Heat Pump Space Conditioning with Heat Recovery

An International Overview

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In a way most heat pumps recover or reclaim heat energy for space heating and cooling, water heating or process heating. In the building sector, the natural heat sources which heat pumps transfer to useful heat, such as outside air, the ground, ground water and sea/lake/river water are in fact all heat sources that consist of solar heat and cannot be directly used for heating due to their temperature. Hence, one can argue that heat pumps which use these sources are (solar) heat-recovery devices. What is more, these heat pumps use renewable energy sources which are replenished continuously by the sun. However, the most obvious source for recovering heat is the building itself, locally and on a larger scale, e.g. districts, cities etc.

In the industrial sector, heat pumps by definition recover waste heat from processes in different types of operation. However, many industrial heat pumps recycle recovered heat within a process, rather than use it externally for space conditioning. These process applications are not discussed here.

Heat recovery by heat pumps for space conditioning can be categorised as follows:

- those that recover heat by using the heat as a heat source;
- those that recover heat for driving purposes, e.g. waste heat-driven absorption chillers.

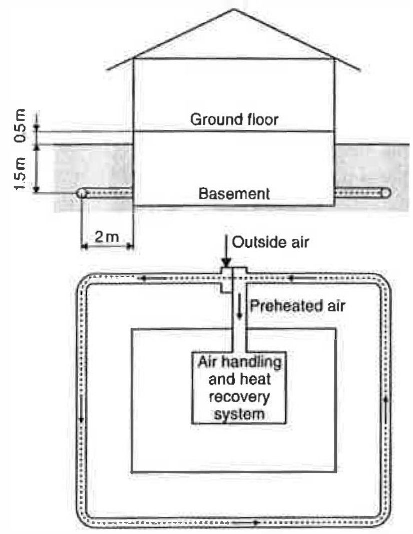
In this overview both types of heat recovery with heat pump technology will be covered, but the emphasis is on their use as a heat source.

Ventilation air

In an ideal building heat-recovery system, all system elements work year-round to recover all the internal heat before adding external heat. Any excess heat is either stored or rejected. Such an ideal system is called a balanced or controlled heat recovery system. When the outside temperature drops significantly, or when the building is closed, internal heat gain may be insufficient to meet the space heating requirements. Heat storage or an external heat source should then supply heat. Innovative use of heat pumping technologies can give large energy savings and high human comfort, as shown in the following.

An attractive heat source for a heat pump is building ventilation air. This heat source is becoming increasingly important. Imposed by frequently renewed building codes, the space heat demand of new houses is decreasing in many countries. Hence, in today's low-energy houses, the ventilation heat losses dominate in relation to the heat transmission losses. New regulations in Germany will further limit transmission heat losses in new houses to 10 W/m^2. On the other hand, driven by growing human comfort needs, the domestic hot water demand is increasing, as inhabitants live in larger houses and use more hot water than in the past. These combined effects lead to new design concepts for low-heating-energy houses with good opportunities for heat-recovery heat pumps. Incorporating a heat-recovery heat pump in a house with a balanced ventilation system can reduce ventilation losses considerably.

▼ *Figure 1: Austrian ground-collector for pre-heating air*



In moderate climates, such a system can be designed for monovalent operation, if the fresh air is preheated by the ground in a ground collector. **Figure 1** shows a collector outline developed in Austria. The ground collector consists of plastic or concrete pipes buried at a depth of approximately 1.5 m.

Balanced ventilation systems with heat-recovery heat pumps are state-of-the-art in large air-conditioned commercial buildings in western Europe. Many buildings are equipped with such a system.

Forced by regulations aimed at high indoor air quality and energy efficiency, balanced ventilation with heat-recovery heat pumps is common in residences in the Nordic countries. In central/western Europe, many houses are traditionally ventilated in a natural manner. However, natural ventilation is not suitable in new, airtight houses, as this does not ensure sufficient air exchange in the building. A growing number of new houses in Europe are equipped with balanced ventilation heat-recovery heat pumps. Countries with building ventilation regulations include, but are not limited to, Switzerland, Sweden, Norway and the Netherlands.

