

ENERGY SUPPLY SOLUTIONS, NEW WAYS AND MEANS: THE USE OF NATURAL REFRIGERANTS AND THE ENERGY CONTRACTING SERVICE

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Abstract: Since 1994, the use of refrigerants containing CFCs is no longer permitted in Switzerland, since they damage the ozone layer. Also since January 2004, there are strict limitations on the use and method of use of the chlorine-free refrigerants which have been employed in their place (FC, HFC). Alternatives for use in heat pumps are offered by natural refrigerants such as carbon dioxide (CO₂), ammonia (NH₃) or propane. The Zurich Municipal Electric Utility (ewz) operates, within the framework of energy-contracting agreements throughout Switzerland, heat pumps and refrigerating machines with a total power of 27 MW. The most important aim of the involvement of ewz in the contracting market is the efficient, cost-effective and at the same time resource and environment protecting provision of energy. Where ever possible, heat pumps and refrigerating machines using natural refrigerants (14.5 MW) are used. Experience so far has been uniformly positive, and reliability is on a par with that of heat pumps using conventional refrigerants.

Key Words: *Heat pump, natural refrigerant, carbon dioxide (CO₂), ammonia (NH₃), propane, energy contracting*

1 INTRODUCTION

Sales figures for heat pumps on the Swiss market have been rising for years. In 1996 just under 4'000 units were sold, in 2007 the figure was around 16'722.

The number of heat pumps sold has thus exceeded that for oil-fired systems for the first time. However, how high the proportion is of the overall number of heat production installations sold can only be estimated. The Swiss Heat Pump Centre (FWS) currently assumes a proportion of around 33 percent. There are many reasons for the steadily increasing sales of heat pumps. Important factors include the massively increasing energy prices in recent years, and the CO₂ tax on fossil fuels which was introduced at the beginning of this year. These factors make the use of heat pumps of interest from a commercial point of view, in long-term comparisons with fossil-fuel based systems. A further influence has been the environmental consciousness of the population as a whole, made more sensitive, amongst other things, by Al Gore's "an inconvenient truth", and in the meantime a wider availability of heat pumps of all performance classes. The simple function and high level of reliability of the installations has also demonstrated to a wider public that heat pump technology has now developed beyond the prototype stage and represents a real alternative to classic heat production installations. According to surveys carried out by the promotional organisation, acceptance is greatest for installations below 20 kW output, of the type used in single-family houses. Here already three quarters of builders in Switzerland decide in favour of heat pumps. At the same time, the number of plants available in the 300 to 900 kW range has increased. Within a year, the number of heat pumps manufactured in this range has almost doubled. By the end of 2006, around 100'000 heat pumps were in operation in Switzerland.

2 REFRIGERANTS AND THE ENVIRONMENT

In the last century, up to the 1930's, refrigeration plants mainly used natural refrigerants such as carbon dioxide (CO₂) or ammonia (NH₃). In the following 30 years, these were gradually replaced by newly-developed synthetic refrigerants on the basis of chlorofluorocarbons (CFCs). These included, for example, R12, R22, R502 or R500. These fulfilled all of the necessary requirements: they were non-flammable, virtually non-toxic, not explosive, thermally and chemically very stable and thermodynamically favourable. The plants operated using these media ran very reliably and safely. In 1974 however, a warning was issued for the first time, by the scientists Frank Sherwood Rowland and Mario José Molina, that the ozone layer was being destroyed by CFCs and the related class of chemical compounds to which these synthetic refrigerants belonged. In the late seventies and early eighties of the last century, the evidence for the harmful effects of CFCs became overwhelming. In 1987 therefore, 50 countries - including Switzerland - signed a protocol in Montreal for the international control of CFCs. The aim of this agreement in the long term is a world-wide prohibition of these climate-damaging materials. If refrigerants containing CFCs are released into the environment - which is possible during manufacture, transport or via leaks in installations - they pose a considerable risk of damage to the ozone layer. Particularly of importance is their high chemical stability and the associated persistence in the atmosphere. In the stratosphere, they react with the ozone layer and destroy it under the influence of light. In addition, CFCs absorb long-wave infra-red radiation and thus contribute to global warming. Their contribution to the anthropogenic Greenhouse Effect has been estimated at around 15 %.

