.1 to 3.7 | — |
| Outdoors, shaded | 2.6 to 5.0 | — |
| Sports arena | 2.9 to 4.2 | 2.6 to 3.7 |
| Sports arena, accelerated ice making | 2.1 to 3.6 | 2.0 to 3.2 |
| Ice recreation center | 4.5 to 6.3 | 3.7 to 5.0 |
| Curling rinks | 5.3 to 10.0 | 4.0 to 5.3 |
| Ice shows | 2.1 to 4.0 | 2.0 to 3.4 |

**Conductive Loads.** If a rink is uninsulated, **heat gain from the ground** below the rink and at the edges averages 2 to 4% of the total heat load. Permafrost may accumulate and frost heaving, which is detrimental to both the rink and the piping, may result. Heaving also makes it more difficult to maintain a usable ice surface, can affect the structural integrity of the building, and is dangerous to the users.

Heat gain from the ground and perimeter is highest when the system is first placed in operation; however, it decreases as the temperature of the mass beneath the rink decreases and permafrost accumulates. Ground heat gain is reduced substantially with insulation. Chapter 25 of the 2005 *ASHRAE Handbook—Fundamentals* gives details on computing heat gain with insulation.

**Heat gain to the piping** is normally about 2 to 4% of the total refrigeration load, depending on length of piping, surface area, and ambient temperatures. The ice and frost that naturally accumulate on headers reduce the heat gain. Insulation can be applied to reduce heat gain to the piping and keep ice from accumulating. However, insulating headers while maintaining visual inspection of joints (floor piping to the headers) is usually impractical. Headers may, with precautions and the use of steel headers and piping, be embedded in the rink floor. Embedded headers contribute to ice freezing and eliminate the trench to rink floor piping penetrations. When headers are embedded in concrete, all joints from the steel floor piping to the headers should, ideally, be welded. It may be difficult to remove air from this type of floor system.

A circuit loop should be placed around the rink perimeter to prevent soft ice from developing at the edges (see the section on Rink

**Table 2 Ice Rink Heat Loads, Indoor Rinks**

| Load Sources Category | Approximate Maximum of Total Load,* % | Maximum Reduction of Load Category Through Design and Operation, % |
|---|---|---|
| *Conductive loads*: | | |
| Ice resurfacing | 12 | 60 |
| System pump work | 15 | 80 |
| Ground heat | 4 | 80 |
| Header heat gain | 2 | 40 |
| Skaters | 4 | 0 |
| *Convective loads*: | | |
| Rink air temperature | 13 | 50 |
| Rink humidity | 15 | 80 |
| *Radiant loads*: | | |
| Ceiling radiation | 28 | 90 |
| Lighting radiation | 7 | 40 |
| Total | 100 | |

*Load distribution for basic rink without insulation below rink floor.

**Table 3 Ice Rink Heat Loads, Outdoor Rinks**

| Load Sources Category | Approximate Maximum of Total Load,* % | Maximum Reduction of Load Category Through Design and Operation, % |
|---|---|---|
| *Conductive loads*: | | |
| Ice resurfacing | 9 | 50 |
| System pump work | 12 | 80 |
| Ground heat | 2 | 40 |
| Header heat gain | 1 | 30 |
| Skaters | 1 | 0 |
| *Convective loads*: | | |
| Air velocity | 0 to 15 | 10 |
| Air temperature | 0 to 15 | 0 |
| Humidity | 0 to 15 | 0 |
| *Radiant loads*: | | |
| Solar load | 10 to 30 | 60 |
| Total | 100 | |

*Load distribution for basic rink without insulation below rink floor.

Piping and Pipe Supports). A circuit loop is especially important if return bends are used and embedded in the concrete. If return bends are embedded in the concrete, the pipe and the return bend should be steel with welded joints.

**Heat gain from coolant circulating pumps** can represent up to 15% of the refrigeration load. Some facilities operate continuously. Energy consumption from pump operation can be reduced by using pump cycling, two-speed motors, multiple pumps, multiple motors driving a single pump, or variable-speed motors with the appropriate controls. High-efficiency pumps and motors should be used. Proprietary variable motor speed controls are also available. Coolant flow should be sufficient at all times for acceptable chiller operation and to maintain a balanced flow through the piping grid.

Equipment components should be selected for low energy consumption; they may be selected to operate at or feature low discharge pressure (oversized condenser), high suction pressure (oversized chiller), multiple compressors, and an intelligent control system. Computer control of the refrigeration system is recommended.

**Ice resurfacing** represents a significant operating heat load. Water is flooded onto the ice surface, normally at temperatures between 55 and 80°C, to restore the ice surface condition. The heat load resulting from the flood water application may be calculated as follows:

$$Q_f = 1000V_f[4.2(t_f - 0) + 334 + 2.0(0 - t_i)]$$

*where*

$Q_f$ = heat load per flood, kJ
$V_f$ = flood water volume (typically 0.4 to 0.7 $m^3$ for a 30 by 60 m rink), $m^3$
$t_f$ = flood water temperature, °C
$t_i$ = ice temperature, °C

The resurfacing water temperature affects the load and time required to freeze the flood water. Maintaining good water quality through proper treatment may permit the use of lower flood water temperature and less volume.

**Convective Loads.** Convective load from air to ice may be as much as 28% or more of the total heat load to the ice (see Tables 2 and 3). The convective heat load is affected by air temperature, relative humidity, and air velocity near the ice surface. Precautions should be taken to minimize the influence of air movement across the ice surface in the design of the rink heating and dehumidification air distribution system. The convection heat load may be estimated using the procedure from Appendix 5 in "Energy Conservation in Ice Skating Rinks" (DOE 1980). The estimated convective heat transfer coefficient can be calculated as follows:

$$h = 3.41 + 3.55V$$

*where*

$h$ = convective heat transfer coefficient, $W/(m^2 \cdot K)$
$V$ = air velocity over the ice,m/s

The effective heat load (including the latent heat effect of convective mass transfer) is given by the following equation:

$$Q_{cv} = h(t_a - t_i) + [K(X_a - X_i)(2852\ \text{kJ/kg})(18\ \text{kg/mol})]$$

*where*

$Q_{cv}$ = convective heat load, $W/m^2$
$K$ = mass heat transfer coefficient
$t_a$ = air temperature, °C
$t_i$ = ice temperature, °C
$X_a$ = mole fraction of water vapor in air, kg mol/kg mol
$X_i$ = mole fraction of water in saturated ice, kg mol/kg mol

When the mole fraction of air is calculated using a relative humidity of 80% and a dry bulb of 3.3°C, $X_a$ is approximately $6.6 \times 10^{-3}$, and $X_i$ for saturated ice at 100% and a temperature of −6.1°C is $3.6 \times 10^{-3}$. On the basis of the Chilton/Colburn analogy, $K \approx 0.23\ g/(s \cdot m^2)$ (DOE 1980).

