ON TOP OF THE WORLD: ARCTIC AIR BASE WARMED WITH HEAT PUMP TECHNOLOGY

Helge Underland
Norwegian Defense Estates Agency

The Arctic city of Bodø, Norway, population 41,000, looks out on the Atlantic Ocean and the island of Langegode. The city's civilian airport is shown in the foreground. Images of the air base are proprietary.

The Main Air Station in Bodø, Norway, has the distinction of being the northermost F-16 base in the world. At 66.5 degrees north, it sits above the Arctic Circle on rugged Atlantic coastline, vulnerable to some of the harshest, most changeable weather on the planet. Snowy conditions and freezing rain during much of the year require Royal Norwegian Air Force pilots to have an extra measure of skill to safely control their planes in the air and on the ground.

Built during World War II, Bodø Air Station grew in strategic importance–and size–during the Cold War. As NATO's northernmost front with Warsaw Pact forces, it became famous in the early-1960s as a base for U2 surveillance missions. Today, its two F-16 fighter squadrons still stand ready to scramble. Nearly 800 people work on site.

To support Bodø's continued key role in national defense, the Norwegian Defense Estates Agency enlarged the air station's facilities, most notably during the 1950s. The expansion included infrastructure renovations, equipping buildings (sometimes in groups of two or three) with oil-fired hot water heating systems. During the 1990s, the decision was made to construct a district heating operation on base, using a heat pump as the main energy source. Currently, that system is efficiently warming barracks, workshops, hangars and other buildings at Bodø Air Station, tapping the nearby seawater for heat energy.

FUEL VERSATILITY

With rivers, waterfalls and lakes in abundant supply, Norway relies on hydroelectric power for almost all of its electricity. The country produces approximately 120 TWh (400 TBtu) of hydroelectricity each year. It imports and exports electricity with Russia, Finland, Sweden and Denmark. Electric boilers are in widespread use and relied on in periods when electricity is cheap (approximately $0.01/kWh). But when the weather gets colder and the price increases, we can switch to oil-fired boilers. Electricity tariffs are less expensive if we can stop the electricity boilers in 60 minutes or less when we change over to oil.

After many years of heating Bodø Air Station with oil-fired boilers, the Norwegian Defense Estates Agency developed a new energy plan for various military bases during the 1980s. The plan recommended eventual construction of district heating systems that could rely on a variety of energy sources–oil, electricity, biofuels or heat pumps.

The original oil-fired boilers were capable of handling 100 percent of the load, with redundant electrical boilers that could handle 60 percent. Since 1990, heat pumps or biofuel boilers, which cover approximately 40 to 60 percent of the load, have been installed in many locations. These various boilers provide backup options and allow the switch between boilers to use whatever fuel is cheapest. Where we have installed a heat pump, it serves the main load, with oil-fired boilers for peak load and backup.

The Bodø Air Base's district heating system started up in 1992, serving approximately 40 buildings. The design heating load in the buildings varied from 72 kW (69 Btu/sec) to 940 kW (890 Btu/sec), totaling 5,400 kW (5,120 Btu/sec). Because of differences in the consumption patterns of various buildings–depending on occupancy, demand at different times of day, etc.–the actual total load was calculated at 3,800 kW (3,600 Btu/sec), and the total energy consumption was projected to be 11 GWh (36.8 GBtu).

This reflects a decrease in heat demand with the conversion of all buildings to district heating. All told, the old heating system previously used 13 GWh (43.4 GBtu). Since district heating has been installed, however, the actual consumption has been 8 GWh (26.7 GBtu) per year.

HEAT PUMP PRINCIPLES

The heat pump was clearly a suitable energy source for the Bodø system, given the area's 274-day heating season, mean temperature of 4.6ºC (40.3ºF) and design temperature (lowest mean temperature of three days) of minus 13.5ºC (7.7ºF). For a heat pump to be economical, it needs to run for a long duration in weather that is not too frigid.

A heat pump can be compared to a refrigerator; where, heat is transported from the inside to the outside–from low temperature to a higher temperature. The four main components of a heat pump: the evaporator, compressor, condenser and expansion valve–are all connected to a closed circuit. The evaporator is where a liquid boils and evaporates under low pressure. Low-temperature energy, in the form of seawater at 7ºC, is added. The vapor is compressed to a higher pressure and higher temperature in the compressor. The hot vapor enters the condenser; where, it is condensed and the heat is transferred to a heating system.

