THE SUNDSVALL SNOW STORAGE–SIX YEARS OF OPERATION

Chapter · January 2007

DOI: 10.1007/978-1-4020-5290-3_21

2 authors:

Bo Nordell
Luleå University of Technology

Kjell Skogsberg
Luleå University of Technology

21. THE SUNDSVALL SNOW STORAGE—SIX YEARS OF OPERATION

Bo Nordell and Kjell Skogsberg
Division of Architecture and Infrastructure, Luleå University of Technology, SE-97187 Luleå, Sweden

Abstract. Ice storage for cooling is an ancient technology which was common until the beginning of the 20th century, when chillers were introduced. During the past few decades new techniques using both snow and ice for comfort cooling and food storage have been developed. Cold is extracted from snow or ice by re-circulation of water or air between the cooling load and the snow/ice. The snow cooling plant in Sundsvall, Sweden, is used for cooling of the regional hospital. The stored natural and artificial snow is used for comfort cooling from May to August. It was taken into operation in June 2000 and is the first of its kind. Here the plant is described and the experience of its first six years of operation is presented.

Keywords: snow, cooling, energy storage, renewable energy, pilot plant, operation

21.1. Seasonal Snow and Ice Storages

In seasonal snow/ice storages frozen water is stored from winter to summer, when the cold is utilized. The snow/ice can be stored indoor, on ground, in open ponds/pits and under ground, Figure 200.

If snow/ice is stored indoor it is done in a more or less insulated building. In a cavern no insulation except the ground is needed. When the snow/ice is stored on ground or in ponds it is necessary with thermal insulation, henceforth denoted insulation. Both natural and artificial snow and ice may be used and there is no size limitation for snow cooling systems. This snow cooling plant in Sundsvall is an open pond with larger pieces of wood chips as thermal insulation.

The basic idea of such systems is that snow/ice is stored in a more or less water tight pond where a cold carrier is cooled by the snow, to utilize the large latent heat of fusion. For comfort cooling about 90% of the extracted energy is in the phase change, i.e., the melting. The cold carrier is either circulated between the load and the snow or rejected after it has been used for cooling.

H. Ö. Paksoy (ed.), Thermal Energy Storage for Sustainable Energy Consumption, 349–366.

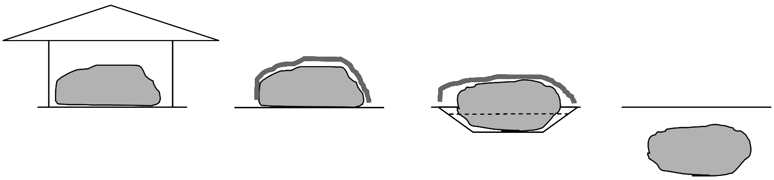

Figure 200. Outline of different snow storage methods; from left to right; indoors, on ground, in open ponds/pits, and under ground

In all implemented systems the cold carrier is in direct contact with the snow, but it is also possible to have closed systems where the cold carrier flows in pipes. Air, melt water, sea water, ground water or some other fluid might be used as cold carrier.

Snow is normally defined as precipitation formed of ice crystals and ice as solid water with hexagonal structure and density about 920 kg m^{-3}. In snow storage the main issue is to have enough amounts of frozen water at low cost why the only relevant distinction is the density. If natural snow or ice is too expensive or not available in enough quantity, it is possible to produce frozen water. Artificial snow and ice made with different types of water sprayers, including snow blowers (snow guns). The production rate depends on equipment, relative air humidity, and temperatures of the air and water.

Thermal insulation on snow can be loose fill, sheets and roof like structures. Loose fill insulation is different types of wood chips, rice shell, debris (mineral particles), etc. Sheets can be both plastic and filled tarpaulins, e.g. with straw. Superstructures are more or less rigid constructions that are partly or totally removed/opened during the winter.

There is always some heat leakage when storing snow in a surrounding above 0 °C. In pond storage the resulting natural melting is divided in ground melt, rain melt and surface melt. The surface melt occurs by heat transfer from radiation and ambient air. Ground melt is caused by heat transfer through the sides and bottom of the storage, Figure 201. The remaining snow is the volume that is used for cooling.

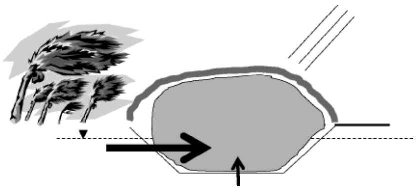

Figure 201. Natural snow melt in open pond snow storage

21.1.1. TECHNIQUES AND EXAMPLES

There are a number of suggested and implemented techniques of snow and ice storage for cooling applications. In Japan about 100 projects have been realized during the last 30 years, and in China there is about 50–100 snow and ice storage systems (Kobiyama, 2000). Also Canada, USA and Sweden have made efforts in the field. Below both realised and suggested techniques are presented.

21.1.1.1. *Himuros and Yukimoros*

A Himuro is a house, or a room, where vegetables are stored together with ice to prevent decay of the food. In a Yukimuro snow is used instead of ice. The house/room can be situated in or on the ground. This is the traditional way to use snow/ice for cold storage. The food is stored in shelves and the snow/ice is stored in carriages or in one section of the room. The food/snow ratio varies from 1/1 to 4/1 depending on climate and thermal insulation of the building. Cold distribution occurs by natural convection and can be roughly controlled by shutters, curtains, etc (Okajima et al., 1997). The temperature in a Himuro/Yukimuro is a few degrees above 0 °C and the relative humidity is about 90–95%. One important drawback is that humidity and temperature cannot be controlled with any precision (Kobiyama, 1997).