In locations with high ambient wet-bulb temperatures, dehumidification of the building interior should be considered. This process lowers the load on the icemaking plant and reduces condensation and fog formation. Traditional air conditioners are inappropriate because the large ice slab tends to maintain a lower than normal dry-bulb temperature.

**Radiant Loads.** Indoor ice rinks create a unique condition where a large, relatively cold plane (the ice sheet) is maintained beneath an equally warm plane (the ceiling). The ceiling is warmed by conductive heat flow from the outside and by normal stratification of arena air. Up to 35% of the heat load on the ice sheet comes from radiant sources. On outdoor rinks radiant sources are the sun or a warm cloud cover. Vertical hanging cloth suspended from east-west horizontal overhead wires has been used to reduce the winter sun load.

In indoor and covered rinks, lighting is a major source of radiant heat to the ice sheet. The actual quantity depends on the type of lighting and how the lighting is applied. The direct radiant heat component of the lighting can be as much as 60% of the kilowatt rating of the luminaires. A radiant heating system can be another source of radiant heat gain to the ice. If radiant heat is used to maintain the comfort level in the promenade or spectator area, the radiant heaters should be located and directed to avoid direct radiation to the ice surface. The infrared components of the lighting can be estimated from manufacturers' data.

The infrared heat gain component from the ceiling and building structure, which is warmer than the ice surface, can be calculated by applying the Stefan-Boltzmann equation as follows:

$$q_r = A_c f_{ci} \sigma \left( T_c^4 - T_i^4 \right)$$

$$f_{ci} = \left[ \frac{1}{F_{ci}} + \left( \frac{1}{\varepsilon_c} - 1 \right) + \frac{A_c}{A_i} \left( \frac{1}{\varepsilon_i} - 1 \right) \right]^{-1}$$

*where*

$q_r$ = radiant heat load, W
$A_c$ = ceiling area, $m^2$
$A_i$ = ice area, $m^2$
$\varepsilon$ = emissivity
$f_{ci}$ = gray body configuration factor, ceiling to ice surface
$F_{ci}$ = angle factor, ceiling to ice interface (from Figure 1)
$T$ = temperature, K
$\sigma$ = Stefan-Boltzmann constant = $5.67 \times 10^{-8}\ W/(m^2 \cdot K^4)$

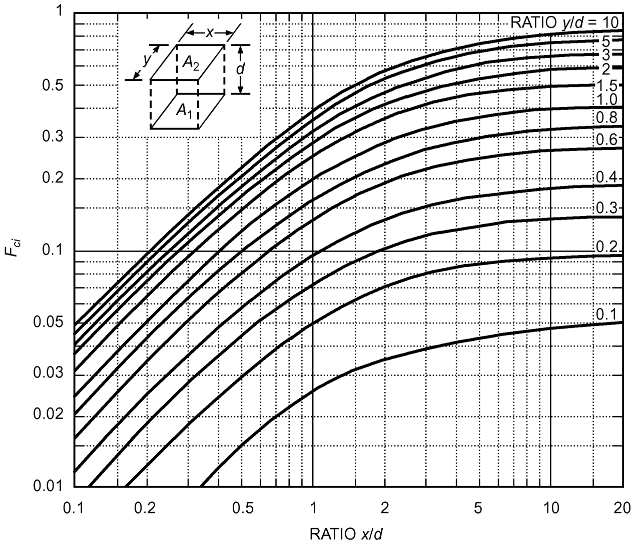


**Fig. 1 Angle Factor for Radiation Between Parallel Rectangles $F_{ci}$**

**Example 2.** An ice rink has the following conditions:

Ice dimension: $26 \times 60$ m = 1560 m$^2$
Ice temperature: –4°C (269 K), $\varepsilon_i = 0.95$
Ceiling radiating area: $28 \times 60$ m = 1680 m$^2$
Ceiling mid-height: 7.6 m
Ceiling temperature: 16°C (289 K), $\varepsilon_c = 0.90$

$$x/d = 28/7.6 = 3.7$$

$$y/d = 60/7.6 = 7.9$$

From Figure 1, $F_{ci} = 0.68$

$$f_{ci} = \left[\frac{1}{0.68} + \left(\frac{1}{0.90} - 1\right) + \frac{1680}{1560}\left(\frac{1}{0.95} - 1\right)\right]^{-1} = 0.610$$

Then

$$\begin{aligned} q_r &= 1680 \times 0.610 \times 5.67 \times 10^{-8}(289^4 - 269^4)/1000 \\ &= 101 \text{ kW} \end{aligned}$$

The ceiling radiant heat load can be reduced by lowering the temperature of the ceiling, keeping warm air away from the ceiling, increasing the roof insulation, and, more significantly, lowering the ceiling material's emissivity to shield the ice from the building structure.

Ceiling and roof materials and exposed structural members may have an emissivity as high as 0.9. Special aluminum paint can lower the emissivity to between 0.5 and 0.2. Polished metal such as polished aluminum or aluminum foil have an emissivity of 0.05.

Because a low-emissivity ceiling is cooled very little by radiant loss, most of the time its temperature remains above the dew point of the rink air. Thus, condensation and dripping is substantially reduced or eliminated.

Low-emissivity fabric or tiled ceilings are frequently incorporated into new and existing rinks to reduce radiation loads, decrease condensation problems, and reduce the overall lighting required.

Radiant heat gain to the ice, especially in outdoor rinks, can be further controlled by painting the ice about 25 mm below the surface with whitewash or slaked lime. Commercial paints, generally water based, with a low solar absorptivity are also available.

## ICE RINK CONDITIONS

Properly designed indoor rinks, as well as properly designed renovated rinks, can be operated year-round without shutdown. However, some indoor rinks operate from 6 to 11 months and shut down for various reasons, including maintenance, rink construction, inability to control indoor conditions, or unprofitable operation during part of the year. Outdoor, uncovered rinks generally operate from early November to mid-March above 40° North latitude. However, if sufficient refrigeration capacity is provided, the ice can be maintained for a longer period.

Indoor rinks operate successfully even in warm tropical climates. Relative humidity, temperature, and ceiling radiant losses must be controlled in these climates to prevent fog, ceiling dripping, and high operating cost.

Steel frame, brick, concrete, and various forms of plastic have been used to enclose ice skating rinks. Rinks have also been built under air-supported structures for seasonal use and are usually over a multipurpose surface.

Arena heating is frequently provided for skater and/or spectator comfort. Where airflow may be directed to the ice surface, space heating should not be combined with a dehumidification system. Space heating and dehumidification have different objectives: the dehumidification system removes moisture from the ice surface, whereas the space heating system provides comfort conditions for spectators. Warm air movement over the ice surface is not desirable; any air movement over the ice surface is detrimental to the control of ice and space temperature. Heat recovery from the refrigeration system may be used for limited heating, supplementing the heating system. Infrared heating has been used successfully for spectator areas. Ice rink temperatures are usually maintained between 5 and 15°C; however, for skater or spectator comfort, higher temperatures are sometimes preferred. Relative humidity in the arena depends on factors such as building construction, indoor temperature, and outdoor wet bulb temperature.