Finally, a high-pressure refrigerant is expanded through the expansion valve, which regulates between high and low pressure. In this way, the temperature in a liquid can be increased by adding high-quality energy (electricity) in small amounts and low-quality energy, in the form of seawater or ambient air, in large amounts. In general, approximately one part electricity is added to three parts low-quality energy.

When planning began on the Bodø district heating system, it was known that chlorofluorocarbon-based refrigerants would be banned, so alternatives were considered. The new refrigerants had not yet been sufficiently tested, so the old well-known ammonia (NH_3), R-717, was chosen. Although it had been widely used in refrigerating plants, it had not previously been used in a heat pump. NH_3 has very good thermodynamic properties. It does not damage the ozone layer or harm the environment in any way. In a certain mixture with air, however, it is explosive and toxic.

Compressors in refrigeration plants typically are built for a pressure of 25 bar (363 psi), with a condensation temperature of approximately 50ºC (122ºF). For the district heating system, however, we wanted a higher temperature. The design temperature of the heating systems in the buildings on the system was 80ºC (176ºF). Therefore, we needed a compressor of approximately 40 bar (580 psi).

ENERGY FROM THE SEA

Bodø central heating plant consists of two heat pumps of 2 MW (1,896 Btu/sec), one electric boiler and two oil-fired boilers at 3.8 MW (3,600 Btu/sec) (Figure 1). The central heating plant is located close to the beach, approximately 200 m (656 ft) away. Seawater is drawn from a depth of 170 m (558 ft); where, the temperature is constantly 7ºC (44.6ºF) throughout the year. The seawater drains into a 7-m deep basin (19.7-ft); where, two submerged pumps are located. Their total capacity is 180 m^3/hr (47,600 gal/hr).

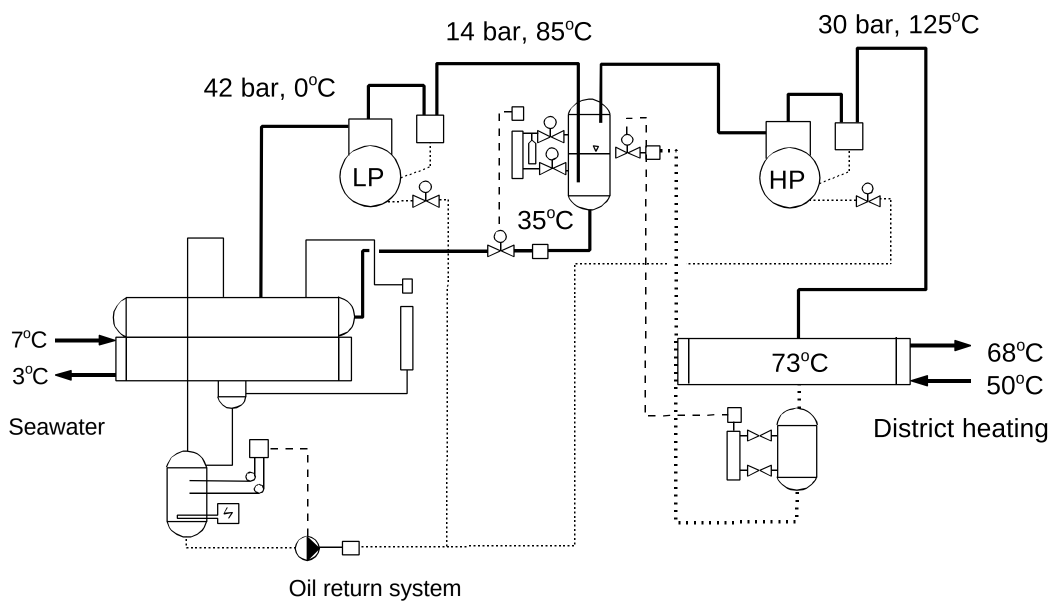

Figure 1. ***The Bodø, Norway, Main Air Station District Heating System. Since it began in 1992, this system has relied on heat pump technology as its main energy source.***

The heat pump consists of two separate aggregates with shell-and-tube condensers and evaporators. Each has a two-stage piston compressor with "inter-stage" receivers. (An inter-stage receiver is similar to an inter-cooler for a two-stage air compressor; it is necessary to reduce gas temperature between the low-pressure and high pressure compressors.) The compressors consist of a low-pressure compressor with 16 cylinders and a high-pressure compressor with six cylinders (Table 1). The two-stage compressor is preferred because it needs less power than a one-stage compressor, and therefore, performs better. Given the pressure, temperature and the use of NH_3, it is necessary to use a two-stage compressor to prevent the oil from decomposing.

