Annex 29

Ground-Source Heat Pumps - Overcoming Market and Technical Barriers

Final Report

Operating Agent: Austria

IEA Heat Pump Programme

2010

Report no. HPP-AN29-1

Published by

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Production

IEA Heat Pump Centre, Borås, Sweden

ISBN 978-91-86622-29-9
Report No. HPP-AN29-1

Preface

This project was carried out within the Heat Pump Programme, HPP which is an Implementing agreement within the International Energy Agency, IEA.

The IEA

The IEA was established in 1974 within the framework of the Organization for Economic Cooperation and Development (OECD) to implement an International Energy Programme. A basic aim of the IEA is to foster cooperation among the IEA participating countries to increase energy security through energy conservation, development of alternative energy sources, new energy technology and research and development (R&D). This is achieved, in part, through a programme of energy technology and R&D collaboration, currently within the framework of over 40 Implementing Agreements.

The IEA Heat Pump Programme

The Implementing Agreement for a Programme of Research, Development, Demonstration and Promotion of Heat Pumping Technologies (IA) forms the legal basis for the IEA Heat Pump Programme. Signatories of the IA are either governments or organizations designated by their respective governments to conduct programmes in the field of energy conservation.

Under the IA collaborative tasks or "Annexes" in the field of heat pumps are undertaken. These tasks are conducted on a cost-sharing and/or task-sharing basis by the participating countries. An Annex is in general coordinated by one country which acts as the Operating Agent (manager). Annexes have specific topics and work plans and operate for a specified period, usually several years. The objectives vary from information exchange to the development and implementation of technology. This report presents the results of one Annex. The Programme is governed by an Executive Committee, which monitors existing projects and identifies new areas where collaborative effort may be beneficial.

The IEA Heat Pump Centre

A central role within the IEA Heat Pump Programme is played by the IEA Heat Pump Centre (HPC). Consistent with the overall objective of the IA the HPC seeks to advance and disseminate knowledge about heat pumps, and promote their use wherever appropriate. Activities of the HPC include the production of a quarterly newsletter and the webpage, the organization of workshops, an inquiry service and a promotion programme. The HPC also publishes selected results from other Annexes, and this publication is one result of this activity.

For further information about the IEA Heat Pump Programme and for inquiries on heat pump issues in general contact the IEA Heat Pump Centre at the following address:

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Summary

Ground source heat pumps (GSHP) gain importance world-wide with respect to energy efficiency in heating and cooling operation. The ground acting as a seasonal store offers the possibility of damping the effects of the outside air temperature fluctuations, in colder climates it enables monovalent heating operation of the heat pump, and for utilities it is - compared with outside air operated heat pumps - a tool for demand side management measures.

In the last decades, heat pumps have acquired fundamental shares in markets such as Japan and the United States. Other markets including Europe, with the exception of Sweden and Switzerland, and other continental zones are struggling to develop the implementation of heat pump technologies as basic heating and comfort cooling devices.

Since the Eighties heat pump units and the components used like advanced compressors and flat plate heat exchangers, respectively, have been improved significantly. The development of heat source systems and heat sink systems on the one side and the system approach on the other side took much more time, and the development in the direction of highly efficient systems is still going on.

Within the framework of the IEA Heat Pump Programme 3 Annexes on ground coupled heat pumps have been carried out,

- Annex 2: Vertical Earth Heat Pump Systems,
- Annex 8: Advanced in-ground Heat Exchange Technology for Heat Pump Systems, and
- Annex 15: Heat Pump Systems with Direct Expansion Ground Coils,

showing the importance of this technology for both cooling and heating operation. A completely different use of the ground happens in the case of large systems with both cooling and heating demand. In such a case natural recharging of the ground no longer works, i.e. the heat extracted through heating operation has to be recharged artificially and an excellent solution is to use heat removal from cooling operation. However, taking this type of utilisation of the ground, the ground becomes a store, and the temperature changes in this store are the result of heat extraction/heat removal over the year.

In this context the Energy Conservation through Energy Storage Implementing Agreement has carried out

- Annex 13: Design, Construction and Maintenance of UTES Wells and Boreholes.

Taking these 4 Annexes both Programmes came to the result that

- Ground coupled systems offer in the case of heat pumping systems stable operating conditions.

- Ground-coupled heat pumps are presently dominating the heating-only heat pump market in Europe.
- Ground coupled heat pumps have been also identified as an interesting and energy efficient solution for the heating and cooling market in North America; there is also a large interest from other countries like Japan and China in this technology.
- In the case of large systems the ground can be used as a store, which offers in the case of heating and cooling operation at least improved conditions at the beginning of both the heating and the cooling season. Additionally, direct-cooling becomes possible.

The work of this IEA Heat Pump Programme Annex 29 includes a state of the art review and a market study on GSHPs, a matrix of GSHP applications depending on climate, ground conditions and applications, a study on how to improve technical performance and cost of GSHP systems, the identification of market barriers and innovative approaches to increase the acceptance and with the acceptance the market share of this highly efficient technology.

Heat pumps are an old technology, which has not been extensively used as long as both energy prices and the efficiency of electricity generation have been low. The oil crises have changed this situation, and now Kyoto is a further reason for the increasing market deployment of this technology. Based on recent developments, the following conclusions can be drawn:

- Heat pumps offer the possibility of reducing energy consumption significantly, mainly in the building sector, but also in industry. Basic second law thermodynamics show the advantages: while a condensing boiler can reach a primary energy ratio (PER) of 105 % (the theoretical maximum would be 110 % based on the lower calorific value), heat pumps achieve 200 % and more, with hydro or wind energy even 400 % and more.

- The drive energy is most commonly electricity, and for the future improved power generation systems based on renewables and fossil fuels have to be taken into consideration. The efficiency of gas-fired combined-cycle power plants available on the market is presently about 58 %, with oil as fuel similar values are possible. Ground-source (“geothermal”) heat pumps combined with low-temperature heat distribution systems achieve seasonal performance factors (SPFs) of 4 and higher, which means PERs of 220 to 280 %.

- Heat pumping technologies, i.e. refrigeration, air conditioning and heat pumps, have undergone and are undergoing several changes in working fluids and design. However, the efficiency today is generally better than before these changes and keeps rising. Thus, not only the environmental effects of the working fluids are being reduced, but also the effects of power plants producing the drive energy for the heat pumps – due to higher SPFs, higher power plant efficiencies, and an energy sources mix with lower CO_2 emissions. Therefore, the TEWI (Total Equivalent Warming Impact) is reduced significantly. Phasing out HFCs is not so much a problem of technology, it is a problem of efficiency. Applications will remain where "safety" refrigerants, i.e. non-toxic and non-flammable fluids, have to be used also in the future. But the natural refrigerants such as ammonia, propane, CO_2 and some others will get an increasing share. The question of environmental acceptability seems to be solved. The main point, however, is efficiency, and the energy requirement has to be minimized.

- Ground-coupled heat pumps gain importance world-wide with respect to energy efficiency in heating and cooling operation. The ground acting as a storage offers the possibility of damping the effects of the outside air temperature fluctuations, in colder climates it enables monovalent heating operation of the heat pump, and for utilities it is a tool for demand side management measures. New developments like improved heat pump units, advanced direct-expansion heat pumps or heat pumps combined with heat pipe based vertical probes show that there is still room for new ideas, which may be necessary for being competitive and successful in the future.

- Direct-expansion ground-source heat pumps already achieve SPFs between 4 and 5, if the building standards are being kept and the design of the overall system has been made carefully. Such high SPFs are the work of highly skilled system constructors; they do not sell heat pump units, they sell systems. The choice of the refrigerants they use, i.e. presently R-410A, propane and CO_2 for heat pipes, is motivated by efficiency, reliability, environmental considerations, safety and regulations. Direct-expansion systems, either with horizontally installed collectors or with bore holes down to 60 m, show increasing sales figures, and they dominate the Austrian market. But one has also to consider the building stock, and retrofitting this building stock will become the heat pump market of the future. New developments like improved heat pump units, advanced direct-expansion heat pumps or heat pumps combined with heat pipe based vertical probes show that there is still room for new ideas, which may be necessary for being competitive and successful in the future.

- The choice of an air conditioning systems for a commercial building depends on the climatic conditions, on the building and on the utilisation of the building. In the meantime the design of the building became the main factor concerning energy consumption. The air conditioning system has the task to compensate external and internal loads and to provide hygienic conditions and year round comfort for the customers. Additionally the air conditioning system offers possibilities to carry out this task with a minimum amount on energy by shifting heat from spaces, which have to be cooled to spaces, which have to be heated at the same time. Using the ground as a store additionally heat and cold can be stored to a certain extent and used for providing cold without additional energy input, i.e. for direct cooling, and for increasing the heat source temperature for heating. Using low-ex systems these effects can be further increased.

- Sorption systems - absorption, adsorption and DEC systems - also gain importance. The efficiency of sorption units has been improved significantly by introducing welded flat plate heat exchangers for reducing heat transfer losses.

- With highly efficient systems the advantages of thermodynamic heating and cooling can be demonstrated and used for reducing the energy demand significantly.

The potential for reducing CO_2 emissions assuming a 30 % share of heat pumps in the building sector using technology presently available is about 6 % of the total world-wide CO_2 emission. With advanced future technologies in power generation, in heat pumps and in integrated control strategies up to 16 % seem to be possible. Therefore, heat pumps are one of the key technologies for energy conservation and reducing CO_2 emissions.

Contents

1 Introduction

Ground source heat pumps (GSHP) gain importance world-wide with respect to energy efficiency in heating and cooling operation. The ground acting as a seasonal store offers the possibility of damping the effects of the outside air temperature fluctuations, in colder climates it enables monovalent heating operation of the heat pump, and for utilities it is - compared with outside air operated heat pumps - a tool for demand side management measures

The work of this IEA Heat Pump Programme Annex 29 includes a state of the art review and a market study on GSHPs, a matrix of GSHP applications depending on climate, ground conditions and applications, a study on how to improve technical performance and cost of GSHP systems, the identification of market barriers and innovative approaches to increase the acceptance and with the acceptance the market share of this highly efficient technology.

1.1 Background

In the last decades, heat pumps have acquired fundamental shares in markets such as Japan and the United States. Other markets including Europe, with the exception of Sweden and Switzerland, and other continental zones are struggling to develop the implementation of heat pump technologies as basic heating and comfort cooling devices.

Since the Eighties heat pump units and the components used like advanced compressors and flat plate heat exchangers, respectively, have been improved significantly. The development of heat source systems and heat sink systems on the one side and the system approach on the other side took much more time, and the development in the direction of highly efficient systems is still going on.

The first heat sink /heat source for cooling/heating operation was outside air, and outside air is still dominating heat pump systems for both heating and cooling. However, in the case of continental climates outside air has some disadvantages: The main cooling demand happens at the highest outside temperatures, the main heating demand at the lowest outside temperatures.

The characteristics of ground water as heat sink/heat source are completely different compared with outside air; ground water has, depending of the depth of the groundwater table, a more or less constant temperature, which means that heat pumps for cooling as well as heating can be operated at much better heat source/heat sink conditions. The problem is the limitation of the availability of ground water, additionally, licensing may cause problems.

A heat sink/heat source, which is, similar to outside air, almost not limited by availability, is the ground. Limitations can be the ground temperature in very hot regions and the composition of the ground, i.e. solid rock, clay and sand can be easily used as heat sink/heat source, the utilisation of clay or sand with embedded rocks or cracked rock with gaps is more or less impossible.
However, in cold regions with mainly heating demand ground-coupled systems are dominating the market, and the share of systems for cooling is also increasing.

Within the framework of the IEA Heat Pump Programme 3 Annexes on ground coupled heat pumps have been carried out

- Annex 2: Vertical Earth Heat Pump Systems,
- Annex 8: Advanced in-ground Heat Exchange Technology for Heat Pump Systems, and
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showing the importance of this technology for both cooling and heating operation. A completely different use of the ground happens in the case of large systems with both cooling and heating demand. In such a case natural recharging of the ground no longer works, i.e. the heat extracted through heating operation has to be recharged artificially, and an excellent solution is to use heat removal from cooling operation. However, taking this type of utilisation of the ground, the ground becomes a store, and the temperature changes in this store are the result of heat extraction/heat removal over the year.

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Taking these 4 Annexes both Programmes came to the result that

- Ground coupled systems offer in the case of heat pumping systems stable operating conditions.
- Ground-coupled heat pumps are presently dominating the heating-only heat pump market in Europe.
- Ground coupled heat pumps have been also identified as an interesting and energy efficient solution for the heating and cooling market in North America; there is also a large interest from other countries like Japan and China in this technology.
- In the case of large systems the ground can be used as a store, which offers in the case of heating and cooling operation at least improved conditions at the beginning of both the heating and the cooling season. Additionally, direct-cooling becomes possible.

However, using this excellent heat sink/heat source, it is necessary to consider the system including the building – with small specific loads - the heat source and the heat sink system – a new approach is low-temperature heating and high-temperature cooling – the heat pump unit and the system control. Taking all these aspects as a whole highly efficient systems can be realised.

One problem of ground coupled systems compared with air based systems is the higher investment cost for making use of this excellent heat sink/heat source system. Therefore it is necessary to base such systems on a life cycle cost basis, where they really can show their advantages compared with other heating and/or cooling systems.

1.2 Project Description

Ground source heat pumps cover

- Ground-coupled (heat is directly extracted/removed from/to the ground)
- Groundwater (heat is extracted/removed from/to groundwater)
- Surface water (heat is extracted/removed from/to surface water like ponds, lakes, ort the sea)

Ground source heat pumps (GSHPs) provide heating, cooling and hot water.

- The ground dampens temperature variations and leads to high GSHP efficiencies
- The initial costs of GSHP systems are most commonly higher, but operating and maintenance costs are lower (Climates requiring heating and cooling are most promising)

Ground source heat pumps can be applied for different climates, different ground properties, for small and large systems, and for heating-only as well as heating and cooling applications.

Climate

The climate has a strong influence on the ground temperature available and on the operating conditions of a heat pump systems (cold, moderate and hot climate, hot an humid climate, oceanic climate with small temperature fluctuations or continental climate with large temperature fluctuations).

Ground properties

Ground properties are responsible for the type of ground utilisation and the heat disposal/heat extraction method, i.e. open or closed loop system. In the case of a closed loop system they are also responsible for the ground heat exchanger type used.

Small systems

The common characteristic of small systems is natural ground recovery, mainly by solar radiation collected by the ground surface. Small systems are in use for heating as well as heating and cooling, they can be used, depending on the climate and the distribution system, for direct cooling (without heat pump operation), at least at the beginning of the cooling season.

Large systems

For large system recovery of the ground has to happen by heat removal and heat extraction. Sometimes additional systems for recharging the store have to be provided. Heat removal can happen by direct cooling (without heat pump operation) and indirect cooling (with heat pump operation).

The work in this Annex will include:

1. Study of ideas to improve technical performance and cost of GSHP systems such as
   - heating-only vs. heating and cooling systems
   - open vs. closed loop system
   - horizontally installed systems vs. different vertical systems
   - direct expansion and secondary loop systems
   - use of different secondary fluids like CO2
   - heat-pipe based vertical probes with CO2 as working fluid
   - direct and indirect cooling
   - recharging and moisture migration in soil
   - surface collection (parking lots, runways etc.)

2. Identification of market barriers and innovative approaches to increase GSHP acceptance such as
3. Increasing acceptance by quality ensurement measures
4. Enlarging guarantees for ground coil systems
5. Overcoming high first cost through contracting models covering the heat source system, the heat pump system or the whole heating or heating and cooling system
6. Identification of market barriers and innovative approaches to increase GSHP acceptance such as
   - high first cost
   - regulations
   - tariff structures (DSM)

1.2.1 OBJECTIVES

Investigation of ideas and depending on climate and application identification of systems that could improve performance and market attractiveness of GSHP Systems.

The goal of this Annex is the demonstration of the economic and the environmental benefits of ground coupled systems.

1.2.2 STRATEGY AREA

The strategy areas covered in this project will be

- Technology (new and cost effective in-ground heat exchangers and systems for heat extraction and removal),
- Environment (benefits from reduced drive energy, but also reducing the impact on the ground), and
- Market Deployment (dissemination of experiences already made in participating countries).

1.2.3 PROJECT APPROACH

Task sharing, with some cost sharing of Operating Agent expenses for coordination, project management, one or two workshops, and reporting.

Note: a key element in this project is sharing of information and experiences among participants.

1.2.4 PRODUCT OR DELIVERABLES

Interim reports for discussion and review by marketing experts nominated by each of the participants. The information gathered should be used to assist

- The Research community,
- Utilities,
- Manufacturers, and
- Planners.

The final product should include different types of publications, one for each category of target groups:

- Policy makers
- Planners
- Designers and Installers.
- End-users (and design community) provided in the native language of the participating countries.

The overall intention is to develop improved technical and marketing solutions that can assist in development of a much larger GSHP diffusion

1.3 Participants in Annex 29

Austria
Hermann Halozan, Hermann Schranzhofer, Rene Rieberer, Graz University of Technology
Bernhard Widerin, ENERCRET Nägele Energietechnik GmbH & Co
Andreas Bangheri, Heliotherm
Karl Ochsner, Ochsner Wärmepumpen
Karl Mittermayr, Mtec Mittermayr

Canada
Vasile Minea, Hydro Quebec Institut de recherche

Japan
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Norway
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Mattias Stenlund, Monica Axell, Roger Nordman, SP Provning Forskning
Per Lundquist, Peter Hill, KTH
Göran Hellström, Lund Univerity of Technology
Anna-Maria Gustafsson, Bo Nordell, Lund University of Technology
Per Fahlén, Chalmers University of Technology
Martin Forsen, SVEP

USA
Moonis R. Ally, John J. Tomlinson, Van Baxter, Oak Ridge National Laboratory

Arun Vohra, U.S. DOE Space Conditioning, Refrigeration & Water Heating Program

Guests
Peoples Republic of China
Wei Xu, China Academy of Building Research

2 ACTIVITIES OF ANNEX 29

The topic ground source heat pumps has been discussed at several meetings of the Executive Committee of the IEA Heat Pump Programme. Within the framework of the IEA Heat Pump Programme three Annexes on ground coupled heat pumps have been carried out, Annex 2: Vertical Earth Heat Pump Systems, Annex 8: Advanced in-ground Heat Exchange Technology for Heat Pump Systems, and Annex 15: Heat Pump Systems with Direct Expansion Ground Coils; the Energy Conservation through Energy Storage Implementing Agreement has carried out Annex 13: Design, Construction and Maintenance of UTES Wells and Boreholes. Many countries showed interest, but the final decision was missing.

September 13/14, 2003
To overcome this situation an expert meeting was initiated by Austria. It took place at the facilities of arsenal research in Vienna, 10 counties expressed their interest and 7 countries - Canada, Germany, Slovakia, Spain, Sweden, Switzerland, and Austria attended this meeting, apologies came from China, Japan, and Netherlands.

October 28/29, 2003
At the Executive Committee Meeting of the IEA Heat Pump Programme in Boras, Sweden, October 28 – 29, 2003, based on the expert meeting in Vienna Annex 29 has been started officially. Starting date was January 1st, 2004, the end was planned with June 30th, 2006. Seven countries have decided to join, i.e. Canada, Japan, Norway, Spain, Sweden, the United States of America, and Austria as Operating Agent.

September 13, 2004
The KickOff Meeting of Annex 29 in the facilities of arsenal research in Vienna was attended by eight countries, Canada, the Czech Republic, Japan, Norway, Spain, Sweden, the United States of America, and Austria. In this meeting based on presentations of the participants the working plan of Annex 29 has been discussed in depth and has been finally decided. Unfortunately, the Czech Republic and Spain were not able to attend the Annex.

May 30, 2005
At the 8th International Energy Agency Heat Pump Conference "Global Advances in Heat Pump Technology, Applications, and Markets" in Las Vegas, Nevada, on May 30 – June 2, 2005, in the afternoon of May 30 a workshop on Annex 29 took place. More than 90 attendees of countries all over the world joined this workshop, where representatives of the participating countries Canada, Japan, Norway, Sweden, the United States of America, and Austria presented research and development activities and the market development in their countries.

May 11/12, 2006
On May 11 – 12, 2006, in Linz, Upper Austria, a workshop and a working meeting of Annex 29 took place. In the workshop the representatives of the participating countries Canada, Japan, Norway, Sweden, the United States of America, and Austria as well as participants from Austria representing the European Heat Pump Association EHPA, the Association of the Electric Utilities VEOe, the Heat Pump Association LGWA, the Heat Pump Manufacturers Association BWP gave presentations on the international and national situation of ground source heat pumps. An interesting topic

was the Austrian klima:aktiv programme with the goal to improve the market share of highly efficient heat pumps in Austria. In the afternoon a visit of the heat pump manufacturer NeuraTherm in Regau, specialised on direct expansion ground source heat pumps using propane as refrigerant, took place. At the working meeting on May 12 the country report and the matrix of ground source heat pumps were discussed and a decision on the further working plan was taken.

May 18/19, 2006
At the Executive Committee Meeting in Tokyo, May 18 – 19, 2006, the Operating Agent asked due to a delay in the working plan the Executive Committee for an extension of Annex 29 until the spring meeting 2007 of the committee. Sweden asked for an extension to the fall meeting 2007, and the delegates proposed finishing the Annex with the fall meeting and presenting the results of Annex 29 at the IIR Congress in Beijing, China, August 21 – 26, 2007. The next working meeting of the Annex 29 will take place in Sapporo, Japan, in January 2007.

November 15-17, 2006
The 9. Geothermische Fachtagung in Karlsruhe, Germany, combined with the 6th Symposium on Ground Source Heat pumps, which was organised by Burkhard Sanner, was the platform for a presentation of Annex 29 by Hermann Halozan.

Another participant in Annex 29, Goran Hellstrom, gave interesting presentations on ground source heat pumps in Sweden and on the thermal response test, an important tool for designing large systems. This meeting showed again the importance of ground source heat pump systems.

January 15-17, 2007
In Sapporo, Japan, a workshop and a working meeting of Annex 29 took place. The event has been organised by Prof. Katsunori Nagano, Hokkaido University and his team and Dr. Li, Heat pump technology and thermal storage center of Japan, and it became an excellent meeting. On January 15 a workshop took place at the Conference Hall of Hokkaido University, Sapporo, with interesting presentations of the participants in this Annex from Canada, Japan, Sweden and Austria as well as experts from all over Japan and guests from China. A technical visit covered a snow melting pavement with GSHP at Faculty of Agriculture of Hokkaido University.

On January 16 site visits took place, the participants saw a GSHP demonstration installation at the Tondenkita Public Junior High School, snow melting systems, and GSHP installations at the Hokkaido Electric Meter Industry Co., Inc. and at the Sapporo City University. In the late afternoon there was the possibility for a walk around Jigokudani (the hell valley), a volcanic site, in the evening there was a dinner in the Noboribetsu Grand Hotel, where on January 17 the working meeting of Annex 29 took place.

Decisions were taken on the further steps of the working plan.The final site visit in the afternoon was to a very nice and well designed low energy house in the Naganuma town with a ground source heat pump, a ground air collector for pre-heating and pre-cooling the ventilation air and a CO_2 heat pump water heater.

August 21-26, 2007

In Beijing, P. R. China, the 22nd IIR International Congress of Refrigeration - Refrigeration Creates the Future, ground source heat pumps also played an important role, both in the oral and in the poster presentations. A technical tour went to a large ground source heat pump installation suitable for both heating and cooling using 700 boreholes with a depth of 100 m equipped with double u-tube coils.

November 1-2, 2007

In Beijing, P. R. China, an IEA NEET Workshop took place. One of the few presentations on end-use energy technologies was a session on heat pumps. While the presentation of the HPP covered globally the development of heat pump components, units and systems – one topic were ground source heat pumps, the presentations from China by Prof. XU Wei, Director, Institute of Air Conditioning, China Academy of Building Research and Mr. CONG Xuri, Chairman of the Hundred Group, were concentrated on applications and installations of ground source heat pumps in China.

November 14, 2007

In Brussels, Belgium, a joint workshop of IAs ECBCS and the HPP, took place, where some of the Annexes of the two IAs have been presented. One of these Annexes was Annex 29 Ground Source Heat Pumps – Overcoming Market and Technical Barriers, and it has been demonstrated, what a variety of different solutions using the ground as heat source/heat sink or as a store can achieve highly efficient and environmentally friendly solutions for heating and cooling buildings.

November 15-16, 2007

At the Executive Committee Meeting of the HPP, also in Brussels, Belgium, it has been decided that Annex 29 will be extended until spring 2008. This happened due to the fact that important publications of one participating country were still missing. A further decision was that the final workshop of this Annex will be held on Monday morning, May 19, 2008, in combination with the 9th IEA Heat Pump Conference Advances and Prospects in Technology, Application and Markets, which will take place in Zürich, Switzerland, on May 19-22, 2008.

May 19, 2008

Combined with the 9th IEA-HPP Heat Pump Conference "Advances and Prospects in Technology, Application and Markets", which took place in the Swissotel in Zurich, Switzerland, a workshop on Annex 29 took place, where all the participating countries and China gave presentations on developments ground source heat pump technologies, demonstration projects and the market development. More than 50 people from all over the world attended this workshop.

May 20-22, 2008

On May 20-22, 2008 the 9th IEA-HPP Heat Pump Conference "Advances and Prospects in Technology, Application and Markets", took place in the Swissotel in Zurich, Switzerland. 447 registered participants from 36 countries had the possibility to join 72 oral presentations and 6 HPP Annex workshops and to see 150 posters covering most recent developments on markets and improvements in heat pumping technologies. Ground source heat pumps played an important role in this conference.

May 23-24, 2008

At the Executive Committee Meeting of the HPP, also in Zurich, the final presentation of Annex 29 “Ground Source Heat Pumps – Overcoming Market and Technical Barriers” took place. It has been decided to produce a flyer on the findings of Annex 29. The final report of Annex 29 will be sent out in the next weeks.

3 STATE OF THE ART

3.1 Market Analysis

3.1.1 Austria

Heat pump market in Austria

The Austrian heat pump market started after the second oil price shock, stimulated by tax reduction measures for energy saving investments by the Austrian government and supported mainly by the Upper Austrian Energy Corporation (OKA). After reaching a peak in installations, the market collapsed, was stabilized on a lower level, dropped again and is now recovering, as can be found in Figure **3.1**. In this figure the number of installed systems over the years parted into the four applications, indoor pool dehumidification, ventilation, space heating and domestic hot water (DHW) preparation are shown.

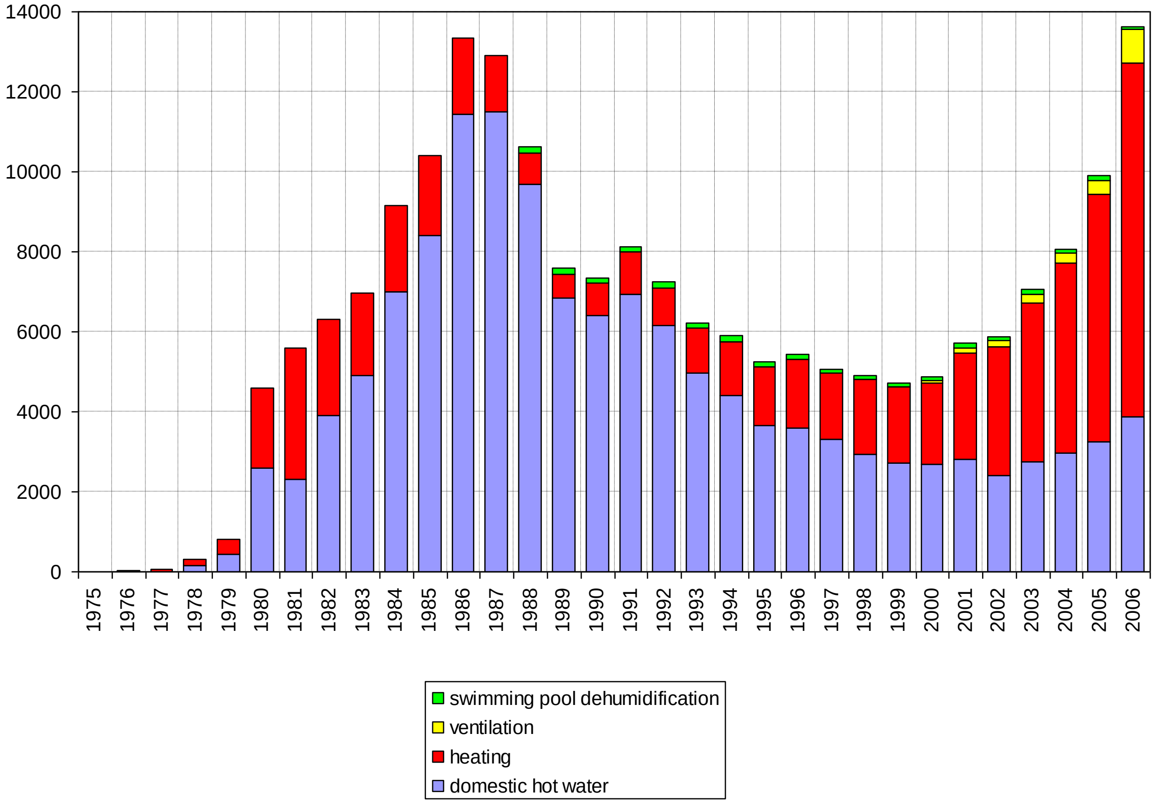


Figure 3.1: Heat pump market in Austria from 1975 to 2006; yearly installed systems (reproduced from Faninger, 2007)

It can be seen that in the first 25 years the main part of installed systems were for DHW preparation. In the last 5 years the number of installed systems for heating is increasing while the number for DHW preparation is nearly constant. This circumstance can be seen more clearly in **Figure 3.2** showing a separated view of yearly installed systems for heating and DHW preparation. Also the part of ventilation systems is more and more of interest due to the application in so-called passive houses.

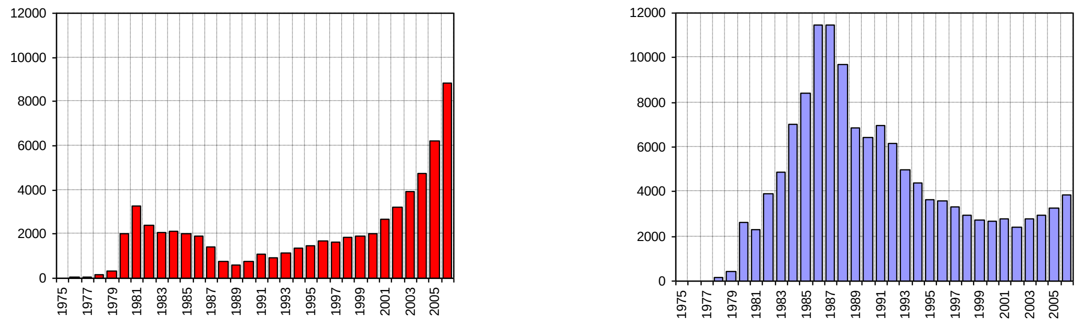


Figure 3.2: Separated view of yearly installed systems for heating (left) and DHW preparation (right) (reproduced from Faninger, 2007)

The distribution of installed heat pumps to the four different applications for the year 2006 is shown in **Figure 3.3** indicating the main part for heating with 64.9 %. The increasing part of ventilation systems in passive houses is also shown with 6.2 %.

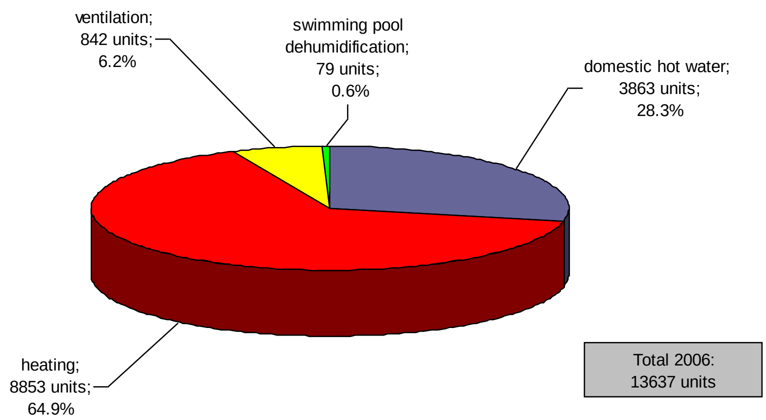


Figure 3.3: Distribution of installed systems to the four applications in 2006 in Austria (reproduced from Faninger, 2007)

Heat pumps installed in Austria were – like in other countries in Northern and Central Europe – either

- Ground water heat pumps for monovalent systems for new buildings equipped with floor heating or low-temperature radiator systems, or

- Outside air heat pumps for bivalent systems, most commonly combined with existing oil-fired boilers, for retrofitting existing buildings with high-temperature heat distribution systems with radiators; this application dominated the market.

The rapid drop of oil price in 1985 in combination with the significant reduction of governmental subsidies reduced sales figures of heat pumps (see Figure **3.1**) and especially bivalent outside air heat pumps integrated into high-temperature hydronic heat distribution systems had – due to their low Seasonal Performance Factor (SPF) – no longer a chance. The operation of the oil-fired systems alone was cheaper than that of a bivalent outside air system.

Ground water heat pumps for new buildings equipped with low-temperature heat distribution systems were still competitive; however, the availability of ground water was limited and licensing often caused problems. Another heat source had to be found, and this heat source was the ground itself. This led to increasing sales figures for systems with ground as heat source and decreasing sales figures for outside air heat pumps, as shown in **Figure 3.4**. Due to the mentioned licensing problems for ground water heat pumps the sales figures for these systems are nearly constant and rather low.