The system should be designed to prevent fogging and surface condensation. A maximum dew-point temperature of 7°C is usually sufficient to eliminate fogging; however, condensation can occur on the ceiling or roof structure because of radiation from the building structure to the ice. Low relative humidity is needed to reduce this condition when a high-emissivity ceiling is exposed to the ice surface. Ceiling emissivity and height are critical factors in controlling roof and ceiling condensation. Low ceilings and dark-colored structures promote condensation because these features favor radiant heat flow toward the ice surface. The result is a low structure temperature that could be near the dew-point temperature of the space. Wire-suspended, low-emissivity ceiling curtains are known to raise the inside surface temperature of the roof structure, thus eliminating the condition where condensation could occur. Low-emissivity ceilings not only reduce heat flow between the roof and the ice surface, but also reflect light. This reduces the lighting requirement and therefore reduces the cooling load imposed on the refrigeration plant. The low-emissivity ceiling must resist damage from hockey pucks and allow free air circulation around its perimeter. Providing too much roof insulation can promote condensation by reducing the inside ceiling temperature.

Ventilation should be the minimum required for the building occupancy so that humidity introduced with outdoor air is kept as low as is feasible, but enough outdoor air must enter to maintain acceptable indoor air quality (see ASHRAE *Standard* 62.1). Makeup air should always be conditioned before being introduced to the arena space. Because of the high enthalpy difference between indoor and outdoor air, exhaust air energy recovery using enthalpy wheels improves efficiency. Mechanical makeup air dehumidification systems may be downsized up to 50% when using enthalpy wheels. It is more energy-efficient to dehumidify makeup air separately from the recirculated air, because makeup air usually has a much higher dew-point temperature. Self-contained, air-cooled, compressor-equipped dehumidifying units, as well as desiccant drier types with gas or electric regeneration, are available to control humidity. The owning and operating costs of various dehumidification and defogging systems should be evaluated.

Carbon monoxide and nitrogen dioxide are pollutant emissions from gasoline- or propane-fueled ice resurfacers. The concentration of these chemicals can reach dangerously high levels if they are not controlled or eliminated. In some areas, regulations require sensors to detect and alarm at unsafe chemical concentrations. Check health regulations for local requirements. Air circulation is conducive to removing carbon monoxide produced by ice-resurfacing equipment. Carbon monoxide is usually in the highest concentration below the top of the boards and near the ice surface. Gas-engine resurfacing machines should be equipped with catalytic exhaust convertors to reduce carbon monoxide emissions. Electric-powered resurfacing machines eliminate the need for additional makeup air otherwise required to dilute and ventilate the combustion products generated by internal combustion engines.

Each rink user group has its own preference for the type of ice used. Hockey players and curlers prefer hard ice; figure skaters prefer softer (i.e., warmer) ice so they can clearly see the tracings of their skates; and recreational skaters prefer even softer ice, which minimizes the buildup of shavings and scrapings.

With approximately 7°C air temperature and one 25 mm ice thickness, ice at –6.5 to –5.5°C is satisfactory for hockey, –4 to –3°C for figure skating, and –3 to –2°C for recreational skating. A 0.5 K higher ice temperature may be feasible when water with a low mineral content is used for resurfacing. To achieve these ice temperatures, the coolant temperature is maintained about 3 to 6 K lower than the ice temperature. The temperature of the coolant must be lowered to maintain the same ice conditions when there are higher wet-bulb temperatures or abnormally high loads, such as when television lighting is used.

## EQUIPMENT SELECTION

### Compressors

Two or more refrigeration compressors should be used in an ice rink system. When two compressors are used, one compressor should be specified with ample capacity to maintain the ice sheet under normal load and operating conditions. When greater capacity is required during initial ice freezing or under high heat loads, the second compressor picks up the load. In multiple-compressor installations, a multistage thermostat microprocessor control, programmable logic controller (PLC), or computerized control system may be used to control the operation of the compressors. The multiple compressors serve as backups; they maintain the ice in the event of compressor failure or a service requirement.

Compressors and evaporators normally operate at a suction pressure corresponding to a mean temperature difference of 4 to 6 K between the coolant and primary refrigerant in systems operating with secondary coolants, or between the ice and the refrigerant in direct-refrigerant rinks.

Most arenas with a single sheet of ice use two or three reciprocating compressors. With trends toward multiple ice sheets served from a central plant, screw compressors are widely used. Development of smaller, more economical screw compressors has led to the use of screw compressors in applications that traditionally used reciprocating compressors.

### Evaporators

Ideally, there should be one chiller (evaporator) for each ice surface. However, economics sometimes dictates one chiller serving multiple ice surfaces.

Chillers for indirect systems normally are shell-and-tube (with and without surface enhancement), immersed-tube, or plate-and-frame. Gravity-flooded or direct-expansion feed is usually used for the primary refrigerant.

Flooded shell-and-tube chillers used for cooling glycol or calcium chloride may be manufactured from carbon steel. Stainless steel is recommended for constructing plate-and-frame chillers used for cooling glycol. Titanium is recommended for plate-and-frame chillers used for cooling calcium chloride. Aluminum is not recommended for chillers cooling calcium chloride with ammonia.

The chiller for direct-cooled systems is composed of piping installed in the floor under the ice surface. Typically, direct halocarbon systems are fed by direct expansion or liquid recirculation. The operating charge should be considered for this type of system. Local codes may impose restrictions on the size and use of direct systems.

Care should be taken in designing common evaporators for multiple-rink facilities; the high load from one rink should not affect ice temperature on the other rinks.

### Condensers and Heat Recovery

Ice arenas and curling rinks typically reject heat to a water source or the atmosphere.

Wells, lakes, or rivers can be good sources of condenser cooling water, if they are available. Capacity is easy to regulate and the low coolant temperature maintains low condensing pressures, which saves energy. Condensers require high-quality water, though, which may need treatment to prevent scale formation, fouling, or corrosion in the condenser tubes. Water and sewage costs usually prohibit the use of water for condensing on a “once-through” basis.

Cooling towers used in conjunction with water-cooled condensers, evaporative condensers, or air-cooled condensers are alternatives to once-through water-cooled condensers. When selecting a cooling tower or evaporative condenser, not only the maximum expected wet-bulb temperature during the skating season should be considered, but also suitable controls to cover the wide range in capacities and protection against freeze-up needed in cold weather. A water treatment specialist should also be consulted.