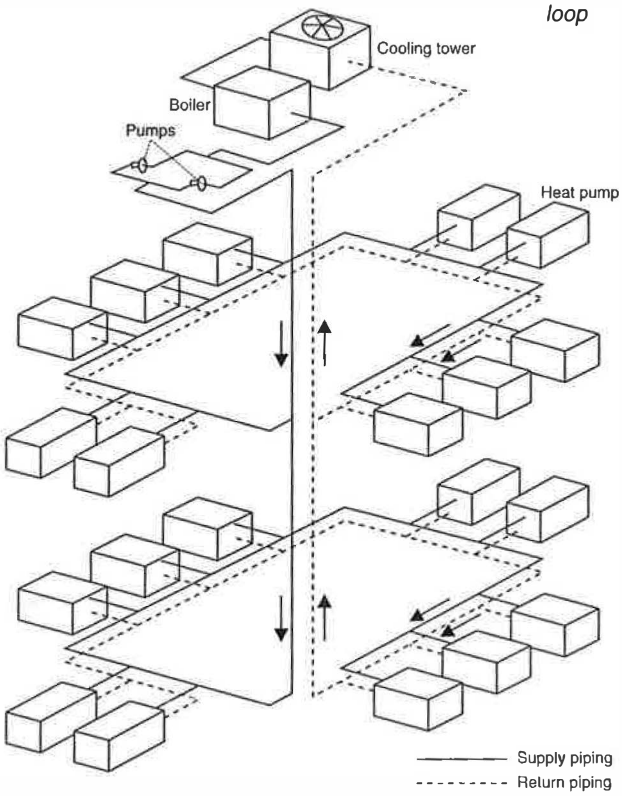
Water-loop heat pumps

Throughout the world, water-loop heat pump systems are very successful in recovering heat within a building. These systems are mostly applied in commercial buildings. In these systems water-to-air and water-to-water heat pump units use the building water loop to supply or reject heat in conditioning another liquid or air source in each zone of a building. These installations have a common two-pipe system, to which the heat pump units are connected, which also comprises a common closed circuit evaporative cooling tower for rejecting excess heat, see **Figure 2**. Most of the time the water loop conveys rejected heat, but a secondary heat source is usually provided, typically a boiler. The water loop temperature is maintained at a temperature between 16 and 32°C. The application flexibility of these systems is tremendous. Their use varies from providing hot or cold water for preconditioning outside air, to providing space cooling or heating in a hydronic system. In a variation of the water-loop heat pump system in the US, the building sprinkler system is used as part of the loop water distribution system. On a technology level, tremendous progress has been made in the US to improve unit energy efficiency. Further efficiency gains can be achieved through system applications.

In Japan and increasingly in other regions of the world, multi-zone split heat pump heat-recovery systems are being installed. Such systems come in many varieties and configurations. See page 16 for further details of a typical Japanese system.

Swimming pools

A classical application of heat recovery for space heating with a heat pump is in swimming pools, both for private homes and public facilities. The UK and Australia are leading in heat-recovery heat pumps for swimming pools in private homes. The heat pump acts typically as a dehumidifier of the pool room ventilation air. Mainly latent heat is recovered from the humid air by the heat pump. The heat produced by the heat pump is supplied to air or water, depending on the design. Usually the heat is transferred to the air in winter only.



◀ *Figure 2: Heat-recovery system using water-to-air heat pumps in a closed loop*

Energy storage

Integration of space heating, cooling and heat recovery in a system of heat pumps and underground energy storage is another solution for energy efficiency in commercial/institutional buildings. An example of such an installation in an office building located in the Netherlands was described in newsletter vol. 14/no. 3 (page 14). In summer, heat from ventilation air is transferred to ground water at 8°C which is reinjected in the warm well for use in winter. If the cooling capacity of the ground water is too small, the heat pumps provide additional capacity. In winter, the stored heat in the aquifer at 17-20°C is used as the heat source for the heat pumps, recovering heat from ventilation air. The cooled-off water is used for cooling the computer rooms and the rest is injected in the cold well for use in summer. The COP of the heat pumps is 4.1.

Retrofitting

Heat recovery for space heating with heat pumps is not only useful in new construction but also in retrofit situations, as the following two examples explain.