21.1.1.2. *Indoor Snow Storages*

In the Japanese All-Air-Systems air is used as the cold carrier. Warm air is blown through water made holes in the snow. The snow gets covered with a thin water layer where particles and gases are absorbed, i.e., the air is cleaned during the cooling. Hole spacing is about 1 m and the snow lies on a steel grid (Iijima et al., 1999). There are All-Air-Systems where both temperature and humidity is controlled (Kobiyama et al., 1997).

21.1.1.3. *Ice Box/Fabrikaglace*

The Icebox, or Fabrikaglace, is a Canadian invention. It consists of an uninsulated box inside an insulated shelter. Thin sprayed water layers, a few mm, are frozen in the inner box by cold air blown over the water. It is possible to form ice blocks more than 20 m thick during one winter and there is no size constraint. To extract cold the melt water is pumped to a heat exchanger and then re-circulated over the ice. Thermal expansion and ice creeping was handled by flexible walls. The tested Ice boxes varied from a few up to 250 MWh with cooling powers 8–1,600 kW but the high construction costs required large plants or high cooling powers (Buies, 1985; Morofsky, 1984). The coefficient of performance (COP) was about 90–100 (Abdelnour et al., 1994; Morofsky, 1982).

21.1.1.4. *Underground Storages*

Snow storage in underground caverns has so far not been implemented. Johansson (1999) investigated the prerequisites of snow cooling during the summer, with focus on under-ground storage. Storages of 25,000–150,000 m^3 were studied, assuming snow density 650 kg m^{-3}. Simulations gave that natural melting was about 3–6% the first years and 1–3% the tenth year. In many of the studied applications the pay-back time was less than one year.

In 1995 potatoes and rice were stored in an abandoned road tunnel in Japan. At the end of the winter the tunnel was filled with snow that was covered with aluminum coated tarpaulins. The products were stored both beside the snow piles and under the tarpaulins. Rice from the same harvest was stored in a grain magazine and at a research centre for comparison. The rice in the tunnel had best quality after two month. The potatoes under the tarpaulins kept its quality longest and it was found that the storage method was feasible over the whole year (Suzuki et al., 1997).

21.1.1.5. *Open Storages*

A number of different open pond snow and ice storage techniques have been suggested. In Ottawa a storage for 90,000 m^3 of snow in an abandoned rock quarry ($120 \times 80 \times 9.5$ m^3, $L \times W \times H$), was studied. The mean cooling load was 7,000 kW. A light colored PE plastic tarpaulin was suggested as insulation, with melt water re-circulation for cold extraction. The estimated payback time was 10 years (Morofsky, 1981).

Näslund (2000) investigated a district cooling system in Sundsvall, mid Sweden, with sea water and stored snow. The cooling load was 7,900 kW and 7,450–8,560 MWh. Natural snow from streets and squares were complemented with artificial snow made by snow guns or water spraying. The estimated snow proportion was 43.6–66.8% and 122,500 m^3 of snow was needed. Two layers of 0.01 m plastic sheets with thermal conductivity 0.04 W m^{-1} K^{-1} was recommended as insulation. The plant has not yet been realized (2005).

Näslund (2001) investigated a combined system with river water as base load and snow cooling as back up, for an industrial application. The cooling need was 1,500 kW at 5 °C and 1,500 kW at 15 °C, continuously. The needed snow amount was 78,800 ton, stored in a $120 \times 100 \times 3\,m^3 (L \times W \times H)$ pond with water tight asphalt bottom. The estimated investment cost was about 950,000 Ä.

André et al. (2001) investigated a snow cooling plant in northern Sweden for operation all year round with winter base load 2 MW and summer peak load 6 MW. The idea was to use the local snow deposit and combine with artificial snow. The system consisted of two main ponds and one smaller pond.

A Japanese study investigated the possibility to use snow for atomic power plant cooling, to increase electricity production. With 38,400,000 tons of snow the sea water temperature should be lowered 9 °C but only 1,800 MWh of extra electricity would be produced every year, because of few operation hours per day. It was suggested that a layer of 0.15–0.3 m rice husk should be used as insulation (Kamimura and Toita, 2004).

In a similar Swedish project with snow cooling of a waste gas power plant 2,080,000 ton of snow would increase the annual electricity production 30.7 GWh. The snow should be stored in a $400 \times 400 \times 20\,\mathrm{m}^3 (L \times W \times H)$ pond with water tight sides but open bottom. Here 0.2 m of wood chips was suggested as insulation (Falk et al., 2001).

21.1.1.6. *Water Purification*

Another application is to combine ice production and water purification since impurities are pressed out as water freezes. It is possible to freeze sea water or polluted ground water and use the cleaned melt water for both cooling and drinking. In Greenport, New York, sea water was cleaned from 3.0% to 0.00005% by freezing (Taylor, 1985).

21.2. The Sundsvall Hospital Snow Cooling Plant

The snow cooling plant at the Sundsvall Regional Hospital, mid Sweden, is an open pond solution designed for 60,000 m^3 of snow. The plant is owned and operated by The County Council of Västernorrland (CCV). The cooling operation started in June 2000. This is the first open storage with melt water re-circulation and a wood chip layer as thermal insulation. Monthly mean air temperatures during the cooling season (May to August) is 8–15 °C and daytime temperature often reaches above 25 °C. The hospital floor area is 190,000 m^2 and the plant is managed by the owner of the hospital.