Air-cooled condensers can be designed to produce reasonable discharge pressures in northern climates, particularly where the rink is used mostly in the spring, fall, and winter months. They can be economically sized and require no water, so the possibility of freezing is eliminated. This type of condenser, however, is not economical for year-round operation, and for seasonal operation it must have wide-range capacity control.

One alternative to rejecting heat to a water source or to the atmosphere is to recover waste heat and put it to use. This process harnesses all or a portion of this wasted heat and uses it to preheat a secondary fluid before the primary refrigerant enters the condenser. Both reciprocating and screw compressors have potential for heat reclaim. Abundant heating energy is available from discharge gas, by either desuperheating or condensing.

In addition to the power saved by heating a secondary fluid with the refrigerant, the load to the condenser is reduced and reduction in condenser fan and pump motor operation results in further electrical savings. A lower operating head pressure reduces compressor motor power requirements and increases the operating life of the refrigeration equipment. Condenser fouling is also reduced because of the lower discharge temperature.

Superheat from discharge gas is reclaimed via a thermal contact surface in which superheated refrigerant transfers its energy to the cooler fluid on the opposing side. When water is used as the fluid to be heated, it is often recirculated through a storage tank and used on demand.

Heat of condensation is typically reclaimed through a designated condenser piped in parallel with the main condenser.

Whether to reclaim superheat or heat of condensation depends on the amount of heat that may be used and the temperature level the designer wishes to attain.

To minimize the possibility of contamination of potable fluids by a rupture in the exchanger, a double wall of heat transfer surface between the fluid and the refrigerant is required. Any leakage of primary refrigerant into the space between the inner and outer walls is vented to the atmosphere. Double wall-vented construction has become the accepted standard for heat-recovery units heating potable fluids and is required by law when used for this purpose.

The exchanger material must be suitable for use with both the refrigerant and the process fluid and must meet code requirements. Standard materials that usually meet these requirements are 304 and 316 stainless steel and titanium. Some applications for using waste heat are space heating, ice resurfacing, underfloor heating, building makeup air, boiler water makeup and domestic hot water use.

Most installations in large plants show a payback period of 18 to 30 months. Ice facilities with an 8 month operating season typically have a 3 to 5 year payback. Paybacks depend on the degree of heat reclaim, hours of operation, and cost of the fuel source, and must be analyzed on a project-by-project basis.

Figure 2 illustrates a desuperheater and a condenser piped for waste heat recovery.

### Ice Temperature Control

Ice temperature may be controlled by (1) sensing the average temperature of the secondary coolant, (2) infrared sensor(s) hung over the ice surface, (3) thermocouples or thermistors embedded underneath or in the ice, or (4) thermocouples or thermistors placed in a well in the concrete floor under the ice surface.

Thermostats that sense return coolant temperature or the differential temperature between the supply and return coolant can be

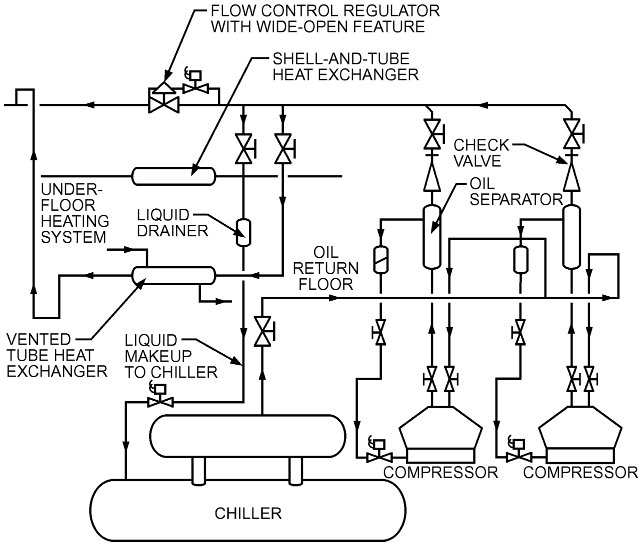


**Fig. 2 Typical Waste Heat Recovery Piping**

used to control the refrigeration system. They may also be used in controlling operation of the coolant pump. To be effective, a differential sensor should sense a small temperature difference. The return coolant temperature can be sensed by multistage sensors that sense a larger temperature difference. Another strategy varies coolant flow by controlling the pump speed on a signal from an ice temperature sensor. Direct-refrigerant systems can be controlled by regulating compressor operation from an ice temperature sensor. This method has been used with a direct refrigerant impulse pumping system. Compressor capacity and pump operation may be controlled from the low-pressure receiver when refrigerant pumps are used to circulate refrigerant.

## Rink Piping and Pipe Supports

High-flow-rate secondary systems use standard mild steel pipe 20, 25, or 32 mm in diameter; thin-walled polyethylene plastic pipe 25 mm in diameter; or UHMW (ultrahigh molecular mass) polyethylene plastic pipe 25 mm in diameter. These are placed at 90 or 100 mm centers on the rink floor. One proprietary low-flow-rate secondary coolant system uses 6 mm tubing made of flexible plastic with tube spacing averaging 20 mm or one dual tube every 40 mm. Direct-refrigerant rinks generally use 16 to 22 mm steel tubing, which is placed on 75 mm centers for outdoor rinks and 100 mm centers for indoor rinks.

The pipe grid must be kept as close to level as possible, regardless of the rink piping system used. When a pipe rink surface is open with sand fill around and over the pipes, the pipe usually rests on pressure-treated sleepers set level with the subbase; however, the sleepers can be omitted in a rink that is to be operated year-round. The piping is then spaced with clips, plastic stripping, or punched metal spacers.

In permanent concrete floors, the pipe or steel tubes are supported on notched iron supports or welded chair supports. The latter must be used in the case of plastic pipe.

## Headers and Expansion Tanks

Secondary coolant rinks using large-diameter pipe generally run the piping lengthwise, with the supply and return headers across one end and the return bends located on the opposite end. Supply and return headers may be positioned in a header trench and the return bends may be positioned in a return bend trench. This allows regular inspection of the clamps and joints. However, to avoid having header and return bend trenches, some facilities have successfully used straight headers running across the rink between the blue line and center ice, buried below the floor piping grid. The cooling grid piping then crosses over the top of the headers to ensure consistent slab temperatures. Curved headers buried at one end of the rink have also been used. Rinks using small-diameter tubing generally run crosswise, with the supply and return headers along one side. Direct-refrigerant rinks generally run lengthwise, with the supply header at one end and the return header at the opposite end in a balanced system. The header must be sized to ensure an even distribution of coolant through every pipe. The systems are generally designed with low coolant velocities, which do not need balancing valves. If at all possible, the return header should be placed at the same elevation as the rink piping, with a minimum of two air vents to eliminate trapping of air.