A 186-unit apartment building in Canada had been equipped with a 75 kW cooling capacity roof top chiller to provide space cooling, with four air make-up units fuelled by natural gas. A gas-fired boiler supplied hot water for domestic use to an 18 m^3 storage tank. The old system was inefficient for climate control and expensive to operate. The chiller was replaced with three water-source heat pumps which reclaim heat previously lost through the chiller. The heat pumps provide domestic water and air make-up heating. Each heat pump was designed to deliver 33 kW of heat at 53°C from a water source of 11°C. The original gas-fired boiler supplies backup heat. The energy required for the heat pumps to satisfy the total heating and cooling load was approximately equal to the energy consumption of the replaced chiller alone, without the benefit of reclaimed energy. The payback period of the system was only 1.9 years and, in addition, the building now has efficient climate control for year-round comfort.

In a Swiss village, 165 houses had oil-fired boilers which supplied heat for space and water heating and consumed 300 m^3 fuel oil annually. To reduce oil consumption and energy costs, the system was retrofitted with six heat-recovery air-to-water heat pumps, two of which are located in the garage and four on the roof of the building. Ventilation air from the kitchens, the bathrooms and the garage in the basement provide the heat source for the heat pumps. The heat produced is distributed by radiators. The amount of heat produced is sufficient to meet the water heating demand in summer and the space heating demand in the intermediate seasons. Fifty percent of the annual heat demand can be met by the heat pump. For peak loads, two high efficiency boilers with a total capacity of 1 MW have been installed. The replacement by heat-recovery heat pumps annually saves 40% energy, or around 120 m^3 fuel oil. The incremental investment costs of the system were 5-10% and the payback period of this retrofit was less than 10 years.

Various other examples of beneficial replacements can be given.

Large-scale heat recovery

Heat recovery with heat pumps is possible on any scale, i.e. in residences, commercial/institutional buildings and on a district scale. In Japan, district heating and cooling are common in large urban areas such as Tokyo, Nagoya and Osaka. Population growth in these areas has initiated new trends in building architecture and thus a new philosophy has developed for efficient and environmentally friendly energy supply systems for districts. Buildings changed from single structures to integrated structures with inter-connections via walkways, sky bridges etc. Underground streets, arcades, atriums etc. are all linked and conditioned for easy access and human comfort. The energy and control requirements of such building complexes are extensive, for a reliable and safe energy infrastructure. Often a simultaneous space heating and cooling demand exists in these districts due to internal heat gains in today's well-insulated, airtight buildings. On the other hand, large quantities of urban waste heat are produced and rejected unused, until recently. In Japan, the so-called unused energy sources are increasingly being exploited. A national programme supports the development of suitable technical solutions and applications. Typical waste heat sources are refuse incineration plants, sewage treatment facilities, power stations, transformer substations, underground power transmission cables and underground railway stations. Heat-recovery heat pumps are extremely suitable to meet the energy demands in such situations. Three examples of district energy infrastructures that apply heat pump technology are briefly described in the following.

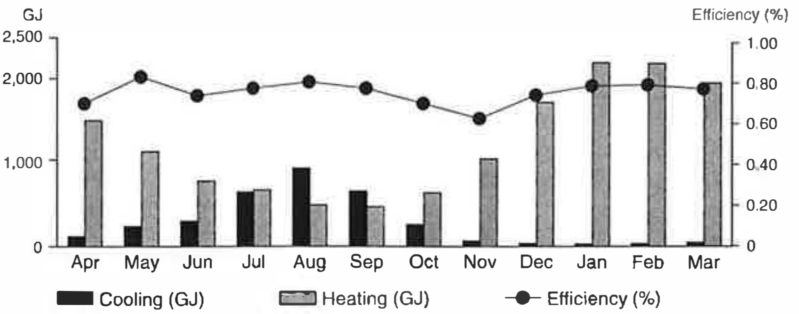
Hikarigaoka district

This is a redeveloped area of 186 hectare in metropolitan Tokyo. It consists of 42,000 residences, schools, hospitals and commercial zones. The dominating heat demand is from the residences. In winter and during the intermediate seasons, the waste heat from cooling the commercial/institutional buildings is insufficient to meet the heat demand of the residences (see **Figure 3**). Additional heat is supplied by heat-recovery heat pumps which use the condenser heat from the power generation process in a refuse incineration plant and heat from cooling a super high-voltage power transmission line. The ratio of peak heating to cooling demand is 8.3 and the overall annual efficiency of the system is 80%.