2.1 Legislation in Switzerland

As a joint signatory of the Montreal Protocol of 1987, which came into force two years later, Switzerland began to revise the corresponding laws which were associated with the use of refrigerants (see Table 1). The use in new installations of refrigerants containing CFCs was prohibited from 1994 onwards. Within the framework of the implementation of the Kyoto Protocol for protection from global warming, which Switzerland also ratified, in 2002 a prohibition also followed of the use of partly halogenated refrigerants (HCFCs) in new installations. In April 2003, the Swiss Federal Council decided on a change to the Materials Directive (Stoffverordnung = StoV). The adaptation of the regulations concerning ozone-layer destroying substances which are stable in air were carried over without alteration in 2005 into Appendix 2.10 of the new Chemical Risks Reduction Directive (ChemRRV). Since 1st January 2004 ozone-layer destroying refrigerants (CFCs) are completely prohibited. In addition, they may no longer be retro-filled into existing plants. At the same time, an authorisation requirement was introduced for stationary plants with more than three kilograms of refrigerant which is stable in air (HFC). This authorisation is only granted when the maker can prove that, according to the current state of technology, no replacement substance or alternative procedure is available. Both new plants and conversions of existing plants are subject to authorisation. For industrially-manufactured heat pumps with permanently sealed refrigerant circuits, in the case of residential buildings, the authorisation requirement first comes into force on 1st January 2009. The restrictions on the operation of such plants have also been made more stringent: The operator must use appropriately-trained personnel with special authorisation for the handling of refrigerants, keep a maintenance log and carry out periodic checks for leakage. The aim of the more stringent rules is to promote the use of natural refrigerants which are not subject to authorisation and reporting obligations. In this case, other regulations would be applicable.

Table 1: Use of refrigerants in Switzerland

[illegible]

2.2 Alternative refrigerants

The increasingly stringent legislation has obliged the industry to search for alternatives to CFC-based refrigerants. On the one hand, chlorine-free refrigerants - so-called FC and HFC - have been developed, on the other hand, interest has been re-awakened in proven natural refrigerants such as NH_3 and CO_2 .

The range of chlorine-free refrigerants includes both discrete products and mixtures. Due to the relinquishment of chlorine as a chemical component, they do not have an adverse effect on the ozone layer, on the other hand they do continue to have - when released into the atmosphere - a considerable global warming potential and for this reason represent only a transitional solution. As described in the previous chapter, their use is subject to authorisation and associated with operational restrictions. The advantages of the chlorine-free refrigerants include, amongst other things, their wide application range, their non-flammability and their classification as non-toxic products (see Table 2).

In addition to NH_3 and CO_2 , natural refrigerants also include propane, n-butane and isobutane. The latter are primarily used in domestic appliances, in larger refrigeration and heat-production plants however, NH_3 and CO_2 are normally used. They are both a part of natural material cycles, have no negative influence on the ozone layer and no (NH_3) or only slight (CO_2) global warming potential. With comparable or better energy efficiency, installations using natural refrigerants have recognisable to significant environmental advantages compared with systems using partly-halogenated refrigerants. An exception is propane, due to its potential to create photochemical ozone creation potential. This has been demonstrated by an investigation into the environmental impact of natural refrigerants. If installations using natural refrigerants show a poorer energy efficiency, it is necessary to make an assessment of the individual indicators of environmental impact, such as the demand of non renewable primary energy sources, global warming potential, ozone-layer destruction potential, photochemical ozone creation potential, acidification potential, aquatic ecotoxicity, etc. in order to answer the question of environmental advantages.

A few of the advantages and disadvantages are summarised in the following Table 2.