Pre-studies and a small field experiment were made in 1998. In the theoretical study a cooling need of 1,000 MWh was assumed, and natural melting of a 15,000 and a 30,000 m^3 snow pile without cover and with 0.1 and 0.2 m of saw dust as insulation was simulated (Nordell and Sundin, 1998).

The simulations showed that 15,000 m^3 of snow was not enough in any case. An un-insulated 30,000 m^3 snow pile would be gone by mid-June and consequently the storage had to be thermally insulated. With 0.1 and 0.2 m of saw dust as thermal insulation the remaining snow volumes were 12,169 and 19,040 m^3, Figure 202.

21.2.1. CONSTRUCTION

The snow storage was built in 1998/1999. It is a shallow watertight pond (130·64 m) with slightly sloping (about 1%) asphalt surface, Figure 203. The

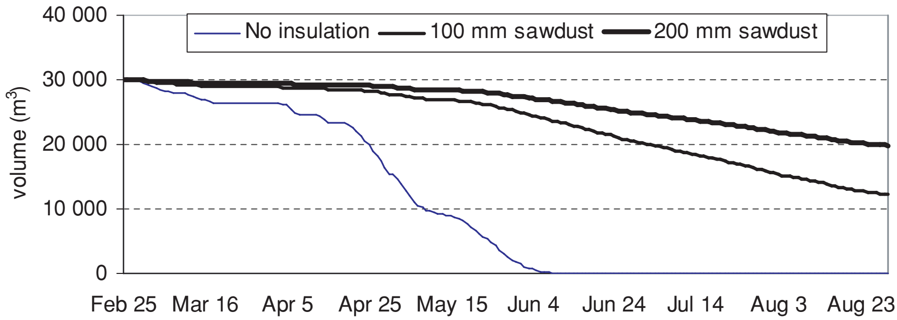

Figure 202. Natural melting of 30,000 m^3 of snow with 0.1 and 0.2 m of sawdust and without thermal insulation (from Nordell and Sundin, 1998)

0.1 m asphalt layer is overlaying 0.5 m gravel, 0.1 m insulation, and 0.8 m of sand.

Cold is extracted by pumping melt water through heat exchangers connected to the cooling system inside the hospital. The heated melt water is then re-circulated to the snow where it is cooled and new snow melts. The original re-circulation inlets are 36 valves located at the sides of the storage. The outlet is two openings in the pump house that is located in the lower corner of the pond. The water is cleaned by different filters, and pumped by two pumps (0.035 and 0.050 m^3 s^{-1}) to the heat exchangers (1,000 + 2,000 kW), Figure 204. The comfort cooling system of the hospital also includes one 800 kW chiller. The system primarily runs on snow cooling and the chiller supports when necessary.

21.2.2. FIVE YEARS OF OPERATION

During five years of operation at a full scale demonstration plant many experiences are made. Here the main results and findings are presented.

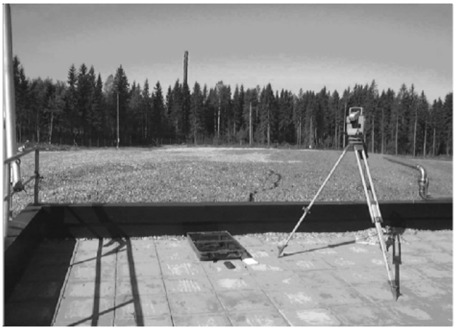

Figure 203. Right: Part of the snow pond with pump house and half of the hospital. Left: Snow covered with wood chips in beginning of the cooling season. Picture taken from the pump house

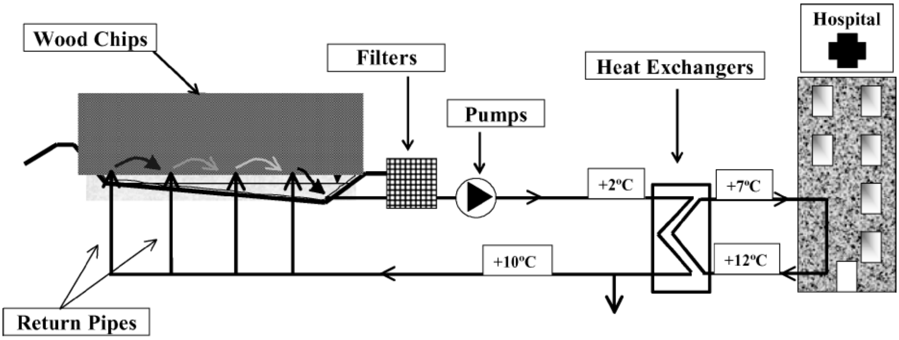

Figure 204. Outline of the Sundsvall snow cooling plant

1. *Snow*: Both natural snow from streets and squares and artificial snow, made with snow guns, was used. The artificial proportion was 38–59%. The stored snow volumes, measured with a geodetic total station, were 18,800–40,700 m^3. The snow density varied from 578–735 kg m^{-3}, with mean density about 650 kg m^{-3}. The first year snow and wood chips were spread with a tractor and an excavator. The other years a snow groomer was used which made spreading much more efficient.