Hakozaki district

This is a reconstructed area in Tokyo near the Sumida river and consists of apartment buildings, commercial and institutional buildings. In summer, domestic hot water is produced from cooling the buildings, however, there is still an excess of waste heat. This heat is rejected into the river to avoid hot areas in the district. In winter, heat pumps extract heat from both the buildings'

▼ *Figure 3: Monthly load profile and efficiency; Hikarigaoka district.*



ventilation air and the river. The ratio of peak heating to cooling demand in this district is 0.15, and the annual energy efficiency is 127%.

Fuchu district

This district has been converted from an industrial site into a computer centre for service companies. Here the cooling demand exceeds the heating demand for most of the year. Only in winter does heat demand sometimes dominate. A large capacity heat storage system will be installed to store waste heat from space cooling for use in space and water heating. The heat pump will mainly operate at night during low-tariff periods. The peak heating to cooling demand ratio of this system is 0.06 and the annual overall energy efficiency is 151%.

Recovery from sewage water

An outstanding application of heat-recovery heat pumps are systems that extract heat from sewage water. Such heat pumps perform extremely well with high coefficients of performance (COP). A major technical challenge used to be the availability of these systems, as the heat extraction part required special solutions to avoid clogging and low evaporator temperatures. Many installed systems have demonstrated that these challenges have been met. A district-size system (14 MW heating) which also provides space cooling has been operating in Norway for several years now (see Newsletter Vol. 12/3, page 15). Several systems have been installed in urban areas in Japan over the past 10 years.

Absorption technology

A growing trend in recovering waste heat in an effective manner is with space cooling, especially in commercial and institutional buildings. Many utilities and building owners have discovered this new market for space cooling. Cold is produced by an absorption chiller powered by waste heat recovered from a cogeneration system that comprises an internal

Austria

In Austria, exhaust air heat recovery is very common in commercial/institutional buildings equipped with an air-conditioning system. Heat exchangers are generally used, some with the added function of recovering moisture. Heat recovery rates range from 50% to over 90%. For small and medium applications, systems using a combination of a heat exchanger with an air/air heat pump have been introduced in the market recently, either for residential buildings or for small commercial/institutional applications, such as restaurants and school buildings. At moderate outside temperatures such systems can be used for space heating.

Large commercial buildings can be split up in sections with different internal gains. This means that heating operation starts at different outside temperatures and that some sections need to be heated while other sections require cooling. Using a four-pipe heat/cold hydronic distribution system with fan coils, the cooling load can be shifted by heat pumps to the temperature level required for heating. Depending on the built-in volume and the equipment used, heat demand in such buildings can be met by utilising the internal gains only for outside temperatures down to 0°C (or higher).

In the case of integrated energy systems, all thermal waste produced by exhaust air, waste water, and refrigeration equipment is collected in stores. Using a heat pump, the temperature is shifted to the level required and used for space heating, and hot water production. Applications of such systems can be found in hospitals and recreation centres, as well as hotels and holiday resorts. Other heat sources are only required for peak load operation.

Source: Hermann Halozan, Austrian National Team

The Netherlands

In the Netherlands heat pumps are considered a powerful heat-recovery technology. Various low-energy housing projects are under construction in which small capacity heat-recovery heat pumps are installed, with ventilation air as the main heat source for the heat pump.

Because of the dense natural gas infrastructure in the building and industry sectors and the favourable tariff structure, cogeneration has penetrated widely in these markets. Unfortunately, these energy installations are not always the best solution from an energy quality point of view. However, the continued market penetration of cogeneration increasingly leads to new energy-efficient opportunities, such as combinations with heat pumps. Combining cogeneration and heat pumps can provide system energy savings as high as 46% compared to boilers.

An example of an advanced installation currently being built with the support of a national incentive scheme is a project in a holiday park, where the existing cogeneration plant will be expanded with three units, creating a total power capacity of 1.5 MWe. Six electric heat pumps will be installed, four of which are integrated in the buildings' air-handling system recovering heat from ventilation air. One will recover heat from swimming pool water, and one will recover heat from ventilating the cogeneration machine room at 30°C.