Table 2: Selection of advantages and disadvantages of various refrigerants

	Fluorocarbons	NH₃	CO₂
Advantages	• wide range of applicability • no ozone depletion potential • non flammable • not toxic • good material compatibility	• high volumetric cooling performance • no ozone depletion potential • no global warming potential • very cost-effective • easy to obtain	• very high volumetric cooling performance • no ozone depletion potential • minimal global warming potential • non-flammable • very cost-effective • easy to obtain, available in the long term • good material compatibility • small pipe dimensions possible
Disadvantages	• high global warming potential • subject to authorisation and reporting • long-term availability uncertain	• toxic (venting into open air necessary) • corrosive to copper • explosive at high concentrations	• high pressures, necessitating special components • Monitoring difficult • Availability of components

3 ENERGY CONTRACTING FROM EWZ

User demands for comfort in their home and working environments have increased in recent years, thus also increasing the requirements on the energy supply. Heat, cooling, hot water and fresh air must be available 365 days a year 24 hours a day in the required quantities and at the required temperature. At the same time, protection of the environment and the moderate and sustainable use of resources has become an important subject. These altered framework conditions pose a great challenge for the owners or operators of buildings, and require considerable know-how and outlay for operation.

Energy Contracting is the name of the service which the Zurich Municipal Electric Utility (ewz) - one of the 10 largest energy suppliers in Switzerland - has been offering now for 10 years. ewz plans, finances, realises and operates ecologically and economically meaningful energy supply solutions. The desired heat, cooling, conditioned air or other media are supplied to the customer for the duration of the contract - usually 15 to 30 years - at contractually-agreed and indexed prices. The customer has to pay a basic price for the installed performance and a working price for the quantity of energy supplied. The motivations of customers for using the Energy Contracting service are many: high availability of energy supply, innovation under acceptable commercial conditions, outsourcing of the investment and operating risk, inclusion of ecological aspects, calculable costs, optimised and safe operation, one contact partner, and much more.

Currently, across the whole of Switzerland, ewz operates 130 plants and 54 are under construction. In addition to residential and commercial properties, this also includes special properties such as the Badrutt's Palace Hotel in St. Moritz, the Training and Tuition Centre of the Zurich GC Football Club in Niederhasli, the Zurich Enclosed Stadium and the Mülligen Post Centre in Schlieren.

The primary goal of ewz is to construct installations which provide the necessary energy efficiently, cost-effectively and at the same time in a manner which safeguards resources and

the environment. At the project-development phase, innovative concepts are sought both in architecture and in the energy supply. The ground plot, orientation and shape of the planned building influence the energy requirement, as do the insulation and sealing level of the building shell. ewz is responsible for the successful implementation and realisation of the individually-developed energy supply solution.

Since it is responsible for the entire life-cycle of the plant during the term of the contract and also carries the operating risk, it is very interested in efficient operation.

The focus is primarily on projects in which the use of fossil energy carriers and CO₂ emissions can be reduced. For example by utilising previously unused energy sources - such as waste heat from computer centres or sewage plants - made useable by integrated heat networks, or by the use of environmental heat from lakes, groundwater or the earth. In the year 2007, ewz supplied its customers with 75'800 MWh of energy, 854'300 m³ of water for heating and cooling purposes and saved, in comparison with conventional (purely fossil) operated plants, a total of 9'500 tonnes of CO₂.

4 NATURAL REFRIGERANTS IN USE - EXAMPLES FROM PRACTICE

From the environmental point of view, particular attention is also focused on the type of refrigerants used in the heat pumps. First choice at ewz are natural refrigerants. Chlorine-free refrigerants are normally only used when natural media either cannot meet or over-fulfil the required performance parameters. The goal and motivation of ewz is, through the construction of more innovative solutions using natural refrigerants, to demonstrate their commercial and technical feasibility in practice and thus to prepare the way for their wider use. Many years of experience with heat pumps and refrigerating machines already in operation with natural refrigerants (total 14.5 MW) have clearly shown one thing: As regards reliability, there is no discernible difference from conventional plants. The following examples show the wide range of application of these heat pump installations.