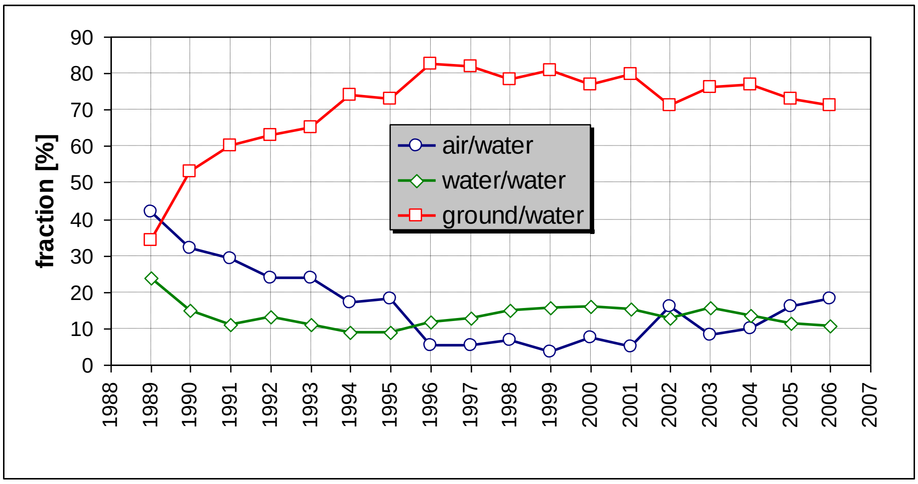


Figure 3.4: Rates of heat sources for heat pumps (heating only) in Austria between 1989 and 2006 (reproduced from Faninger, 2007)

For 2006 the rates of heat sources are shown in **Figure 3.5**. The all over share of ground source heat pumps (direct expansion, water/water and brine/water) is about 82 %, whereas air/water systems are only 18 %.

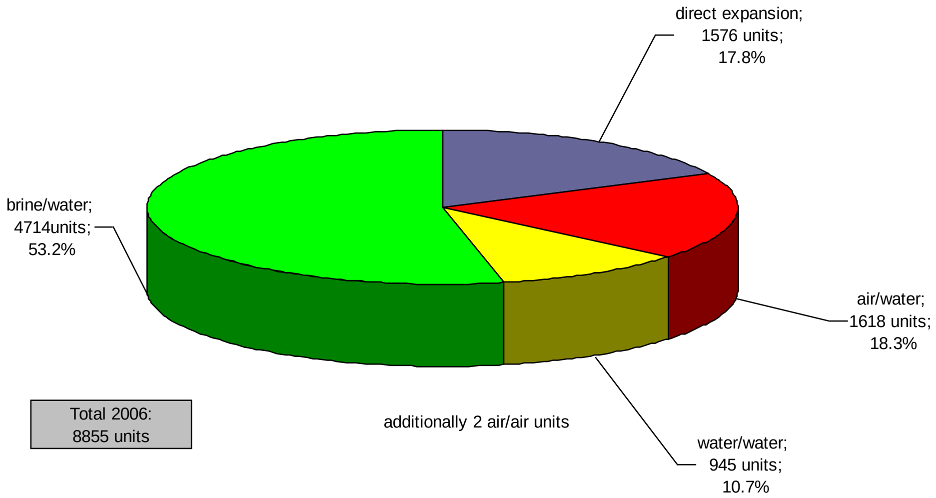


Figure 3.5: Rates of heat sources for heat pumps in Austria in 2006 (reproduced from Faninger, 2007)

The main part of ground source heat pumps is the share of brine/water systems (53.2%). Nevertheless, there is also a share of 17.8% direct expansion systems installed. For these systems a higher SPF can be achieved due to the fact that the working fluid is used directly as heat exchanging fluid in the ground collector. The decrease of share of direct expansion systems in the last years (see **Figure 3.6**) is caused by the circumstances that there are more brine/water systems on the market available and that the number of ground coil systems is increasing.

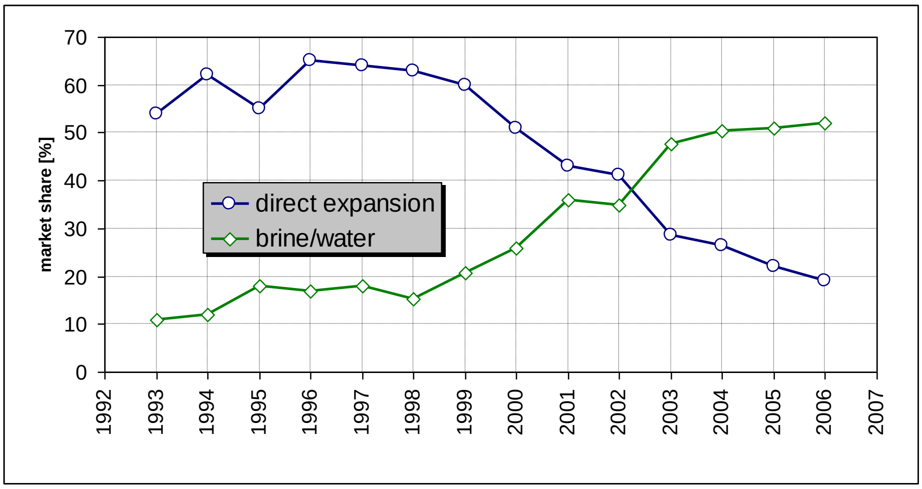


Figure 3.6 Share of ground source heat pumps related to the total number of heat source systems between 1993 and 2006 (reproduced from Faninger, 2007)

Faninger does not give absolute values for these two systems because there is an ongoing competition and such numbers would cause speculation which is not in the interest of companies in Austria. Nevertheless, these values can be calculated roughly using data from his report (Faninger, 2007). The results in **Figure 3.7** show that the numbers of soled units with direct expansion are nearly constant over the years whereas the numbers for brine/water systems are strongly increasing since 2002.

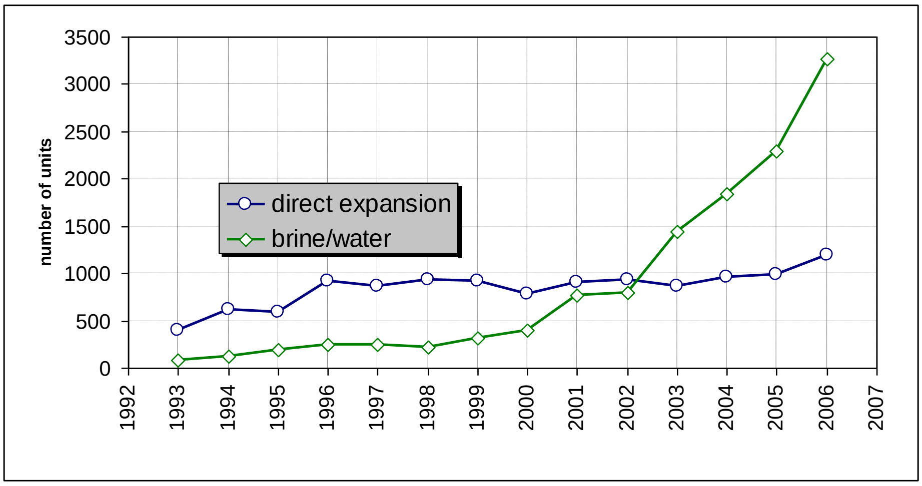


Figure 3.7 Number of soled ground source heat pumps (direct expansion and brine/water systems) between 1993 and 2006 (calculated data taken from Faninger, 2007)

With ground source heat pumps for low energy buildings SPFs of 4 to 5 can be achieved nowadays. For air/water heat pumps in heat recovery systems for passive houses including a ground chiller for air preheating SPFs of 3 are possible. Also ecological aspects are remarkable: In the case of the Austrian electricity mix compared to fuel oil the CO_2-equivalent for all heat pump systems installed results in

493 149 tons/year. For the 219 500 solar thermal systems operated at the end of 2005 in Austria (a total of 3 009 million m²) the CO_2-equivalent is 443 746 tons/year. This comparison shows the importance of the heat pump technology for future-oriented energy supply in Austria.

It could also be of interest for the reader to compare heat pump sales figures with those of other renewable energy heating systems. **Figure 3.8** shows that the number of heat pump units in operation increased more or less monotonous since 1975. The market for wood chips and pellets systems started much later, had a very strong increase in the last years but didn't reach the numbers of heat pumps in operation.

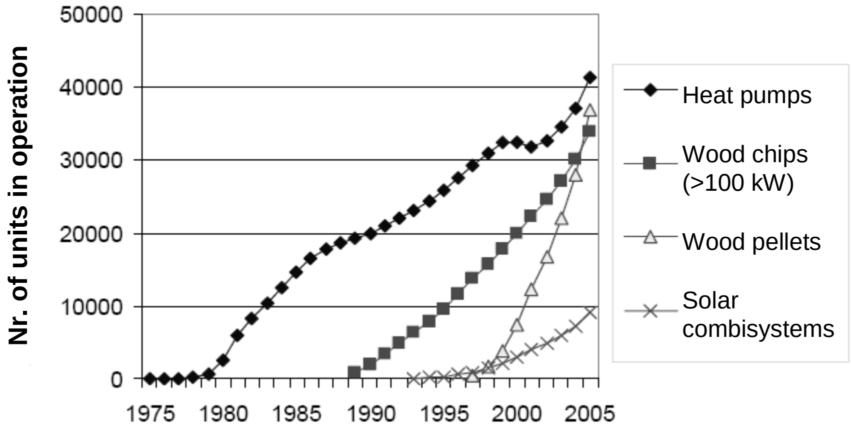


Figure 3.8: Number of installed units of different renewable energy heating systems in Austria from 1975 to 2005 (Schriefl, 2007)

The solar-combi systems (for space heating and DHW preparation) are no real competitor for the other alternatives.

In the year 2002 the relative rates (relating to the apartments) of pellets systems, wood chips systems, biomass district heating and heat pump systems were between 1 and 2 % for one- and two family houses respectively 0.5 and 1 % for all other buildings (see **Table 3.1**). The figures show clearly that the main application area is the one and two family house and again that the heat pump is dominating.

Table 3.1: Relative rates of apartments different „alternative" heating systems in 2002 (Schriefl, 2007)

Heating System	One- and Twofamily House	Multifamily House	all residential buildings
Pellets	1.12%	0.06%	0.57%
Wood Chips	1.81%	0.17%	0.95%
District Heating	1.37%	0.23%	0.77%
Heat Pump	2.17%	0.00%	1.04%
Solar Combisystem	0.45%	0.00%	0.21%

Nevertheless, it should be stated that in the area of domestic hot water preparation the market for heat pumps was decreasing in the last years whereas the figures for solar thermal systems strongly increased (see **Figure 3.9**).

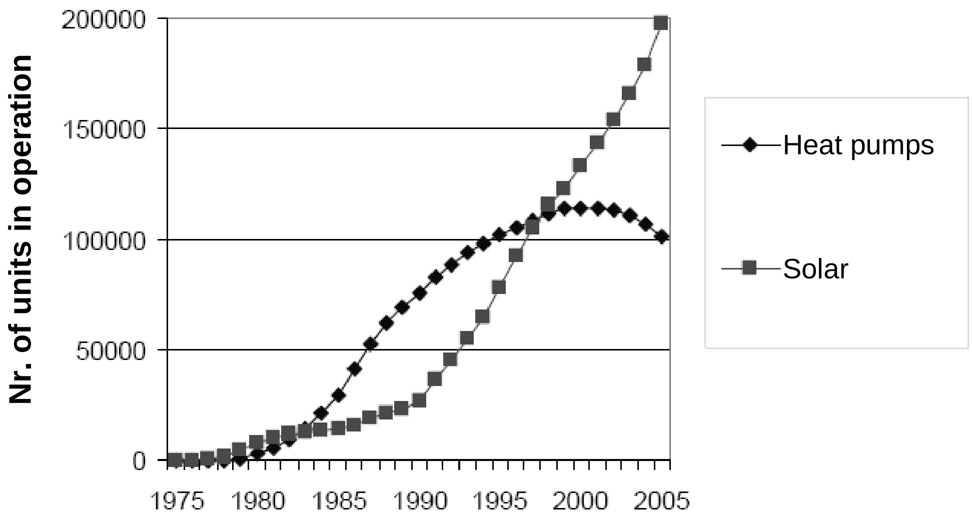


Figure 3.9: Number of solar thermal systems and heat pump systems in operation for domestic hot water preparation from 1975 to 2005 (Schriefl, 2007)

Energy costs in Austria

There are several statistics available. Basically the values can be calculated by using the VDI 2067 (Wirtschftlichkeitsberechnung nach der Annuitätenmethode) or according to ÖNORM M7140. Here some results are presented calculated by the "Energie AG Oberösterreich" Schupfer, Zivkovic (2006).

Figure 3.10 show the costs in cent for useful heat of different types ("Wärme Oberösterreich GmbH" is the company that unites all district-heating activities of "Energie AG" in Upper Austria). It can be seen that the costs for fossil fuel like oil, coke and gas is rather high whereas natural sources like pellets and wood is much lower. The cheapest in this ranking is the ground source heat pump in combination with a floor heating system leading to only 2.51 cent/kWh.

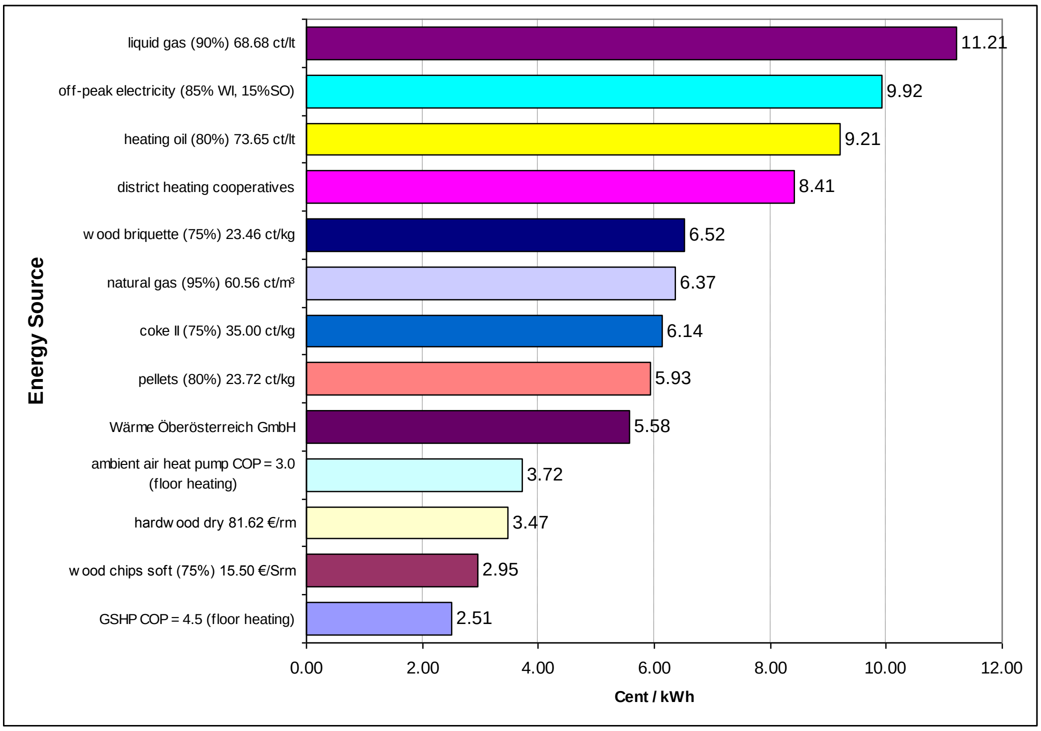


Figure 3.10: Useful heat for 1 kWh, fuel costs without additional charges; values from 1.9.2006 (reproduced from Schupfer, Zivkovic, 2006)

In **Figure 3.11** the resulting yearly operating costs are shown for different heating systems. As expected from **Figure 3.10** again the costs for systems using fossil fuel are much higher than for renewable sources and the GSHP system is the cheapest one. Nevertheless, it should be stated that in the case of investment costs the case is just the other way around. Here the GSHP is the most expensive system and systems with oil or gas are much cheaper (see **Figure 3.12**).

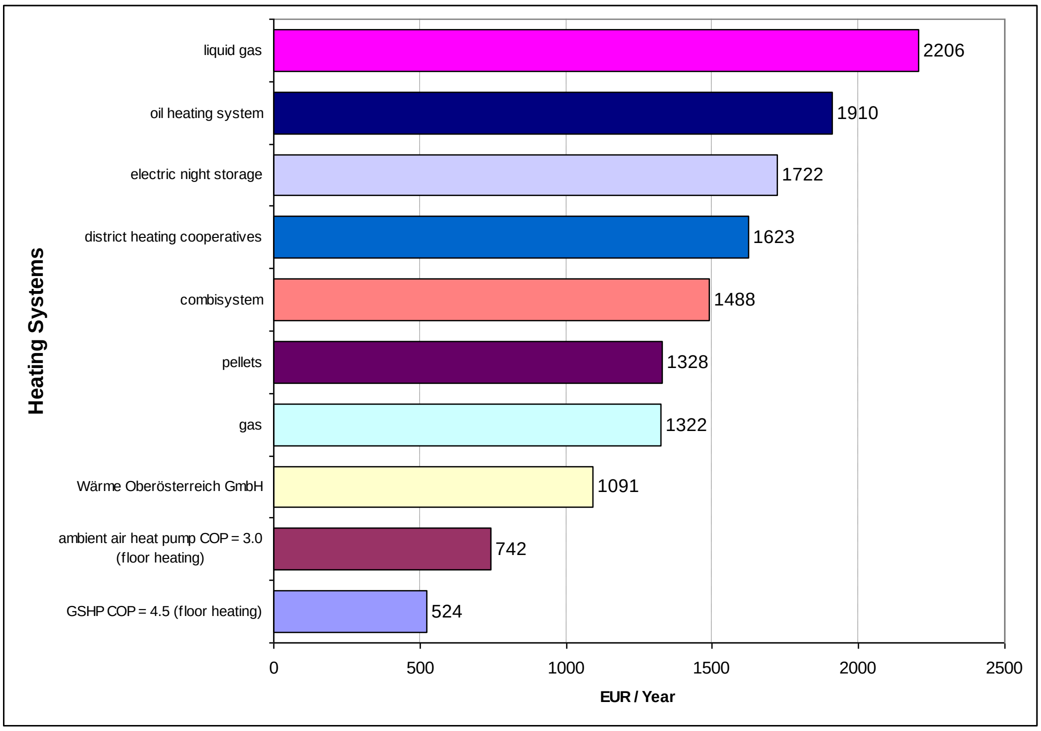


Figure 3.11: Yearly operating costs for different heating systems; residential building with 175 m² and a heating load of 9 kW; without domestic hot water preparation; values from 1.9.2006 (reproduced from Schupfer, Zivkovic, 2006)

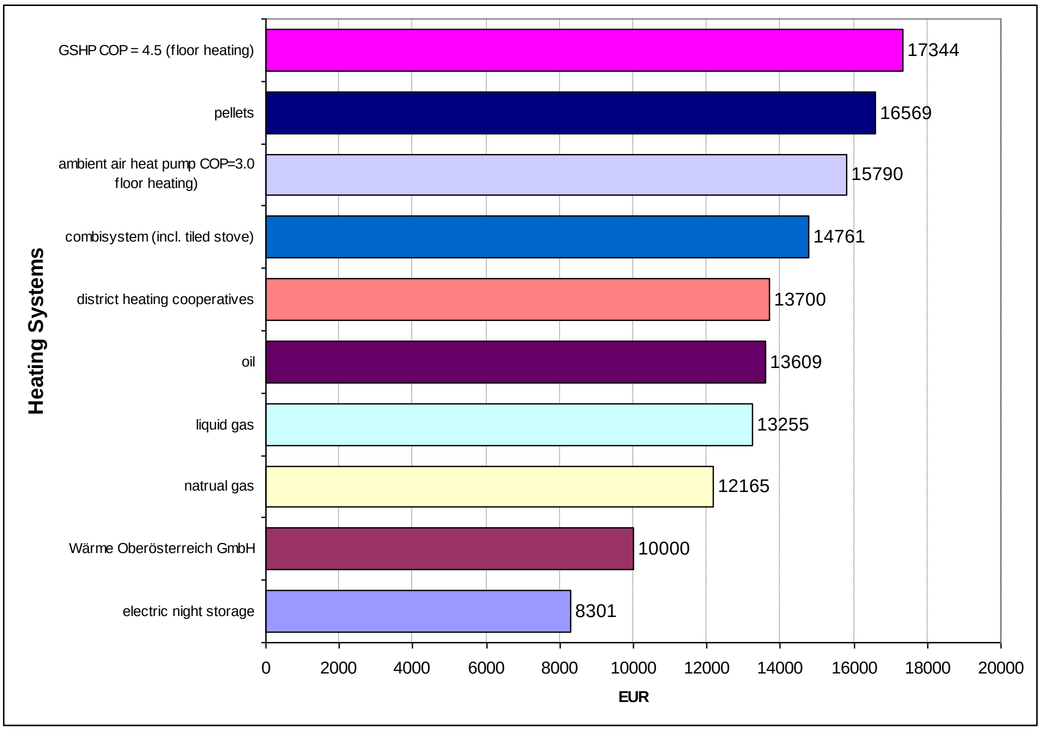


Figure 3.12: Investment costs for different heating systems; oil and Pellets without tank resp. store room; residential building with 175 m² and a heating load of 9 kW; without domestic hot water preparation; values from 1.9.2006 (reproduced from Schupfer, Zivkovic, 2006)

A possibility to compare the costs for different heating systems is to look at the operation costs for 20 years including the investment costs (**Figure 3.13**). And again the GSHP system is the cheapest one and for the fossil fuel systems the highest costs can be expected.

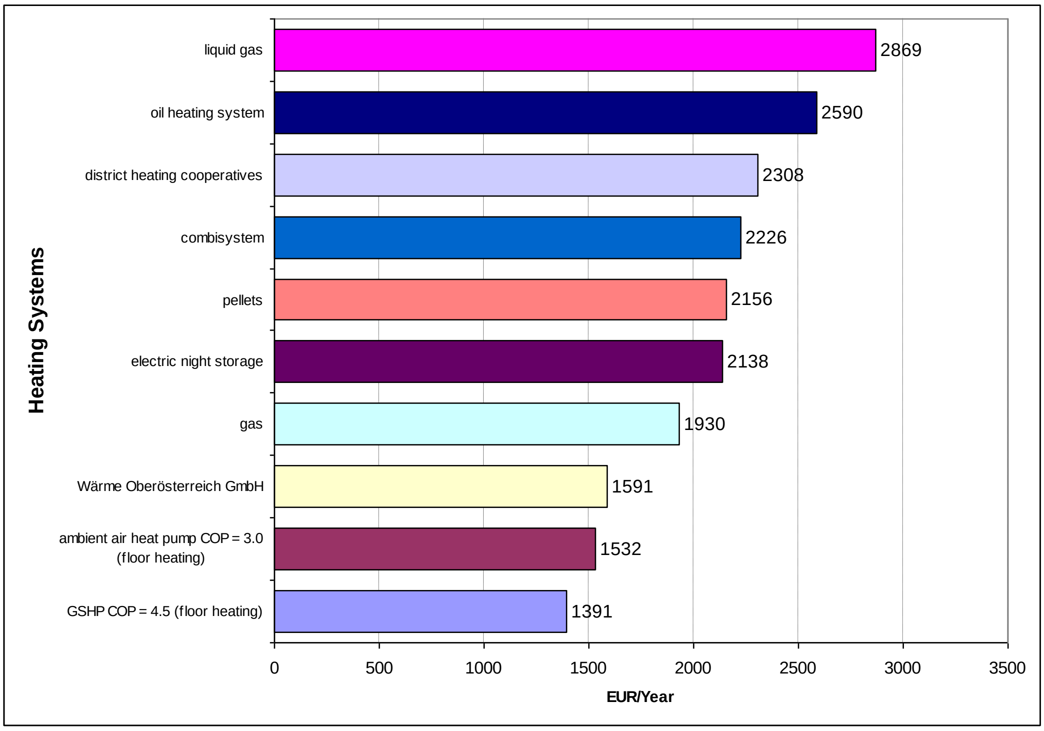


Figure 3.13: Average total costs (investment and operation) per year for different heating systems over 20 years; oil and Pellets without tank resp. store room; residential building with 175 m² and a heating load of 9 kW; without domestic hot water preparation; values from 1.9.2006 (reproduced from Schupfer, Zivkovic, 2006)

It should be stated here that these values are strongly dependent on the chosen parameters for the calculation. Different institutions publish different results and there is often no detailed information about the parameters. The investment costs depend strongly on the used system (e.g. a horizontal ground heat exchanger is much cheaper in Austria than a borehole heat exchanger). Additionally, the costs for different energy carrier are varying (e.g. the price for pellets was strongly increasing in Austria between August 2006 and January 2007 and decreased again afterwards as shown in **Figure 3.14**).

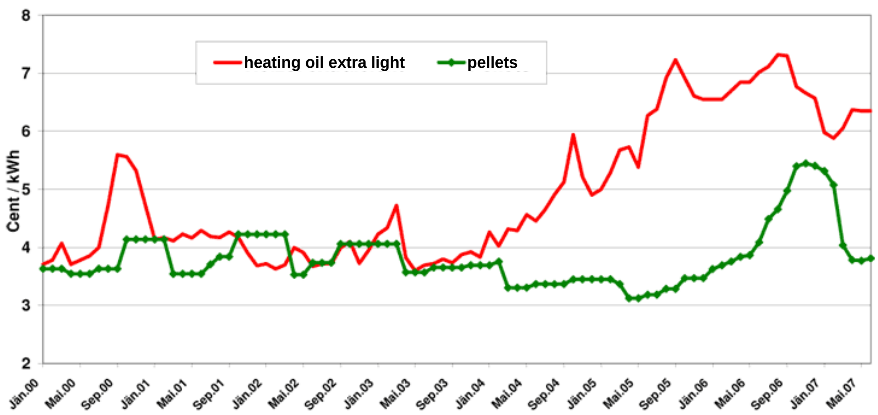


Figure 3.14: Price development of pellets and heating oil (calimax)

The Institute for economic oil heating systems (IWO) states that due to their calculations relating to the ÖNORM M7140 a heating oil system is the cheapest one for a one family house with 130 m², 10 000 kWh/year heating demand, 8 kW heat load and a calculation period of 15 years including taxes and without any subsidy (see **Figure 3.15**).

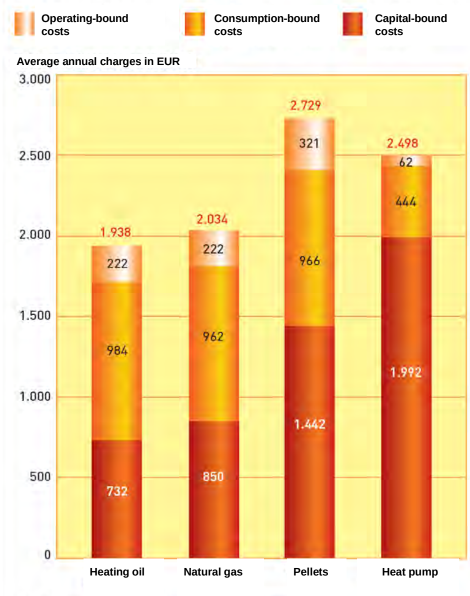


Figure 3.15: Comparing costs for different heating systems for a one family house with 130 m², 10 000 kWh/year heating demand, 8 kW heat load and a calculation period of 15 years including taxes and without any subsidy; price basis December 2006 (IWO)

The "Bundesverband Wärmepumpen Austria" (BWPA) published calculations on the price basis from October 2006 (**Figure 3.16**) where again the heat pump system is the cheapest one even with the – in Austria – more expensive borehole heat exchanger.

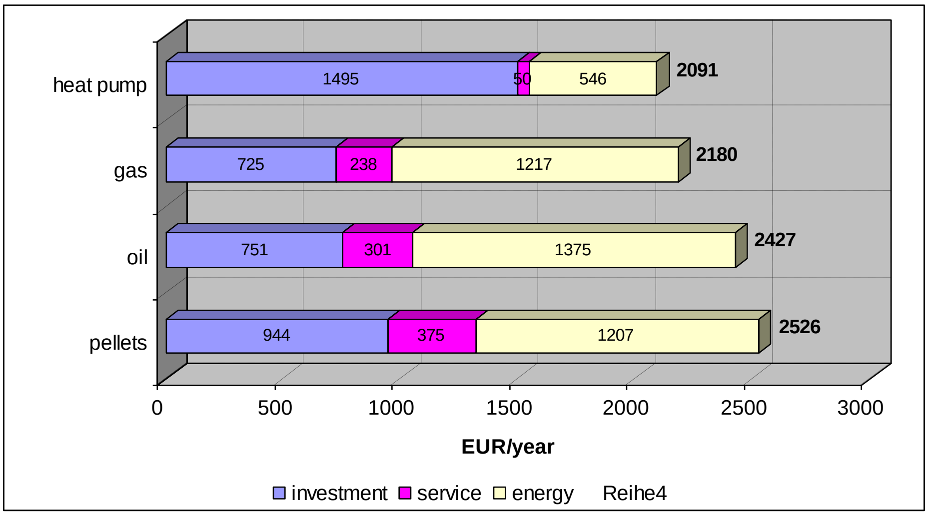


Figure 3.16: Comparing costs for different heating systems for a one family house with 130 m², 12 kW heat load and a calculation period of 20 years; price basis: October 2006 (BWPA)

The costs for modern heat pump systems are nowadays not higher than for a conventional heating system. For a calculation and comparison it is important to consider all types of cost. These types are investment costs (e.g. chimney, oil tank, well, boiler), operating costs (e.g. chimney sweep, maintenance service) and consumption costs (e.g. heating oil, gas, electricity). Most power supply companies offer cheaper special charges for ground source heat pumps (separate electricity meter is necessary). These special charges for heating and DHW preparation are sometimes much lower than usual charges. The costs for heat pumps depend of course on the heat output. Proceeding form the assumption of a heated area of 180 m² a heating output of about 8-9 kW (new buildings need about 40 W/m²) is necessary. With this basis average system costs (incl. control, buffer storage and circulating pump) are available for example at www.erdwaerme.at (see **Table 3.2**).

Table 3.2: Average costs of different heat pump systems for heating and DHW preparation incl. sales tax (taken from www.erdwaerme.at)

air heat pump system	approx. 10 000 – 12 000 Euro
ground source heat pump system	approx. 8 500 – 11 500 Euro
ground water heat pump system	approx. 9 000 – 12 000 Euro

The costs for the heat source and the heat distribution system are not included. Average values for these costs are given in **Table 3.3** for the different heat source systems.

Table 3.3: Average costs of different heat source systems incl. sales tax (taken from www.erdwaerme.at*)*

air/water	approx. 200 – 600 Euro (independent of heating power)
brine/water (vertical)	approx. 650 – 950 Euro/kW
brine/water (horizontal)	approx. 250 – 300 Euro/kW
water/water (2 wells with 15 m each)	approx. 4 500 – 5 500 Euro

It should be stated here that all these values are only guiding values and real values can be different due to special conditions (e.g. local geological conditions).

The Building Stock in Austria

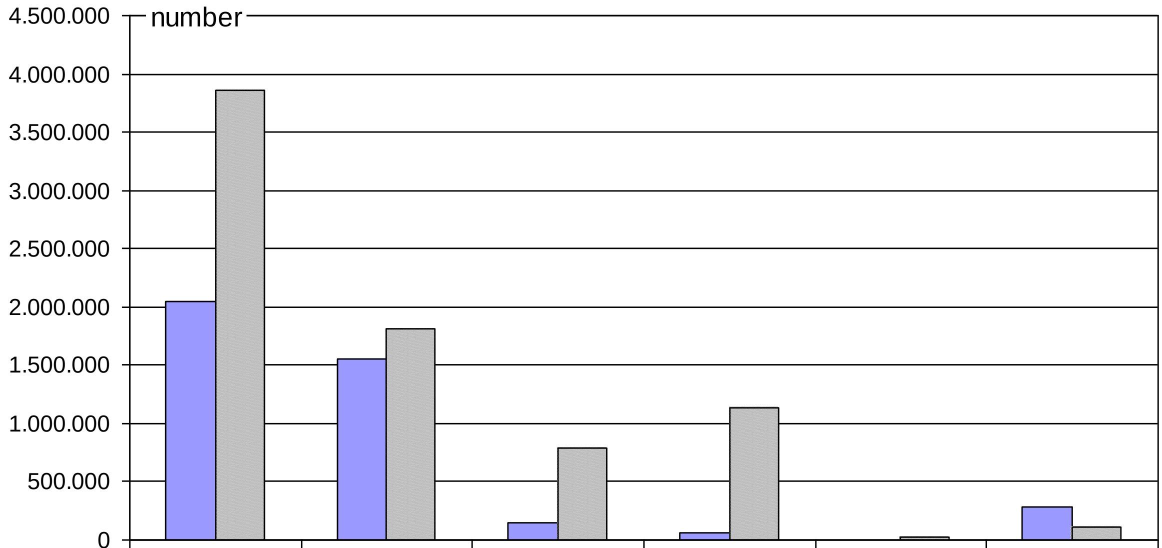
The application of heat pumps depends also strongly on the condition of buildings, which was definitively improved the last 30 years.

Table 3.4 summarizes heat load, oil fuel consumption and heating energy demand for old buildings, conventional and progressive new buildings.