Combinations of cogeneration and electric (heat recovery) heat pumps for space heating are outstanding from an energy efficiency point of view. They provide cost-effective solutions in regions with a well-developed gas infrastructure or abundant gas from biomass.

Source: HPC

combustion engine or a gas turbine. Here the recovered heat drives the absorption chiller. Such installations have to compete with high efficiency electric compression chillers, but in many situations a cost-effective solution can be offered, depending on local energy tariffs and tariff structures. Typical application examples of these equipment combinations are found in hospitals and office buildings.

Absorption technology can also be effectively used to recover heat from flue gas cleaning in refuse incineration plants. In a typical installation the cooling water from the cleaning process is at a temperature of 43°C and provides an attractive heat source for the heat pump. The absorption heat pump is powered by saturated steam at 135°C , or hot water from the refuse-fired boiler. Most installations are found in Sweden and Denmark and, in recent years, new installations have been built in Japan. One company in Gothenburg, Sweden, operates five absorption units at their incineration plant. The heat produced by the heat pumps is supplied to the local district heating network. All heat pumps are single-stage water-lithium bromide systems. An overview of existing installations in Sweden is given in **Table 1**. At least two similar new installations are being designed in the Netherlands.

▼ *Table 1: Heat recovery with absorption heat pumps for space heating from refuse incineration (Sweden).*

Location	Driving energy	Year of installation	Total cooling capacity (MW)
Avesta	hot water	1988	2.5
Eksjö	hot water	1986	3.2
Gothenburg	steam	1988	28
Uppsala	steam	1997	18

Norway

Modern building design, increased comfort demands, higher internal loads, more computer systems etc. have increased the space cooling demand considerably in commercial and institutional buildings, even in cold climates.

Approximately 8,000-10,000 split air-conditioning units have been installed in residential and commercial buildings in Norway. The r versible units can provide both heating and cooling, but since they are not connected to central hydronic or ventilation systems, no energy recovery is accomplished during cooling operation.

An increasing number of water chillers are installed in hotels, conference centres, office buildings etc. Combined chiller and heat pump systems (i.e. space conditioning heat pumps), that provide maximum flexibility, high energy efficiency and favourable profitability, are not widely applied. This is mainly due to lack of information and competence among building owners, consulting engineers, contractors etc.

Figure 1 shows an example of a bivalent heat pump system for simultaneous space heating, space cooling and preheating of domestic hot water in a commercial building.

The bivalent heat pump is operated in heating or cooling mode. When heating is the predominant load, the heat pump extracts heat from the cold distribution system (12) and the heat source (4). The three-way valve (6) is used to control the flow distribution between the two heat sources. The condenser heat from the heat pump (3) and heat from the peak load boiler are used for space heating (11) and for preheating of domestic hot water (8). In summer, when the cooling demand is the dominating load, the cold distribution system is used as the sole heat source, and the three-way valve (6) closes towards the heat-source heat exchanger (5). Surplus heat from the heat distribution system is given off to the heat source (4, serving here as the heat sink) via heat exchangers (13) and (5).

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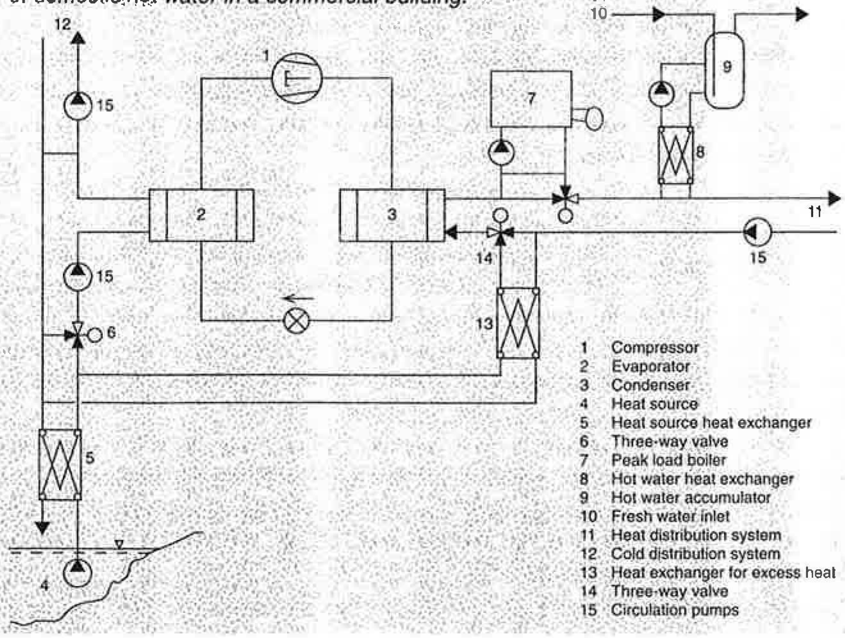
▼ *Figure 1: Bivalent heat pump system for space heating, space cooling and preheating of domestic hot water in a commercial building.*