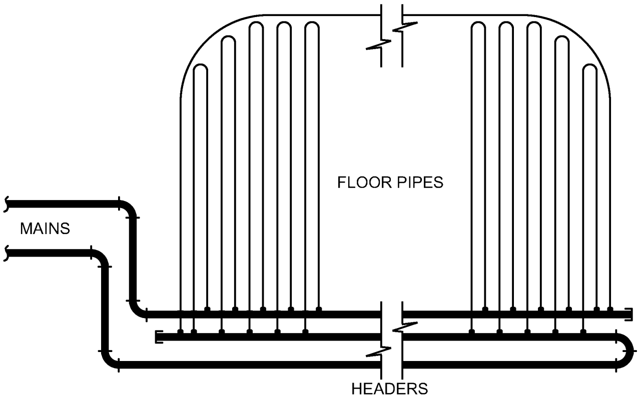


**Fig. 3 Reverse-Return System of Distribution**

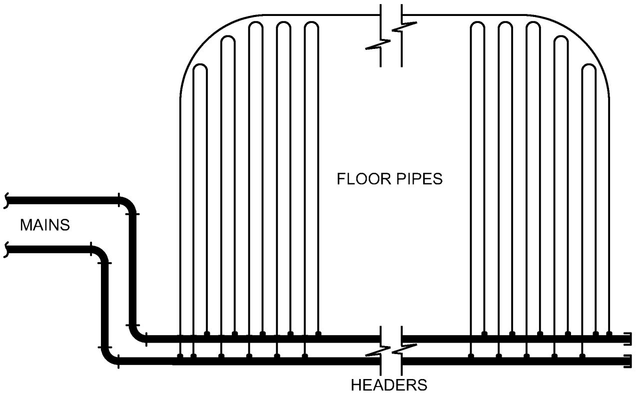


**Fig. 4 Two-Pipe Header and Distribution**

The three-pipe reverse-return header and distribution arrangement (Figure 3) is used occasionally. A properly sized two-pipe header system (Figure 4) is frequently applied and gives nearly uniform circuit flow with no discernible differences in the ice surface temperature or conditions. To allow for thermal contraction and expansion, headers and main piping should be free to move without producing excessive stress.

Polyvinyl chloride (PVC) distribution headers are becoming popular because they have a very low maintenance requirement and accumulate less frost than steel headers. These headers should be used with proper allowances for expansion and contraction. The coefficient of thermal expansion for steel is relatively low and very close to that of concrete; the PVC pipe expansion coefficient is much higher. Schedule 80 wall thickness is used to provide a solid connection to the pipe nipples leading to the floor piping. PVC pipe can become brittle at low temperatures, so the pipe should not be used to support equipment weights, and the nipples should not be placed where they could be knocked or stood on. Pipe clamp connections are not considered permanent joints and should ideally remain accessible for inspection and tightening. However, use of clamped return bends and header connections cast in the concrete floor slab has been successful.

A closed secondary coolant system requires an expansion tank to safely accommodate the expansion and contraction of the coolant resulting from fluid temperature changes. The expansion tank must be installed so that it cannot be isolated from the system.

## Coolant Equipment

The coolant circulating pumps must be sized for the particular type of rink and system involved. Large-diameter pipe rinks require 180 to 270 mL/s per kilowatt of refrigeration to maintain the required 1 to 2 K temperature differential between incoming and outgoing coolant. These operate at approximately 170 kPa (gage). Low-flow-rate dual tubing or mat rinks use about 40 mL/s per kilowatt. Differentials of 2 to 3 K are normal, but 6 to 7 K differentials can be experienced in high-load conditions. Temperature averaging is achieved in mat rinks by closely spacing adjoining counterflow tubes operating at approximately 280 to 350 kPa pressure.

## Ice Removal

For auditoriums and sports arenas, the rink surface should have provision for deicing in less than 4 h. In deicing, the floor is heated to about 10°C so that the bond between the floor and ice is broken; the ice is then removed with power tractors.

A standard heat exchanger can be used, with piping arranged so that all the coolant can be pumped through the heater, with coolant flowing in the tubes and steam or hot water in the shell. Approximately 630 to 1100 W per square metre of rink surface is needed to heat the coolant in the system enough to warm the floor and break the ice bond.

## Storage Accumulators

To reduce large cooling demands associated with frequently producing ice in short time periods, some older, large-event facilities incorporate storage accumulators that act as a source of low-temperature, large-volume secondary coolant.

When refrigeration on the ice surface is not required, a large volume of coolant in the accumulator may be cooled to approximately –32°C and be ready to be pumped into the rink piping when needed. The cold-coolant accumulator should store enough to cool the entire system coolant volume from 18 to –18°C. This cold-coolant tank usually holds more than three times the volume of the cooling system's charge.

Use of accumulators has been declining. Instead, ice-making equipment is sized to handle the demand loads.

## Energy Consumption

Energy consumption for an ice rink facility is unique. Maintenance of internal conditions is affected by the cold ice sheet. Lighting, ventilation, heating, and dehumidification systems depend on the facility's use and occupancy. Energy consumed by refrigeration equipment is affected by construction, operation, water quality, and various use factors. To reduce heat load and energy consumption,

- Install low-emissivity ceilings to reduce refrigeration and lighting loads and to allow compressors to operate at a higher saturated suction temperature.
- Reclaim refrigerant superheat to preheat shower water, heat ice resurfacing water, melt ice shavings, heat the subfloor, etc.
- Select a pumping system and controls to reduce or stop coolant flow during part load conditions.
- Install an energy management system.
- Insulate the subfloor and header piping.
- Control temperature and humidity in the arena to reduce sensible and latent heat gain to the ice.
- Install high-efficiency luminaires.
- Use demineralized or very-low-mineral-content water for ice and resurfacing.
- Do not operate the underfloor heating system more than necessary to prevent frost formation.
- Maintain the secondary coolant temperature no lower than necessary to maintain the desired ice quality.
- Maintain high suction pressure and low discharge pressure.

## Dehumidifiers

To minimize the potential for rink fog or ceiling dripping, a properly designed dehumidification system should be installed. Operating season, arena location, and utility costs should all be considered when selecting a system.

**Desiccant systems** use adsorption or absorption to remove moisture from rink air. These systems can provide arena ventilation while delivering dew-point temperatures below freezing. Desiccant systems come in many forms, from stand-alone dehumidifiers to total environmental control systems incorporating air conditioning, heating, and energy recovery. Single desiccant units, centrally located, have been used successfully to dehumidify multiple rinks.

**Self-contained mechanical refrigeration units** rely on the moisture removal capabilities of an evaporator to reduce the moisture content of air inside a rink. Either hot-gas or electric defrost is provided to remove ice that forms on the evaporator surface. These units are typically manufactured with hermetic or semihermetic compressors in the range of 3.5 to 5.5 kW. Multiple units are selected to suit the size of the facility and moisture removal needs. Typically, a standard hockey rink requires two self-contained units.