Table 3.4: Improvement of thermal data for buildings over the years (arsenal, 2006)

	heating demand [kWh/(m².a)]	fuel oil consumption [l/(m².a)]	heating load [W/m²]
old building (till 1950)	> 450	> 45	> 300
old building (1950 - 1970)	< 400	< 40	< 265
old building (since 1970)	< 250	< 25	< 165
conventional new building	< 100	< 10	< 65
low energy building	< 40	< 4	< 27
passive house	< 15	< 1.5	< 10

The Austrian building stock consists of about 2.05 million buildings (3.9 million dwellings). It is dominated by about 1.56 million one family houses or semi detached houses. This category, called buildings with “one or two dwellings” represents 76 % of all buildings in Austria. Nearly the half (47 %) of all Austrian dwellings can be related to this category. About 50 % of the dwellings are in buildings with “three to ten dwellings” and in buildings with “eleven or more dwellings”. The rest of the dwellings belong to the category “for associations” or to the category “non-residential buildings”. As shown in **Figure 3.17** the number of non-residential buildings is one order of magnitude smaller than the number of residential buildings (Statistik Austria, 2006).



	total	1 or 2 dwellings	3 to 10 dwellings	11 or more dwellings	for associations	non-residential buildings
building	2.046.712	1.557.420	142.351	61.196	3.488	282.257
dwelling	3.863.262	1.809.380	791.584	1.134.782	21.663	105.853

Figure 3.17: The Austrian Building Stock classified according to the main use (Statistik Austria, 2006)

In the year 2001 the Austrian building stock had a total useful floor area of about 299 million m². As shown in **Figure 3.18** the smallest fraction (ca. 7 %) originates from the time of the world wars (1919-1944), the largest part (97.6 million square meters) from the time between 1961 and 1980. In this time an average of 5.13 million m² of useful floor area was built per year, i.e. ca. 33 % of the total current building stock has been built in this period. In the next period (1981-1990) the activity concerning new buildings in the residential sector was even higher, with an average of 6.4 million m² of useful floor area per year (Statistik Austria, 2006).

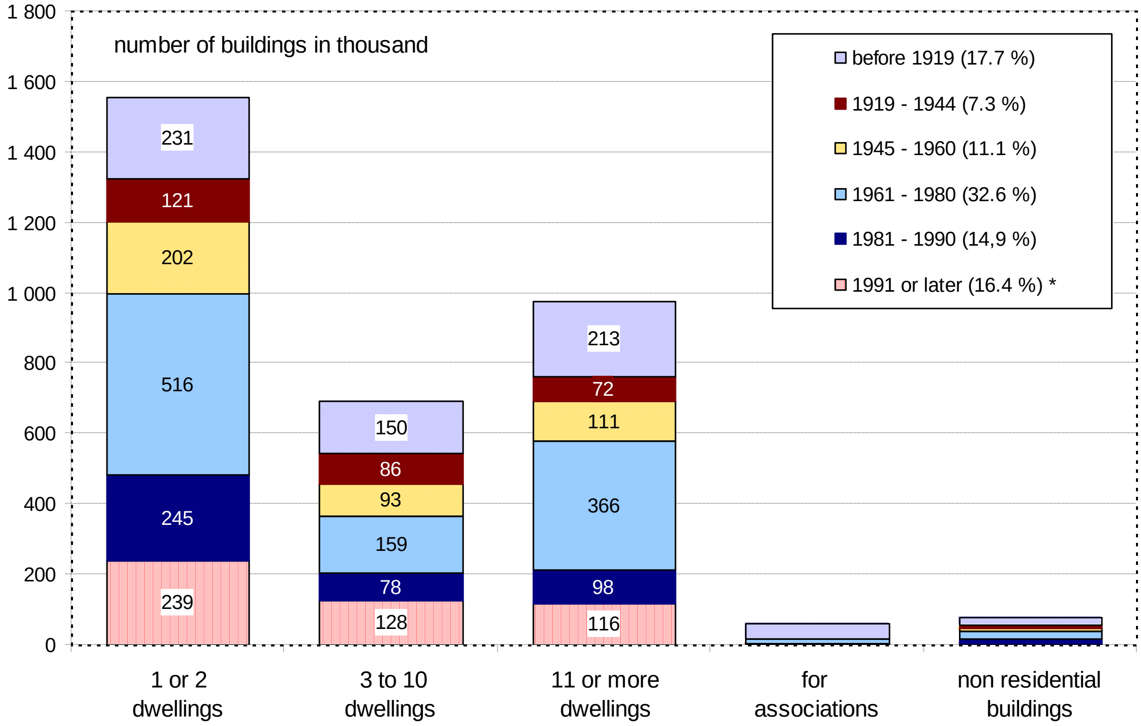


Figure 3.18: Number of Austrian buildings in the year 2001, assigned to different periods of erection; * this period includes the number of buildings, which could not be assigned to another period (Statistik Austria, 2006)

The buildings of the Austrian building stock are mainly (86.4 %) privately owned (see Figure 3.19). The predominant share (1.48 million) is represented by one- or two-family houses. 61 % of the buildings registered as non-residential are also privately owned according to Statistik Austria. The second- and third-biggest part of the building owners are “other companies” (ca. 3.2 %) and “municipal authorities” (ca. 3.1 %).

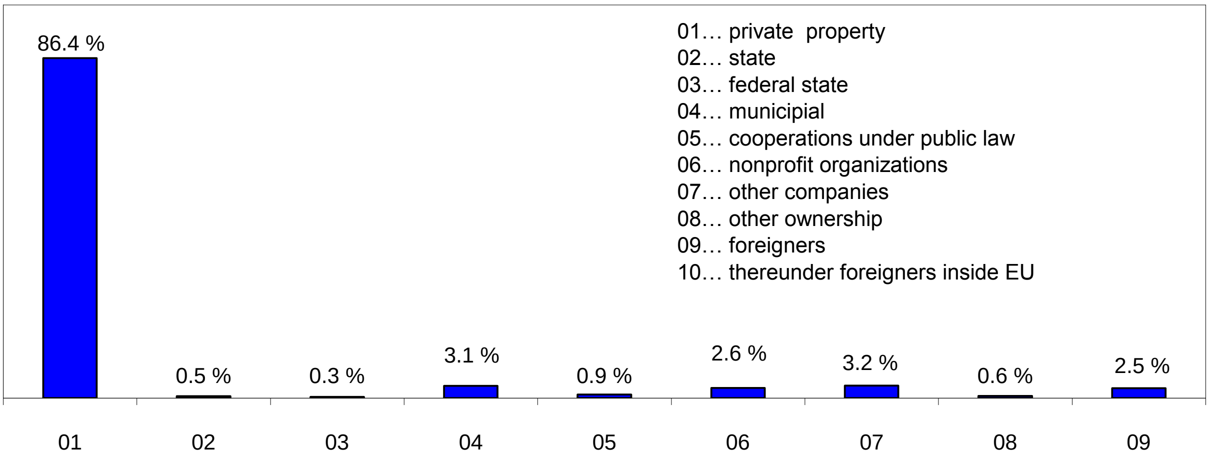
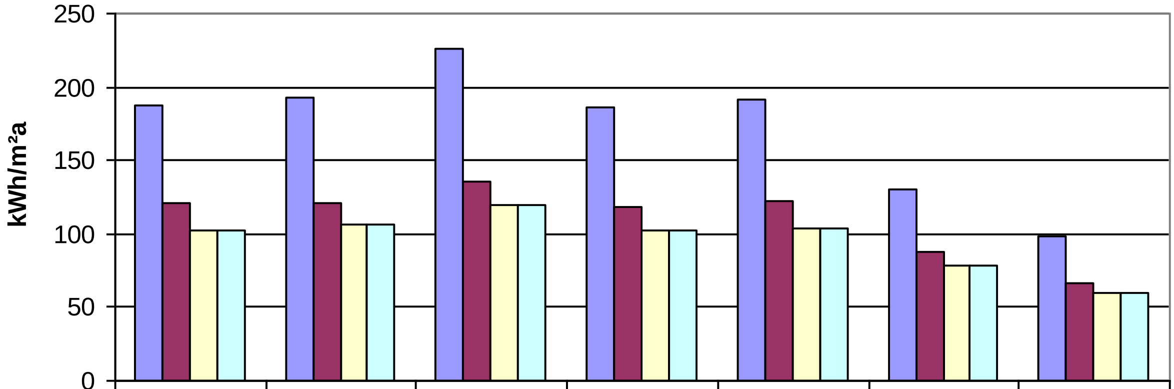


Figure 3.19: Percentage of buildings in the Austrian building stock, classified by ownership (Statistik Austria, 2006)

The energy demand for space heating (useful energy) of residential buildings is dominated by buildings with one or two dwellings. The share of the energy demand of multi dwelling buildings is 37 % although about 50 % of all dwellings are located in multi dwelling buildings. This is due to the higher V/A ratio (compactness) and therefore far less specific energy demand and smaller dwelling size. The average dwelling size for buildings with one or two dwellings is 113 m² floor area per dwelling compared to 70 m² floor area per dwelling for buildings with more than two dwellings (Wirtschaftskammer Österreich (HRSG.), 2006).

The evolution of the energy demand of buildings over the building age is similar for many middle European countries. As shown in **Figure 3.20** buildings with one dwelling built in Austria before 1945 have a specific useful energy demand for space heating of about 190 kWh/(m²a). For dwellings built between 1945 and 1960 this value is 230 kWh/(m²a) (Wirtschaftskammer Österreich (HRSG.), 2006). This period was the time of fast and cheap production of living space after the Second World War. Since then the specific energy demand of buildings steadily decreased due to the first oil price shock in the end of the 1970s. This development was enabled by the availability of more effective insulation materials and advanced window technology, supported by a growing environmental concern. For buildings built after the year 1991 the useful heating demand is in the range of 100 kWh/(m²a), which is already less than half of the values of the period from 1945 to 1960. For multifamily buildings the value was already 60 – 70 kWh/(m²a) in 1991. The trend is in the direction of values even far lower. With current (2006) building codes and subsidy schemes values of about 50-60 kWh/(m²a) for single (and two) dwelling buildings and 40-50 kWh/(m²a) for multi dwelling buildings are achieved. Houses built according to the Passive house concept show that the space heating demand can be decreased to 15 kWh/(m²a).



	before 1919	1919 - 1945	1945 - 1960	1961-1970	1971 - 1980	1981 - 1990	after 1991
SFH	188	193	226	186	191	130	99
MFH-S	121	121	136	118	122	88	67
MFH-B	103	106	120	103	104	78	60
NRB	103	106	120	103	104	78	60

Figure 3.20: Specific space heating energy demand (useful energy) of single and (two) dwelling buildings (SFH), multi family buildings (MFH, MFH-S: small MFH, MFH-B: large MFH) and non- residential buildings (NRB) in Austria classified by the building age (Wirtschaftskammer Österreich (HRSG.), 2006); Original data source: Jungmeier et al., 1996

The requirements to reach such small heating demands are an optimal thermal insulation of the building envelope and an effective mechanical ventilation using air heat recovery. Thus the energy demand of new buildings decreased drastically in the last 50 years (Wirtschaftskammer Österreich (HRSG.), 2006).

The evaluation of the Austrian building stock by Statistik Austria with regard to the used heating system shows a clear dominance of central house- or apartment heating systems. **Figure 3.21** shows that a total of 74.6 % of all principal residences is heated with one of these systems. District heating is used seldom in the one- and two family house sector. The fraction of buildings supplied by district heating is increasing with an increasing size of the building, whereby 12.2 % of all principal residences are supplied by district heating. The fraction of buildings heated with single stoves has been decreasing for the last century, and was about 11.7 % in the year 2001.

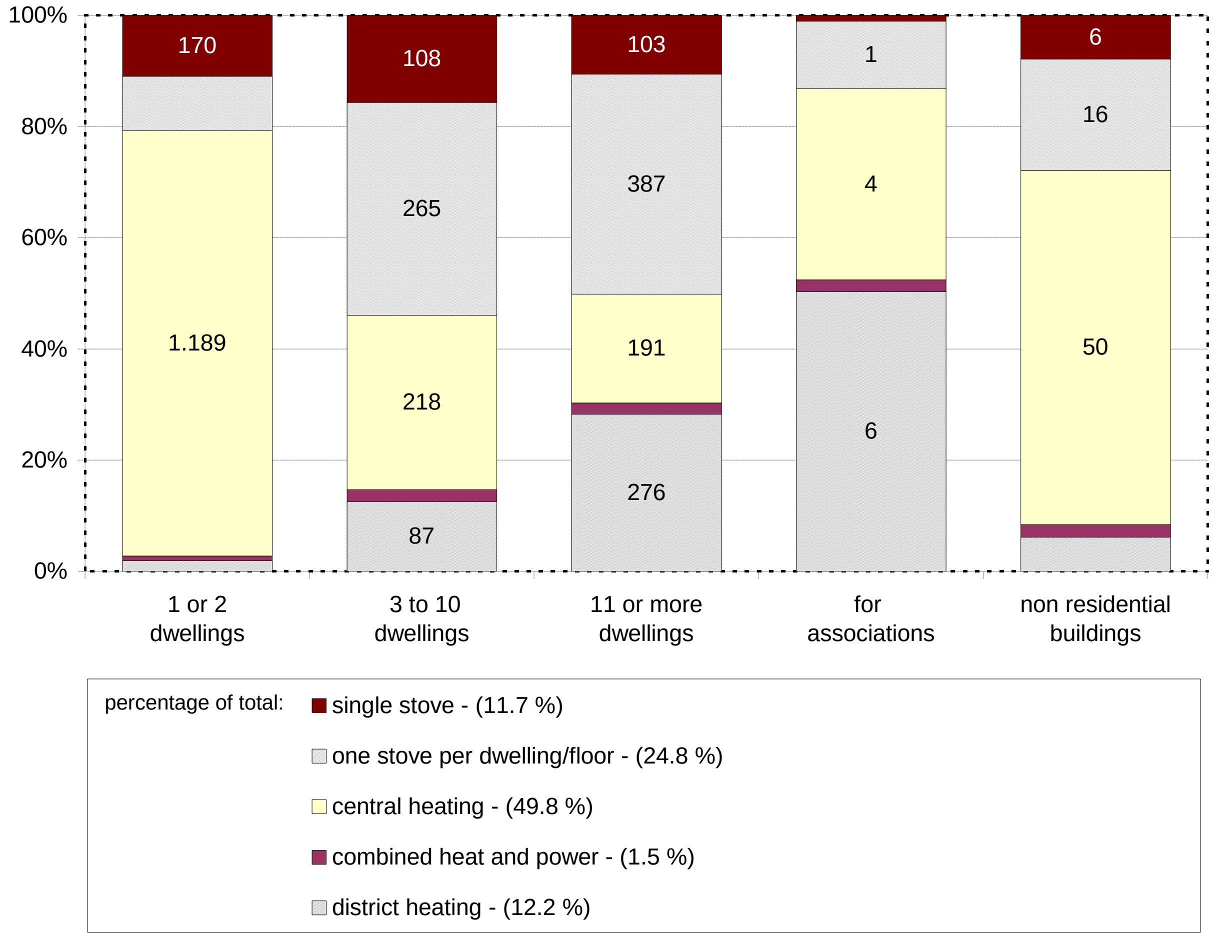


Figure 3.21: Heat delivery systems in Austrian dwellings per building type in 2001. The figures inside the columns show the number of systems in 1000.

The analysis of the energy sources used for the heating of buildings (see **Figure 3.22**) shows a dominance of fossil fuels. A total of 61.2 % of the principal residences in Austria is supplied with heat out of gas, oil, coal and briquets. The data published by Statistik Austria shows a continuous increase of the grid-bound supply with gas and district heating in the last decade. The fraction of coal, coke and briquets has decreased from about 30 % in the year 1980 to about 2.9 % in the year 2001.

In the framework of the Kyoto-protocol the states of the European Union committed themselves to the reduction of green house emissions. For Austria a reduction of 13 % was defined. In fact the Austrian emissions show an increase since 1990, instead of a decrease. The "Evaluation report of the climate strategy of Austria" (Österreichische Energieagentur, 2005) shows an increase of the emissions to 91.57 million tons compared to the year 1990 (78.54 million tons). This is an increase of 16.6 % and is 23.2 million tons higher than the Austrian Kyoto aim.

The breakdown of the Austrian CO_2-emissions according to sectors is shown in **Figure 3.23**. The highest increase occurred in the sector of traffic. For the basis year 1990 the equivalent CO_2-emissions of the traffic sector are quoted with 12.7 million tons. Since 1990 the emissions have increased continuously and reached 23.0 million tons in 2003. The equivalent CO_2-emissions in the sector "space heating and small consumers" were nearly constant in the period from 1990 – 2003. The small increase from 15.1 to 15.3 million tons is due to the cold winter 2002/2003. As the number of apartments has increased by about 15 % in the same period, there has been an according reduction of the specific emissions.

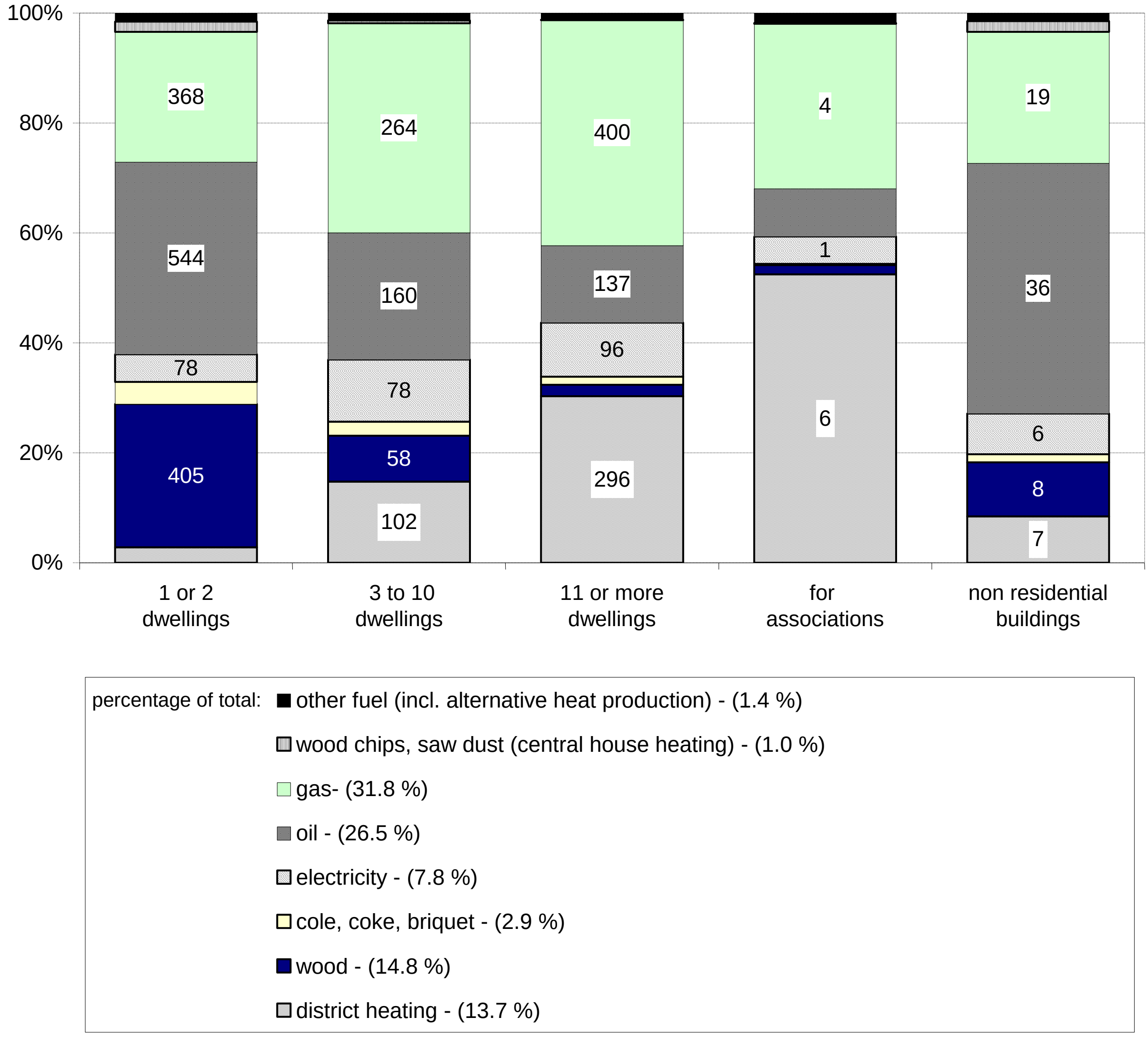


Figure 3.22: Energy sources per building type for 3.32 million Austrian dwellings in the year 2001. The figures inside the columns show the number of systems in 1000.

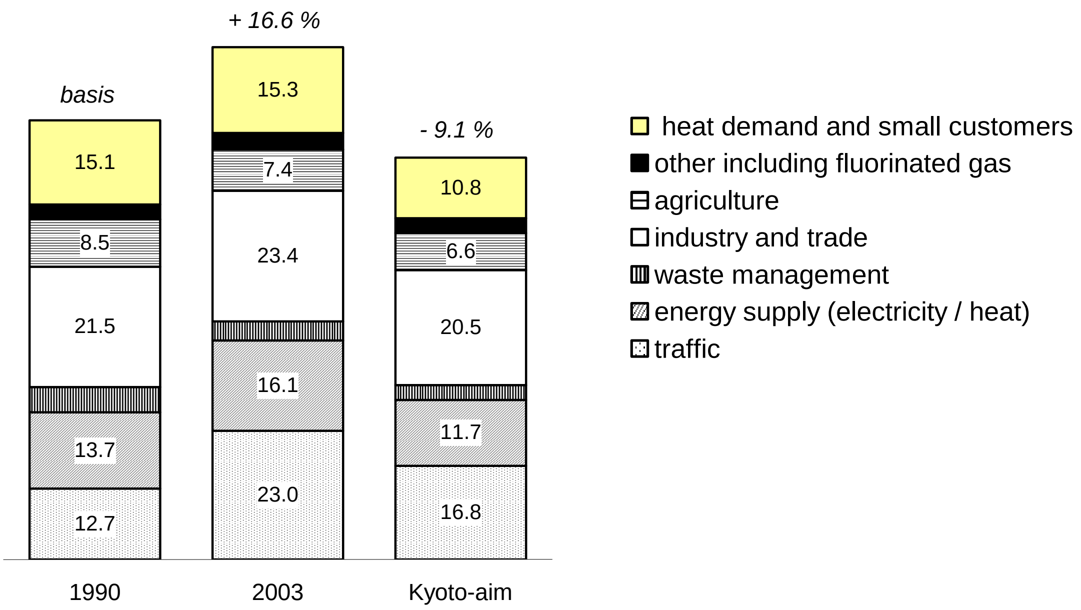


Figure 3.23: CO_2-emissions classified by sector (Österreichische Energieagentur, 2005)

The average useful floor area, which is available for every inhabitant in Austria, and also the average number of apartments per capita have been increasing for the last decades. According to the last building and apartment count in 2001, an average useful floor area of 38.2 m² was available for each inhabitant (see **Figure 3.24**).

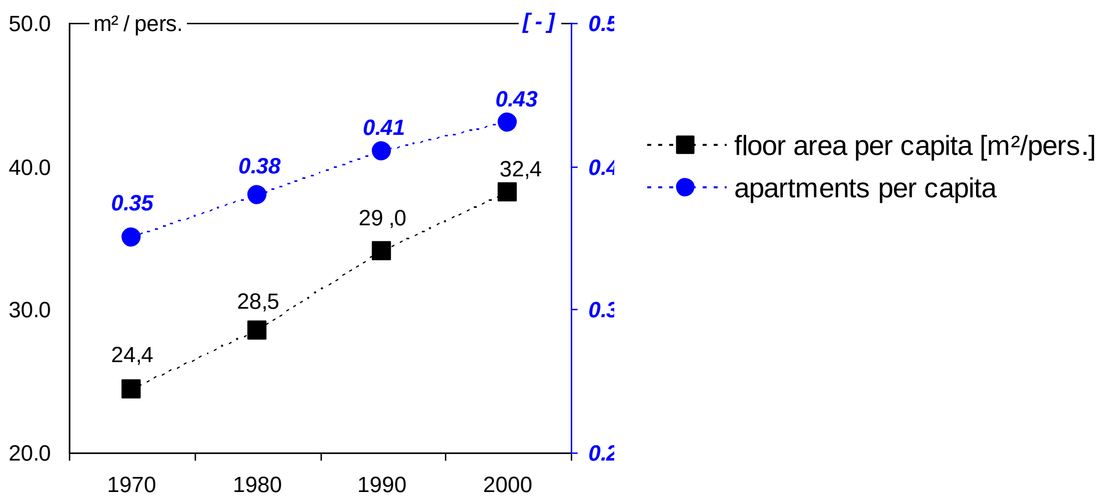
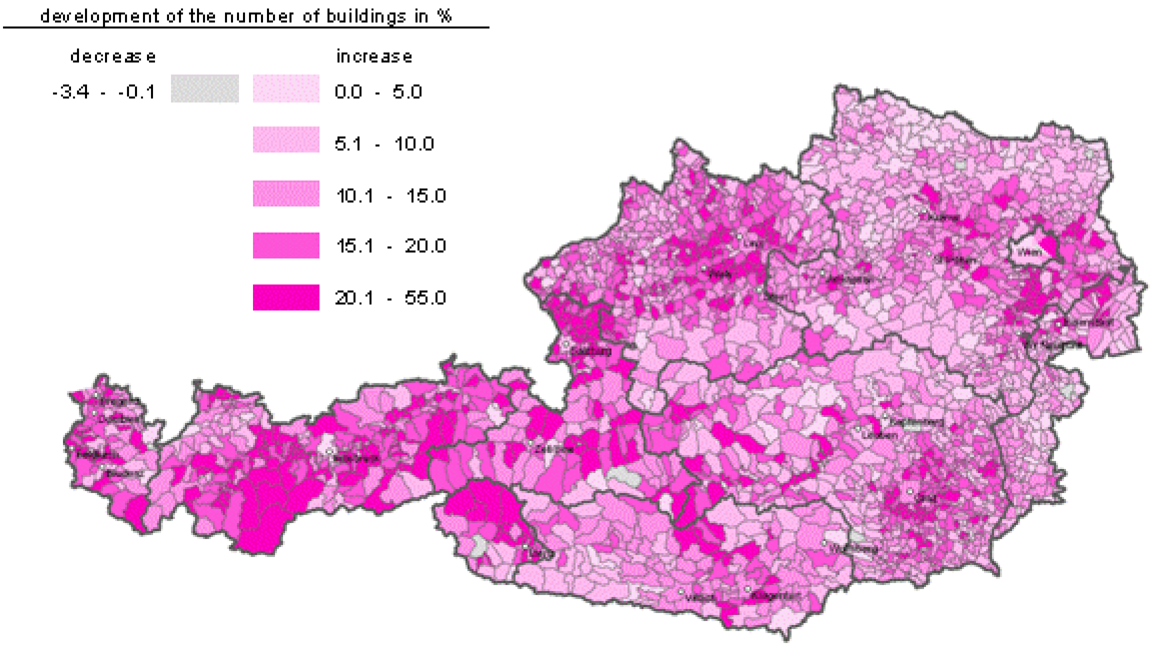


Figure 3.24: Development of the apartments per capita and the mean floor area per capita in the Austrian building stock

In the period from the year 1991 to the year 2001 there has been an enormous enlargement of the Austrian building stock (see **Figure 3.25**). In the year 1991 there have been about 1.81 million buildings in Austria. Until the year 2001 this number raised up to about 2.05 million buildings (increase of 13.1 %). This development certainly had an effect on the number of apartments. The number of apartments increased from about 3.39 million apartments in the year 1991 up to 3.86 million apartments in the year 2001 (increase of 13.9 %). All over Austria there have only been ten counties were the number of apartments increased by less than 10 % (Statistik Austria, 2004).



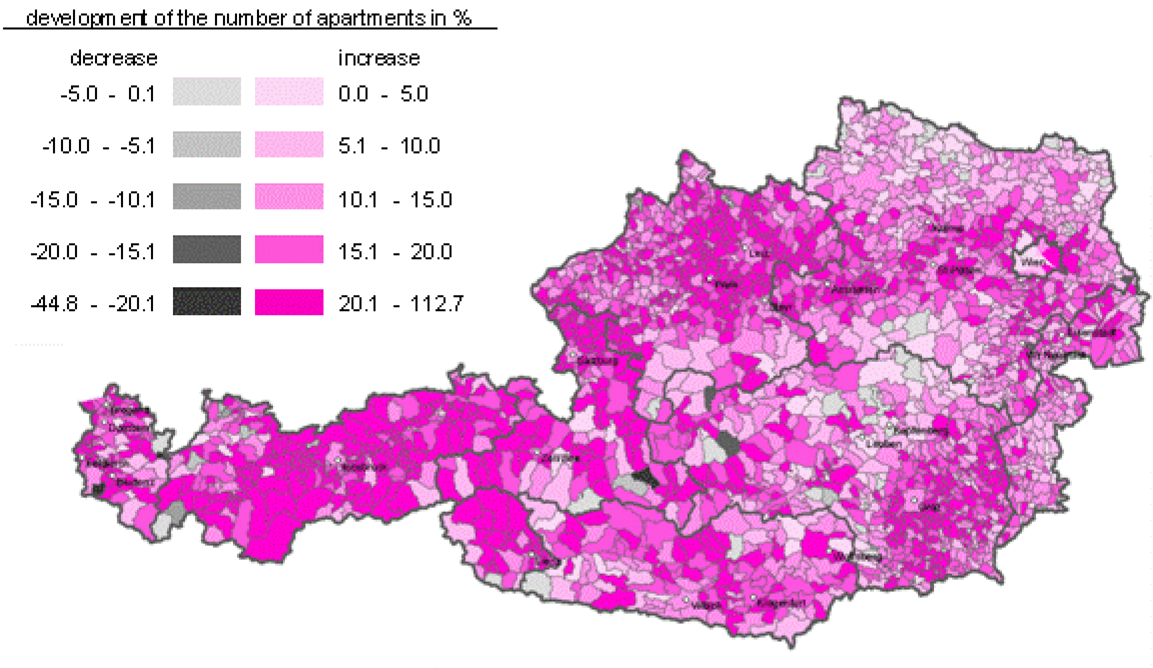
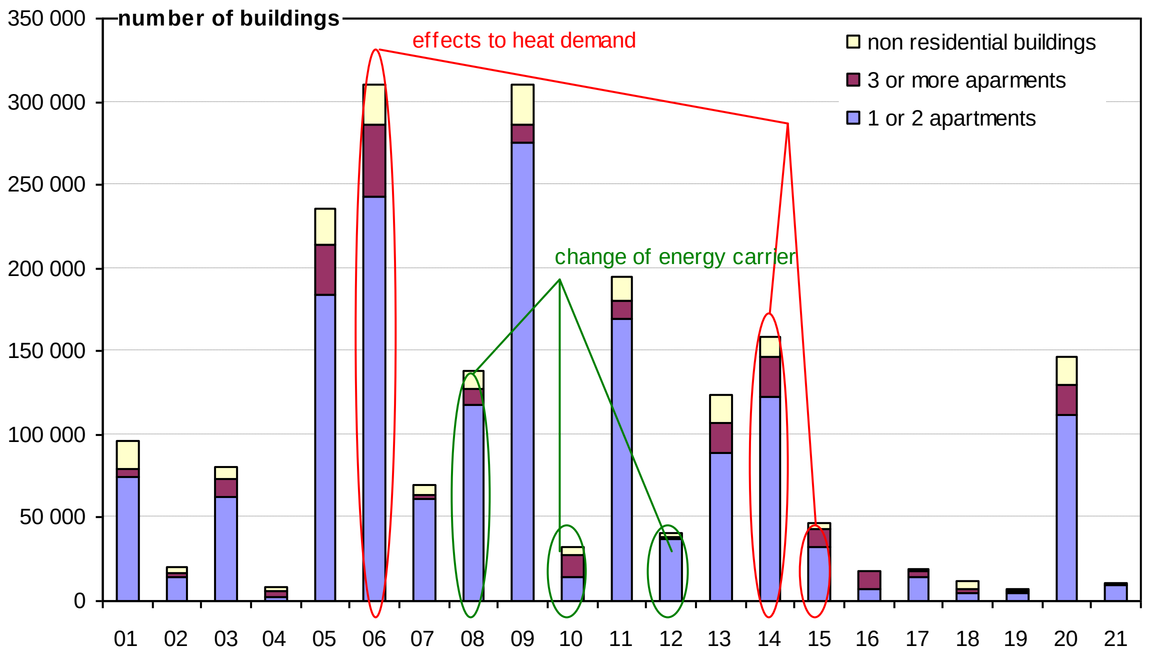


Figure 3.25: Development of the Austrian building stock and development of the density of apartments in the period 1991 – 2001

Figure 3.26 gives an overview of the renovation activities (period 1991 - 2001) in the building sector in Austria. The main renovation measure that has an effect on the heat demand of buildings is the renewal of windows (measure 06), followed by the renovation of facades with additional thermal insulation (measure 14). The “change of the energy carrier” (measures 08, 10 and 12) can also have an effect on the CO_2-emissions. Except for the “fitting of alternative heating systems” both an increase and a decrease of CO_2- emissions is possible.



01… enlargement of existing buildings > 4 m²
02… addition of another floor
03… attic conversion
04… installation of an elevator
05… new roof covering
06… renewal of windows
07… connection to water pipe
08… connection to natural gas
09… connection to sewer
10 …connection to district heating
11… installation of central heating for building
12... installation of alternative heating system
13... facade renovation without heat insulation
14... facade renovation with additional heat insulation
15... other measures of heat protection
16... combination of apartments
17... division of apartments
18... conversion from aparments to office or other work places
19... conversion from office or other work places to aparments
20... renewal of sanitary facilities
21... installation of a clarification plant

Figure 3.26: Overview of the renovation activity in Austria, number of buildings renovated in the period from the year 1991 to the year 2001, concerning different measures (Statistik Austria, 2004)

Influence of different building construction types and windows on the energy demand

For optimizing the energy demand for heating and cooling not only the heating or cooling system is of an interest but also the building itself. The influence of different wall constructions, window orientations, window sizes or window types and the use of external shading devices were investigated in several Projects. The aim is here to use combinations leading to buildings with low energy demand to pave the way for monovalent heat pump systems.