   Different snow and ice making systems have been tested. The first years both fan type snow guns and one LowEnergyTower were used. The fan-type machines required a lot of maintenance and surveillance the first years and a lot of the snow from the LowEnergyTower landed outside the storage. The last year's two fan type snow guns have been used, mounted on 5 m high towers and now only operated in the wind direction. This worked well.
2. *Cooling*: The cooling needed varied largely. More than 75% of the total cooling load was delivered by the snow system and unnoticed 2000, when snow cooling started late, the snow cooling portion have increased. The maximum cooling load increased because the cooling system inside the hospital was increased, as planned, Table 1. It will continue to expand to about 3,000 kW and 3,000 MWh in about 2010 (Larsson, 2005).

   The snow cooling system mostly met the total cooling demand until the end of June/beginning of July when also the chiller run, because the re-circulation system was too small. Snow cooling stopped between middle of August and beginning of September all years. With increased operation experiences the snow cooling has met the total cooling load during a larger part of the cooling season, Figures 205 and 206.

   The total Coefficient of Performance (COP_{total}) was the ratio between the delivered cooling energy and total energy needed to produce the cold. This included total operation energy and yearly material depreciation, defined as the total energy required manufacturing and constructing the system

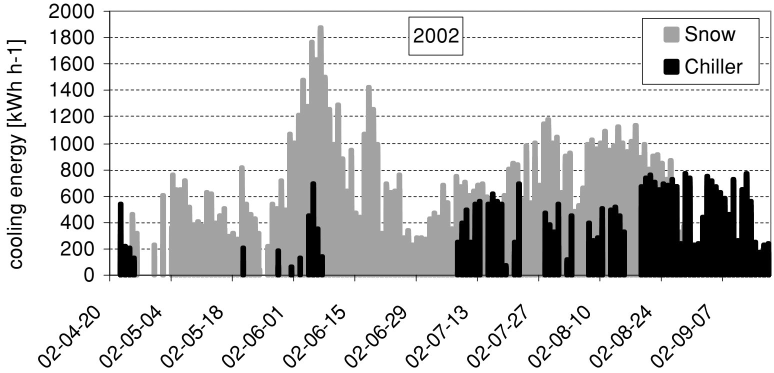

Figure 205. Hourly cooling amounts from snow cooling system and chiller in 2002

divided by estimated technical lifetime (Hagerman, 2000; Wichmann, 2003). The COP_{total} was based on the assumption of the same total cooling amount, from extrapolation.

The amount of artificial snow was calculated as the ratio of water for snow making over estimated snow amount, i.e., snow making loss was not included.

3. *Thermal insulation*: The snow is thermally insulated with a 0.2 m layer of larger pieces of wood chips, 20–150 mm. The wood chips decayed fast and it was necessary to add new material every year. After three years all wood chips were rejected, and new wood chips were bought. It might be necessary to replace all insulation also coming years because the insulation qualities deteriorates when wood chips mix with sand and gravel from the snow.

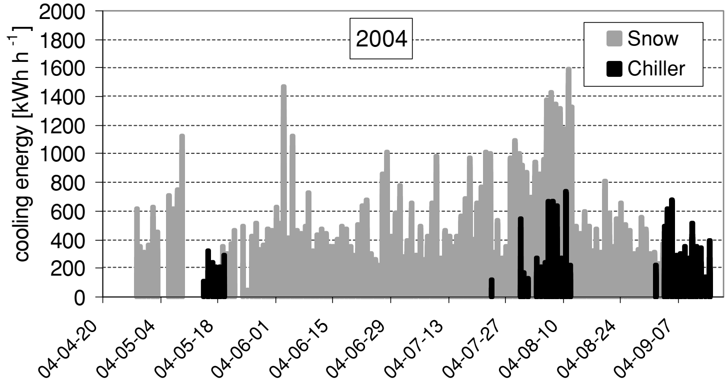

Figure 206. Hourly cooling amounts from snow cooling system and chiller in 2004

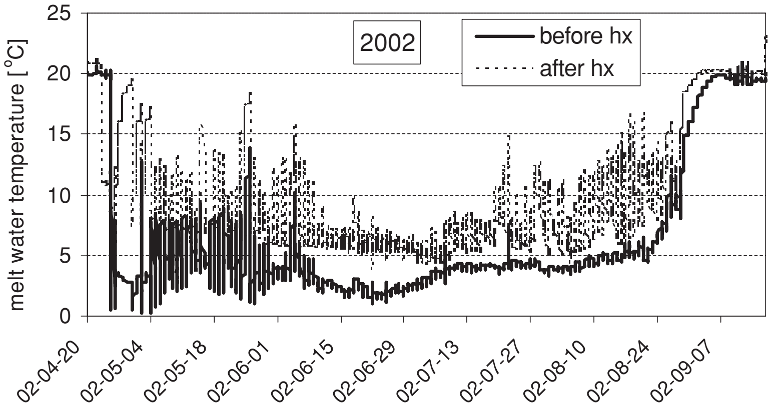

Figure 207. Melt water temperatures before and after the heat exchangers (hx), in 2002

In 2003 CCV made a minor experiment with 2·5 m insulation sheets, U-value 13.6 W m^{-2} K^{-1}, covering an area of about 10·10 m. In the beginning the insulation functioned well but as the snow started to melt uneven the sheets slid apart. The staff had to adjust the sheets frequently and it was concluded that this solution was less good than wood chips (Larsson, 2005).