Some older facilities use secondary coolant from the arena to dehumidify the air. The temperature of the secondary coolant is too low for dehumidification purposes and should be mixed by recirculation to suit the application. This method of dehumidification is not energy efficient.

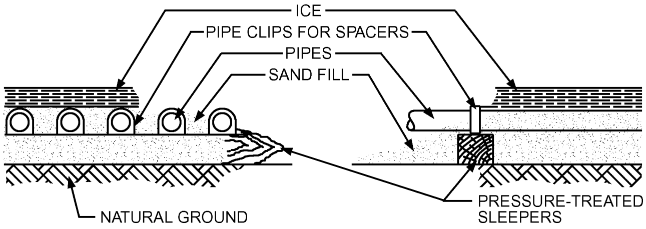
# RINK FLOOR DESIGN

Generally, five types of rink surface floors are used (Figure 5):

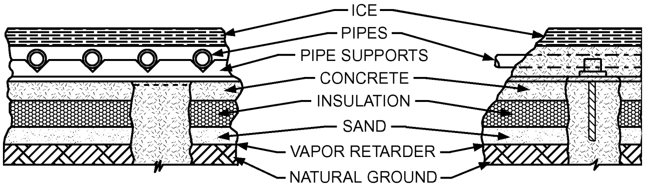
- Open or sand fill, for plastic or metal piping or tubing
- Permanent, general-purpose, with piping or tubing embedded in concrete on grade
- All-purpose, with piping or tubing embedded in concrete with floor slab insulated on grade
- All-purpose floors, supported on piers or walls
- All-purpose floor with reheat; for use when the water table and moisture are severe problems or when the rink is to operate for more than 6 months

The open sand fill floor is the least expensive type of rink floor. The cooling pipes rest on wood sleepers over a bed of crushed stone or other fill. Clean, washed sand is filled in around the pipes. Curling rink floors, as well as hockey and skating rinks, where first cost is a factor and the building is not intended for other uses, are usually constructed in this manner. Clay or cinders should never be used in the bed or for fill around the pipes. Tubing rinks do not need supports or sleepers; the tubes are laid on accurately leveled sand.

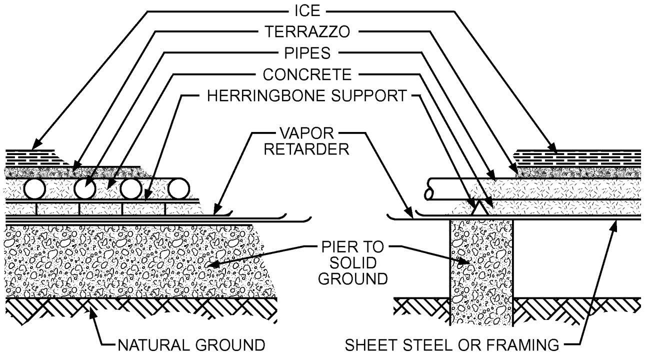
Rinks using 25 mm plastic pipe or the mat type are usually covered with sand to a depth of 13 to 25 mm to provide additional strength to the ice surface and to reduce cracking. Many portable outdoor rinks have used this arrangement for laying plastic pipes or tubing mats on top of existing sodded areas, black top, or concrete. More permanent installations of outdoor semiportable rinks have used this same arrangement where recreational space is at a premium. Such an installation consists of steel pipes supported on notched steel sleepers, which in turn are supported on concrete piers down to solid ground.



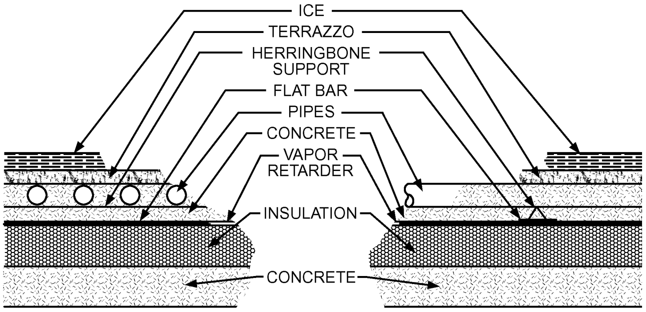
OPEN- OR SAND-FILL FLOOR WITH NO INSULATION



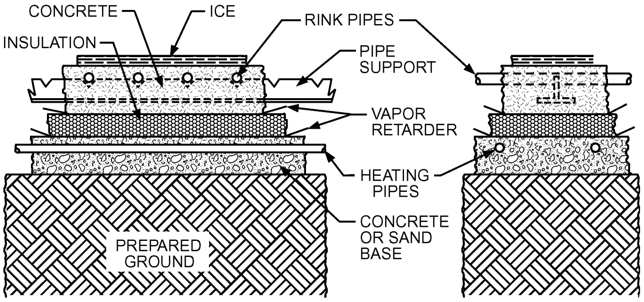
PERMANENT OR GENERAL-PURPOSE FLOOR



PERMANENT OR ALL-PURPOSE FLOOR



ALL-PURPOSE FLOOR



ALL-PURPOSE FLOOR WITH REHEAT

**Fig. 5 Ice Rink Floors**

To obtain a better return on investment, most indoor rinks that operate with an ice surface for only a portion of the year have a permanent general-purpose concrete floor with subfloor insulation and heat pipes so that the floor may be used for other purposes when the skating season is over. The floor should withstand the average street load and is usually designed with 25 or 30 mm steel or plastic pipe embedded in a steel-reinforced concrete slab 100 to 150 mm thick, depending on the anticipated loading and coolant pipe diameter.

In sports arenas, where the ice is removed and the floor made ready for other sports and entertainment, the ice floor must be constructed to withstand the frequent change from hot to cold. The refrigerating machinery must be of sufficient capacity to freeze a sheet of ice 16 mm thick in 12 h. This type of floor is always insulated.

Subfloor insulation must be installed when quick changeovers are desired, when the subsoil has a high moisture content, when the floor is elevated, or when the rink is in continuous use for more than 9 months. Subfloor insulation reduces refrigeration load on ice-making equipment and slows down, but does not eliminate, cooling of the subsoil on surfaces installed on grade.

## Drainage

The suitability of an ice rink's subsoil greatly influences the rink's success. Complete ice surfaces have had to be rebuilt because of poor drainage and the ultimate heaving of the ice surface. Thus, skating rinks should not be built on swampy or low-lying land unless adequate drainage is provided.

Moist subsoil freezes in the ground to a depth of 1200 mm or more. The frozen water will heave the ice surface when freezing occurs 150 mm deep or more. Heaving creates an uneven skating surface; moves and raises walls, piers, and header trenches; cracks walls and piping; and eventually necessitates drainage and rebuilding of the rink floor.