In a study within the project “Building of Tomorrow” the thermal behaviour of a one-family house under defined climate conditions, different wall structures and specified user conditions was investigated (Padinger R., et al., 2003).
In particular the effect of different periodically set back intervals on the energy demand was examined using results produced by TRNSYS building simulations.
For the simulation the data of an already built one-family house are used as bases and commonly accepted user profiles are defined.

Five different wall structures for the reference building are defined and the important thermal parameters are documented. A short summary is given in the following list:

KV1	Wood frame construction with wood beam ceiling and lightweight internal walls
KV2	Brick construction (vertically perforated brick; 38 cm) with ferro concrete ceiling and brick construction for the internal walls
KV3	Brick construction (vertically perforated brick; 38 cm; 10 cm insulation) with ferro concrete ceiling and brick construction for the internal walls
KV4	Solid wood construction (17.6 cm; 10 cm flax insulation), 500 kg/m³
KV5	Ferro concrete construction with expanded polystyrene insulation and brick construction for the internal walls

For the comparison one thermal zone in the first floor in the north-west corner was chosen and for all construction types (KV1 – KV5) the surfaces for recording temperature data were defined and indicated with unique names. The development of the simulation model with 46 thermal zones was done with TRNSYS.

For the location of the simulated building Graz was chosen. The climate data for this location in the last 11 years were analysed and different test scenarios under the condition of the climate data in Graz were defined taking into account several different reduction periods for the indoor set temperature. Additionally, the dimensioning of the heating system was done and the time point for switching on/off was determined. A total of 30 Simulations were carried out for each of the 5 construction types and each of the 6 defined test scenarios under the climate conditions for the location Graz in the year 1998.

For all construction types the data were evaluated for the calculation of the yearly energy requirement for space heating. Especially the potentials for energy saving due to the different temperature reduction periods were analyzed.
For the defined surfaces the temperature sequences are compared in exclusive time periods for all construction types (KV1-KV5).

The yearly energy demand for five different construction types of the reference building were investigated for different test scenarios.

The bases for the simulations were measured climate data of the year 1998 in Graz, which is an average year for this location. **Table 3.5** compares the heating requirement of the 5 different construction types, whereas the room set temperature is 21°C and a hygienic air change rate of 0.5 h^{-1} was assumed.

Table 3.5: Yearly heating requirement (HR) and heating load at -10°C ambient temperature for the 5 different construction types relating to the overall floor space of the reference building.

	KV1	KV2	KV3	KV4	KV5
HR [kWh/m^2a]	81,6	91,3	77,3	76,0	93,7
Heating load [W/m^2]	42,0	48,5	40,9	40,4	49,5

To study the potential for energy saving due to the reduction of the indoor set temperature during absence of inhabitants 6 different test scenarios were defined:

"Three week vacation"	A three week vacation during the heating period; temperature reduced to 15°C and 5°C resp.
"One week vacation"	A one week vacation during the heating period; temperature reduced to 15°C and 5°C resp.
"Weekend home"	The building is occupied only at the weekends (Sa – Su); temperature reduced for the other days to 15°C
"Working day home"	The building is occupied only at working days (Mo – Fr); temperature reduced for the weekend to 15°C
"Daily set back"	The building is not occupied during daytime (7 – 18 o'clock); temperature reduced during this period to 15°C
"Night set back"	Temperature reduced during the night (23 – 6 o'clock) to 15°C

Thus, during absence of inhabitants the room temperature is reduced from 21°C to 15°C (and additionally to 5°C for the first two scenarios). Additionally, the air change rate during absence is reduced to 0 whereas the infiltration due to gaps is constant at 0.1 h^{-1}. For the scenario "night set back" the hygienic air change is left at 0.5 h^{-1}.

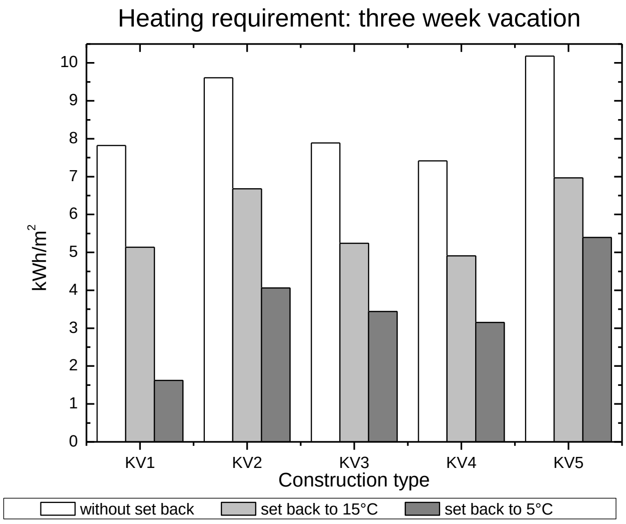


Figure 3.27: Heating demand relating to the floor space calculated for three week vacancy. The white columns show the heat demand without temperature reduction, the light grey and dark grey columns the heat demand with reduction to 15°C and 5°C respectively.

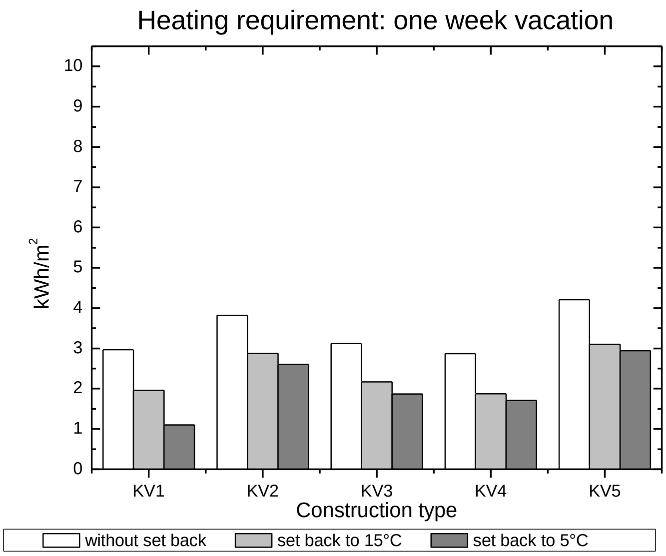


Figure 3.28: Heating demand relating to the floor space calculated for one week vacancy. The white columns show the heat demand without temperature reduction, the light grey and dark grey columns the heat demand with reduction to 15°C and 5°C respectively.

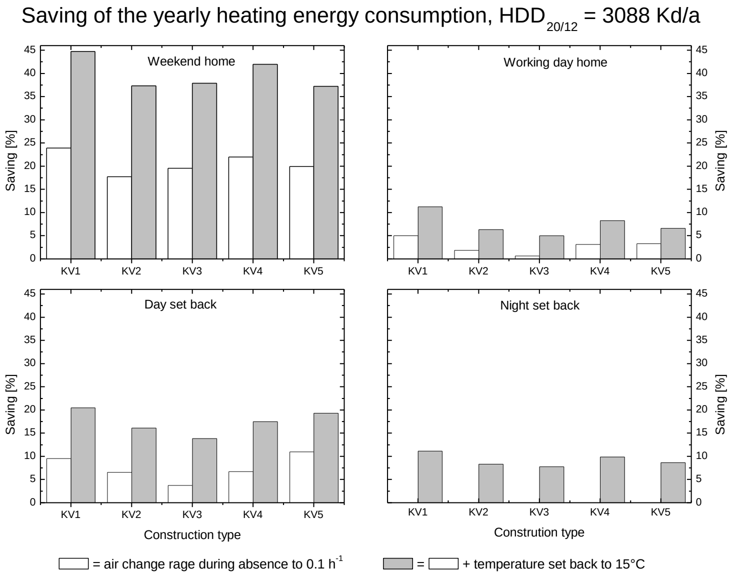


Figure 3.29: Savings of the yearly heating demand for the 5 construction types compared to the values in Table 3.5. For the 4 scenarios "weekend home", "working day home", "daily set back" and "night set back" the savings due to air change reduction (white columns) and due to reduction of temperature to 15°C (grey columns) during vacancy are shown.

For the estimation of thermal comfort for this study the so-called ppd-index (predicted percentage of dissatisfied) is used. This value shows the expected percentage of persons not satisfied with the thermal conditions in a certain thermal zone. The lesser the ppd-index the better is the thermal comfort. **Figure 3.30** show a statistical evaluation of the ppd-index for the 5 construction types in the case of a "weekend home". The difference between the light weight constructions (KV1 and KV4) and solid constructions (KV2, KV3 and KV5) can be seen clearly.

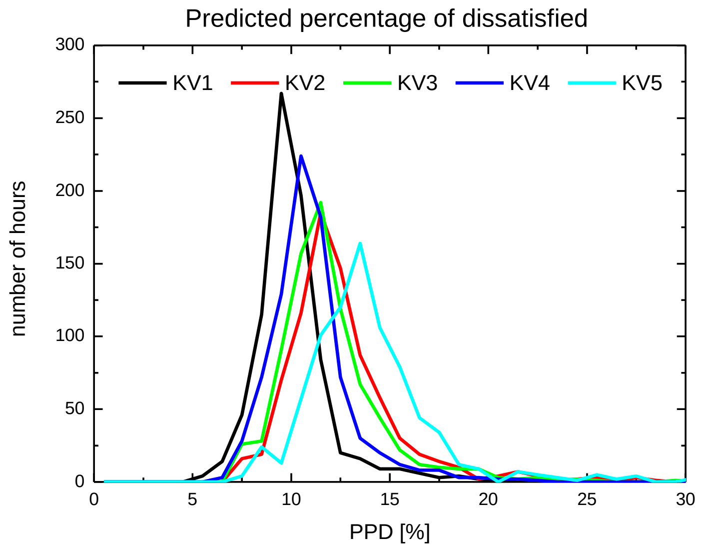


Figure 3.30: Statistical evaluation of the ppd-index during attendance of people for the scenario “weekend home”.

Due to more thermal storage mass for the massive construction types lower surface temperatures can be expected for these construction types. This leads to a lower thermal comfort in such buildings. The analysis show that in this case the wood frame construction (KV1) leads to the highest surface temperatures followed by the solid wood construction (KV4) and the brick construction with additionally insulation (KV3). On the other side the brick construction (KV2) and the concrete construction (KV5) show lower surface temperatures. The results are true for all scenarios but the differences between the construction types are most obvious for the test scenario “weekend home”. For this scenario the statistic evaluation is shown in **Figure 3.31**.

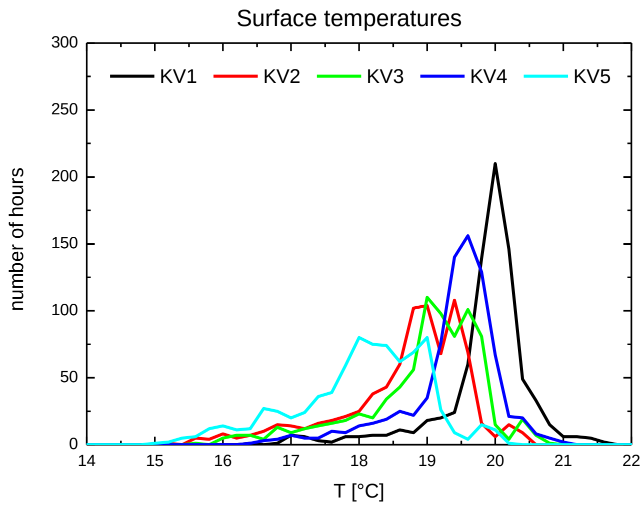


Figure 3.31: Statistical evaluation of the surface temperatures during attendance of people for the scenario “weekend home”.

Additionally, the problem of condensation at the inside surfaces during temperature reduction is investigated. Naturally the risk of condensation increases with lower room temperature and longer time intervals of temperature reduction. For this reason the scenario of "three week vacation" was evaluated concerning the indoor humidity. In this case for the time interval of reduced temperature the relative humidity in a wood frame construction building (KV1) increases to more than 90% if the temperature is reduced to 5°C. Nevertheless, the surface temperature at the inside of this building is only a little bit lower than the indoor air temperature, thus a condensation at the surface even in this extreme case is rather improbable. Also non critical is the situation for the concrete construction type (KV5) because the temperature decreases not to very low values due to the high storage masses. The relative humidity increases in this case only to approximately 80%. No problems will be caused for both construction types for a temperature reduction to 15°C. In this case the relative humidity is always lower than about 50%. To summarize these results it should be pointed out that for a temperature reduction to 5°C during three weeks especially for light weight construction types a certain risk of condensation at the inside surfaces of the building could not be neglected. Temperature reductions to 15°C should cause no problems and due to a calculated interpolation of the simulation results even a reduction to 10°C should be possible without any condensation.

Summary of the results

This investigation shows the thermal behavior of a typical one family house (100 m²) for five different construction types from wood frame light weight construction to massive Ferro concrete construction. The yearly energy demand for heating is between 76 and 96 kWh/(m².a), as **Table 3.5** shows. For the simulations a room temperature of 21°C, a hygienic air change of 0.5 h^{-1} and a climate with a heating degree day value of $HDD_{20/12}$ = 3088 Kd/a was chosen. The influence of temperature reduction for different time periods on the energy demand for heating was studied and the results of the simulations show, that in all cases a reduction of the room temperature leads to a reduction of the energy demand. The saving potentials are summarized in **Table 3.6** and Table 3.7.

Table 3.6 Relative energy saving potentials for night, day, weekend and week set back (indoor temperature reduced from 21 to 15°C)

	night set back	day set back	weekend set back	week set back
	no vacancy	vacancy 11h / d	vacancy 2d / week	vacancy 5d / week
indoor Temperature	21/15 °C	21/15 °C	21/15 °C	21/15 °C
Construction type				
KV1 wood frame	**-11.2%**	**-12.1%**	**-6.6%**	**-27.4%**
KV2 Brick	**-8.3%**	**-10.2%**	**-5.0%**	**-23.8%**
KV3 Brick + insulation	**-7.7%**	**-10.5%**	**-4.4%**	**-22.8%**
KV4 Solid wood	**-9.7%**	**-11.7%**	**-5.3%**	**-25.6%**
KV5 Ferro concrete + insulation	**-8.8%**	**-9.4%**	**-3.4%**	**-21.6%**

For showing the influence of window size and window orientation the TASK32 Reference building (Heimrath R., Haller M., 2007) was used to simulate with TRNSYS16.1 (TRNSYS 16) the energy demand for heating and cooling.

For the reference location Graz, Austria was chosen. The hourly climatic data profile corresponds to the profiles delivered with the TRNSYS simulation software (TRNSYS 16) in the standard format '.tm2'. These data profiles are based on the commercial database Meteonorm® (Meteotest, 2003). **Table 3.8** shows the characteristics of the used climatic data set.

Table 3.7 Relative energy saving potentials for one week and three week vacancy (indoor temperature reduced from 21 to 15 and 5°C respectively)

	one week vacancy		three week vacancy	
indoor Temperature	21/15 °C	21/5 °C	21/15 °C	21/5 °C
average ambient Temperature	-4.4 °C	-4.4 °C	-1.4 °C	-1.4 °C
Construction type				
KV1 wood frame	**-33.0%**	**-61.6%**	**-32.6%**	**-75.0%**
KV2 Brick	**-20.5%**	**-29.5%**	**-25.0%**	**-55.6%**
KV3 Brick + insulation	**-18.2%**	**-30.3%**	**-22.0%**	**-52.4%**
KV4 Solid wood	**-30.3%**	**-39.4%**	**-34.1%**	**-59.1%**
KV5 Ferro concrete + insulation	**-19.1%**	**-23.4%**	**-26.1%**	**-43.7%**

Table 3.8: Characteristics of the climatic data set for Graz

Lat. [°]	46.59	T_{ave} [°C]	8.4
Long. [°]	15.27	T_{min} [°C]	-14.8
Alt. [m]	342	T_{max} [°C]	29.6
I_G [kWh/m²]	1143	RH [%]	79.1
I_B [kWh/m²]	482	$HDD_{20/12}$ [Kd]	3739
I_D [kWh/m²]	661	HD [d]	215

Lat. [°]	Geographical Latitude
Long. [°]	Geographical Longitude
Alt. [m]	Geographical Altitude
I_B [kWh/(m².a)]	Beam incident irradiation on the horizontal plane
I_D [kWh/(m².a)]	Diffuse incident irradiation on the horizontal plane
I_G [kWh/(m².a)]	Global (Total) incident irradiation on the horizontal plane
T_{AVE} [°C]	Average yearly ambient air temperature
T_{MIN} [°C]	Minimum ambient air temperature
T_{MAX} [°C]	Maximum ambient air temperature
RH [%]	Average relative humidity
$HDD_{20/12}$ [K.d]	Heating Degree Days for a room temperature of 20 °C and a balance point temperature (ambient temperature above which no heating is needed due to internal gains) of 12 °C
HD [d]	Heating Days / Accumulated length of heating periods in a year

The reference object is a free-standing, two storey single family building. The effective floor area on one storey, including the areas covered by the internal walls and the access areas, is 70.0 m². Both stories are simulated as one common thermal zone. In TASK 32 (Heimrath R., Haller M., 2007) four single family houses (SFH) with different heating loads (15, 30, 60 and 100 kWh/(m².a)) were defined. The various materials, layer thicknesses and energy performance data describing the wall construction of all four reference buildings are listed in **Table 3.9**. For examining the influence of different window sizes and orientations the building SFH 15 was used.

The glazed area for these calculations is only on one façade, has three different values (20 m², 30 m² and 40 m²) and four different orientations (north, east, south and west). The thermal properties for the windows are summarized in **Table 3.10**.

Table 3.9: Construction of building elements for the 15, 30, 60 and 100 kWh/(m².a) single-family house (Heimrath R., Haller M., 2007)

assembly	layer	layer thickness				density	conduct.	capacity	U - Value construction			
		SFH 15	SFH 30	SFH 60	SFH 100				SFH 15	SFH 30	SFH 60	SFH 100
		[m]	[m]	[m]	[m]	[kg/m³]	[W/mK]	[kJ/kgK]	[W/m²K]	[W/m²K]	[W/m²K]	[W/m²K]
external wall	plaster inside	0.015	--	--	--	1200	0.600	1.00	**0.154**	**0.154**	**0.283**	**0.491**
	Viertl brick	0.210	--	--	--	1380	0.700	1.00				
	EPS	0.240	--	0.120	0.060	17	0.040	0.70				
	plaster outside	0.003	--	--	--	1800	0.700	1.00				
	Σ	0.468	0.468	0.348	0.288							
ground floor	wood	0.015	--	--	--	600	0.150	2.50	**0.157**	**0.157**	**0.270**	**0.561**
	plaster floor	0.060	--	--	--	2000	1.400	1.00				
	XPS	0.220	--	0.120	0.060	38	0.037	1.45				
	concrete	0.150	--	--	--	2000	1.330	1.08				
	Σ	0.445	0.445	0.345	0.285							
roof ceiling	gypsumboard	0.025	--	--	--	900	0.211	1.00	**0.119**	**0.119**	**0.275**	**0.380**
	plywood	0.015	--	--	--	300	0.081	2.50				
	rockwool	0.280	--	0.120	0.060	60	0.036	1.03				
	plywood	0.015	--	--	--	300	0.081	2.50				
	Σ	0.335	0.335	0.175	0.115							
internal wall	clinker	0.200	--	--	--	650	0.230	0.92	**0.962**	**0.962**	**0.962**	**0.962**

Table 3.10: Thermal properties of windows for the 15 kWh/(m².a) single-family house (Heimrath R., Haller M., 2007)

building	***U_{WINDOW} [W/m²K]***	***g-Value [-]***	***U_{FRAME} [W/m²K]***	***construction [mm]***	***window ID [-]***
SFH15	***0.52***	***0.585***	***1.6***	***4/16/4/16/4***	***13006***

In the case of full occupancy 3.3 people are present simultaneously in the reference building. This value is based on a mean value from several building-objects evaluated during an Austrian study published in (Streicher W., 2004). No distinction is made between weekdays and weekend.
The heat dissipation to the surroundings is assumed to be 100 Watt per person. This value is in accordance with the ISO 7730 standard (ISO 7730, 2005) and is based on the following scenario:

Degree of activity – seated at rest
sensible heat: **60 W/person**
convective gains: *40 W/person*
radiative gains: *20 W/person*
latent heat: **40 W/person**
humidity: *0.059 kg/hr person*

The average internal gains through inhabitants are about 145 W or 1.04 W per square meter net area of the building. This results in a yearly heat gain of 9.03 kWh/m² by the inhabitants of the building.

The total electricity consumption of an average household amounts up to 3043 kWh/year (Feist W., 1998). We assumed that 58% of this electric energy (12.6 kWh/(m².a) or 1.44 W/m² in our case), remain inside the building as thermal energy and are classified as internal electrical gains.

The rate of heat dissipation from electric equipment depends on its operational status and is thus correlated to the occupancy profile in the building. The assumed electrical heat dissipation is assumed to be dependent on the hour of the day and on the day of the week (Heimrath R., Haller M., 2007). This weekly profile is based on outcomes from an Austrian study (Streicher W., 2004), were about 60 flats are measured in detail.

Overheating due to the solar gains through the glazed areas is reduced by external shading devices. Control of the external shading is modeled as a function of the incident solar irradiation on the horizontal and depending on the room temperature.
Control strategy (all points must be fulfilled, off-values for hysteresis in parenthesis):

- Total global irradiation on the horizontal is above 300 (200) W/m²
- Room temperature must be above 23.8 (22.8) °C
- 24 hours average ambient temperature must be above 12 °C

A natural air change rate of 0.4 1/h is assumed due to leakages in the building envelope during wintertime. In summertime a free driven night ventilation mode is activated if the following conditions are met:

- Time between 21:00 and 8:00
- Daily average temperature is above 12 °C
- Room temperature is above 24 °C
- Ambient temperature is 2 K below the actually room temperature

This free driven tilted window ventilation is simulated with Type 358 based on the method from A. Weber (Weber A., 1997) using a simple but CFD validated Bernoulli – approach. The air exchange rate through the window is calculated depending on the temperature difference between room and ambient temperature, the geometry of the window and the window opening tilt angle.

The controls of the heating system were set in a way, that the room temperature is kept around T_{ROOM} = 20 ±0.5 °C and never drops below 19.5 °C during heating season.
The necessary cooling set temperature of the reference system is defined according to the upper cooling line of DIN 1946/2 with two straight lines depending on the ambient temperature (see **Figure 3.32**).

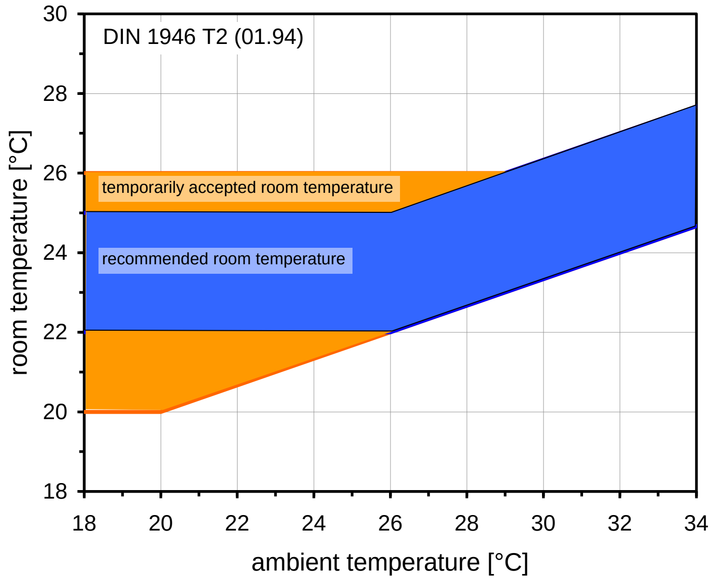


Figure 3.32: Boundary set temperatures for heating and cooling according to the DIN 1946/2.

The resulting energy demand for heating and cooling regarding the described parameters for the simulation are shown in **Figure 3.33** (with controlled external shading) and **Figure 3.34** (without any external shading). Heating demand is lowest for south orientation of the window whereas the maximum cooling demand is calculated for the west and east orientation. Without shading the influence of the window size on the heating and cooling demand is very high. With the given shading control strategy the cooling demand can be strongly reduced (approx. to a tenth). The heading demand is increasing a little bit which shows that there should be potential to improve the shading control strategy (not part of this work). The influence of the window size is in this case rather low.

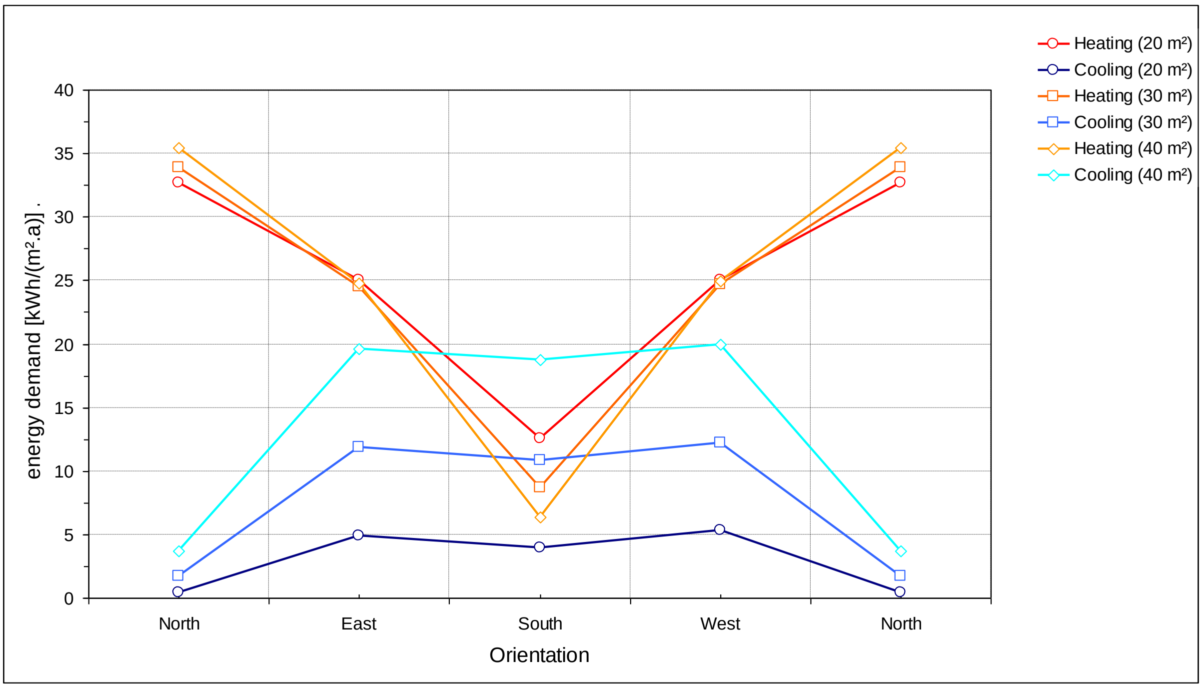


Figure 3.33: Energy demand for heating and cooling without external shading

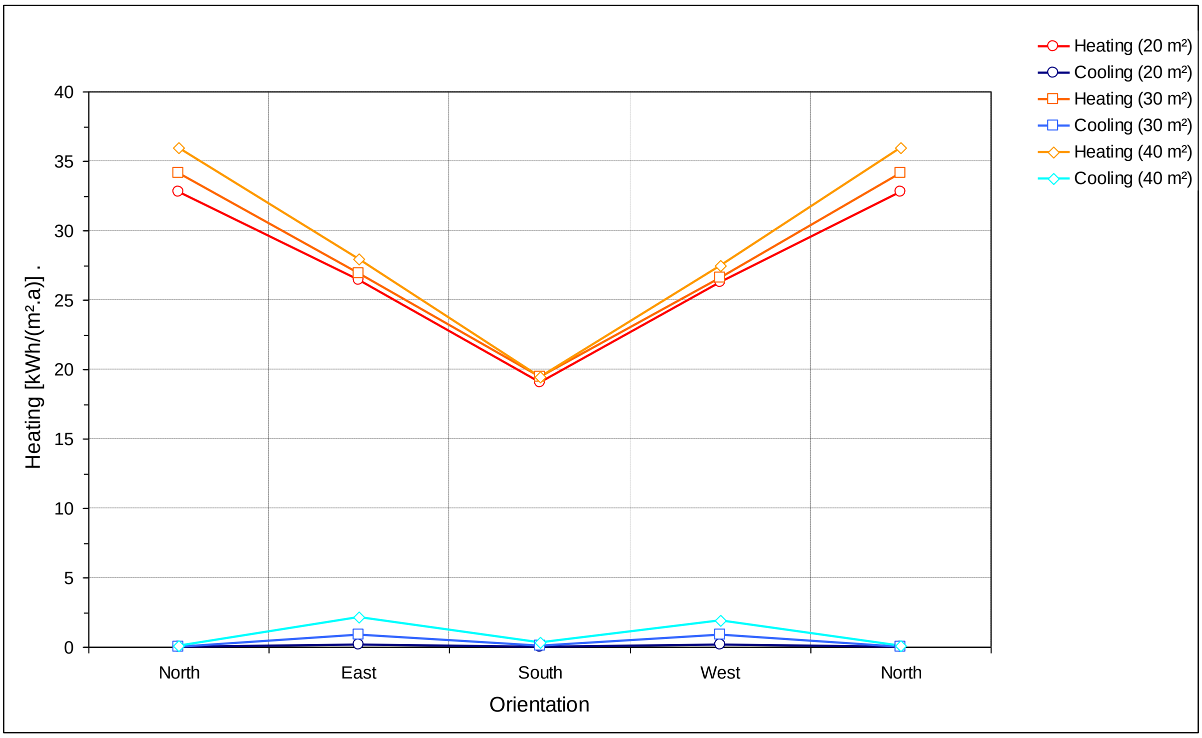


Figure 3.34: Energy demand for heating and cooling with controlled external shading

3.1.2 Canada

The market analysis identify shipments of ground-source heat pumps in Canada in both residential and non residential (commercial/institutional) sectors, by type (open or closed-loop, horizontal, vertical, and direct expansion), size and cabinet type, and by region.

Ground Source Heat Pump shipments

Table 3.11 and **Figure 3.35** below summarize the shipments for ground source heat pumps in Canada between 1990 and 1994 (Caneta Research Inc., 1994 and Caneta Research Inc., 2003).

Table 3.11: Ground Source Heat Pumps Shipments in Canada (1990 – 1994)

Year	1990	1991	1992	1993	1994
Shipments	2027	1981	2781	3067	1200

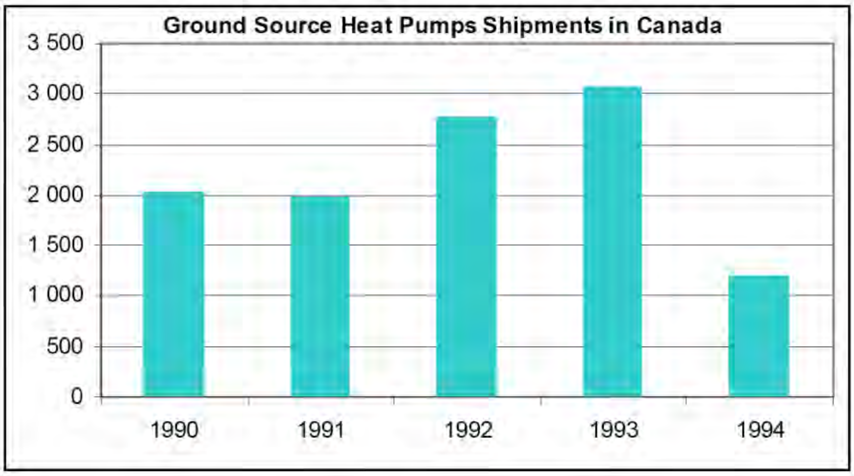


Figure 3.35: Ground Source Heat Pumps Shipments in Canada (1990 – 1994)

Table 3.12 and **Figure 3.36** indicate the shipments of all water source heat pumps, including GSHPs, in Canada between 1997 and 2002. It assumes that the split between conventional water-loop and ground source units is the same in Canada as in the United States. The data is published by ARI and distinguishes water source units as either ARI 320 or ARI 325/330 certified product. The latter are ground source units.