4. *Melt water re-circulation*: The melt water re-circulation system is important since it delivers the cold to the hospital, but the system in Sundsvall however caused problems. The melt water temperature before the heat exchangers was mostly 2–5 °C until the end of July/middle of August. Then temperatures started to increase because of snow decrease and shortages in the re-circulation system. Around the inlet valves snow melted quickly why wood chips fell off, resulting in both increased natural melting and that re-circulated water found short cuts along pond sides. To decrease side-melting new re-circulation hoses were installed. The first year the hoses were placed on top of the snow, resulting in holes and exposed snow. In 2001 the hoses were placed at the far side, and in 2002–2004 the hoses were placed under the snow. In 2002 the hoses were damaged by the snow groomer but in 2003 and 2004 the outlet water temperature decreased, Figures 207 and 208.

The average cooling load, melt water flow, melt water temperature before the heat exchangers and melt water temperature increase in June + July 2001–2004 are seen in Table 24. The melt water flows during these periods corresponded to a detain time of 1.5–3 days, assuming that 2/3 of the volume beneath the water surface was occupied by snow.

The temperature increase in the heat exchangers was usually 1–8°C. The decreased temperature difference in 2002–2004 was due to algae growth

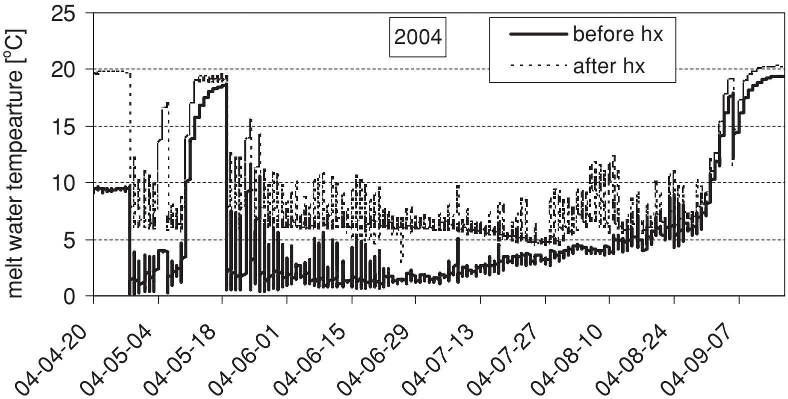

Figure 208. Melt water temperatures before and after the heat exchangers (hx), in 2004

in heat exchangers and decreased temperatures on the secondary side of the heat exchangers, from 13.0 °C in 2001 to 8.1 °C in 2004, before heat exchangers. The algae growth decreased the heat transfer and maximum flow rate. The heat exchangers were cleaned with lye one to three times per summer, and then the temperature difference increased again. CCV believed that increased decay rate of the old wood chips and high temperatures in heat exchangers caused the growth. Algae growth decreased radically during 2003 when new wood chips were used.

It is possible to avoid short cuts and decrease outlet melt water temperature by spraying re-circulation melt water on top of the snow instead, but so far CCV has avoided this because they do not want pollutions carried in the air to the hospital. For 2006 the melt water circulation will be extended with sprayed ground water and water outlets at the pond bottom centre, to decrease the water temperature further.

5. *Weather:* Air temperature, relative humidity, precipitation, solar radiation, air velocity and wind direction were measured by a weather station at the snow storage pump house. The summers of 2000–2004 were warmer and rainier than mean summer of 1961–1990. In 2002 the summer mean temperature was 4.1°C warmer than the average year. In 2001 and 2002

TABLE 24. Melt water outlet data for 2001–2004

June+July	2001	2002	2003	2004
Average snow cooling load (kW)	457.5	453.4	476.6	276.9
Average melt water flow ($m^3 d^{-1}$)	1,842.6	2,567.7	2,272.7	1,595.0
Average melt water outlet temperature (°C)	4.1	3.3	3.0	2.2
Average melt water temperature increase (°C)	4.9	3.6	3.8	3.7

TABLE 25. Monthly mean temperatures and total monthly precipitation during the cooling seasons of 2000–2004 at the Sundsvall Regional Hospital Snow Storage. Mean values between 1961–1990 are from the Sundsvall airport 30 km away

	Mean temperature (°C)				Precipitation (mm)				
	May	June	July	August	May	June	July	August	Total
2000	9.5	12.6	16.5	15.0	45.4	72.3	146.4	37.3	301.4
2001	9.3	15.1	17.8	15.4	33.0	15.4	68.8	221.8	339.0
2002	11.4	17.6	18.4	19.4	84.0	95.0	62.0	21.2	262.2
2003	8.7	14.1	18.9	15.6	41.0	79.6	13.0	134.2	267.8
2004	9.3	14.0	16.5	16.7	26.8	52.8	97.0	88.2	264.8
1961–1990	7.8	13.4	15.3	14.0	35	41	58	64	198

there was 52.2% and 71.2% more precipitation than the average year, Table 25.

Mean values of 1961–1990 are from the Sundsvall Airport, located about 30 km from the snow cooling plant. There was good correlation between measured air temperature and precipitation and values from the airport climate station, compared during 60 days the summer of 2000. The airport climate station is run by the Swedish Meteorological and Hydrological Institute.

The ground temperature under the storage pond was measured both above and below the ground insulation at 0.6–0.7 m depth. Above the insulation the ground temperature followed the air temperature with a slight trailing when no water or snow covered the storage bottom, otherwise it was 1–5 °C above zero. The ground temperature below the insulation was about 4–5°C from spring to end of snow cooling season, and then increased a few degrees.