4.1 GC Campus Niederhasli near Zurich

For the last three years, the Grasshoppers Football Club (GC) at Niederhasli has operated their own training and tuition centre. Here all players, from new trainees to the first team, find an optimal training environment. In addition to the five football pitches, the campus includes a service building with changing rooms, showers, a restaurant, residential college for football talents, schoolrooms and offices for the administrative staff of the club.



Figure 1: GC Campus at Niederhasli



Figure 2: CO₂ heat pump

Two heat pumps are used for the supply of the campus building with heat for heating and sanitary hot water. The larger of the two has four compressors and produces an output of 140 kW. It is provided with the chlorine-free refrigerant R134a. The heat requirement can be completely met by this heat pump. In addition, ewz has installed a second, smaller heat

pump with an output of 60 kW. This works with CO₂ as refrigerant. In consultation with the customer, ewz decided to install one of the first commercially-used CO₂ heat pumps in Switzerland. This has now been successfully in use for more than two years. In warm weather, both heat pumps use the outside air as source. During the colder times of year, 23 ground probes each with a bore depth of 150 metres are available. While the larger heat pump is mainly used for the heating of the rooms, the CO₂ heat pump serves for the production of the hot water. The CO₂ plant allows cold drinking water at 10°C to be heated to sanitary hot water at 65°C and more, with an annual performance factor of 3.3. Figure 3 shows the comparison of the sanitary hot water operation of an R134a with a CO₂ heat pump. The water thus heated is stored until use in the showers in three reservoirs with a total volume of 7'500 litres.

The extremely positive experiences with the CO₂ heat pump have encouraged ewz to install more plants of this type.

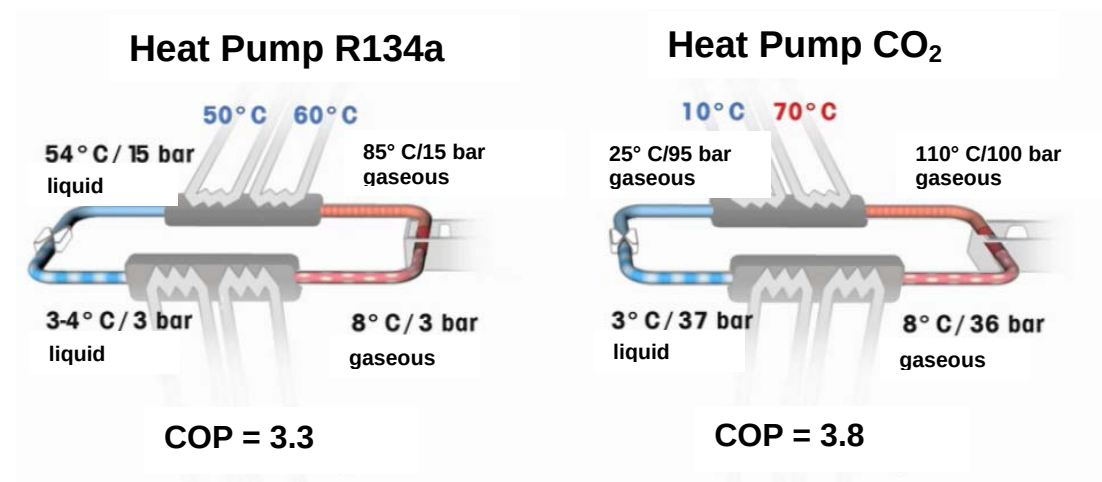


Figure 3: Comparison of the heat pumps in sanitary hot water operation

Table 3: Energy data, GC Campus

Heat requirement, heating and hot water per year	488 MWh
Heat pump (R134a)	140 kW
Heat pump (CO ₂)	60 kW
Ecology	
- Saving of fossil fuels per year	514 MWh
- Corresponding CO ₂ reduction per year	135 t

4.2 Badrutt's Palace Hotel, St. Moritz

Badrutt's Palace Hotel in St. Moritz is one of the most famous of hotels. Illustrious and well-known guests have been staying here for the last 150 years. The building includes 135 rooms and 30 suites, various restaurants and banqueting rooms, plus fitness and wellness facilities. Until now, the hotel complex was mainly heated with oil, and to a lesser extent with direct electricity. In 2006 the heating plant was due for replacement. The idea from ewz to install in Badrutt's Palace Hotel an innovative energy supply solution, in which the water of an Alpine lake (1724 metres above sea level) was to be used as heat source, inspired those responsible and the directors of the hotel decided to conclude an Energy Contracting agreement with ewz.