Table 3.12: Water Source Heat Pumps Shipments in Canada (1997 – 2002)

	1997		1998		1999		2000		2001		2002	
	WL	GS	WL	GS	WL	GS	WL	GS	WL	GS	WL	GS
ARI Split	80%	20%	82%	18%	82%	18%	86%	14%	80%	20%	82%	18%
Canada Total	9,307		21,314		15,237		11,934		13,557		13,691	
Ground Source (same split as US)	1,861		3,841		2,742		1,671		2,711		2,464	

WL – water loop heat pumps (ARI 320). GS – ground-source heat pumps (ARI 325/330)

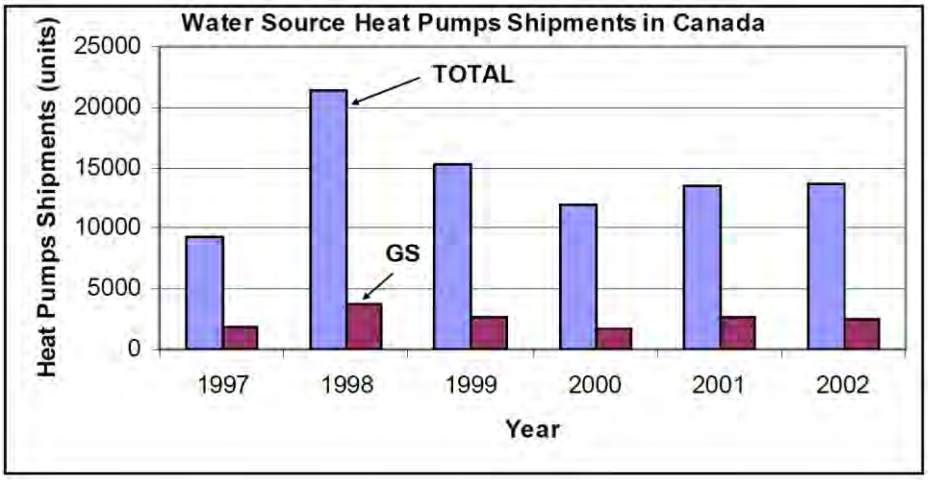


Figure 3.36: Water Source Heat Pumps Shipments in Canada (1997 – 2002) GS – Ground-Source Heat Pumps

Ground Source Type

The shipment data in **Table 3.11** was broken down (1990 – 1993) into the different ground-source types: closed-loop, open-loop and direct expansion (DX). **Table 3.13** provides these estimates for the different ground source types (Caneta Research Inc., 1994).

Table 3.13: Ground Source Heat Pumps in Canada (1990 – 1993)

	1990	1991	1992	1993
Closed-Loop	1115	1090	1530	1687
Open-Loop	811	792	1112	1227
DX	101	99	139	153

The consensus of three industry contacts was that closed-loop units accounted for 55% of the Canadian market, open-loop for 40% and DX for only 5%. There is no reason to believe that the split by type has varied over the past 10 years.

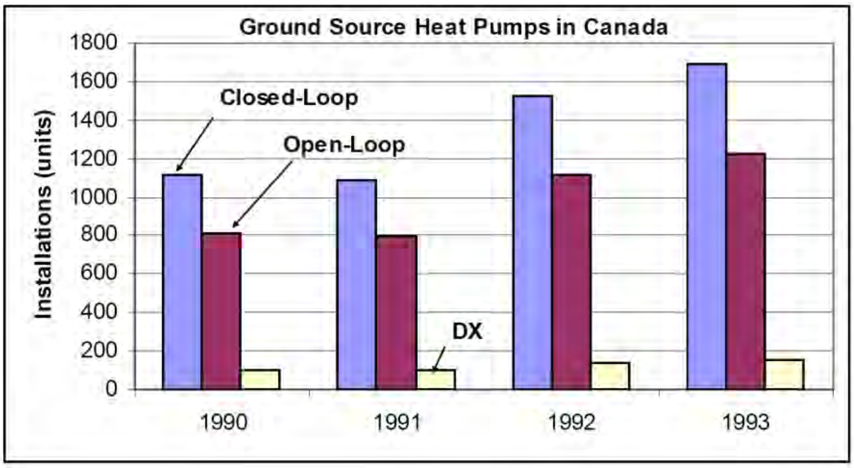


Figure 3.37: Ground Source Heat Pumps in Canada (1990 – 1993)

Heating/Cooling Capacity

The data obtained in 2002 provided capacity breakdowns of the shipments (Caneta Research Inc., 1994). Assuming that the ARI shipments reported are also representative of Canadian sales, shipments by equipment size are as shown in **Table 3.14**. The shipments by capacity do not vary significantly from year to year.

Table 3.14: Distribution by Unit Size (ARI 325/330) (Data for 2002)

Unit Size	% of Shipments
Under 6000 - 10,400	1.6
10,500 - 21,900	8.7
22,000 - 38,900	38.2
39,000 - 64,900	42.9
65,000 and up	8.3

Cabinet Type

The ARI also reports shipments broken down by cabinet type and size for the ground source category.

Table 3.15 presents data for 2002. As with unit size or capacity, this does not change significantly from year to year. The "other" category includes split and console cabinet configurations. Console cabinets are used in perimeter zones in commercial buildings. Split units are used to add-on to existing furnaces or fan-coils.

Table 3.15: Shipments by Cabinet Type and Size (%)

	% of Size Category			
Size (Btu/h*)	Horizontal	Vertical	Other	% of Total
Under 6000 - 10,400	88%	12%	0%	1.6
10,500 - 21,900	58%	35%	6%	8.7
22,000 - 38,900	29%	58%	13%	38.2
39,000 - 64,900	21%	69%	10%	42.9
65,000 and up	25%	69%	6%	8.4

*3412 Btu/h = 1 kW

Table 3.15, for each size range, provides the percentage (%) of units which are horizontal, vertical or other. Also shown is a percentage (%) of total column, which is the percentage (%) of total units shipped that are in that size category. About 30% of the ground source units shipped are between 39,000 and 64,900 Btu/h capacity and have vertical cabinets. Another 22% have vertical cabinets with unit capacities between 22,000 and 38,900 Btu/h. Horizontal cabinet units account for only 29% of all ground source units shipped; while vertical cabinet units account for 61%.

As the most common use of vertical cabinets is in residential, as opposed to commercial buildings, this information provides a very rough estimate of the residential and non-residential market split -- approximately 60%, 30%, respectively.

Estimate of Market Shares – 1993 and 2002

In 1993 and in 2002, the information provided in confidence by industry contacts estimates that ground source heat pump market shares were as shown in Table 3.16.

Table 3.16: Industry Estimation of the GSHP Market Shares (1993)

Manufacturer	Market Share	
	1993	2002
-	%	%
Water Furnace	41	36
Climate Master	28	30
Florida Heat Pump	13	12
Others	18	22

These market shares apply to all ARI member manufacturer shipments. There are non-ARI manufacturers in the US and a couple Canadian manufacturers, but their combined production is very small.

Split between Residential and Non-Residential Markets and by Region

The split between residential and non-residential markets and sales by region in Canada is indicated in **Table 3.17** and **Figure 3.38** (Marbek Resource Consultants Ltd., 1999). The majority of the GSHP systems there are in Ontario and in Western Provinces.

Table 3.17: Non-Residential and Residential Markets and Sales by region in Canada (1997)

Region	U/M	Market	
-	-	Non-Residential	Residential
TOTAL sales in Canada	units	600 - 750	900 to 1,500
Of which Ground Source Shipments	%	40	n/a
British Columbia	%	27	n/a
Ontario	%	20	38
Nova Scotia	%	17	a/a
Manitoba	%	14	n/a
Québec	%	9	n/a
Alberta, Saskatchewan, New Brunswick and Newfoundland	%	13	n/a

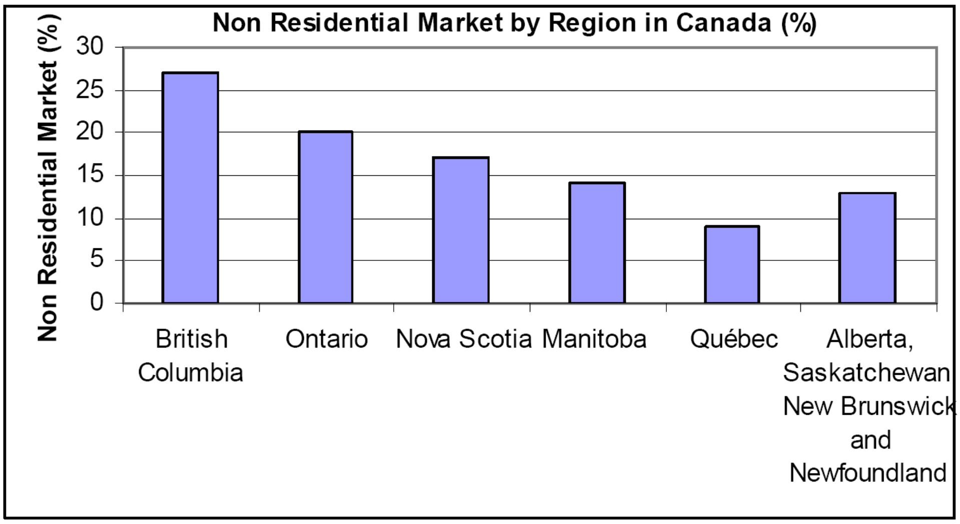


Figure 3.38: Non-Residential Markets and Sales by Region in Canada (1997)

In 2004, Natural Resources Canada has estimated at 5,000 non-residential and at 30,000 residential systems across Canada, displacing the emission of 0.5 MT of greenhouse gases (GHG).

The Future
The Canadian federal government will increase the use of one green heat technology by five-fold over the next four years. Natural Resources Canada (NRCan) has set a target to install 25,000 earth energy systems in business and institutional facilities by 2008, according to its Sustainable Development Strategy (2004). The targets will almost double the 2004 level of residential and non residential installations. Moreover, if the residential market retains its ratio, government support "could spur the installation of another 150,000 residential units" which would increase the number of installed units by 2008 to more than 200,000 systems in both sectors. The GHG emission displacement at that level would be more than 3 MT (estimation).

3.1.3 Japan

General
In comparison with the matured air source heat pump market in Japan of about 7-8 million units per year, the market development of GSHP have been very slow with the total cumulative installation of only about 130 to 140 systems. Figure 3.39 shows annual installation rate of GSHP systems from 1981 to 2005. There are 107 heating/cooling and hot water supply systems and 27 snow melting systems as of March, 2005. The total number is still very small but rapid increase is observed in the last couple of years.

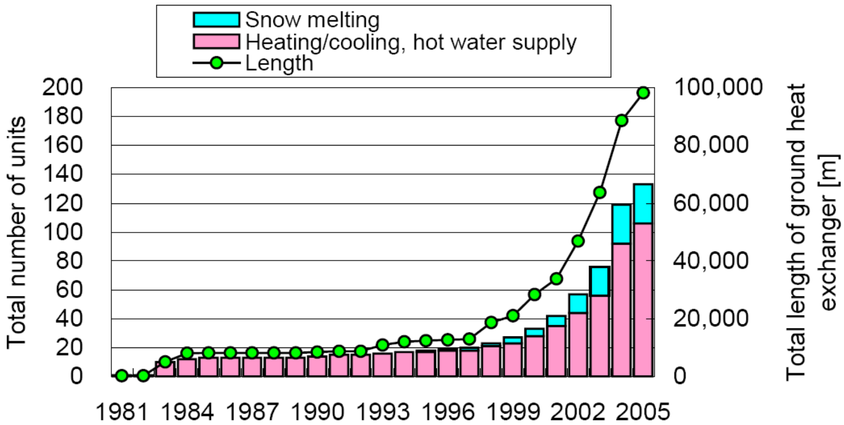


Figure 3.39: Annual installation number of GSHP systems

Background
History until 2000

[1980-1990]
Well water source heat pumps were developed and installed in large numbers in Japan after the Second World War until around 1970. However, it was after the second oil crisis that the ground coupled system was introduced in actual buildings. A small (venture) company in Hokkaido developed a ground coupled heat pump by remodeling a chiller from a major manufacturer, and sold several tens of them to single-family houses, multi-family houses and commercial buildings like hospitals

and hotels. Also, other ground coupled systems were adopted for multi-family houses and hotels in Tokyo and Kansai regions around the same time. But after that, the market of ground coupled system fell into stagnation as the oil price declined.

[1991-2001]
Several ground coupled systems including GSHP for air conditioning and hot water supply were introduced in swimming pools and hot baths in and around Hiroshima. At first, the developer received the technical assistance from Switzerland. These kinds of facilities have an advantage of effective utilization of waste heat during summer, to warm the pool water or poolside as well as for heat recovery in the ground. There are nine such systems so far in Japan.

Current situation in Japan after 2001
A couple of groups or associations to study and promote GSHP system were organized in Japan influenced by the rapid spread of the system in Europe and North America and the enactment of the Kyoto protocol. They offer opportunities to exchange information and organize seminars for technological improvements. The Geo-Heat Promotion Association of Japan is another organization, in which provide substantial databases on the web. The New Energy Development Organization, NEDO, also promotes GSHP system as an energy efficient system.

Division of Ground Thermal Energy System was established to be supported by 3 kinds of private companies in Hokkaido University in 2004. The laboratory specializes in the research and development of GSHPs and another utilization of ground thermal energy.

Now, the Ministry of Environment, NEDO and some local governments including Tokyo and Osaka subsidize for the introduction of the GSHP system. Hokkaido Electricity Power Company also gives subsidy in order to spread heating systems with heat pumps. Additionally, some house manufacturers offer their own subsidies independently.

Market Analysis
Figure 3.40 indicates applications and operations of 134 GSHP systems. **Table 3.18** shows the detailed classification in terms of boring methods, ground heat exchangers and devices for heat extraction.

Single-family houses
52 GSHP systems are applied to single-family houses. It should be noted that 41 systems of them were built after 2002 and the number has been increasing rapidly in the last couple of years. One reason for this is that a package type GSHP unit for single-family houses was introduced to the market in 2004. It is mainly used for space heating in the cold climatic area.
The use of steel foundation piles has been increased to 11 although vertical borehole type heat exchangers still have larger share. This is another reason for the recent increase. Many systems of that kind are for both heating and cooling.

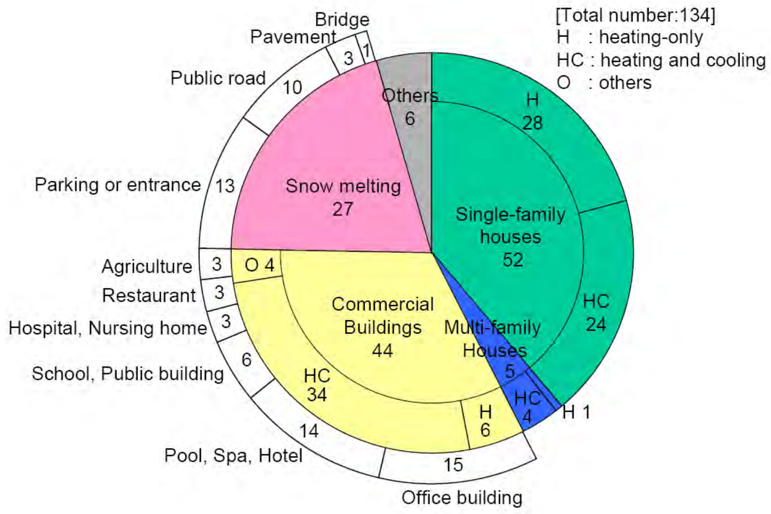


Figure 3.40: Applications and operations of the 134 GSHP systems as of March, 2005 (Source:Study Group on Geothermal & Heat Pump Systems in the Heat pump & Thermal Storage Technology Center of Japan)

Table 3.18: Detailed classification of the GSHP systems (Source:Study Group on Geothermal & Heat Pump Systems in the Heat pump & Thermal Storage Technology Center of Japan)

Type				Single-family house	Multi-family house	Commercial building	Snow melting	Others	Total
Horizontal	Radial well					2			2
	others					2			2
Vertical	Foundation pile	Cast-in-place concrete				2			2
		PHC	Open			2			2
			Close		3	4			7
		Steel	Large (>600mmϕ)			1			1
			Small	11		1			12
	Borehole	Double pipe	Metal	2	1	1	8	2	14
			HDPE	2		5	1		8
			Metal+ HDPE	2	1	1	1		5
		U-tube	Copper	1		1		1	3
			HDPE	32		22	17	3	74
	Earth drill			2					2
Total				52	5	44	27	6	134

Multi-family houses

The installation number is only 5 and all of the systems were built in the 1980's.
Commercial and institutional buildings

There are various applications in commercial and institutional buildings. It should be noted that practical applications have been increasing in public buildings such as schools, pools and hospitals. It is interesting to note that some systems are applied to agriculture and chain restaurants. Vertical borehole system has 50% share but lately the use of PHC or steel foundation piles as ground heat exchangers has attracted more attention also in commercial buildings. The combination of steel foundation piles and vertical boreholes has been applied to a school building to be completed in 2006.

Snow melting systems

There are various applications in commercial and institutional buildings. It should be noted that practical applications have been increasing in public buildings such as schools, pools and hospitals. It is interesting to note that some systems are applied to agriculture and chain restaurants. Vertical borehole system has 50% share but lately the use of PHC or steel foundation piles as ground heat exchangers has attracted more attention also in commercial buildings. The combination of steel foundation piles and vertical boreholes has been applied to a school building to be completed in 2006.

Discussion about the market barrier

Several market barriers to be solved on the GSHP system now in Japan are discussed as follows.

- Competition with air source heat pumps

  In Japan, air source heat pumps have been already diffused even in the cold region. It allows the reduction of the initial cost. So it is expected that the GSHP system shows the advantage from the system performance and running cost points of view for the spread to the market.
  Measurement of the secure variations of the performance will also lead to the diffusion of the GSHP in Japan since the collected data can provide availability of the GSHP system from both environmental and economical points of view in the real sense of the term.

- Variation of heat pump units and the cost reduction

  Various sizes of heat pump units are needed in both residential and commercial buildings. Additional functions, such as hot water supply and waste heat recovery, are also preferable. Performance of such multi functional heat pumps should be considered at the following stage of the system design of the GSHP system. Cost reduction is also necessary in order to compete with air source heat pumps.

- System design

  One of most important issues is to establish the total design system putting together technical elements. In particular, design of the secondary side should be noticed more since GSHP systems cannot provide high temperature to the target room continually compared to conventional boiler systems. It has been sometimes reported that poor insulation leads to lack of thermal comfort at lower room temperature in the GSHP system. A research group is developing a guideline of the system design now in Japan.

- Evaluation of performance

  Temperature conditions in the performance test of GSHPs should be standardized also in Japan. It will lead to avoid shortage of heating or cooling output. Furthermore, the measured performance should be reflected for evaluation of the system performance in appropriate simulation programs.

- Interest of consumers and the government

A residential GSHP system got a prize from the Minister of the Environment of Japan and was introduced to the world by the Minister in COP11 in 2005. Although interest for environment and energy conservation have been increasing recently also in Japan, economical efficiency tends to be prevailed in Japan. Besides it, visibility of the GSHP is still lower than photovoltaic (PV) systems as the utilization of natural energy resources. Cooperation of both national and local governments is necessary for increase of the visibility as well as activities of research groups.

3.1.4 Norway

General

Figure 3.41 shows the annual installation rate for heat pumps in Norway during the period 1992 to 2003, whereas **Figure 3.42** displays the accumulated heat production and energy saving for the installations in GWh per year. The data are based on information from the Norwegian heat pump association, NOVAP (http://www.novap.no) and SINTEF Energy Research.

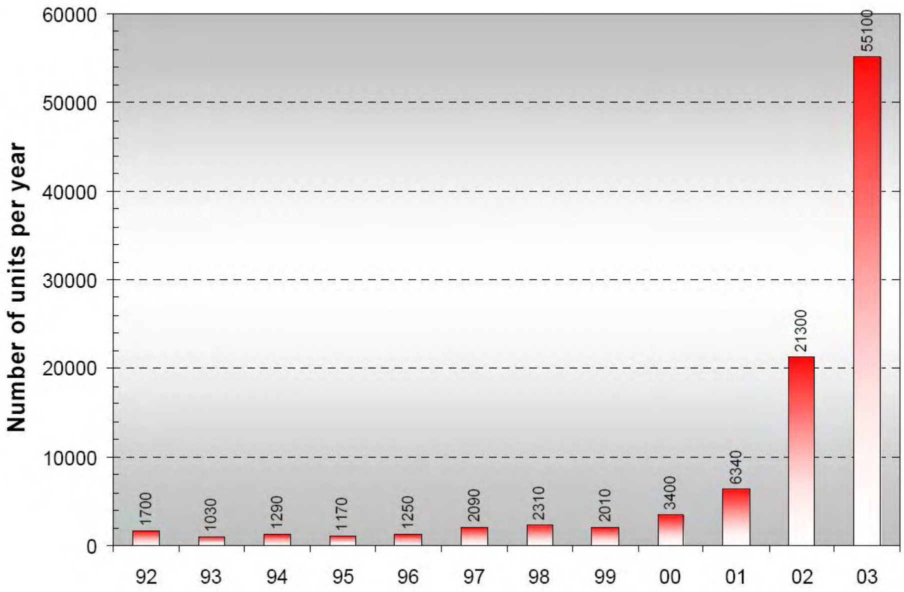


Figure 3.41: Annual installation rate for Norwegian heat pumps during the period 1992-2003.

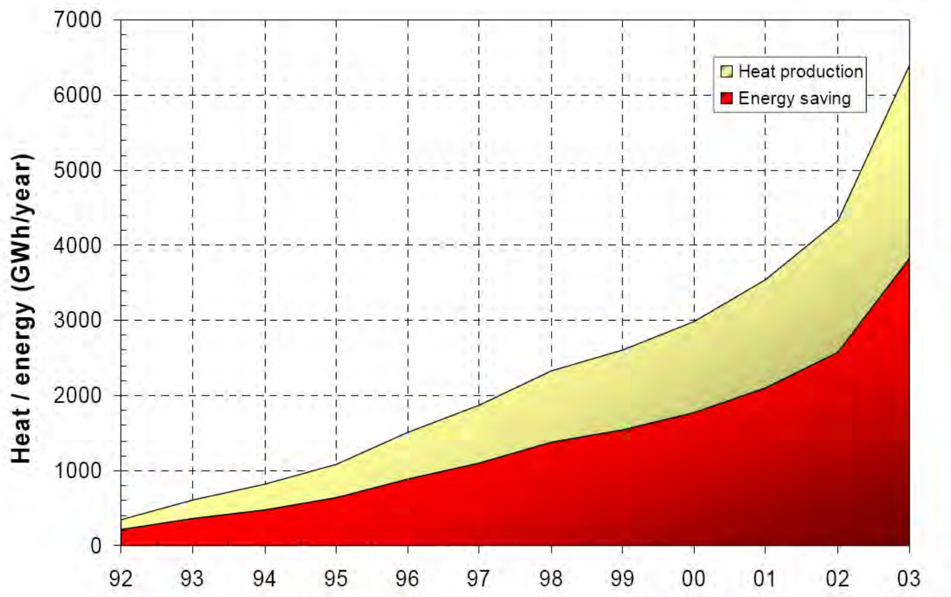


Figure 3.42: Accumulated heat production and energy saving during the period 1992-2003.

Figure 3.43 shows the annual installation rate for heat pumps in Norway sorted by heat sink and/or heat source (air-to-air, ventilation air, air-to-water, water/brine-to-water).

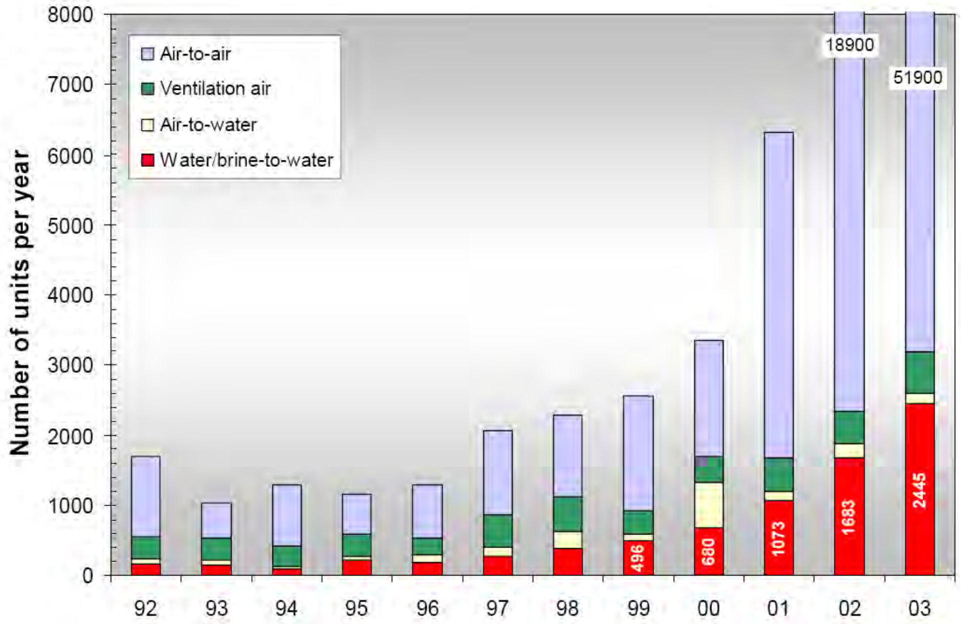


Figure 3.43: Annual installation rate for heat pumps in Norway during the period 1992-2003 sorted by heat sink and/or heat source.

Since 1998 the growth rate for the water-to-water and brine-to-water heat pump market (incl. GSHPs) has varied between 25 to 55%, and in 2003 growth rate was about 45%. Most of the installations are residential systems for combined space heating and hot water heating installed in new residences, and the main heat source is vertical boreholes in bedrock.

Market Opportunities for GSHP Systems in Norway

The Norwegian market for ground-source heat pump (GSHP) systems in residential and nonresidential buildings is expected to grow the coming years as a result of:

- Relatively high energy prices – strengthens the competitive power of heat pumps vs. conventional heating and cooling systems (direct electric heating systems and oil-/gas-fired boilers, possibly in combination with separate cooling systems in non-residential buildings).

- Relatively low interest rates – favourable for capital intensive installations such as GSHPs.

- Establishment of ENOVA SF, which is owned by the Norwegian Ministry of Petroleum and Energy. The main mission of Enova SF is to contribute to environmentally sound and rational use and production of energy, relying on financial instruments and incentives to stimulate market actors and mechanisms to achieve national energy policy goals. The main objectives are improved energy efficiency, more flexibility in the energy supply (decreased dependence on direct electricity for heating), and an increased share of renewable energy sources. – e.g. more focus on hydronic heat distribution systems in buildings, small- and large-scale district heating systems and heat pumps. Enova SF administers an Energy Fund of 650 million € over a ten-year period (2002-2012).

- New national buildings codes – will lead to a reduction in the space heating demand, but the demand for reheating of ventilation air and the space cooling demand will most likely increase in many types of non-residential buildings. The load profiles for heating and cooling matches the operating characteristics of GSHP systems utilizing underground thermal energy storage, leading to profitable and energy efficient installations. The new building codes will come into effect from January 2006.

- New EU directive (2002/91/EC), "Energy Performance of Buildings". The directive focuses on reducing the total energy use in buildings – i.e. heating, cooling and electricity demands. The directive will include new requirements for energy use in new and renovated buildings, energy inspections of heating/cooling systems as well as implementation of Energy Certificates for new buildings, buildings larger than 1000 m^2 that are being rehabilitated, public buildings larger than 1000 m^2 and buildings that are sold or leased. The directive, which will come into effect in Norway from January 2006, is believed to increase the attractiveness of GSHP systems for energy efficient heating and cooling of non-residential buildings.

- Hydronic floor heating systems were installed in 45% of new homes in 2003 – this trend facilitate the installation of GSHP systems (Varmeinfo - statistikk).

- Hydronic heat distribution systems is compulsory in new and renovated governmental buildings with a floor space above 1000 m^2, and hydronic heat distribution systems are also becoming more popular in new non-residential buildings. There is also increasing interest in small-scale and large-scale district heating (and cooling) systems. These factors facilitate the installation of GSHP systems.

- Increasing awareness of the economical, technical and environmental benefits of GSHP systems among end-users in general, the Norwegian public authorities, municipalities, building owners, energy utilities, development companies and consultant engineers.

Examples of current market impediments for GSHPs are:

- The total capital costs for residential GSHP systems including the hydronic heat distribution system are relatively high compared to conventional heating systems such as electric baseboard heaters, electric water heaters, wood-fired stoves, oil/kerosene stoves and gas/oil-fired boilers. As a consequence, GSHPs systems are mainly regarded a viable option in new or renovated residences with a floor space above 150 to 200 m^2.

- Non-residential building owners that lease their buildings are mainly interested in minimizing the capital costs. This hampers the use of capital intensive but energy efficient installations with low operating costs, such as GSHPs in combination with hydronic heat distribution systems.

3.1.5 Sweden

Market segmentation

The total heating market is the first departure point for a market segmentation of heat pumps. However, this statistical information does not immediately reveal the amount of heat delivered from heat pumps. For instance, a relatively large part of the heat delivered through district heating, approximately 6 TWh, is covered by large electrically driven heat pumps utilizing waste heat in sewage water or sea water.

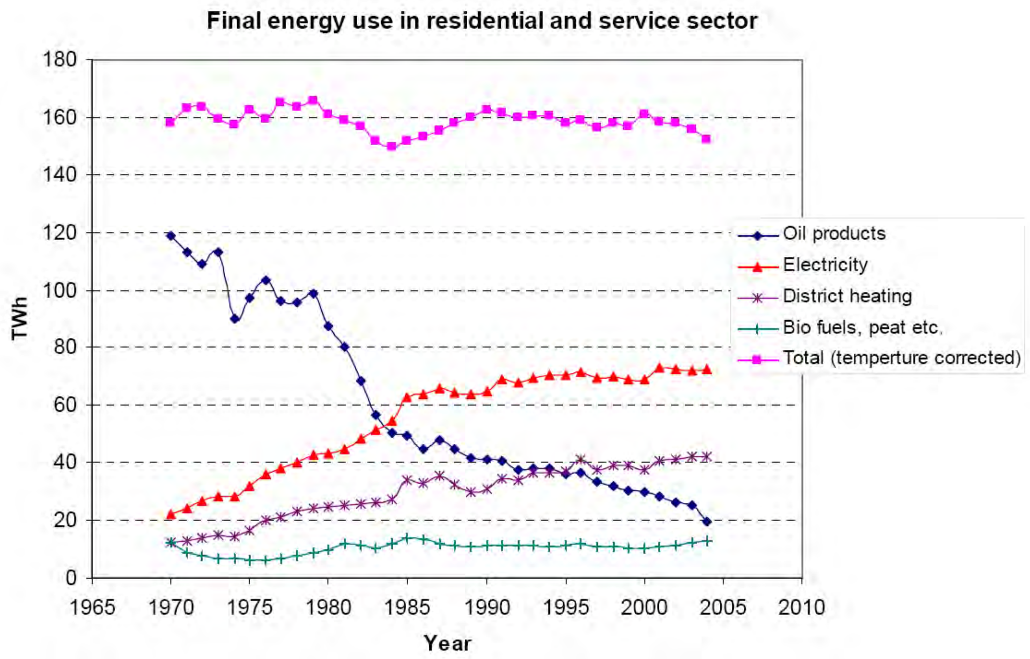


Figure 3.44: Final energy use in residential and service sector by type (STEM, 2005)

By studying **Figure 3.44** several interesting observations can be made:

- The use of oil for heating purposes was totally dominant in 1970 with a 75 % share. Since then it has gradually decreased to approximately 12 % in 2005. During 2006 this value has further decreased but since statistical data is not yet available, an estimate could be around 6-7 %.

- The use of electricity for heating was growing rapidly from 1970 to 1990 but this figure is now leveling off. Retrofitting of direct base board heating in houses built during the seventies and early eighties to various combinations of air/air heat pumps/pellet heaters or even retrofit to hydronic heating systems is likely to reverse the trend through the coming years.

The sub-market for heating of residential single-family houses amounts to a total of 40 TWh of which 4.3 TWh has been estimated to be electricity to heat pumps.

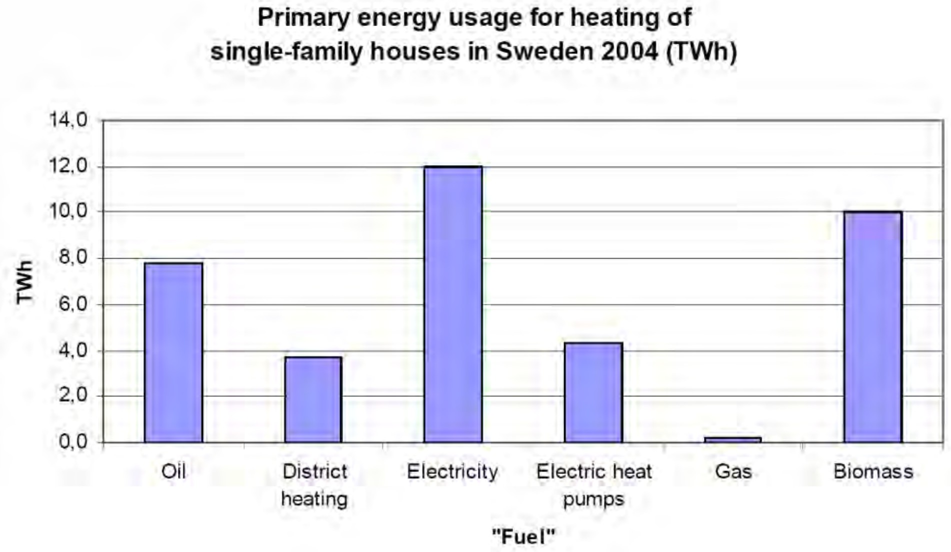


Figure 3.45: Primary energy usage for heating of single-family houses based on data from Statistics Sweden (www.scb.se).

These heat pumps have been estimated (conservatively) to deliver approximately 8-9 TWh heat, which for obvious reasons does not appear in the statistics. One has to bear in mind that energy use normally is counted as "energy supply". There is no available statistics concerning useful energy or "heat losses" from buildings. If the total heat delivered by domestic heat pumps is broken down by heat pump type, assuming typical efficiencies, the dominance of the GSHP system is evident (**Figure 3.46**).