Switzerland

In Switzerland many cantons restrict space cooling. Special permits are rarely given. Nevertheless, controlled air ventilation (CAV) with heat recovery of the ventilation losses is becoming increasingly popular. The main benefits for CAV are summarised below.

In Switzerland, almost a third of primary energy such as oil, gas and coal is used for heating purposes. The CO_2 emissions related to heating are over 40%. To limit this high amount of heating energy, new buildings have a more airtight construction, thereby losing less energy due to natural ventilation of the building envelope. Nowadays the specific energy demand of residential buildings is, on average, over 500 MJ/m² per annum. For new buildings the requirement, according to the standard of the Swiss Engineers and Architects Association (SIA), is a maximum 370 MJ/m² per annum, with a target value of 280 MJ/m² per annum. The latter is almost half of the existing average.

However, the advantage of energy savings by new building structures has a drawback which should not be underestimated. Lower heat losses also mean a smaller ventilation flow rate in the building. This in turn means that air quality is reduced. The occupants open the windows ore frequently and a large amount of the saving potential, gained by the tighter building structure, is lost.

Figure 1 shows an example of a CAV installation. Optionally the air can be preheated by an earth-pipe or by a small heat pump unit before entering the building. The disadvantage of this installation is the double-duct system for supply and exhaust air. There are also installations where the exhaust air is gathered in a central duct and directed across the evaporator without a heat exchanger between the exhaust and supply air. The fresh outside air enters the building through gaps in the wall or specially installed valves in the outside walls.

▼ *Figure 1: CAV with heat recovery.*

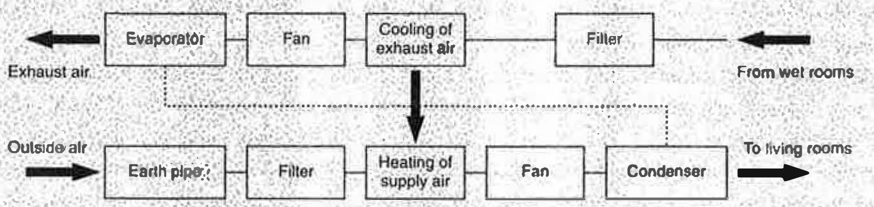
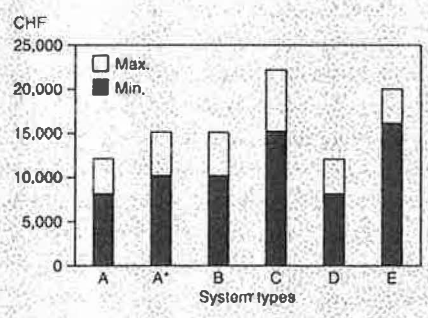


Figure 2 gives an overview of installation costs for various CAV systems in a new single-family house.

Source: Swiss National Team

▼ *Figure 2: Costs for various CAV systems.*



Legend:
- A Plate heat exchanger
- A* Plate heat exchanger with earth-pipe for preheating
- B Exhaust air heat pump for heating of supply air
- C Exhaust air heat pump for heating of supply air and hot water
- D Exhaust air heat pump for hot water
- E Exhaust air heat pump for hot water and support for space heating (outside air via wall valves)

Industrial heat recovery

Recovering heat from industrial processes for space heating has been common practice for years in many industries. Particularly in colder climates with a long heating season, the use of a space heating heat pump that operates on industrial waste heat can be cost-effective. Numerous systems are installed worldwide and have been documented in literature. Typical heat sources include the condenser heat from refrigeration systems, ventilation air from workshops and machine halls, process/equipment air cooling, process waste water, effluent streams etc. A heat-recovery heat pump for space heating in a Dutch washing facility for vegetable packaging is described below. It is a typical example of recovering low-temperature process heat.