6. *Environment:* A number of melt water quality analyses of heavy metals, hydrocarbons, oxygen demands, and nutrients were made. From September 2001 to September 2002 measurements were made in the snow storage, in the stream where melt water is discharged and in the recipient, totally at seven locations. Reference measurements were made at a nearby location not affected by the outlet water. The results were compared with Swedish environmental quality criteria (SEPA, 1990; SEPA, 1999).

The concentration of non-biodegradable compounds (measured as COD-Mn) was rather high, especially in the second half of the cooling season. These were supposed to origin from the wood chips (Ericsson, 2003). The content of phosphorus and some heavy metals in the snow were high, but in the outlet water most substances were considerably reduced. This was related to particle adsorption, as particles settled in the snow basin, which agrees with performed studies (Viklander and Malmqvist, 1993). The effect on the recipient was limited or non detectable for all parameters, relative the reference location (Ericsson, 2003). The phosphorus content in the snow was probably caused by droppings from dogs and birds (Malmqvist, 1983).

An unknown amount of the substances described above were lost in the oil and gravel separator and by flushing of the fine filters. An attempt to make a full mass balance failed.

21.2.3. ECONOMY

The total investment cost of the Sundsvall snow cooling plant was about 14.5 MSEK, or 1.59 M€ . Since this full scale operation plant was made also for experiments, research and demonstration it was difficult to distribute the cost in an appropriate way, e.g. the cost of reconstructions. An estimated cost split up is shown in Table 26 (Larsson, 2005).

The cooling operation costs during 2002/2003 and 2003/2004 are seen in Table 27. The cost of the first three years was not available, but CCV estimates that the total operation cost has decreased each year. The "Snow handling incl. production" was expensive in 2002/2003, when a contractor was responsible. The depositing of urban snow became an income from the winter 2002/2003, since CCV received a fee of 150 SEK per lorry-load of snow. "Cold production" means operation cost during the summer, excluding electricity and water. "Post season work" includes removing and storing wood chips, removing sediments and cleaning the pond.

"Electricity" depends largely on the amount of artificial snow. The cost of water has decreased due to their private well being used since 2002, on the other hand the electricity usage increased. The municipal water cost was 5 SEK m^{-3}.

TABLE 26. Investment costs for Sundsvall Regional Hospital snow cooling plant

	(kSEK)	(k€)
Pond construction	4,800	527.5
Ground thermal insulation	1,000	109.9
Fence + vehicle approach	700	76.9
Pump house	1,000	109.9
Pumps, pipes, etc	4,000	439.6
Electrical installations	1,000	109.9
Control system	600	65.9
Planning	1,400	153.8
Total	14,500	1,593.4

TABLE 27. Operation cooling cost from the Sundsvall Regional Hospital snow cooling plant (Larsson, 2005)

	2002/2003	2003/2004
Artificial snow share	37%	52%
Artificial snow amount (m^3)	13,984	18,408
Snow handling incl. production (SEK)	1,170,030	733,624
Natural snow (SEK)	−141,000	−98,100
Cold production (SEK)	199,781	167,932
Post season work (SEK)	147,652	134,291
Electricity (SEK)	35,551	45,893
Water (SEK)	34,587	33,485
Operation cooling cost (SEK kWh^{-1})	1.62	1.27

Larsson (2005) predicts that the operation cooling cost in 2004/2005 will be 0.85 SEK kWh^{-1}, and about 0.50 SEK kWh^{-1} in 2010. Thanks to the commitment of CCV, occurring problems have been solved, necessary reconstructions have been made and the plant has worked satisfactorily.

21.3. Boundary Conditions for Snow Cooling

The boundary conditions for snow storages on ground are social, political, economical, environmental, natural and system related.

The usage of snow cooling systems presupposes that the technique is known. However, the awareness of modern snow and ice cooling systems is limited to a fairly small number of countries. Also in countries that have snow cooling systems there is generally a low knowledge about the technique, both among engineers and authorities at all levels. There is also a lack of education in system construction and design.

The *political* boundary conditions are connected with financial support, taxes and regulations and laws. For instance the Kyoto Protocol might be an incentive to an increased number of snow cooling plants, since they to a large extent uses renewable energy (Paksoy, 2003).

The *economical* boundary condition varies largely over the world and generally depends on cost of land, water, electricity, fuel and labour. Natural snow is a cost if the snow is collected expressly for cooling but might be an income if snow depositors pay for getting rid of the snow. Besides this snow cooling can both be an alternative to other technologies but also enable alternatives not relevant without natural snow and ice, e.g. in developing countries. For Swedish conditions the estimated economical conditions of a new snow cooling plant was good (Skogsberg, 2005).

The *environmental* boundary conditions both concerns chillers and snow cooling. Reduction of green house gases, elimination of ozone depleting gases, noise reduction, aesthetic concerns and peak shaving (i.e., reducing electricity demand during maximum usage periods) are connected to chillers. Pollutions in snow, noise from snow making, transports and land/ground usage are related to snow cooling (Paksoy, 2003:2). Snow pollutions might be both a draw back and a benefit for the technique. The negative aspect is that pollutions are concentrated at one location and the positive is that pollutions can be measured and controlled, if the storage is water tight.

The *natural* boundary conditions are air temperature, air humidity, precipitation, solar radiation, water availability, ground water flow, ground water level, soil properties and ground water usage. In a snow cooling plant it is primarily necessary with enough amounts of snow, either natural and/or artificial. If the amounts of natural snow vary too much it is necessary with a cold period long enough to produce snow/ice. This production is benefited by low temperatures and low air humidity. In general it is possible to produce enough amounts of snow/ice if it is possible at all, since short and/or warm winters can be compensated by more snow guns.