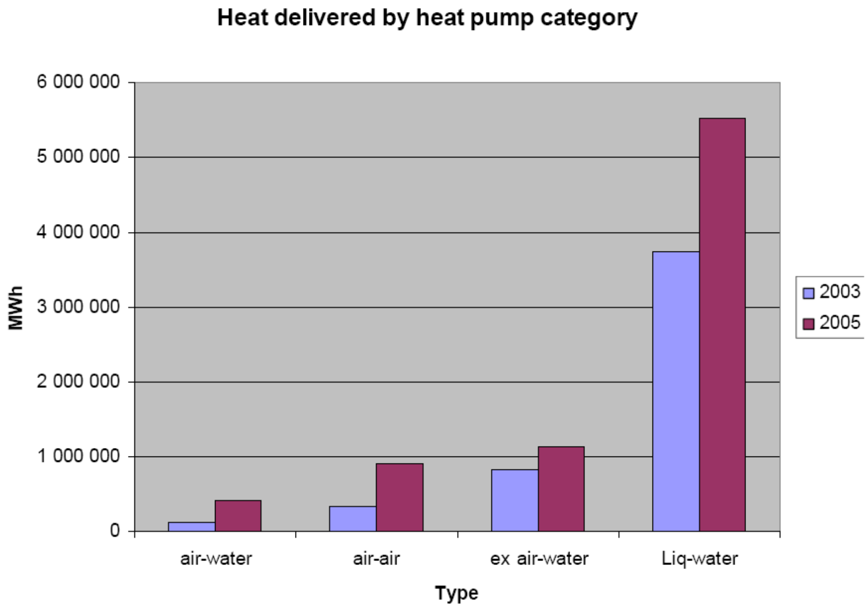


Figure 3.46: An estimation of heat delivered by heat pumps broken down by category. The diagram is constructed by assuming typical seasonal performance factors and information on installed numbers from Figure 3.48 and Figure 3.49 (Forsén, 2005).

The building stock – market penetration per sector (industrial, commercial and residential)

The market penetration per sector is relatively difficult to assess since no dedicated database for various types of sectors exists. It is clear that the market penetration in the residential sector for small detached houses is relatively good with respect to the share of delivered heat. GSHP appears to cover 20 – 25 %. No statistics are available for multifamily dwellings. Larger HPs in district heating systems are not of the GSHP type. The heat source is typically sewage or sea-water. The output of these heat pumps is delivered to the district heating grid and available statistics such as the one given in **Figure 3.47** do typically not distinguish between the primary fuels. There is probably a hidden number of heat pumps due to the fact that a GSHP in the house yields a higher property tax.

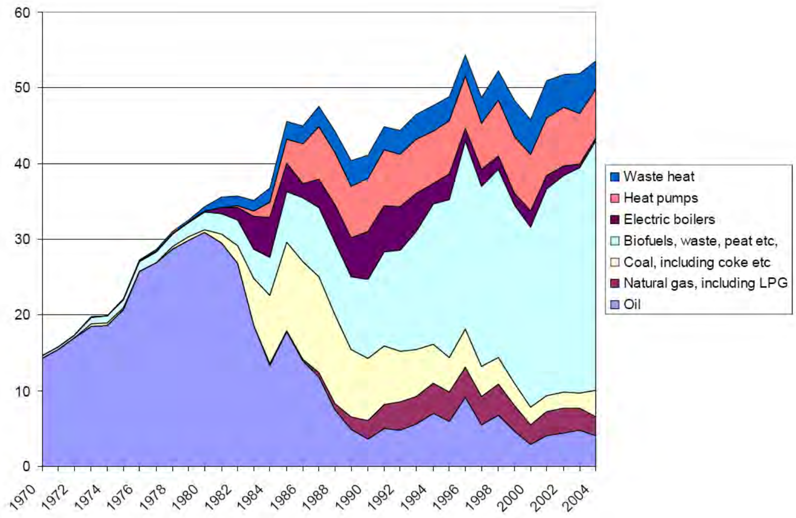


Figure 3.47: Primary "fuel" in district heating (Source: STEM, 2005) in TWh. In this kind of statistics heat from heat pumps is regarded as fuel input.

Available Sales statistics

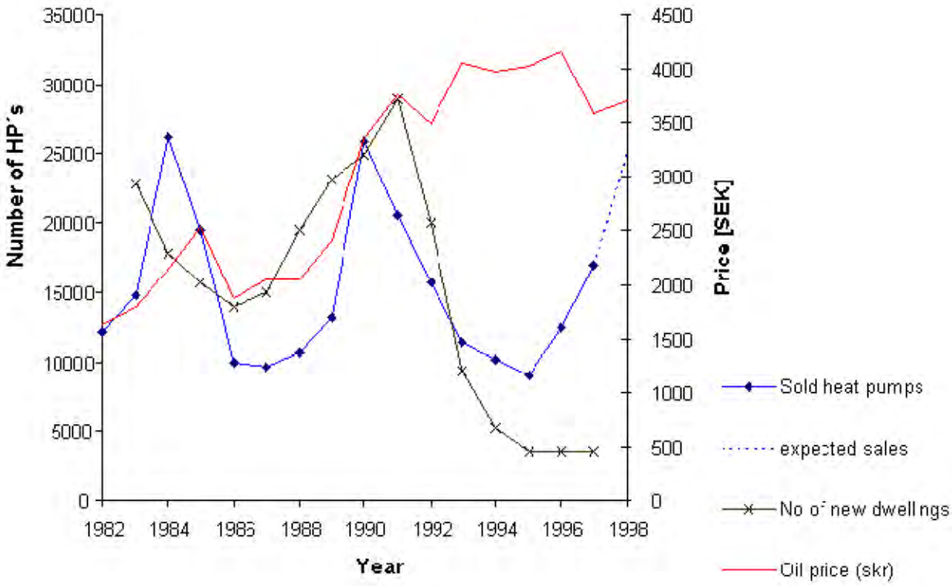


Figure 3.48: Sales statistics for the period 1982 – 1998 . The diagram also shows data on oil price and number of new dwellings built. More historical data on energy prices is given in Figure 3.50.

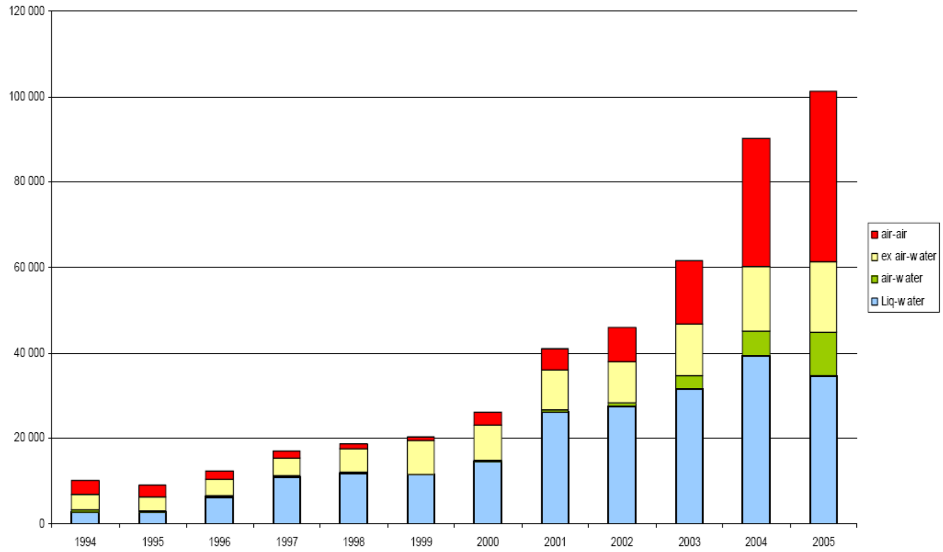


Figure 3.49: Sales statistics for the period 1994 – 2005. Available statistics give data for air/air (red/top), exhaust air/water (yellow/second from top), air/water (green/second from bottom) and liq/water (blue/bottom), (SVEP, 2006).

Current issues and trends (environmental concern, working fluids, legislation, peak electricity)

The heat pump working fluid has been one factor to consider for manufacturers and several attempts have been done to enforce new legislation or labeling promoting increased use of so-called natural refrigerants. Today, the standard choice is typically R407C or other HFC-refrigerants such as R404A, R410A or R134a even though a small number of heat pumps with other fluids such as propane or CO_2 exist on the market. Active research to facilitate the use of other fluids such as CO_2, ammonia or propane is undertaken at universities and research institutes with governmental support.

Table 3.19: Refrigerant phase-out in Sweden (Johansson A., Lundqvist P., 2001)

ASHRAE Number	Primary Replace-ment	Type of refrige-rant	Stop for import or new installations	Stop for refill	Stop for use	Share of the total refrigerant charge in Sweden 1993
R12, R500, R502	**R134a R404A**	**CFC**	**1/1 1995**	**1/1 1998**	**1/1 2000**	**32% 6%**
R22	**R407C**	**HCFC**	**1/1 1998**	**1/1 2002**	**N/A**	**50%**

Economy (oil v.s. electricity price subsidiaries etc.)

The development of energy prices including taxes in Sweden is given in the following graphs.

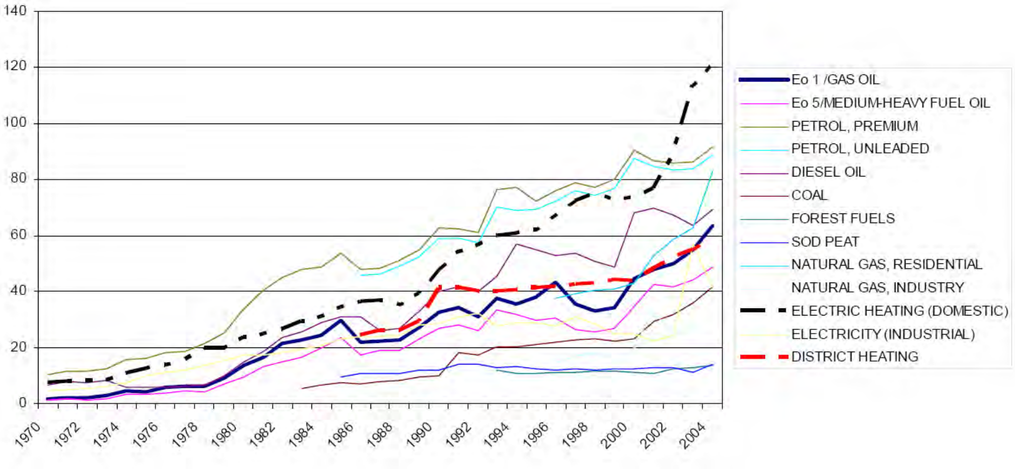


Figure 3.50: Energy prices in öre (100 öre = 1 skr, 7 skr ~ 1$, 2006) for 1 kWh of energy content. Electricity for households (black, dashed), district heating (red dashed) and oil (dark blue) are bold. Efficiencies in conversion equipment are not taken into consideration.

Prices are increasing due to various external and internal factors further discussed later in the national report. The oil price increased rapidly a few times before returning to lower levels again. These variations might seem insignificant in the longer perspective but are important since many predictions used in economical estimates/judgments are based on future prognostication. The price of electricity has increased due to various factors beyond the scope of the report. The major reason is however increased taxes and a harmonization with EU electric market. In 1970 the tax was 6.5 % of the price and in 2004 the tax represented 40 %. If the so-called consumer price index is taken into account the energy prices may be better understood.

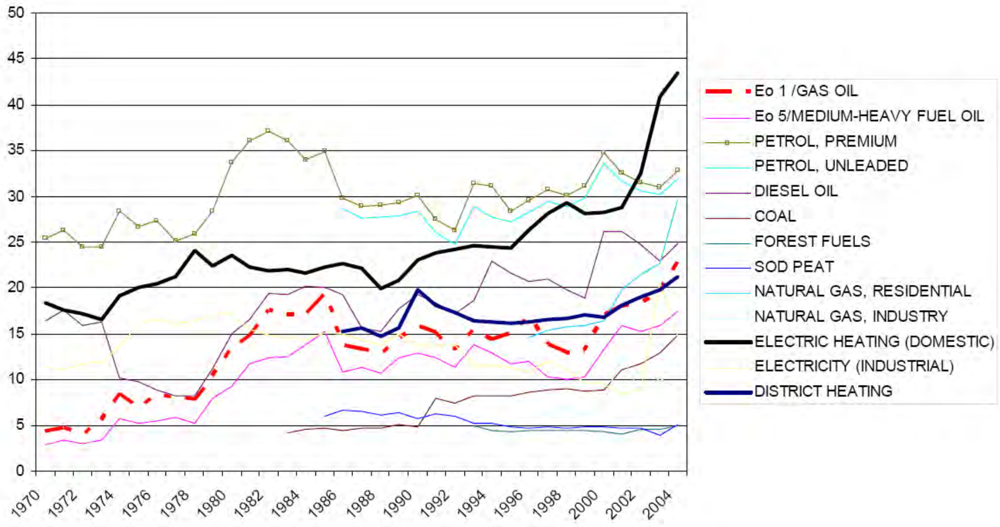


Figure 3.51: Energy prices as above but expressed using the consumer price index. Base year 1980.

An interesting way of representing the importance of energy prices is in relation to choice of the most economic heating system was proposed by professor Eric Granryd many years ago. For very low prices of electricity, no other system than direct electric heating can compete due to capital costs. Similarly, an oil furnace is cheapest for very low prices of oil. Interestingly enough, the general increase in price of electricity and oil strongly benefits heat pumps.

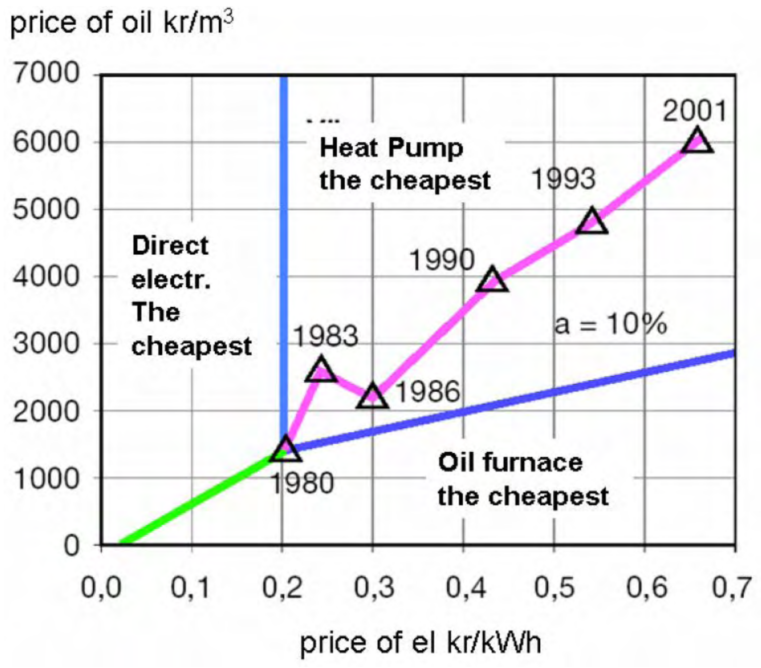


Figure 3.52: Energy price development and choice of most economic heating system taking investment cost and typical interest rate into account

3.1.6 USA

Geothermal Energy Use – The Big Picture

Geothermal energy represents about 0.32% of total energy consumption by all energy sources (coal/coke, natural gas, petroleum, nuclear, hydroelectric, geothermal, biomass, solar, and wind) in the United States and it is also small among renewable energy sources in all sectors (residential, commercial, industrial, electric power). We shall present data to support these figures, but first it is essential to gain an appreciation for its position in terms of energy use in each sector of the economy. This knowledge will shed light on factors that influence market growth and incentives to promote geothermal energy use.

Table 3.20 shows that during five years preceding 2003, the use of geothermal energy remains stable at an averaged 0.3202 ± 0.00882 quads (3.378 x 10^5 TJ ± 9.305 x 10^3 TJ). The comparative picture of geothermal energy relative to the 8 other energy sources listed in **Table 3.20** becomes more evident in **Figure 3.53**. While geothermal energy has remained stable from 1999 to 2003, wind energy is the only energy source that has shown a marked increase between those years.

Geothermal resources capable of supporting electrical generation and/or direct use projects are found primarily in the Western United States. However, geothermal heat pumps extend the utilization to all 50 States (Lund, et. al. “The United States of

America Country Update", Proceedings World Geothermal Congress 2005, Antalya, Turkey, 24-29 April, 2005, pp. 1). The position that geothermal energy occupies among all energy sources used in the United States is shown in and in **Figure 3.53**.

Table 3.20: U.S. Energy Consumption (Quads[(1)]) by Energy Source, 1999-2003 (Source: Energy Information Administration: Data for 2003; Reported Release: August 2004. www.eia.doe.gov/cneaf/solar.renewables/page/trends/table2.html)

Energy Source	**1999**	**2000**	**2001**	**2002**	**2003**
Coal+Coke	21.681	22.645	21.926	22.256	22.824
Natural Gas	23.01	23.916	22.861	23.069	22.49
Petroleum	37.96	38.404	38.333	38.401	39.074
Nuclear	7.61	7.862	8.028	8.145	7.795
Hydroelectric	3.268	2.811	2.201	2.675	2.779
Geothermal	0.331	0.317	0.311	0.328	0.314
Biomass	2.873	2.893	2.626	2.773	2.865
Solar Energy	0.069	0.066	0.065	0.064	0.063
Wind Energy	0.046	0.057	0.068	0.105	0.108
Total	96.848	98.971	96.419	97.816	98.312

(1) 1 Quad = 1.055 x 10^6 TJ

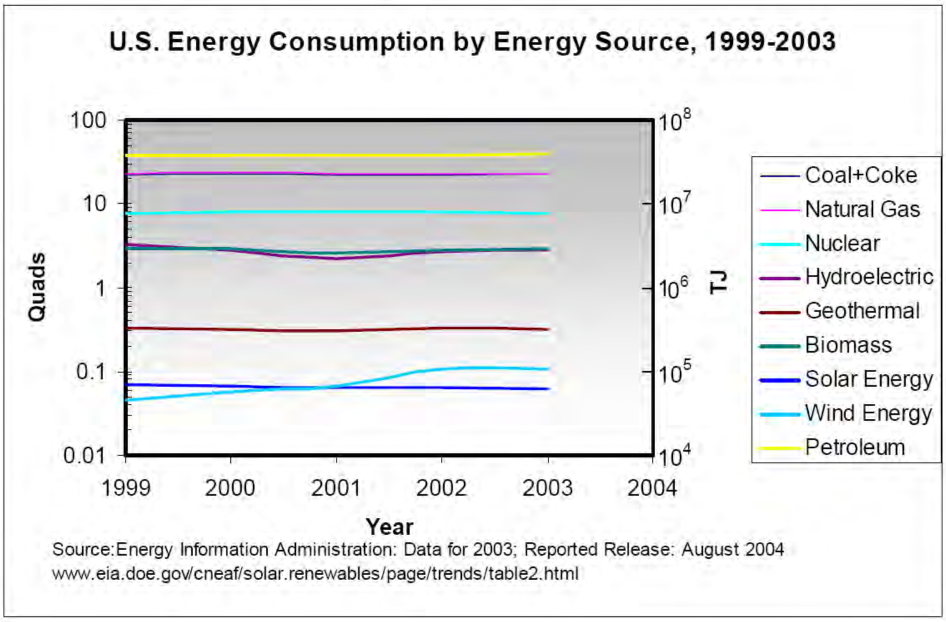


Figure 3.53: U.S. energy consumption from 9 energy sources between1999-2003.

We next show the growth trend of geothermal energy with other renewable sources of energy in the residential, commercial, industrial, and electric power sectors of the economy.

Table 3.21 shows the cumulative use of geothermal energy in the residential sector. Cumulative use includes direct-use for heating and geothermal heat pumps.

Table 3.21: Renewable Energy Consumption (Quads[(1)]) in Residential Sector and Energy Source, 1999-2003

Sector and Source	1999	2000	2001	2002	2003
Residential (Total)	**0.486**	**0.503**	**0.439**	**0.382**	**0.435**
Biomass	0.414	0.433	0.37	0.313	0.359
Geothermal	0.009	0.009	0.009	0.01	0.018
Solar	0.064	0.061	0.06	0.059	0.058

(1) 1 Quad = 1.055 x 10^6 TJ

Table 3.21 shows that among renewable sources of energy used in the residential sector, geothermal use is the least among biomass, geothermal and solar energy although, geothermal has shown positive growth trends between 1999 and 2003, while the other two have shown a slightly negative trend. This is visibly apparent in **Figure 3.54**.

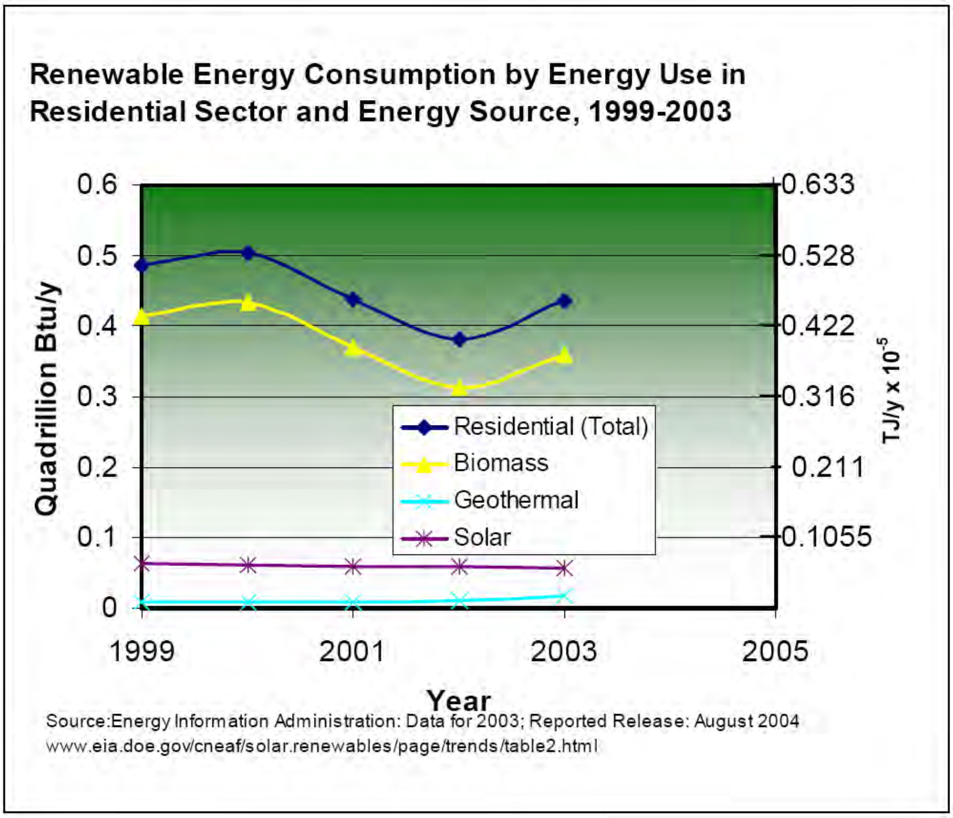


Figure 3.54: Renewable energy source use trends and relative position of geothermal energy in the residential sector, between 1999 and 2003.

In the commercial sector, the geothermal energy utilization is shown in **Table 3.22** and in **Figure 3.55**.

Table 3.22: Renewable Energy Consumption (Quads(1)) in Commercial Sector and Energy Source, 1999-2003.

Sector and Source	**1999**	**2000**	**2001**	**2002**	**2003**
Commercial (Total)	**0.22**	**0.209**	**0.168**	**0.177**	**0.197**
Biomass	0.106	0.1	0.08	0.084	0.09
Wood/Wooswaste	0.052	0.053	0.04	0.042	0.042
MSW/Landfill Gas	0.049	0.041	0.035	0.037	0.042
Other Biomass	0.005	0.006	0.004	0.005	0.007
Geothermal	0.007	0.008	0.008	0.009	0.015
Conventional Hydroelectric	0.001	0.001	0.001		0.001

The EIA database from which this information was downloaded did not provide any information for conventional hydroelectric use in 2002. Also, the totals for energy use in the commercial sector given in row 2 have been calculated from the individual sources because the figures given by EIA appear to be in error.

Use of geothermal energy in the commercial sector has grown since 2002 while other uses of renewable energy has either remained stable or have declined. These trends are shown graphically in **Figure 3.55**.

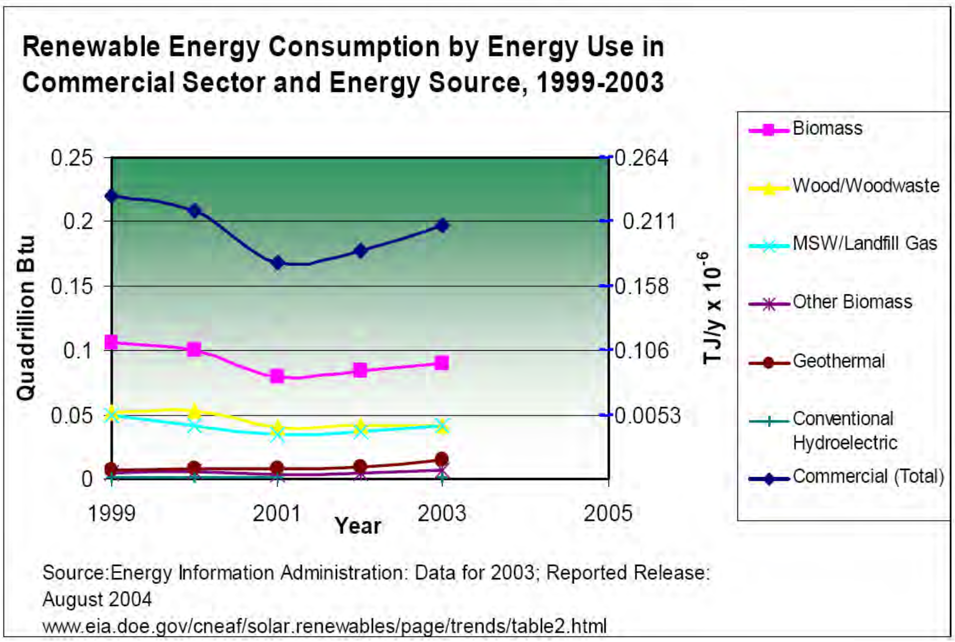


Figure 3.55: Renewable energy source use trends and relative position of geothermal energy in the commercial sector, between 1999 and 2003.

In the industrial sector, geothermal energy ranks last out of 9 renewable sources in terms of usage. Utilization of renewable sources of energy in the industrial sector is shown in **Table 3.23** and in **Figure 3.56**.

As in the case of commercial sector data, the totals for energy use in the industrial sector (**Table 3.23**, row 2) have been calculated from the individual sources because the figures given by EIA appear to be in error. The growth rate of geothermal energy use in the industrial has remained flat from 1999 until 2003, with an increase in 2004. It is not possible to conclude if the slight growth in geothermal energy from 2003 to 2004 is sustainable.

Table 3.23: Renewable Energy Consumption (Quads[(1)]) in Industrial Sector and Energy Source, 1999-2003.

Sector and Source	**1999**	**2000**	**2001**	**2002**	**2003**
Industrial (Total)	**3.635**	**3.608**	**3.223**	**3.454**	**3.439**
Biomass	1.791	1.781	1.593	1.705	1.689
Wood/Woodwaste	1.62	1.636	1.443	1.531	1.524
MSW/Landfill Gas	0.094	0.064	0.074	0.087	0.089
Other Biomass	0.077	0.081	0.076	0.087	0.075
Geothermal	0.004	0.004	0.005	0.005	0.005
Conventional Hydroelectric	0.049	0.042	0.032	0.039	0.057

(1) 1 Quad = 1.055 x 10^6 TJ

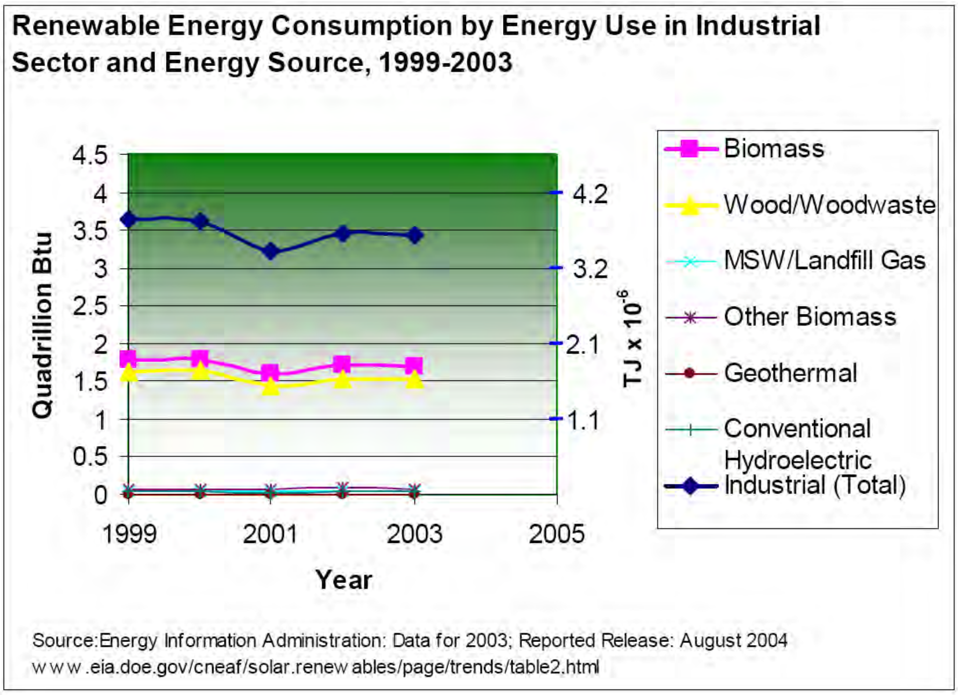


Figure 3.56: Geothermal energy use in the industrial sector ranks last among 9 renewable energy sources in the U.S.

Geothermal energy finds its biggest use in the electric power sector as compared to its use in the residential, commercial and industrial sectors both in ranking as well as in total energy (TJ). This data is shown in **Table 3.24** and **Figure 3.57**. Among renewable sources, geothermal ranks number 3 out of 8 energy sources after hydroelectricity and biomass in the electric power sector.

Lund, et. al. ("The United States of America Country Update", Proceedings World Geothermal Congress 2005, Antalya, Turkey, 24-29 April, 2005, pp. 1) report that, "The present installed capacity (gross) for electric power generation is 2,534 MWe with about 2,000 MWe net delivering power to the grid producing approximately 17,840 GWh per year for a 80.4% gross capacity factor. Geothermal power plants are located in California, Nevada, Utah, and Hawaii. The two largest concentrations of plants are at The Geysers in northern California and the Imperial Valley in southern California."

Table 3.24: Renewable Energy Consumption (Quads[(1)]) in Electric Power Sector and Energy Source, 1999-2003.

Sector and Source	**1999**	**2000**	**2001**	**2002**	**2003**
Electric Power (Total)	**4.487**	**4.031**	**3.432**	**4.083**	**4.125**
Biomass	0.453	0.453	0.45	0.516	0.507
Wood/Woodwaste	0.138	0.134	0.126	0.15	0.161
MSW/Landfill Gas	0.292	0.295	0.31	0.343	0.322
Other Biomass	0.023	0.023	0.014	0.022	0.024
Geothermal	0.312	0.296	0.289	0.305	0.276
Conventional Hydroelectric	3.218	2.768	2.169	2.636	2.722
Solar	0.005	0.005	0.006	0.006	0.005
Wind	0.046	0.057	0.068	0.105	0.108

(1) 1 Quad = 1.055 x 10^6 TJ

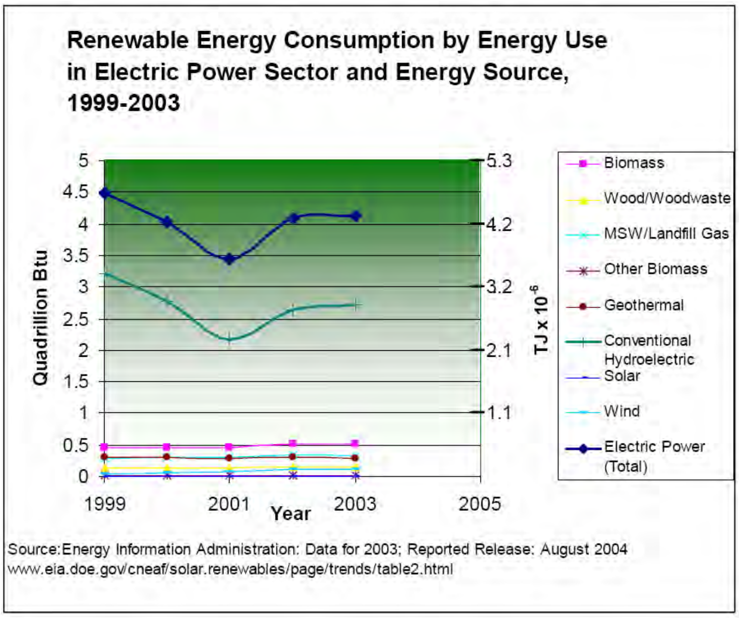


Figure 3.57: After Hydroelectric and Biomass, Geothermal energy ranks 3rd out of eight Renewable Sources used in Electric Power Sector.

Data obtained from Geo-Heat Center, Oregon Institute of Technology, Klamath Falls, OR (Tonya Boyd, personal communications, 2005) clearly indicate that the largest application of geothermal sources is ground-source (geothermal) heat pumps. In 1975, geothermal heat pumps utilization was 286 TJ/y increasing to 20250 TJ/y by 2005. This growth is depicted in **Figure 3.58**.