Figure 4: Badrutt's Palace Hotel St. Moritz



Figure 5: Lake water pipe prior to sinking

The final installation achieved is a first at this height above sea level. In addition to the hotel, the new plant supplies a schoolhouse and neighbouring multi-family houses with heat. In order to produce the heat, the cold water from Lake St. Moritz, which is at 4 degrees Centigrade in winter, is sucked up from around 10 metres below its surface, used as the source for a heat pump and then, via a second pipe, returned to the lake. The outlet for this is around 300 metres from the bank and 35 metres below the surface of the water. Thus it is ensured that the natural temperature stratification of the lake is not disturbed and the formation of the ice covering in winter is not endangered.

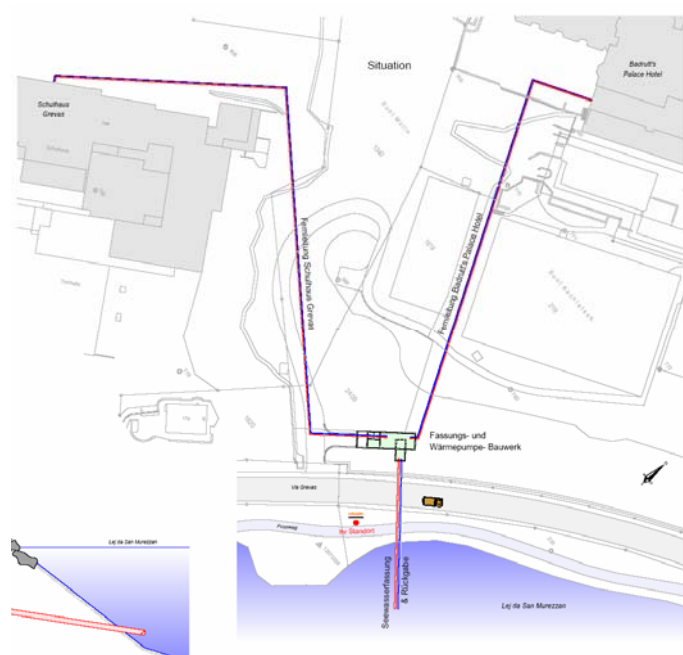


Figure 6: Overview of pipe network, St. Moritz



Figure 7: Building for heat pump

The heat pump used, with an output of 1.1 MW, works with NH_3 as refrigerant and produces water with a temperature of 73 degrees Centigrade. This is stored in three reservoirs, each with a capacity of 40'000 litres. In addition to the heat pump, the waste heat from the hotel's own waste incineration plant is used. In order to cover peak usage periods and to ensure security of supply, three modern oil-burning boilers are available. The use of lake water at such a low temperature was only possible, in view of the necessary high final temperature, due to the use of NH_3 as refrigerant. Although the large rise in temperature would have been achievable using conventional refrigerants, the consequence would have been a lower annual performance factor. This would not have satisfied the high requirements of ewz on the energy efficiency of the plant.

Table 4: Energy data, Badrutt's Palace Hotel and Schoolhouse

	Hotel	Schoolhouse
Heat requirement, heating and hot water per year	5'600 MWh	955 MWh
Heat pump (NH_3)	1.1 MW	
Oil-fired boilers (peak load)	4.5 MW	400 kW
Ecology		
- Saving of heating oil per year	4'000 MWh	750 MWh
- Corresponding CO_2 reduction per year	1'000 t	200 t

4.3 Mülligen Post Centre

Within the framework of the reorganisation of letter post traffic, last year the Swiss Post Office converted its existing parcels centre at Mülligen in Schlieren near Zurich into a letter sorting centre. Each hour, in the 1'000'000 m^3 building, around 40'000 letters are sorted and processed. During the conversion the energy centre, which supplies the post centre with heat and cooling, was also renewed.