Not only should there be a complete drainage system around the footings of the rink to prevent seepage, but there should also be one under the rink surface itself. This is particularly important when a sand fill floor is used; a good system ensures that ice melted after the skating season completely drains away and the sand dries out as quickly as possible.

## Subfloor Heating for Freeze Protection

Subfloor heating, by electrical heating cables or a pipe or tubing recirculating system using a warm antifreeze solution, is found in most new rinks to prevent below-floor permafrost development and heaving. Pipes or tubing are on 300 to 600 mm centers located under 50 to 100 mm of insulation. They are generally installed in sand rinks, which are used year-round, although they may be poured into a concrete base slab with insulation between the base slab and the rink slab (see Figure 5).

Alternatively, heating pipes may be laid directly in the subfoundation below the rink pipe or insulation. However, an uninsulated installation requires a greater depth between heating and ice-making pipes to prevent an increased load.

Neither water nor warm air should be used for subfloor heating. Water, if inadvertently allowed to freeze, cannot be readily melted out. In time, warm air ducts become filled with frost and ice because of high rink humidity and air duct leakage.

Usually, the same fluid used for the coolant in the ice-making system is used for subfloor heating; it can be heated to the necessary temperature (4.4 to 5.6°C) in a heat exchanger warmed by compressor waste heat. Subfloor insulation should be of a rigid moisture-proof board, such as high-density polystyrene foam, and be completely enveloped in a polyethylene vapor retarder.

## Preparation of Rink Floor

When building on natural ground, regardless of whether a sand fill or a permanent general-purpose floor is intended, proper preparation of the bed is important unless the rink is built on elevated sand and gravel subsoil. If the rink is to be built on clay, part clay, or rock subsoil, water should be prevented from collecting in low areas. Either the clay or rock should be excavated or the rink level should be built up with crushed stone and gravel to a height of about 1200 mm, after which it should be well rolled. Water should not be used for settling the fill.

For sand-fill rinks, quickly draining melted ice at the end of the skating season ensures rapid drying of the sand and rink piping and results in a longer life for the steel piping. Cinders should never be used as fill in open sand-fill rinks because of the possibility of sulfur in the cinders, which, when damp, accelerates corrosion of steel piping.

Ensure a level surface over the entire rink, with no more than ±3 mm in any 1 $m^2$ area and ±6 mm overall.

## Permanent General-Purpose Rink Floor

When constructing a permanent general-purpose floor, the same subsoil precaution must be taken as for a sand-fill rink. The concrete floor should withstand, at a minimum, the average road pavement load.

When local conditions make it advisable, the rink floor should be insulated. Insulation may be laid on a level concrete or sand base.

The concrete mixture should have a 28 day strength of 140 to 240 kPa and be put in place properly (a concrete engineer is recommended to specify concrete, its placement, and curing). Suitable cross-reinforcing and pipe supports are necessary.

Concrete floors with mat tubing are poured in two courses. A first course is poured and leveled; the mats are then rolled out and positioned. A 150 m by 150 mm wire mesh is laid on top of the mats; then a second course, with grouting between it and the first, is poured on top of the first course, mats, and wire. Water pressure should be kept in the tubing to spot any leaks or cuts that may develop. Once started, the pouring of each course of the concrete floor should be continuous, with interruptions not to exceed 15 min.

General-purpose rink floors should not be defrosted too frequently. When a rink constructed with a general-purpose floor is to be used during the ice season for purposes that require an ice-free floor, it is preferable to place an insulated portable-section wood floor over the ice for each occasion.

## All-Purpose Floors

If a rink floor as used in sports arenas is to withstand both the expansion and contraction of frequent frosting and defrosting and thermal shock because of the circulation of very-low-temperature coolant, then extra precautions must be taken in its construction, such as provisions for the free movement of the freezing slab with respect to the subfloor.

## Header Trench

A well-constructed header trench of sufficient size to house the headers and connections and the subfloor heating system, if applicable, is essential unless the steel distribution headers are cast into the concrete slab as part of the rink. Provisions for movement of pipes caused by thermal expansion and contraction should be incorporated into the design. This trench should be equipped with removable covers and be well drained to facilitate drying out. The headers and piping in the trench are not usually insulated, which allows for periodic inspection and painting of the piping. Provision must be made for purging air from the rink piping and header system.

## Snow Melt Pit

When ice is resurfaced mechanically, a thin layer of ice is removed (as snow) and replaced by a thin layer of clean, warm water. The snow may be placed outdoors and allowed to melt, but in many jurisdictions, this is not allowed, and it must be disposed of by other means. A common method of disposal is to place the snow in a snow melting pit.

The snow melting pit should be provided in the ice-resurfacer holding area. For a single rink, the capacity of the pit should be sufficient to hold and melt double the quantity of snow removed in one resurfacing (approximately 1450 kg of snow or ice). In addition, space must be allowed for water spraying, water reservoir, and free-board. About 450 to 725 kg of snow can be generated every 45 min for each active rink in a facility.

Heat to melt this snow can be obtained from a number of sources. By maintaining sufficient standing water in the pit, the stored heat can be used to melt the snow as it is dumped. The heat retained in the standing water should be sufficient to melt the entire load of snow as it is dumped. The temperature of water in the pit can be then restored over the next 45 min by several heating sources:

- Cold domestic water supply
- Hot domestic water supply
- Waste heat from the refrigeration plant on a recirculated system
- Waste heat from the jacket-cooling water from ammonia compressors

To minimize water consumption, a supplementary heat source is recommended, such as the waste heat from the refrigeration plant. Approximately 88 000 W of waste heat at 21 to 27°C is recommended for one rink. The standing water in the snow melt pit should not be circulated directly through conventional heat exchangers.

One successful layout of a snow melt pit is shown in Figure 6. Typical pit dimensions for a single rink are 2.4 by 3 by 1.8 m. A large standpipe drain is required to handle the overflow of water during the snow dump. This drain should be equipped with a removable screen (minimum 300 mm diameter) to handle the large volume of trash scraped off the ice with the snow. The standpipe drain also allows for a standing water level to be maintained. For cleaning purposes, the pit can be pumped out with a portable sump pump when required.

Spray headers are also recommended around the top of the pit 0.6 m above the water level to assist in snow melting if the water temperature is not high enough. Spray nozzles on 0.6 m centers with a cone spray pattern are recommended. The spray header should be located so snow being dumped into the pit does not hit the header. Spray headers can be supplied with warm or cold domestic water. The snow melt pit should have a closable lid to prevent moist air from infiltrating the refrigerated rink space.

The snow melt pit is not intended for disposal of ice paint, which clogs the drain and is not permitted in most sewer systems. The layer of painted ice is not affected when the ice resurfacer is used to maintain the ice surface. When ice is being removed at the end of the skating season, the entire ice surface is scraped up and should be disposed of in a temporary dump that allows the ice paint to be separated. The temporary dump can be constructed in a parking lot using a wood frame and plastic ground sheet. When the ice has melted, the ice paint can be rolled up in the ground sheet and disposed of in an environmentally friendly manner.