The NH_3 is heated with seawater and boils in the evaporator at 4 bar (58 psi) and minus 0.7ºC (33.3ºF). The low-pressure compressor compresses the vapor to 14 bar (203 psi), 100ºC (212ºF). The hot vapor enters the inter-stage receiver. The high-pressure compressor compresses the vapor from 14 bar, 38.7ºC (102ºF) to 30.7 bar (445 psi), 108ºC (226ºF). The hot vapor enters the condenser; where, it is cooled to 74ºC (165ºF), and the condensation heat is transferred to the district heating system. The fluid enters the inter-stage receiver through the expansion valve, and from the inter-stage receiver to the evaporator through the second expansion valve.

The two aggregates are connected in series. The water in the district heating system enters the first aggregate (the "master"), which is always running, at 60ºC (140ºF) and leaves at 64ºC (147ºF). It enters the second aggregate (the "slave"), which runs only if necessary, at 64ºC and leaves at 68ºC (154ºF). The heat factor is 3.4 at the master and 3.2 at the slave.

PERFORMANCE TRACK RECORD

In the nearly 12 years since Bodø's district heating system began operating, the Norwegian Defense Estates Agency has been pleased with the installation's efficiency and positive environmental benefits (Table 2).

The project cost a total of 38 million NOK ($5.5 million). It was originally decided that the system would be built as a prototype demonstration plant and as such, it received economic support from the Norwegian Water Resources and Energy Directorate. The agency granted 1.2 million NOK ($175,000) for instrumentation for follow up in the run-in and test period.

The heat pump installation has had a positive influence on the environment by reducing air pollution. Since startup of the new system, carbon dioxide emissions have been cut each year by 3,048,700 kg; sulfur dioxide by 4,760 kg; nitrous oxides by 2,830 kg; and sulfur by 2,300 kg. In total, these emissions are the equivalent of 400 cars each driving 15,000 km per year.

Recently, six more buildings have been connected to the Bodø district heating system, further optimizing the heat pump's performance.

In general, the Norwegian Defense Estates Agency is quite satisfied with its large heat pump installations around the country. There are, for example, two systems in Bergen, at Sjøkrigskolen and Haakonsvern, which use seawater as the heat source, and an ambient air-based system in Stavanger. Those use R-134a as a refrigerant. Other systems also use groundwater as a heat source.

In Oslo, the agency is evaluating the heating and distribution system of the landmark Akershus Fortress, a medieval castle and museum. The design heating load for this

Table 1. Compressor Technical Data, Bodø Air Base Heat Pump System

	Low-Pressure Compressor	High-Pressure Compressor
Manufacturer	SABROE	SABROE
Model	SMC 116 S	HPC 106 S
Rotational Speed RPM	1475	1475
Max. Shaft Power	155 kW (147 Btu/sec)	124 kW (118 Btu/sec)
Piston Displacement	905 m^3/hr (239,000 gal/hr)	330 m^3/hr (87,200 gal/hr)

Table 2. Bodø Air Station District Heating System Statistics 2003

Maximum Output	2 MW (1,896 Btu/sec)
Delivered Quantity of Energy	8 GWh/yr (26.7 GBtu)
Used Quantity of Energy to Run the Heat Pump	2.5 GWh/yr (8.4 GBtu)
Coefficient of Performance	3.4
Total Cost for the District Heating System and the Heat Pump	38 million NOK ($5.5 million)
Extra Cost for the Heat Pump	8 million NOK ($1.2 million)
Payback for the Heat Pump	6 years

In the Bodø district heating system, vapor enters this low-pressure compressor and then the barrel-like "inter-stage receiver," where temperature is reduced before the vapor continues into the high-pressure compressor.

The Bodø system's heat pump consists of two separate aggregates with shell-and-tube condensers and evaporators.

is 6 MW (5,700 Btu/sec). A heat pump system using NH_3 is under consideration for this facility.

Heat pump technology is a sustainable method of heating. Its use reduces consumption of oil and gas, decreasing air pollution. To obtain the best performance, it is important to have a continuous heat source. It is also important to balance the distribution systems and design them with the lowest possible operating temperature. This will reduce the input energy to the compressor and increase the coefficient of performance.

In the long term, only those technologies that are sustainable can address the dual challenge of protecting the ozone layer and containing adverse climate effects. In the experience of the Norwegian Defense Estates Agency at Bodø and other sites, ammonia-based heat pumps are a good choice and right for the future.

ACKNOWLEDGMENT

Reprinted from First Quarter 2004 *District Energy* magazine with permission of International District Energy Association, copyright 2004.