Figure 8: Mülligen Post Centre



Figure 9: Energy centre

The new energy supply plant for the letter centre is part of the Energy Network for Schlieren, which is being planned, built and operated by ewz as energy contractor. In its final form, the Association will provide 52'000 MWh of heat annually. The Post Centre, as first stage, has a heat requirement of 9'500 MWh per year. The core of the Energy Network is the waste water purification plant at Werdhölzli, in which the waste water from the city of Zurich is purified. The purified water exiting from the plant has, even in cold winters, a minimum temperature of around 10 degrees Centigrade. It is thus well suited as the source for a heat pump. Part of the purified water is pumped via a pipeline to the letter centre, around 1.5 kilometres distant. The combined heat pump/refrigeration plant installed there works with NH₃ as refrigerant and uses the energy contained in the purified waste water to heat water to 65 degrees Centigrade. The heat pump covers around 50 percent of the heat requirement of the post centre. The other 50 percent are covered partly by the waste heat from the refrigeration plants which are needed for the operation of the centre and partly by existing, conventional gas boilers.

Table 5: Energy data, Mülligen Post Centre

Heat requirement, heating and hot water per year	9'500 MWh
Heat pump (NH ₃)	5.6 MW
Refrigerating machine (NH ₃)	4.3 MW
Gas-fired boilers (peak load)	6.3 MW
Ecology	
- Saving of fossil fuels per year	6'100 MWh
- Corresponding CO ₂ reduction per year	1'200 t

4.4 Energy Network Fraumünster, Zurich

Since 2001 ewz have been using water from Lake Zurich for the generation of heat and cooling within the framework of Energy Contracting agreements. Within the lake basin of Zurich, three energy networks are currently either operating, under construction or being planned, which use lake water as a source of heating or cooling. One of the projects is the Fraumünster Energy Network, with which three major buildings are supplied with heat and cooling: the church at Fraumünster, the Fraumünster Post Office and the Town Hall of the City of Zurich. Two further buildings are supplied with lake water for heating and cooling purposes.



Figure 10: Lake water pipeline prior to sinking into the Limmat

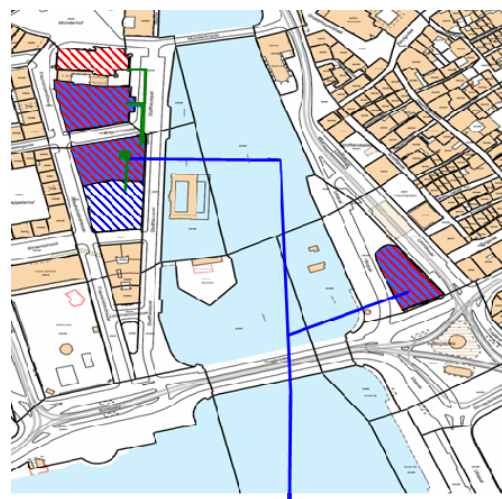


Figure 11: Overview, lake water pipeline

A pipeline around 400 metres long carries water from Lake Zurich to the energy centre in the Fraumünster Post Office. There a combined heat pump/refrigeration plant is installed. The original plan was to use a chlorine-free refrigerant. However, during the projection phase, ewz decided instead to use the natural refrigerant NH_3 which had proved itself to be very well suited to the planned requirements. The heat and cooling produced is distributed to the connected buildings via a local pipe network (water).

Table 6; Energy data, Fraumünster Energy Network

Heat requirement, heating and hot water per year	2'560 MWh
Heat pump (NH_3)	1.2 MW
Refrigerating machine (NH_3)	800 kW
Gas-fired boiler (peak load)	1.0 MW
Ecology	
- Saving of fossil fuels per year	2'840 MWh
- Corresponding CO_2 reduction per year	560 t

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