Pallets and crates for vegetables need frequent cleaning with warm water. A study indicated that the best application for the waste heat from the cleaning process was space heating. A closed cycle air/water-to-air compression heat pump extracts the waste heat from the air-cooled washing machine. The heat stored in the process water settling tank can be used as an additional heat source by the heat pump. The heat produced is transferred to the ventilation air of the space to be heated. The heat pump has been added to the air heaters. The heating capacity of the heat pump is 80 kW. In peak demand situations, the existing air heaters (115 kW) are used parallel to the heat pump.

Conclusion

Using energy resources as efficient as possible is a 'must'. More than ever, this requires dedicated actions from governments, the energy sector and industry. Heat pumps should be their preferred choice as they represent a sustainable energy technology, which makes efficient use of renewable energy

Japan

With the increased year-round cooling load in office buildings, heat recovery with a heat pump system is widely used in Japan. Today, a variety of heat pump heat-recovery systems exist and these are incorporated in building space conditioning. They are basically classified into two types: central systems and decentralised unitary systems.

The typical central heat pump heat-recovery system is usually coupled to water thermal storage tanks, which are often located in the basement as part of the building structure. A double bundle water-to-water heat pump with a centrifugal or screw compressor is used for simultaneous heat and cold production. Air-source heat pump systems with heat recovery from ventilation air are also used for commercial buildings. These central heat pump systems are used as a large capacity all-electric district heating and cooling energy supply system, and they are ideal in a district with buildings that incorporate a computer centre or department store.

The current outstanding feature in Japan, in addition to the well-known water loop unitary systems, is the multi-split heat pump system with heat recovery function This has been developed in a variety of system configurations, as both air-to-air and water-to-air multi-split systems. An outdoor unit is used for heat supply or rejection. Each indoor unit can be individually switched to heating or cooling mode, responding to the requirement of the occupants. This results in a flexible system with heat recovery for simultaneous heating and cooling demand.

Source: Mr Takeshi Yoshii, Japanese National Team

USA

In 1996, the space conditioning market in the US grew for t e fifth succes sive year. This growth is attributed to the replacement market for residential and light commercial products. With approximately 100 million housing units and 5 million non-residential buildings in the US, the majority of which have some kind of air conditioning, these systems are all potential candidates for replacement with newer, more efficient equipment. Interest rates in previous years also played a role in maintaining this trend by giving home owners enough disposable income to replace (rather than repair) central cooling systems.

In 1996, combined shipments of unitary products, room air conditioners, and central residential heating equipment reached 14.3 million units, (up 11% from 1995), and is 53% above the 1992 shipment p rformance. Unitary shipments totalled 5,670,665 in 1996, (up 12%). In addition, for the third year running, shipments of electric air-to-air heat pumps – a subset of unitary products – topped 1 million. Approximately every fifth unitary product in the US is a heat pump, a product now found in 10 million homes.

An example of this trend is an application of a heating, ventilating and air-conditioning system with water-source heat pumps and ozone-safe refrigerants at a new all-electric Wal-Mart "Supercentre" under construction in Moore, Oklahoma. The fully integrated mechanical system includes sophisticated ventilation and humidity controls, and heat recovery from refrigeration through water-loop heat pumps. Once construction is completed, the Electric Power Research Institute will monitor the mechanical system's performance and make data available to those interested in pursuing similar projects. Wal-Mart personnel expect the annual energy savings to be USD102,000, given the cost of the combined electric and gas systems typically installed in Wal-Mart Stores. The bulk of the savings should come from the efficiency of the HVAC design with additional savings from the store's refrigeration and lighting systems.

Source: Julia Kelley, Oak Ridge National Laboratory

and waste heat sources. Millions of units and systems demonstrate this every day.

It can be argued that most heat pumps are heat-recovery devices, as they regain low-temperature solar heat from natural stores and heat which has previously been used in space conditioning, cities and industrial processes. Not only do heat pumps recover heat for upgrading, they also recover heat for driving purposes, which makes them a highly flexible technology. Heat pumps are able to recover heat more effectively than most other technologies.

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