During the cooling season the climate affects both natural melting and cooling demand why the difference in needed snow amounts between a normal year and a warm year is double influenced. Natural variations in the climate must be carefully considered during dimensioning. Furthermore seasonal snow storage is a long-term investment; estimated life time is 40 years, why also the global warming influences predictions.

The water availability is important if artificial snow is used. It is however possible to save water in the pond during a period and use it for snow making when the temperature is low enough. It is also be possible to reuse water if pollution problems can be handled.

The ground water flow and level influences both natural melting and suitable storage constructions. Large ground water flows increases the ground melt of both water tight and permeable ponds, if cold pond water flows into the ground. Soil properties also influence the pond construction. In water tight ponds snow pollutions are concentrated and treatable. If the pond on the other hand is permeable it is necessary to study how pollutions migrate. This is more important if nearby ground water is used for drinking or irrigation.

The *system* conditions concerns load characteristics and needed energy, temperature and humidity. This affects the cold distribution system and how suitable snow cooling is for a certain project. Melt water from snow is about 0 °C at normal conditions why snow cooling for freezing applications are not directly applicable. It is however possible to run freezers towards melt water instead of warm air, which is beneficial both since the temperature difference between the cold and the warm side decreases and because heat transfer to a liquid is better than to a gas. It is however necessary with further studies of chillers to enable condenser temperatures of about 5 °C (Hill, 2004). The needed cooling energy and maximum cooling load influences the plant size and design, but in general a snow cooling system has no power limit since the cold carrier is circulated through the snow at the same rate as it is pumped to the object that is being cooled. With open water circulation systems there is however a delay between water inlet and outlet why a melt water buffer in the pond is necessary to meet load variations. There are snow cooling systems where humidity can be controlled, if air is used as cold carrier.

21.4. Conclusions

In seasonal snow/ice storages frozen water, snow or ice, is stored from winter to summer, when the cold is extracted. The basic idea is that a cold carrier (water or air) is cooled by the snow, to utilize the large latent heat of fusion, and then delivers the cold. The cold carrier is either circulated between the load and the snow or rejected after it has been used for cooling.

There are a number of suggested and implemented ways to store the snow/ice. If the snow is stored underground it is not necessary with thermal insulation. Otherwise a more or less insulated building or insulation directly on the snow is needed. There are different types of insulations; loose fill, sheets and superstructures, with different advantages and disadvantages.

Both natural and artificial snow and ice may be used and there is no size or power limitation for snow cooling systems. Here the main issue is to have enough amounts of frozen water at low cost why the only relevant snow/ice distinction is the density. If natural snow or ice is too expensive or not available in enough quantity, it is possible to produce frozen water. Artificial snow/ice is made with different types of water sprayers, including snow blowers (snow guns). The production rate depends on equipment, relative air humidity, and temperatures of the air and water.

At present (2005) there is one modern Swedish snow cooling plant at the regional hospital in Sundsvall. It has been in operation for six years, and it has mostly worked well. The plant is an open shallow pond with water tight asphalt bottom and larger pieces of wood chips as thermal insulation. The outlet water is cleaned in some steps, and after cooling the heated melt water is re-circulated back to and through the snow, where it is cooled again. To keep a constant water level in the pond some heated water is rejected gradually. Based upon the experiences from Sundsvall it is estimated that a new large-scale plant could deliver cold at competitive cost, with a considerably higher COP.

There are a number of boundary conditions for snow storages; social, political, economical, environmental, natural and system related. Except that the usage of snow cooling systems presupposes that the technique is known the prerequisite as financial support, taxes, regulations and laws are important. The relevant economical boundary conditions are cost of land, frozen water, electricity, fuel and labor. The environmental boundary conditions concerns reduction of green house gases, elimination of ozone depleting gases, noise reduction, aesthetic concerns, peak shaving, snow pollutions, noise from snow making, transports and land/ground usage. Two other important conditions concern the climate, both for receiving snow/ice and cooling needs, and ground conditions. The water availability is important if artificial snow is used. There are however possibilities to save and reuse water. The system related boundary conditions concerns load characteristics and needed energy, temperature and humidity.

References

Abdelnour, R., B. Labrecque, and A. Underdown, 1994. Technoeconomic analysis of three seasonal cooling technologies, Ice box, frozen pond and waste snow pit, Proceedings of Calorstock'94 Conference on Thermal Energy Storage, Helsinki, Finland.

André, E., S. Hogdin, and T. Derstroff, 2001. District cooling at Luleå University of Technology. Student Report, Division of Water Resources Engineering, Department of Environmental Engineering, Luleå University of Technology, Sweden.

Buies, S., 1985. Engineering of a life-size Fabrikaglace. Centre de Recherche du Québec (CRIQ), Canada, Technical report No. FAB-85-051.

Ericsson, H.E., 2003. Snökylanläggning, Sundsvalls sjukhus. Uppföljning av kontroll-program 2001–2002 (Snow cooling plant, The Sundsvall Regional Hospital. Follow-up of the control program 2001–2002), Commission 1658119 101, Sweco VIAK.

Falk A., S. Hansson, J. Johansson, and C. Sandström, 2001. Snölager- En kall rapport. Snö för kylning av kraftvärmeverk (Snow storage—A cold report. Snow for cooling of a heat and power plant), Student Report, Division of Water Resources Engineering, Department of Environmental Engineering, Luleå University of Technology, Sweden.