The compounded geothermal heat pump growth rate, r_{hp} is calculated as follows:

$$TJ/y(2005) = TJ/y(1975)\left(1 + \frac{r_{hp}}{100}\right)^n$$

with TJ/y(2005) = 20250, TJ/y(1975) = 286 and n = 30 years

Solving the above equation yields r_{hp} = 15.3%. The growth rate in geothermal heat pumps has been 15.3% from 1975 to 2005.

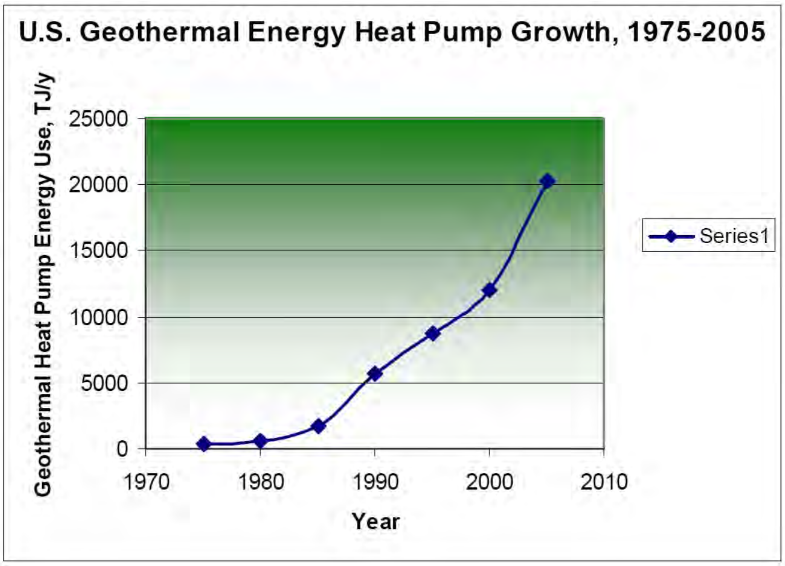


Figure 3.58: Heat Pump (geothermal) Energy Growth in the U.S from 1975 to 2003.

Direct-use energy growth rate (r_{DU}) in the U.S (excluding geothermal heat pumps) from 1975 to 2005 (see **Figure 3.59**) has been much less than the growth rate of geothermal heat pumps, by a wide margin.
Using the data from Geo-Heat (Tonya Boyd, personal communications, 2005), the growth rate is calculated from,

$$TJ/y(2005) = TJ/y(1975)\left(1 + \frac{r_{DU}}{100}\right)^n$$

where, TJ/y(2005) = 9024, TJ/y(1975) = 2847 and n = 30 years yielding r_{DU} = 3.9% annually.

Figure 3.59 shows that the largest geothermal direct-use application is in fish farming, followed by resorts/spas followed by space heating. Note that the rate of space heating applications is on a sharp rise compared to all other applications since 2000. Fish farming and resorts/spas use seems to have tapered off. Direct-use of geothermal energy is least in the industrial sector.

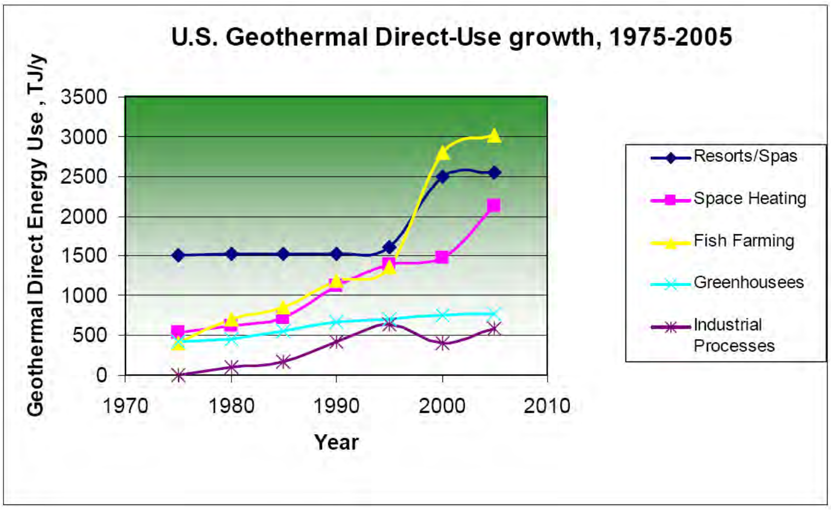


Figure 3.59: Geothermal Direct-Use (excluding geothermal heat pumps) Energy Growth in the U.S from 1975 to 2003.

In the energy consumption picture, geothermal sources are a little more than wind energy and solar energy combined. Geothermal ranks 7th out of the 9 energy sources used in the United States (**Table 3.20**). Maximum use of geothermal energy is in electric power production. In the residential sector, geothermal energy ranks below solar energy, although the rate of geothermal energy use in this sector has increased over the last 3 years. Geothermal heat pumps represent the fastest growth rate (**Figure 3.58**) of all applications of geothermal energy. Geothermal direct-use energy is highest in the fish farming and resorts/spas sectors of the economy (**Figure 3.59**).

4 MATRIX OF GROUND SOURCE HEAT PUMPS

A ground source heat pump (GSHP) is a central heating and/or cooling system that pumps heat to or from the ground. It uses the earth as a heat source (in the winter) or a heat sink (in the summer). This design takes advantage of the moderate temperatures in the ground to boost efficiency and reduce the operational costs of heating and cooling systems

Ground source heatt pumps are also known by a variety of other names, including geoexchange, geothermal, earth-coupled, earth energy or water-source heat pumps. The engineering and scientific communities prefer the terms "ground source heat pumps" or "geoexchange heat pumps" because geothermal power traditionally refers to heat originating from deep in the Earth's mantle. Ground source heat pumps harvest a combination of geothermal power and heat from the sun when heating, but work against these heat sources when used for air conditioning.

The type of system used depends on the site where the system is installed, the climatic conditions and the characteristics of the building.

4.1 Ground-Source Systems

The following nomenclature has been adopted by the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) to distinguish among the various types of earth connection systems:

- Ground-Coupled Heat Pumps (GCHPs) - use the ground as a heat source and sink, either with vertical or horizontal Ground Heat eXchangers (GHXs);
- Groundwater Heat Pumps (GWHPs) - use underground (aquifer) water as a heat source and sink;
- Surface Water Heat Pumps (SWHPs) - use surface water bodies (the sea, lakes, ponds, etc.) as a heat source and sink.

Another specialized type is the Ground Frost Heat Pump (GFHPs) - maintain sound structural fill in natural permafrost around foundations by extracting heat from the fill.

4.1.1 Ground-Coupled Heat Pumps

A ground-coupled heat pump uses the shallow ground as a source of heat, thus taking advantage of its seasonally moderate temperatures. In the summer, the process can be reversed so the heat pump extracts heat from the building and transfers it to the ground. Transferring heat to a cooler space takes less energy, so the cooling efficiency of the heat pump gain benefits from the lower ground temperatures.

Shallow horizontal heat exchangers experience seasonal temperature cycles due to solar gains and transmission losses to ambient air at ground level. These temperature cycles lag behind the seasons because of thermal inertia, so the heat exchanger can harvest heat deposited by the sun several months earlier. Deep vertical systems rely heavily on migration of heat from surrounding geology.

In the case of heating-only operation recharging of the ground has to happen by natural effects, in the case of heating and cooling operation recharging can happen by the exhaust heat from cooling operation; a possible mismatch between heat extraction and heat removal can happen by natural effects.

Ground-coupled heat pumps must have a heat exchanger in contact with the ground to extract or dissipate heat. This component accounts for a third to a half of the total system cost.

Several major design options are available for these, which are classified by fluid and layout:

- direct exchange systems circulate refrigerant underground,
- closed loop systems use most commonly a mixture of anti-freeze and water.

4.1.2 Direct Exchange Systems

The direct exchange ground-coupled heat pump (also called direct expansion, direct evaporation ground coupled heat pump) is the oldest type of ground-coupled heat pump technology. It is also the simplest and easiest to understand. The ground-coupling is achieved through a loop circulating refrigerant in direct thermal contact with the ground (as opposed to a combination of a refrigerant loop and a water loop). The refrigerant leaves the heat pump appliance cabinet, circulates through a loop of copper tubes often protected with a plastic coating against corrosion buried underground, and exchanges heat with the ground before returning to the heat pump. The name "direct exchange" refers to heat transfer between the refrigerant and the ground without the use of an intermediate fluid. There is no direct interaction between the fluid and the earth; only heat transfer through the pipe wall.

Direct exchange systems are slightly more efficient and have potentially lower installation costs than closed loop water systems. Copper's high thermal conductivity contributes to the higher efficiency of the system, but heat flow is predominantly limited by the thermal conductivity of the ground, not the pipe. The main reasons for the higher efficiency are the elimination of the secondary fluid circulation pump (which uses electricity), and the elimination of the water heat exchanger (which is a source of thermal losses).

4.1.3 Closed Loop Systems

Most installed systems have two loops on the ground side: the primary refrigerant loop is contained in the appliance cabinet where it exchanges heat with a secondary water loop that is buried underground. The secondary loop is typically made of High-density polyethylene pipe and contains a mixture of water and anti-freeze (propylene glycol, denatured alcohol or methanol). After leaving the internal heat exchanger, the water flows through the secondary loop outside the building to exchange heat with the ground before returning. The secondary loop is placed below the frost line where the temperature is more stable, or preferably submerged in a body of water if available. Systems in wet ground or in water are generally more efficient than drier ground loops since it is less work to move heat in and out of water than solids in sand or soil. If the ground is naturally dry, soaker hoses may be buried with the ground loop to keep it wet.

Closed loop systems need a heat exchanger between the refrigerant loop and the water loop, and a pump in the water loop. Closed loop systems have lower efficiency than direct exchange systems, so they require longer and larger pipe to be placed in the ground, increasing excavation costs.

Closed loop tubing can be installed horizontally as a loop field in trenches or vertically as a series of long U-shapes in wells. The size of the loop field depends on the soil type and moisture content, the average ground temperature and the heat loss and or gain characteristics of the building being conditioned. A rough approximation of the initial soil temperature is the average daily temperature for the region.

Vertical Systems

A vertical closed loop field is composed of pipes that run vertically in the ground. A hole is bored in the ground, typically 20–120 (240) m deep. Pipe pairs in the hole are joined with a U-shaped cross connector at the bottom of the hole. The borehole is commonly filled with a bentonite grout surrounding the pipe to provide a thermal connection to the surrounding soil or rock to improve the heat transfer. Thermally enhanced grouts are available to improve this heat transfer. Grout also protects the ground water from contamination, and prevents artesian wells from flooding the property. Vertical loop fields are typically used when there is a limited area of land available. Bore holes are spaced 5–6 m apart and the depth depends on ground and building characteristics.

Horizontally Installed Systems

A horizontal closed loop field is composed of pipes that run horizontally in the ground. A long horizontal trench, deeper than the frost line, is dug and U-shaped or slinky coils are placed horizontally inside the same trench. Excavation for horizontal loop fields is about half the cost of vertical drilling, so this is the most common layout used wherever there is adequate land available.

A slinky (also called coiled) closed loop field is a type of horizontal closed loop where the pipes overlay each other (not a recommended method). The easiest way of picturing a slinky field is to imagine holding a slinky on the top and bottom with your hands and then move your hands in opposite directions. A slinky loop field is used if there is not adequate room for a true horizontal system, but it still allows for an easy installation. Rather than using straight pipe, slinky coils, use overlapped loops of piping laid out horizontally along the bottom of a wide trench.

Pond

A closed pond loop is not common because it depends on proximity to a body of water, where an open loop system is usually preferable. A pond loop may be advantageous where poor water quality precludes an open loop, or where the system heat load is small. A pond loop consists of coils of pipe - similar to a slinky loop - attached to a frame and located at the bottom of an appropriately sized pond or water source.

4.1.4 Open Loop Systems

In an open loop system (also called a groundwater heat pump), the secondary loop pumps natural water from a well or body of water into a heat exchanger inside the heat pump. Heat is either extracted or added by the primary refrigerant loop, and the water is returned to a separate injection well. Irrigation trench, tile field or body of water are very often prohibited by law. The supply and return lines must be placed far enough apart to ensure thermal recharge of the source.

Since the water chemistry is not controlled, the appliance may need to be protected from corrosion by using different metals in the heat exchanger and pump. Limescale may foul the system over time and require periodic acid cleaning. Also, as fouling decreases the flow of natural water, it becomes difficult for the heat pump to exchange building heat with the groundwater. If the water contains high levels of salt, minerals or hydrogen sulfide, a closed loop system is usually preferable.

Deep lake water cooling uses a similar process with an open loop for air conditioning and cooling. Open loop systems using ground water are usually more efficient than closed systems because they are better coupled with ground temperatures. Closed loop systems, in comparison, have to transfer heat across extra layers of pipe wall and dirt.

A standing column well system is a specialized type of open loop system. Water is drawn from the bottom of a deep rock well, passed through a heat pump, and returned to the top of the well, where traveling downwards it exchanges heat with the surrounding bedrock. The choice of a standing column well system is often dictated where there is near-surface bedrock and limited surface area is available.

4.1.5 Seasonal Thermal Storage

The efficiency of ground source heat pumps can be improved by using seasonal thermal storage. If heat loss from the ground source is sufficiently low, the heat pumped out of the building in the summer can be retrieved in the winter. Heat storage efficiency increases with scale, so this advantage is most significant in commercial or district heating systems.

Possibilities for a seasonal thermal store are

- Heating and cooling operation with a balanced heat extraction/heat removal into the store or
- A hybrid heating and cooling system where the balance is achieved by additional cooling of the store by a cooling tower ore additional charging of the store by solar energy

The seasonal thermal storage can be formed as

- aquifer thermal energy stores,
- multiple standing column well systems,
- borehole thermal energy storage in the ground,
- using the building foundation as a storage.

Aquifer thermal energy stores

An aquifer is an underground layer of permeable rock, sediment (usually sand or gravel), or soil that yields water. The pore spaces in aquifers are filled with water and are interconnected, so that water can flow through them. Sandstones, unconsolidated gravels, and porous limestones make the best aquifers.

To utilize such an aquifer as thermal energy store there should be no natural water flow. Two wells (typically) on either side with hydraulic coupling are necessary. One well is for the warm water and the other one is for the cold. extracted by the heat exchanger for heating purposes. In summer, the process is reversed and cold water is used for cooling. Once heated, the water is stored in the warm well (Figure 4.1).

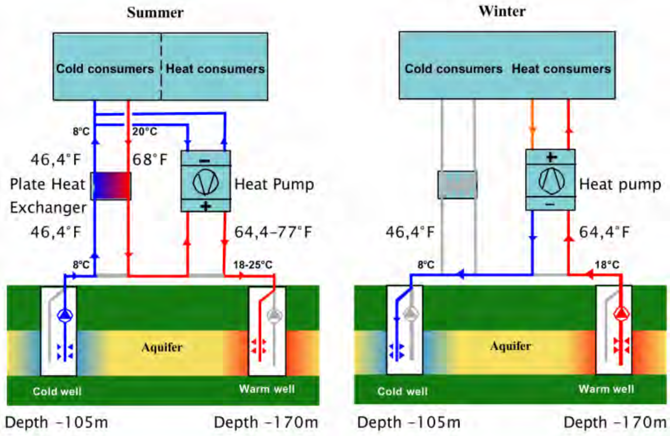


Figure 4.1: Aquifer Thermal Energy Storage

The advantage of this system is that it is environmentally safe; the water which circulates from underground to the heat exchangers and back can not be contaminated as it always remains in the system. Moreover, there is no net loss of water from underground. The only problem is that this system can only be used in areas that are above aquifers with no or negligible natural water flow.

Multiple standing column storage

A multiple standing column well system can support a large structure in an urban or rural application. The standing column well method is also popular in residential and small commercial applications. This type of ground source system has some heat storage benefits, where heat is rejected from the building and the temperature of the well is raised, within reason, during the summer cooling months which can then be harvested for heating in the winter months, thereby increasing the efficiency of the heat pump system.

Borehole energy stores

In such a case the store is made accessible by boreholes. The store is used as heat source when operating in heating mode, with a fluid (usually water or a water–antifreeze mixture) as the medium that transfers the heat from the store to the evaporator of the heat pump, thus utilizing geothermal energy. In cooling mode, the store is used as a heat sink. With Borehole Heat Exchangers (BHE), ground-source heat pumps can offer both heating and cooling at virtually any location, with great flexibility to meet any demands.

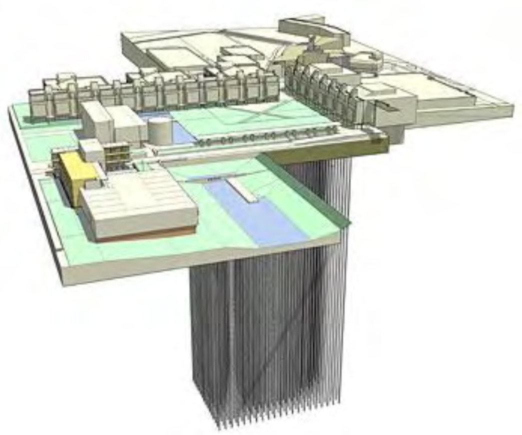


Figure 4.2: Borehole Thermal Energy Store

More than 20 years of R&D focusing on BHE in Europe has resulted in a well-established concept of sustainability for this technology, as well as sound design and installation criteria. Recent developments are the Thermal Response Test, which allows in-situ-determination of ground thermal properties for design purposes, and thermally enhanced grouting materials to reduce borehole thermal resistance.

The building foundation as energy store

High-rise buildings require proper foundations, often consisting of a bed plate and piles, and such piles can form a store similar to a borehole store: but this store is more or less for free: only the piles have to be equipped with coils. Additionally the bed plate can be also used as coil (Figure 4.3).

Figure 4.3: Building Foundation as Thermal Energy Store

All these stores work properly if heat extraction and heat removal are more or less balanced; if not the store will get through the years an increasing or decreasing temperature, which means disadvantages in heating or cooling operation. In such a case a so called hybrid system has to be designed.

In the case of increasing temperatures a cooling tower, in the case of decreasing temperatures an additional system for keeping the temperature level of the store at design conditions are required. This can be a solar thermal system.

4.2 Climatic conditions

4.2.1 Austria

For the conceptual design of buildings and heating and cooling systems the knowledge of the ambient conditions at the particular location is essential. From all climatic values only the ambient temperature and the solar radiation is of an interest. The average temperature in Europe is in the range of -5 °C (parts of Scandinavia) and +20 °C (Mediterranean areas) as shown in Figure 4.4 on the left side. The yearly solar radiation is about 950 kWh/m² in the north and 1750 kWh/m² in the south of Europe (see Figure 4.4 right).

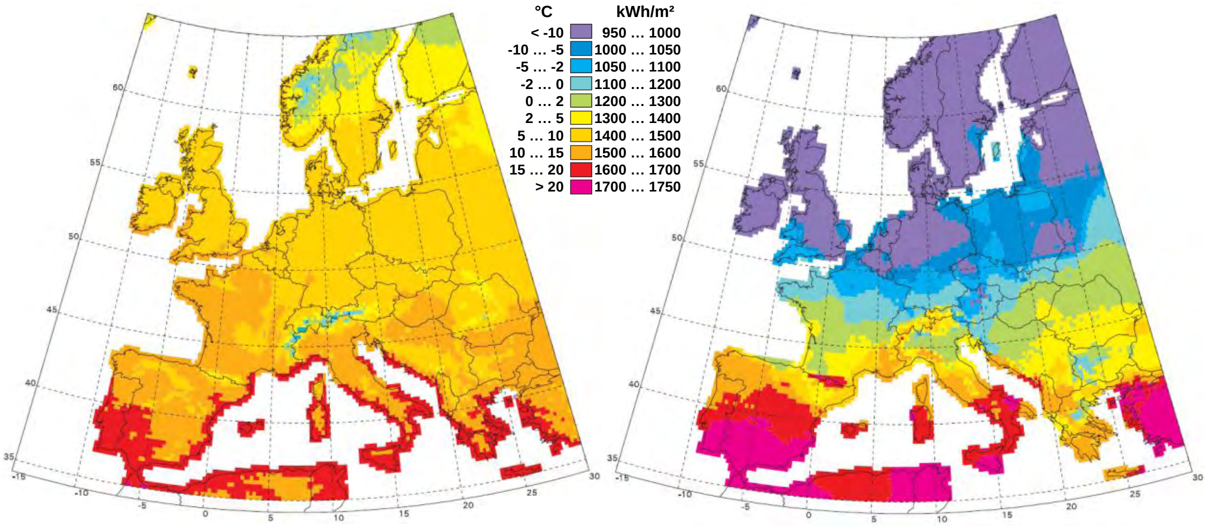


Figure 4.4: Overview average temperature (left) and average global radiation (right) in Europe (Mach T., 2007)

Due to the location of Austria in the middle of Europe ambient temperatures of about -8 to +12 °C (yearly average) and 1100 kWh/m² to 1400 kWh/m² of solar radiation are typical (Figure 4.5). The reason for the different values at different locations is the influence of the Alps where the temperature is lower and the solar radiation higher than in other areas of the country.

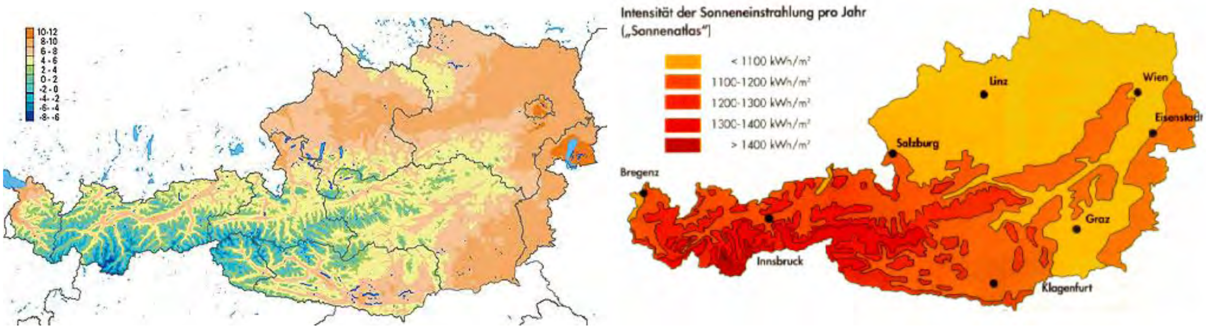


Figure 4.5: Average temperature (left) and average global radiation (right) in Austria (Leitgeb E., Englisch M., 2006 and AustriaSolar)

To give an example for a typical location in Austria Table 4.1 shows some climatic data of Graz from the year 1990 to 2000.

Available data for climatic conditions in Austria

The measurement of climatic conditions in Austria has a long tradition. For many locations different values are available. Some sources are presented in the following sections.

Table 4.1: Climatic data of Graz 1990-2000 (ZAMG): Global Irradiation Iglob, diffuse and direct irradiation Idiff and Idir, average ambient temperature Ta, maximum and minimum ambient temperature Ta,max and Ta,min, average ambient temperature during the heating season Ta,HD, heating degree days HDD20/12 and heating days HD20/12

	Iglob [kWh/m²a]	Idiff [kWh/m²a]	Idir [kWh/m²a]	Ta [°C]	Ta,max [°C]	Ta,min [°C]	Ta,HD [°C]	HDD20/12 [Kd/a]	HD20/12 [d/a]
Graz 1990	1142	580	562	10.0	31.3	-13.2	4.2	3135	203
Graz 1991	1069	587	482	9.0	32.2	-16.2	2.6	3590	214
Graz 1992	1138	603	535	10.5	34.6	-10.7	4.0	3172	199
Graz 1993	1172	628	544	9.9	32.5	-13.8	2.5	3208	187
Graz 1994	1169	583	586	11.2	33.7	-12.6	5.0	3032	207
Graz 1995	1148	581	567	9.9	30.7	-13.2	2.9	3233	196
Graz 1996	1074	556	517	9.0	31.6	-16.4	2.0	3568	207
Graz 1997	1243	571	672	9.8	29.7	-11.4	3.4	3315	202
Graz 1998	1184	576	607	10.3	33.2	-11.5	3.6	3088	192
Graz 1999	1287	659	628	10.4	32.1	-12.4	3.3	3041	184
Graz 2000	1427	655	773	11.4	35.1	-13.1	4.5	2740	178
Graz average 1990 - 2000	1187	598	588	10.1	32.4	-13.1	3.5	3193	197

Measurements by Zentralanstalt für Meteorologie und Geodynamik (ZAMG)

Central Institute for Meteorology and Geodynamics (ZAMG), founded in 1851, is Austria's national weather service agency. The product and service quality conforms to the current scientific state-of-the-art based on experience from R&D projects and a continuous development of methods. ZAMG is well-known as Austrian representative in its areas of activity, having been member in a series of international organizations for many years. ZAMG`s responsibilities include all activities usually carried out by a national meteorological and geophysical service:

- gathering, treatment and storage of the results of meteorological and geophysical examinations.
- advisory and counselling service; expert opinions

- meteorological and geophysical questions connected to the protection of the environment
- information, advice and warning in cases of crises and incidents as well as natural and environmental disasters
- a climatological and geophysical survey of Austria
- practice-oriented research in the complete field of meteorology and geodynamics including related sciences
- co-operation with domestic and foreign as well as international meteorological and geophysical institutions
- promotion of international co-operation between meteorology and geodynamics and other sciences

Figure 4.6: ZAMG classical (left) and phenology (right) gauging stations in Austria (Mach T., 2007)

ZAMG runs 120 classical, 150 partly automated and 110 phenology gauging stations (some of them shown in Figure 4.6). Depending on the equipment of a station the values for air temperature, humidity, wind, solar radiation, ground temperature barometric pressure, precipitation and sunshine duration are measured every second and stored on magnetic tapes as hourly average values or transmitted in 10 minutes average values directly via data line to the headquarter and all data are stored in a data base. For some locations average values over certain periods are available via internet for free (see Figure 4.7). Nevertheless, all data can be ordered in different formats, but this service has to be paid.

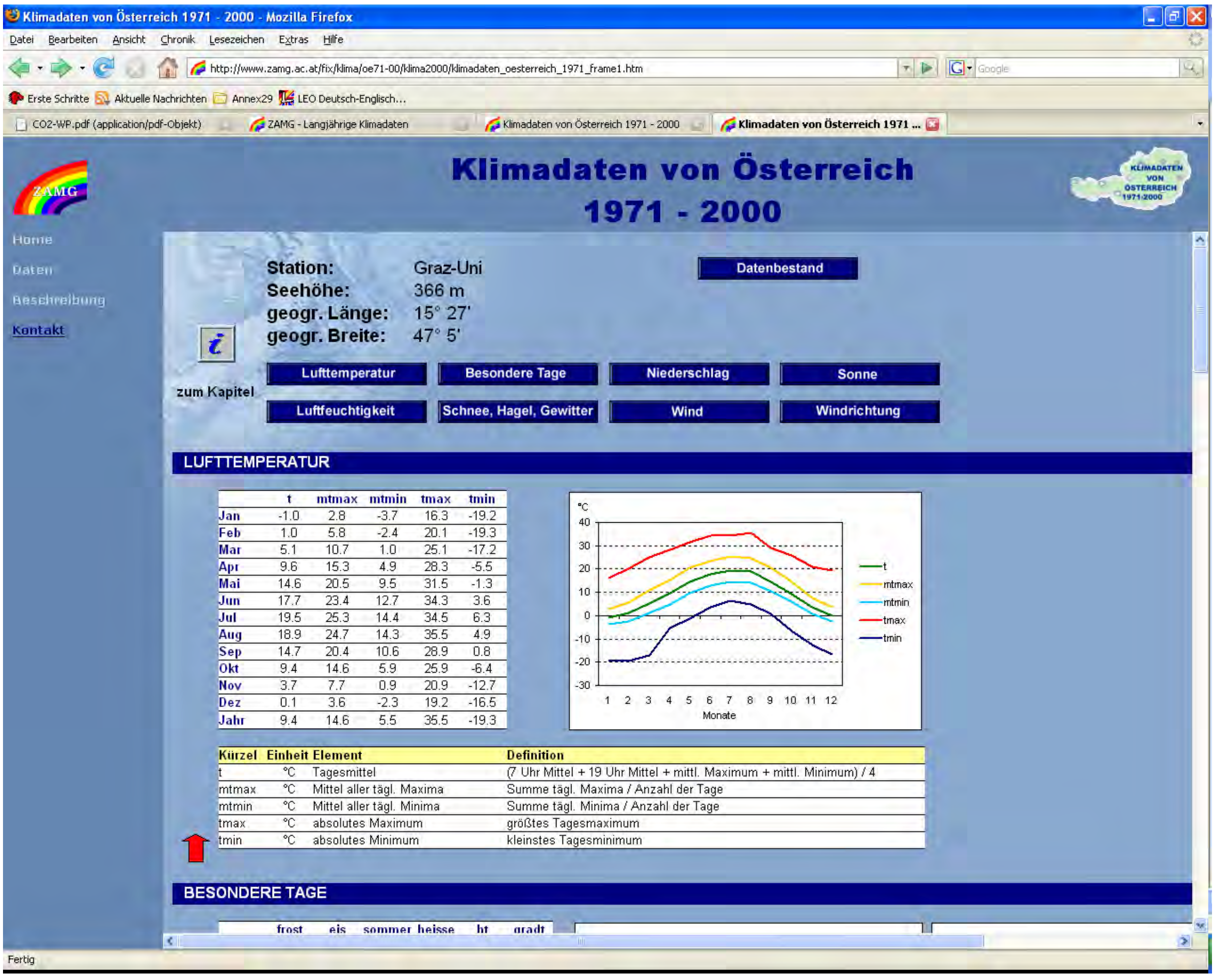


Figure 4.7: Example for online available climate data at the ZAMG homepage

OIB Guideline (Energy Pass)

The OIB (Austrian Institute for Building Technology) was asked to coordinate the activities for European Energy Performance of Buildings Directive (EBPD) implementation and to harmonize the building laws in Austria. This process is on its way since several years. The implementation of the EPBD concerns the Directive 6. This Directive includes the minimum energy performance requirements for new and refurbished buildings. The result of this work is a guideline, an Excel program for the calculation of energy performance figures of buildings and a summary of climatic data which are available for free. Furthermore, the climatic conditions in Austria were summarized in seven different zones (see Figure 4.8 documented in a revised Austrian standard (ÖNORM B 8110-5).

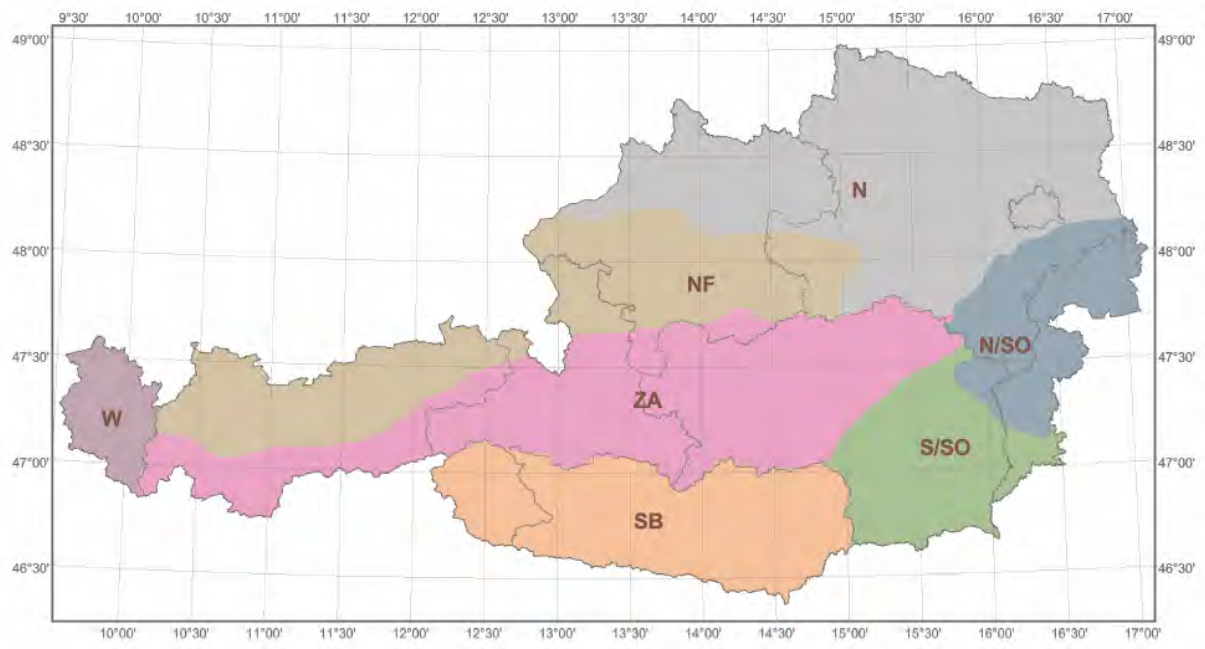


Figure 4.8: The seven defined climate zones due to ÖNORM B 8110-5 (Mach T., 2007)

Weather data generator (METEONORM)
Meteonorm (Meteotest, 2003) is a global climate database combined with a weather data generator. With this program long time average values, current monthly average values and hourly values for a typical year can be generated. In the current version climatic data from more then 7700 meteorological stations are included. An overview of available locations in Europe shows Figure 4.9.