# BUILDING, MAINTAINING, AND PLANING ICE SURFACES

Regardless of the type of rink floor used, when the plant is first placed in operation, the equipment should be operated long enough for a sharp frost to appear on the surface. Then the entire surface should be uniformly covered with a fine spray. This process should be repeated until a 13 mm thickness of ice is built, or until the surface is level. After applying a layer of water-based white paint, another 10 mm thick layer of ice is built before painting the red and blue lines. Red and blue lines are available in plasticized paper; however, they need to be covered with a minimum of 13 mm of ice to protect against damage. It is essential that sand floors be thor-

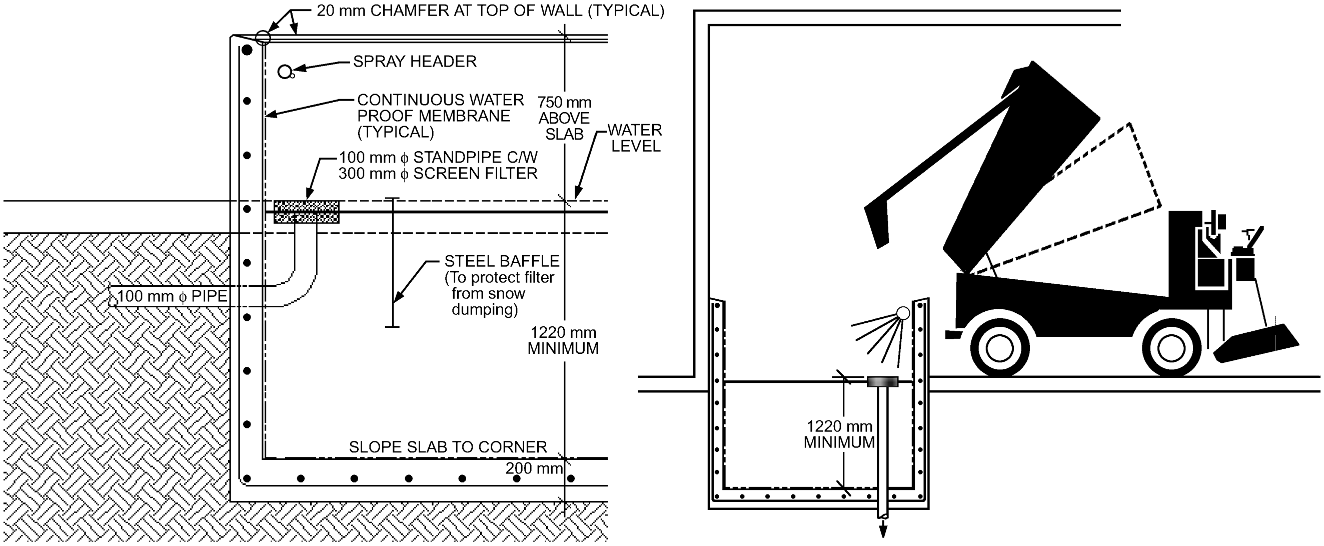


**Fig. 6 Snow Melt Pit**

oughly wet before freezing because dry sand has poor conductivity. The surface should not be frozen any colder than required after this buildup, to allow the ice to temper before it is used for skating, and also to deter cracking.

To maintain an ice surface, it is customary to scrape off the snow after each skating session or hockey period. In all but the smallest rinks, this is done by a motorized resurfacer. On small rinks, scraping is done manually with a wide hardened-steel scraper blade. The most satisfactory method of resurfacing the ice between sessions is to wheel a sprinkler tank filled with hot water over the ice. The sprinkler has an adjustable valve to control the quantity of water, which is sprayed into a terry cloth bag that wipes the fine snow off the ice surface and fills the crevices cut by the skaters. In this manner, the least amount of water is added, reducing ice build-up and refrigeration load.

By far the most common method is the use of automatic resurfacing machines. Mounted on four-wheel drive chassis, the machines plane the ice, pick up the snow, and lay down a new ice surface using hot or cold water. Hot water generally gives harder ice, because air bubbles are removed, but energy costs have led many rinks to alternate hot- and cold-water resurfacings. Rink corners should be at least a 6.1 m (preferably 8.5 m) radius for effective use of this equipment. Smaller equipment is available for studio and small rinks.

Because of inattentive ice making, improper sprinkling equipment, or deep cutting of the ice during public skating, the ice may become uneven and excessively thick. There may be a fairly slight variation in ice thickness across the rink, but more serious is the resulting variation in ice condition. In any case, low spots on the ice must be built up, increasing the thickness and refrigeration requirements.

For example, under assumed conditions, where –8°C coolant would be cold enough to hold a 38 mm thickness of ice, calculations show that –21°C coolant would be required if the ice were allowed to build up to 150 mm, with a corresponding decrease in effective refrigeration capacity and an increase in operating costs. In other words, every additional 25 mm of ice thickness required from the refrigeration system increases costs 8 to 15%, depending on system heat load (DOE 1980).

Because ice 13 to 25 mm thick is satisfactory for skating and is the most economical to freeze and hold, the ice should be periodically planed to maintain this desired thickness.

## Pebbling

Pebbling is a term used to describe the surface finish applied to curling ice. The pebbles, actually water droplets frozen to the ice surface, reduce friction between the bottom of the curling rock and the ice. This makes the rock glide more easily and promotes the “curl” of the rock when a turn is applied to the handle of the rock on release.

The temperature of water used for pebbling is critical and varies by facility, depending on ice surface temperature, water quality, humidity, and application techniques. If the pebbling water temperature is too warm, the pebbles will be too flat. If the pebbling water temperature is too cold, the pebbles can break off when the rock passes over. Pebbles are applied manually from a water can with a hose connected to a perforated sprinkler head. The water can is carried by a shoulder strap and the sprinkler head is held in one hand. The person applying the pebbles usually walks backward down the curling sheet, sprinkling the water in a rhythmic side-to-side motion.

## Water Quality

Water quality affects energy consumption and ice quality. Water contaminants, such as minerals, organic matter, and dissolved air, can affect both the freezing temperature and the ice thickness necessary to provide satisfactory ice conditions. Proprietary treatment systems for arena flood water are available. When these treatments are properly applied, they reduce or eliminate the effects of contaminants and improve ice conditions.

# IMITATION ICE-SKATING SURFACES

A number of different imitation ice-skating surfaces have been marketed; these use semiporous plastic panels dressed with a synthetic lubricant. The coefficient of friction of ice is approximately 0.03 at –3°C and is further reduced by the film of water produced by pressure under the skate. In considering the use of imitation surfaces, the actual friction coefficients of these surfaces, both when freshly lubricated and after a period of use, should be investigated.

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