Hagerman, A., 2000. Snökylanläggning kontra kylmaskiner (Snow Cooling Plant vs. Chillers), Undergraduate Thesis, Division of Resource Management, Mid Sweden University.

Hill, P., 2004. Projektförslag beträffande utveckling av snökyla i Sundsvall (Suggestions for projects concerning snow cooling in Sundsvall), Division of applied thermo-dynamics and refrigeration, Department of Energy Technology, KTH, Sweden.

Iijima, K., M. Kobiyama, Y. Hanaoka, M. Kawamura, and H. Toda, 1999. Absorbability of contaminants from air by snow cooling system, Paper for the 8th Indoor Air 99 Conference in Edinburgh, Scotland.

Johansson, P., 1999. Säsonglagring av kyla i bergrum (Seasonal cold storage in rock caverns), Master Thesis 1999:184 CIV, Luleå University of Technology, Department of Environmental Engineering, Division of Water Resources Engineering, Sweden.

Kamimura, S., and T. Toita, 2004. Concept of Electric Power Output Control System for Atomic Power Generation Plant Utilizing Cool energy of Stored Snow. Presented at the 5th International Conference on Snow Engineering, July 5–7th 2004, Davos, Switzerland.

Kobiyama, M., 1997. Economic Estimation of All-Air Type Snow Air-Conditioning System, Proceedings of Megastock, The 7th International Conference on Thermal Energy Storage. Conference in Sapporo, Hokkaido, Japan (pp. 611–616).

Kobiyama, M., 2000. Department of Mechanical Engineering, Muroran Technical University, Japan, Private Communication.

Larsson, P.-E., 2005. Landstingfastigheter Västernorrland (The County Council of Västernorrland), Sweden, Private Communication.

Malmqvist, P.-A., 1983. Urban storm water pollutant resources. An analysis of inflows and outflows of nitrogen, phosphorus, lead, zinc, and copper in urban areas, Dissertation Series, Department of Sanitary Engineering, Chalmers University of Technology, Gothenburg, Sweden, ISBN 91-7032-106-X.

Morofsky, E., 1981. Project Snowbowl. Public Works of Canada (PWC) Contract EN 280-0-3650.

Morofsky, E., 1982. Long-term latent energy storage—the Canadian perspective, US China Conference on Energy, Resources and Environment.

Morofsky, E., 1984. Developing and introducing an innovative building cooling technique: Strategy formulation based on market and technology considerations, Issues in strategic management, Adm. 6395.

Nordell, B., and Sundin, E., 1998. Snöupplag för säsongslagring av kyla (Snow Deposit for Seasonal Storage of Cold). Division of Water Resources Engineering, Luleå University of Technology, Sweden, April 1998.

Näslund, M., 2000. Fjärrkyla i Sundsvall baserad på sjövatten och lagrad snö (District cooling in Sundsvall based on sea water and stored snow). Master Thesis 2000:132 CIV, Luleå University of Technology, Department of Environmental Engineering, Division of Water Resources Engineering, Sweden.

Näslund, M., 2001. Kylvattenförsörjning till SSAB Hardtech. Förprojektering (Supply of cooling water to SSAB Hardtech. Prestudy), Consultant Report, Energidalen i Sollefteå AB, 881 52 Sollefteå, Sweden.

Okajima, K., H. Nakagawa, S. Matsuda and T. Yamasita (1997). A cold storage for food using only natural energy, Proceedings of Snow Engineering Conference, Balkem, Rotterdam, Netherlands, pp. 569–572, ISBN 90-5410-865-7.

Paksoy, H.Ö. (ed), 2003. Feasible boundary conditions and system configurations for cooling with TES, Subtask 2. Annex 14, Cooling in all climates with thermal energy storage, August 2003, International Energy Agency (IEA), Energy Conservation through Energy Storage (ECES).

SEPA Swedish Environmental Protection Agency, 1990. Bedömningsgrunder för sjöar och vattendrag (Quality criteria for lakes and water courses), General Guidelines 90:4, ISBN 91-620-0042-X.

SEPA Swedish Environmental Protection Agency, 1999. Bedömningsgrunder för miljökvalitetsjöar och vattendrag (Environmental quality criteria – lakes and water courses). Report 4913, ISBN 91-620-4913-5.

Skogsberg, K., 2005. Seasonal Snow Storage for Space and Process Cooling, Doctoral Thesis 2005:30, ISSN: 1402–1544, Division of Architecture and Infrastructure, Luleå University of Technology.

Suzuki, T., S. Kobayashi, K. Tsushima, S. Shao, Y. Teng, and G. Liu, 1997. A case study on the utilization of snow and ice as natural cold energy source for low-temperature storage materials, Snow Engineering, pp. 553–558, ISBN 90 5410 865 7.

Taylor, T.B., 1985. Ice ponds. American Institute of Physics (AIP) Conference Proceedings, November 25, 1985, Vol. 135 (1) 562–575.

Viklander, M., and Malmqvist, P.-A., 1993. Melt water from snow deposits, Proceedings of the Sixth Conference on Urban Storm Drainage, 12–17 September 1993, Niagara Falls, Ontario, pp. 429–434.

Wichmann, P., 2003. Miljökonsekvensanalys av snökylanläggning och kylmaskin (Environmental impact study of a snow cooling plant and a chiller), Master Thesis 2003:322 CIV, Division of RenewableEnergy, Department of Environmental Engineering, Luleå University of Technology, Sweden, ISSN 1402–1617.