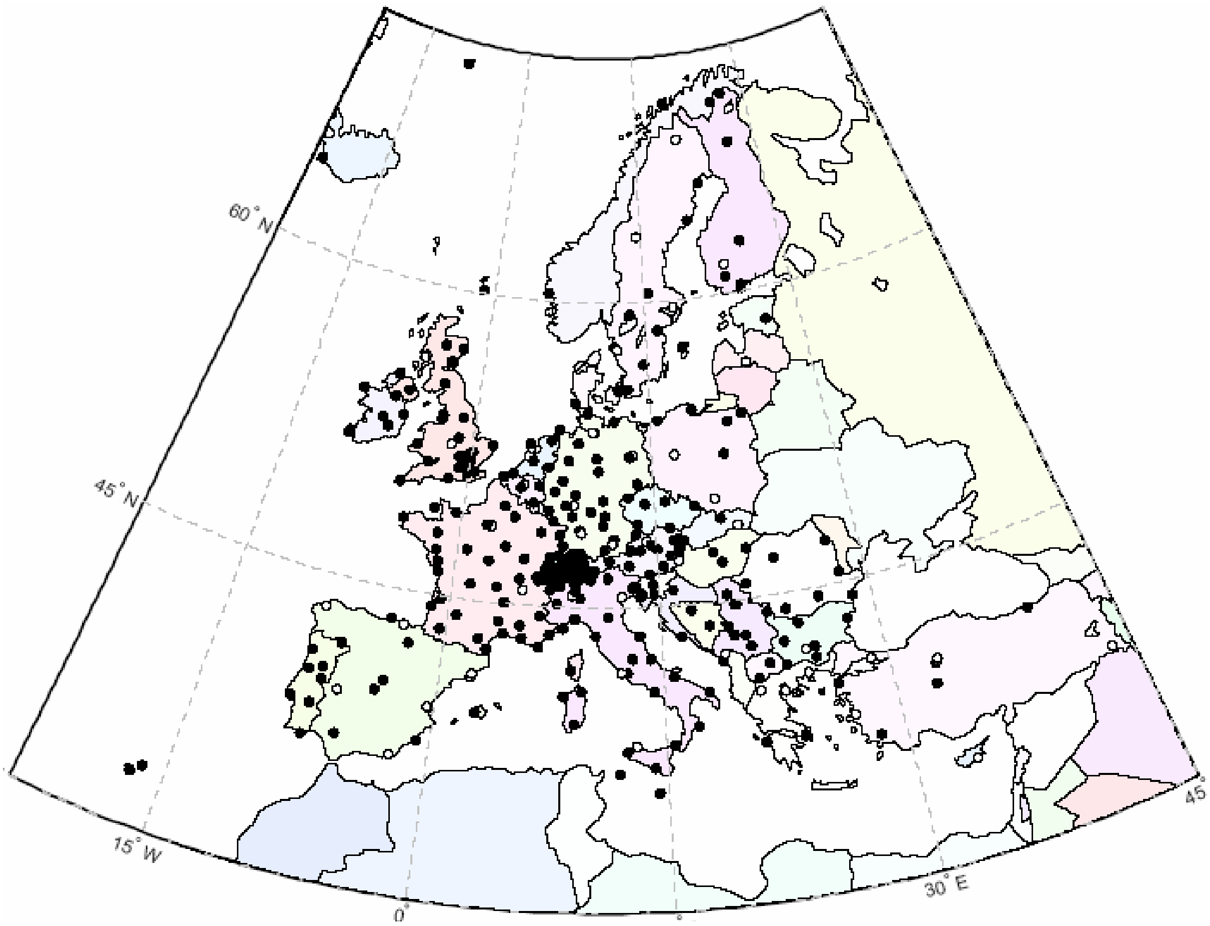


Figure 4.9: Locations in Europe where data are available in METEONORM (Mach T., 2007)

Comparison of different weather data

To show the difference between data from ÖNORM B 8110-5 and METEONORM the average temperature and the yearly global radiation of some sites in Austria were evaluated. The results of the comparison are shown in Figure 4.10.

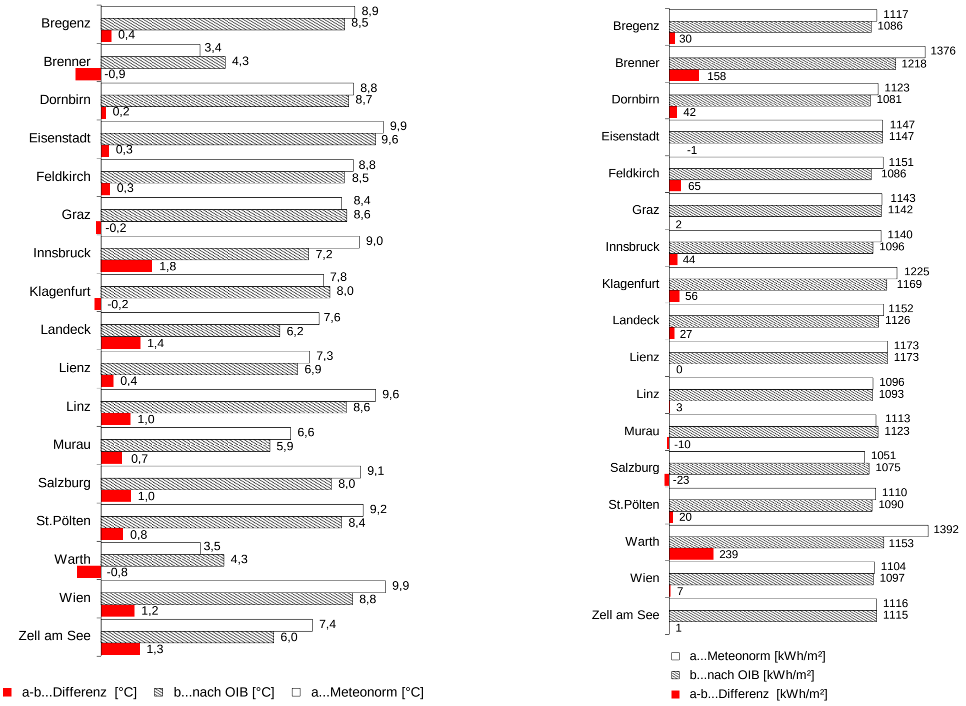


Figure 4.10: Comparison OIB and METEONROM temperature and global radiation data (Mach T., 2007)

The differences strongly depend on the location. The maximum difference for the average temperature can be found for Innsbruck in Tyrol (1.8 K; approx. 20 %). Also for other locations the differences are rather high although Meteonorm calculates the temperature based on measured data. The differences for the global radiation are quite low except for the location Brenner and Warth (Tyrol) where Meteonorm has no measured data in the database and calculates the values by interpolation.

Properties of Ground

There are several possibilities to get data of soil composition and ground water conditions in Austria. Nevertheless, the database for the whole country is rather poor especially concerning the thermal properties.

Soil composition

The Hydrological Atlas of Austria (HAA, 2003) of the Ministry of Agriculture, Forestry, Environment and Water Management (BMLFUW) presents an up-to-date map collection concerning reliable information also for questions in Hydrogeology. It is available in printed format as well as in a PC version on CD-ROM, which also enables background data to be digitally processed for the first time. It focuses on the country as a whole and not on individual hydrological catchments. Access to special hydrological knowledge, compiled by observation, analysis and research, should be made easier for a larger public. The following objectives are covered:

- A homogenous presentation of hydrological information and water management issues for the whole country.

- A compilation of hydrological analyses and statistics in order to supply civil engineers, working in hydrology and water management, with base data.

- The provision of the GIS data sets used for the maps, as well as additional information related to the maps, in a digital format. It is expected, that a wider group of users will utilize a uniform, consistent data basis for hydrological investigations and that these investigations will therefore be more efficient and easier to compare

As an example of all maps available in this Atlas the Hydrogeology map for different soil compositions in Austria is shown in Figure 4.11.

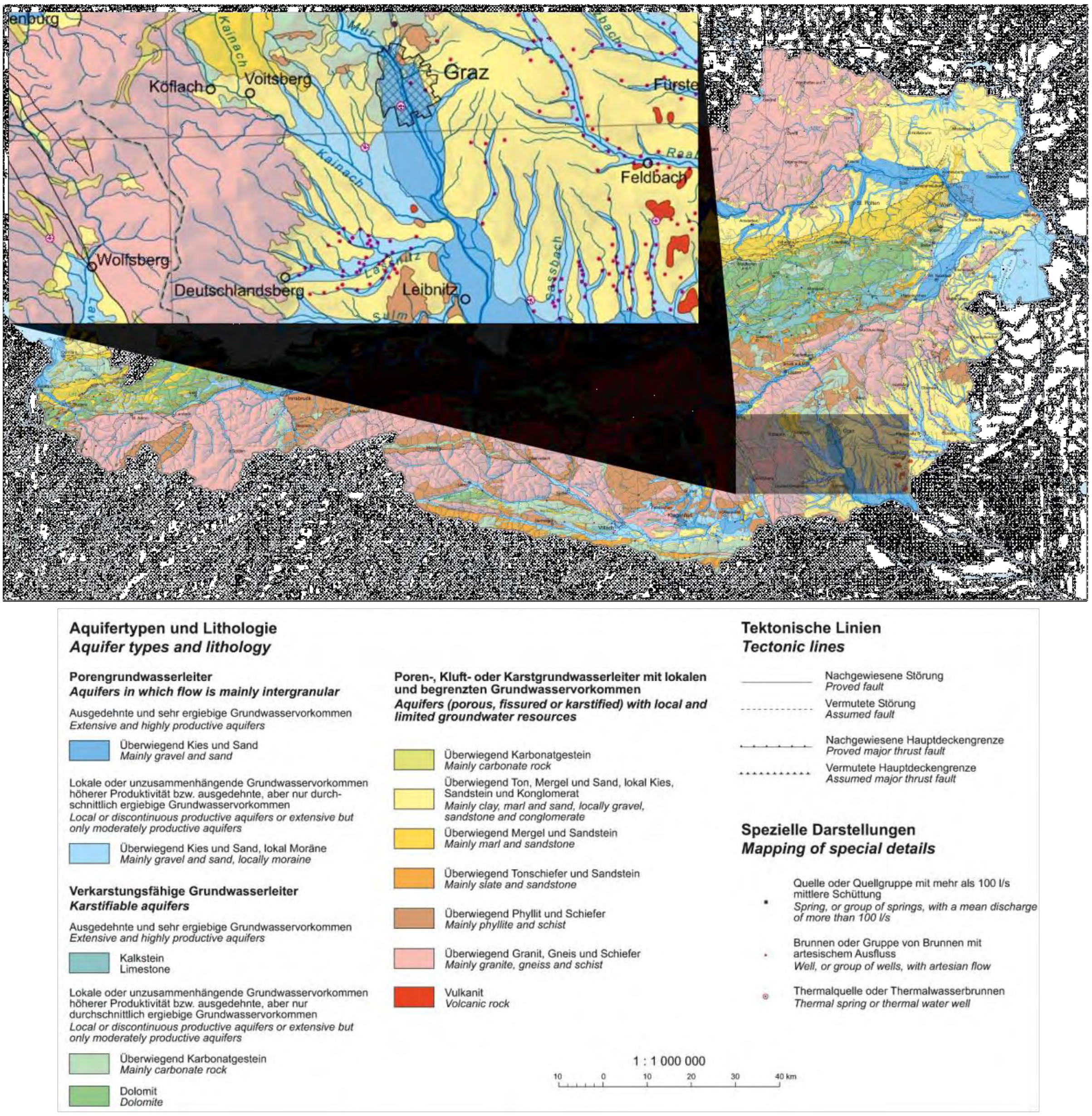


Figure 4.11: Hydrogeology map of Austria with different soil compositions in Austria (taken from HAA, 2003, rearranged by H. Schranzhofer)

Detailed information about soil composition can also be found using online Geo-Information Systems (GIS). On service for the whole country is available at http://geomap.geolba.ac.at/ (see Figure 4.12)

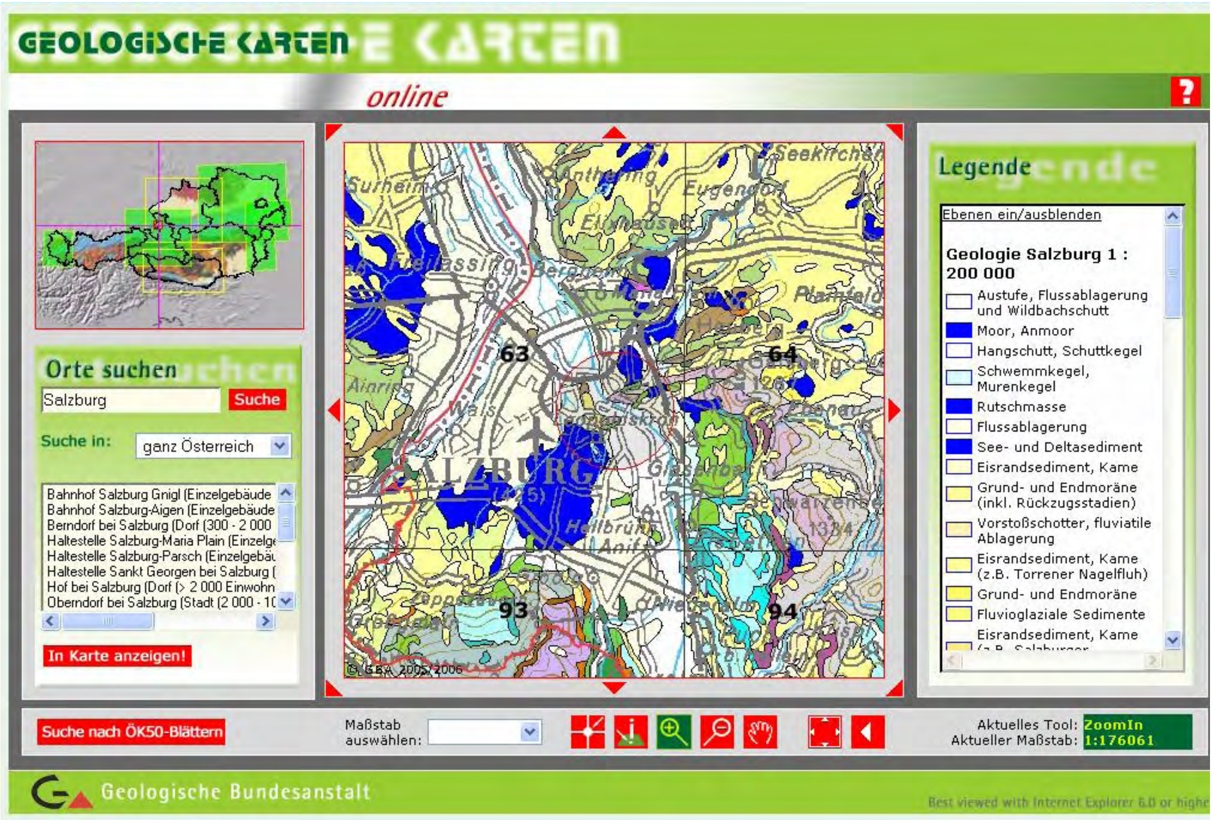


Figure 4.12: Online Geo-Information System (GIS) for Austria (http://geomap.geolba.ac.at/)

For Styria a more detailed one is provided by the provincial government at http://www.gis.steiermark.at/. As an example the lists of soil composition of two areas in the surroundings of Graz are given in Figure 4.13.

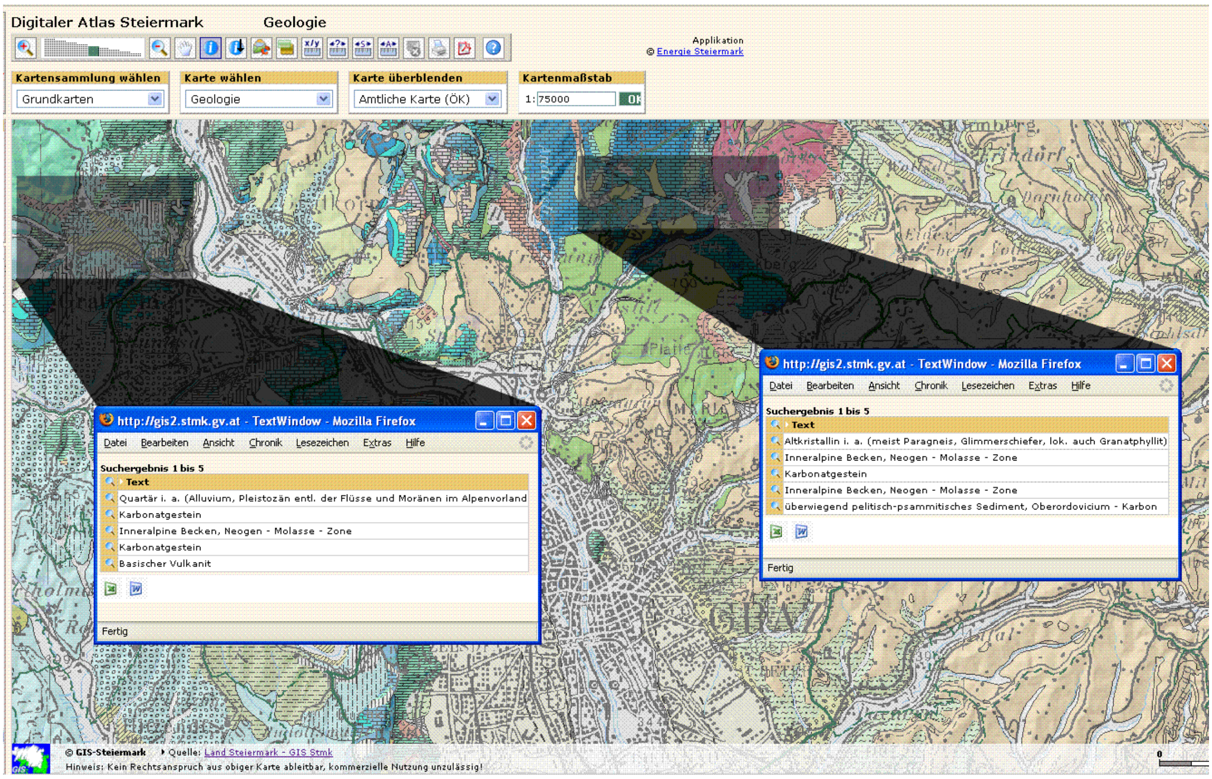


Figure 4.13: Online Geo-Information System (GIS) for Styria (http://www.gis.steiermark.at/)

Ground water

The Federal Ministry of Agriculture, Forestry, Environment and Water Management in Austria (BMLFUW) publish a "Hydrological Year Book" (currently available for the year 2004) where measured data for different parameters concerning rainfall, ambient temperature, surface water and ground water are summarized. Actually, the main focus in this publication lies on water supply and flood water prediction due to the measured data. Thus, not all of the gauging stations in Austria are equipped with temperature sensors for the ground or surface water. For example in the surrounding area of Graz over 130 stations are installed but only 11 of them are equipped with a temperature sensor. The nearest station to Graz where temperature data are available is in Fernitz (approx. 12 km south of Graz) and some of the data are summarized in **Table 4.2**.

Table 4.2: Example for data available in the Hydrological Year Book 2003 of a station nearby Graz (Fernitz)

No.	Station Point of measurement m above the level of the Adriatic / m above ground Start of observation Temperature measuring point in m below ground	DP - station number	Means in m above the level of the Adriatic I / VII	II / VIII	III / IX	IV / X	V / XI	VI / XII	Year
2302	Fernitz, Blt 35455 326.18 / 1.00 1985 6.00	329656	320.08 319.42	319.84 319.40	319.66 319.37	319.56 319.41	319.50 319.43	319.47 319.42	319.55
			Means in °C						
			11.90 11.30	11.50 11.70	11.10 12.20	10.80 12.70	10.70 12.80	10.90 12.60	11.7

As mentioned before the data for ground properties concerning thermal aspects are not always easy available in Austria. To improve the situation a new project called Geothermal Potential in Austria (short name GEO-Pot) is on hand starting in 2008 with the aim to have a Geo-Information-System (GIS) for thermal potential of the ground in Austria at the end of 2009. To achieve this goal several institutions are working together in this project within the frame of “Energy Systems of Tomorrow” which is financed by Ministry of Transport, Innovation and Technology and the Ministry of Economics and Labour of the Republic of Austria.

4.2.2 Canada

Climatic conditions

Most of the recommended outdoor design conditions (temperatures, wind, solar radiation, underground data, etc.) for calculation of the seasonal performance are based on data from the US National Climatic Data Centre and Canadian Atmospheric Environment Service. Design temperatures are based on the assumption that the frequency level of a specific temperature over a suitable time period will repeat in the future. The selected winter and summer temperature frequencies enable to match the risk level desired.

For winter calculations, two frequency levels are offered representing temperatures that have been equaled or exceeded by 99% or 97% of the total hours in the months of December, January and February (a total of 2169 hours). In a normal winter there would be approximately 22 hours at or below the 99% value and 54 hours at or below 97.5% value. In Canada, the two design values are based on only the month of January. The Canadian design temperatures are a few degrees lower than those based on three winter months.

For summer, the dry-bulb temperatures represent values that have been equalled or exceeded by 1%, 2.5% and 5% of the total hours during the months of June through September (a total of 2928 hours). The coincident wet-bulb temperature is the mean of all wet-temperatures occurring at the specific dry-bulb temperature. The three values are based on the month of July only, and the corresponding design values are a few degrees higher that those based on four summer months.

The actual heating load hours, regional heating load hours, and distribution of actual cooling load hours throughout North America are given for six climatic regions. Generally, region IV is the climatic region which is the basis for the published HSPF ratings in the United States, and region V for standard HSPF ratings in Canada. Some standards (i.e., ASHRAE Standard 116-1995) give meteorological data required directly in the calculation procedure for cooling seasonal energy efficiency ratios and heating seasonal performance factors.

Properties of heat sources - Soil and Bedrock

The performances of the ground-source heat pumps depend on the ground’s thermal properties. The ground temperature near the surface cycles with the time of the year. These variations disappear at lower depths, where the ground remains at its mean temperature throughout the year. The thermal conductivity of the soil (k_s) and the thermal diffusivity – a measure of the ground’s ability to conduct energy relative to its ability to store thermal energy ($\alpha = k_s / C_p$) are two soil and rock properties that most affect the design of the heat pump systems (**Table 4.3**).

Table 4.3: Thermal properties of Common Ground Types

Material	Conductivity	Diffusivity	Density	Heat Capacity
	W/(m·K)	m^2/s	kg/m^3	kJ/(kg·K)
Dense Rock (Granite)	3.46	$0.0129 \cdot 10^{-6}$	3 200	0.83
Average Rock (Limestone)	2.42	$0.0132 \cdot 10^{-6}$	2 800	0.83
Heavy Soil – Damp	1.29	$0.0064 \cdot 10^{-6}$	2 096	0.96
Heavy Soil – Dry	0.86	$0.0051 \cdot 10^{-6}$	2 000	0.83
Light Soil – Damp	0.86	$0.0051 \cdot 10^{-6}$	1 600	1.04
Light Soil – Dry	0.34	$0.0028 \cdot 10^{-6}$	1 440	0.83

The moisture content of soil has a considerable impact on its thermal properties. The thermal conductivity of soil is relatively constant above a specific moisture threshold, called critical moisture content (CMC) (**Table 4.4**). Below the CMC, the conductivity drops rapidly. For Canadian locations, thermal instability is not a significant concern. The relatively high tables and smaller cooling loads prevent the moisture content from dropping below critical levels.

Table 4.4: Critical Moisture Content

Soil	Critical Moisture Content (%)
Granular	< 12
Silts	12 – 16
Clays	16 – 22
Organic and Peaty Soils	18
Organic and Expansive Clays	> 22

Water movement has also a significant impact on heat transfer through the ground because the heat transfer by conduction is reinforced by convection due to the moving water.

Groundwater

For groundwater systems, the entering water temperatures are approximated by the mean ground temperatures. In Canada, the groundwater temperatures approximately vary from 6°C (northern regions) to 10°C (South), and maps with isothermal curbs are available for geothermal systems designers (Minea V., 1999). The required qualities of the groundwater are indicated in **Table 4.5**.

Table 4.5: Required qualities to the groundwater

Parameter	Copper heat exchangers	Copper-nickel heat exchangers
Filter (micron)	< 25	> 25
Chloride (PPM)	< 300	300 to 600
Alkalinity	80 - 100	> 100
PH	7 to 9	5 to 10
Sulphide (PPM)	none	< 0,1
Ca-Mg (PPM)	< 350	> 350
CO_2 (PPM)	> 50	50 to 75
Dissolved solids (PPM)	< 1000	1000 to 1500

The local physical, chemical and geological conditions influence the groundwater quality. For the geothermal systems, the water quality is important to minimize the incrustation (chemical, mechanical or biological) problems and the corrosion of the equipment. The incrustation results from the ion's precipitation on different metallic components. Chemical incrustation is caused by the water hardness. The calcium carbonate ($CaCO_3$) is almost in totality responsible for the water hardness and incrustation problems. The risks are notably at the wall strainers level because the groundwater normally flows in closed circuit without any contact with the oxygen. Mechanical incrustation results by accumulation of fines particles, especially on the water strainers. Biological incrustation is caused in presence of specific bacteria. The iron can precipitates on the heat exchangers surfaces or on the strainer. The water hardness is the property that can cause the most of the problems in open-lop systems. For example, the average value for the groundwater in Province of Quebec is 117 mg/L, while the average iron concentration is 0.08 mg/L, lower than the limit allowing precipitation. The corrosion results in reason of the galvanic and chemical phenomenon and is facilitated by the presence of the oxygen, carbon and dissolved salts.

Surface Water

The surface area and depth of the lake or pond have more impact on cooling than on heating performance. In Canada, the surface water temperature is about 10°C in summer and 4.4°C in winter (Minea V., 1999). The average temperature in bodies of surface water drops significantly in winter and it must stay high enough to avoid ice building on the heat exchangers. Shallow lakes or ponds (between 4.6 and 6.2 m) should not have thermal loading in excess of 4.3 kW per 4,045 m^2. For deep, well-stratified lakes (> 10 m), a thermal loading of 24 kW per 4,045 m^2 should be considered as a maximum.

Antifreeze solutions (Brines)

Several factors, as freezing point, environmental impact, cost and availability, heat transfer/pressure drop properties and compatibility with materials, affect the selection of the circulating fluid (brine, antifreeze solution) in indirect GSHP systems. The most common antifreeze solution used in Canada is the water/methanol, but other substances are available (**Table 4.6**). Corrosion inhibitors are usually added to reduce the oxidation of heat pump materials. Some antifreeze compounds, such as the glycols and alcohols, will oxidize into acidic and-products. Stabilizers are usually added as a means of limiting the formation of acids. Although polyethylene may experience some discoloration from several antifreezes, it is considered not to experience any degradation below of 49°C.

Table 4.6: Available Antifreeze Solutions in Canada

Solution	**Concentration* (by weight)**	**Heat Transfer ****	**Corrosivity**	**Toxicity**	**Environment Impact**
	%	**-**	**-**	**-**	**-**
Calcium Chloride	16	120	Unacceptable with stainless steel, aluminum or zinc	Skin/eye irritation	Impact on groundwater quality
Ethanol	25	80	Anti-oxidant should be used	Vapours bum throat and eyes	Unavailable
Ethylene Glycol	22	90	Inhibitors required for steel	Eye/skin irritation	Biodegradable
Methanol	23	100	Biocide required to prevent fouling	High toxicity by inhalation or contact	Biodegrades into water
Potassium Acetate	31	85	Inhibitors required for carbon steels	Handling hazardous	Biodegrades into water
Propylene Glycol	24	135	Inhibitors required for cast iron	Potential eye/skin irritation from dust	High solubility. Adversely affects groundwater

* Required to produce 7.8°C freeze protection; **Relative to methanol (100%)

4.2.3 Japan

Climatic conditions

Average annual temperature and average daily solar radiation

Japan consists of five main islands: Hokkaido, Honshu, Shikoku, Kyushu, Okinawa and other smaller islands. The country extends north to south from the sub-frigid zones to subtropics, so it has a wide range of climates as shown in Figure 4.14. The average annual temperatures are from 6.4°C in Wakkanai-city (Hokkaido) up to 22.4°C in Naha-city (Okinawa). Those of Sapporo, Sendai, Tokyo, Osaka, Kagoshima are 8.2, 11.9, 15.6, 16.3 and 17.6°C, respectively.

The average daily solar radiations are not much different among each city compared to the temperature. They ranges from 11.50 MJ/(m^2·day) in Wakkanai-city to 14.43 MJ/(m^2·day) in Naha-city. Those of Sapporo, Sendai, Tokyo, Osaka, Kagoshima are 12.43, 12.16, 12.02, 12.89 and 13.28 MJ/(m^2·day), respectively.

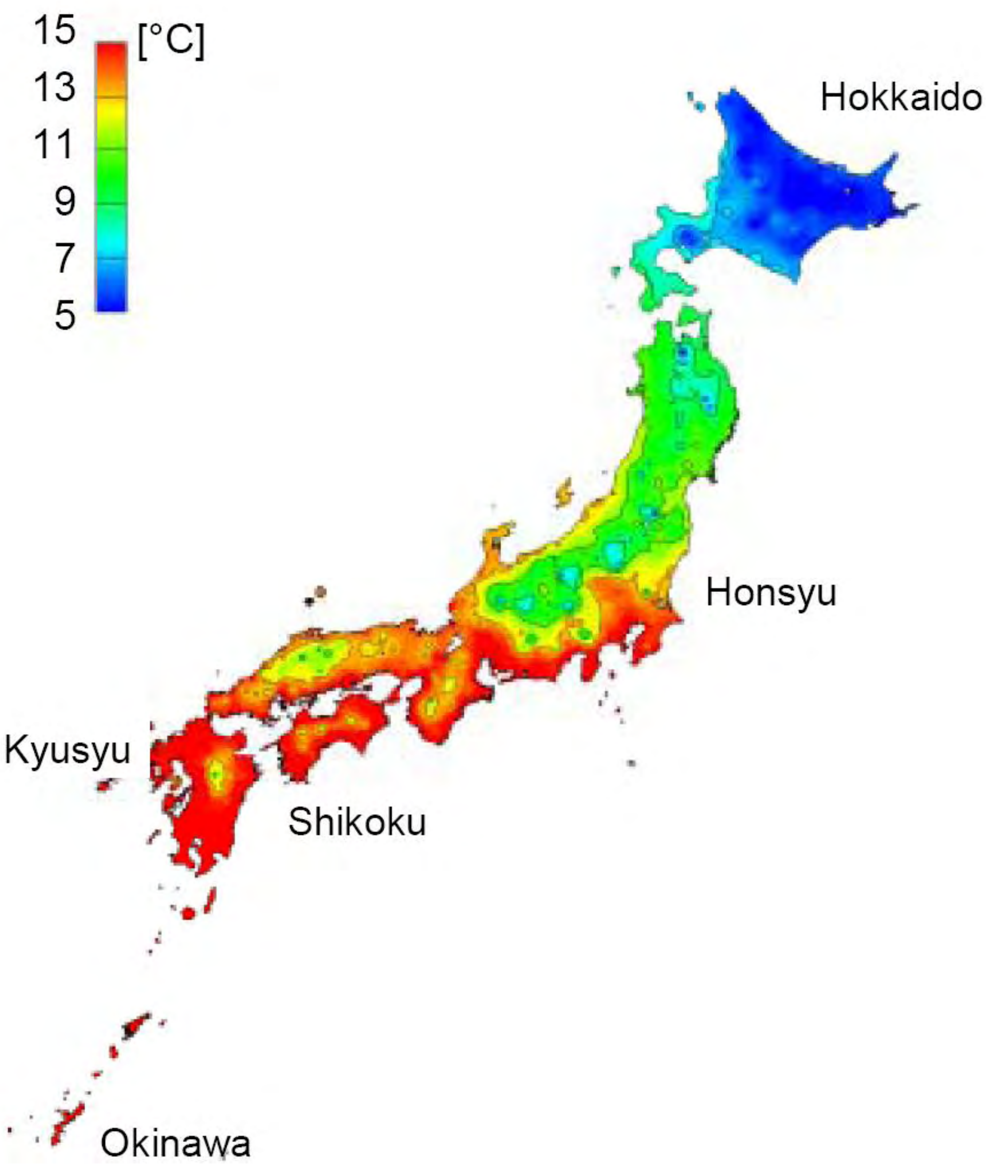


Figure 4.14: Average annual temperatures in Japan (Data from Expanded AmeDAS Weather Data, 2001; Calculated by K.Nagano, S.Takeda, Hokkakido University)

Heating degree day and cooling degree day

Heating degree day is calculated by accumulation of the temperature difference between the outdoor temperature and 14°C, a standard temperature. The accumulation is started when the outdoor temperature goes down below 10°C and is continued until it goes up above 10°C again. Similarly cooling degree day is calculated by using 24°C as the standard. Heating degree day ranges from 0 degree-days in Naha-city to 3218 degree-days in Asahikawa-city. Those of Sapporo, Sendai, Tokyo, Osaka, Kagoshima are 2638, 1594, 900, 850 and 515 degree-days, respectively. Cooling degree day varies from 0 degree-days in Asahikawa-city to 424 degree-days in Naha-city. Those of Sapporo, Sendai, Tokyo, Osaka, Kagoshima are 0, 10, 130, 250 and 515 degree-days, respectively.

Climatic zones

The notification No.2 of the Japanese Ministry of Construction and MITI (at the time) classifies cities, towns and villages in Japan into 6 climatic zones as shown in Figure 4.15 and is called the Next-Generation Energy Conservation Standard. Zone I includes the Hokkaido island and has cool summer and very cold winter with a lot of snow. Zone II and Zone III are located in the northern part of the Honsyu island and have slightly warm summer and relatively cold winter. The west coast of Zones II and III also has heavy snow in winter. Zone IV distributes widely in the rest of the Honsyu island and the northern part of the Kyusyu island. It has moderate winter but hot and humid summer. Zone V is in the southern part of the Kyusyu island and Zone VI is the Okinawa island. Both of them have subtropical climate and rather hot weather throughout the year.

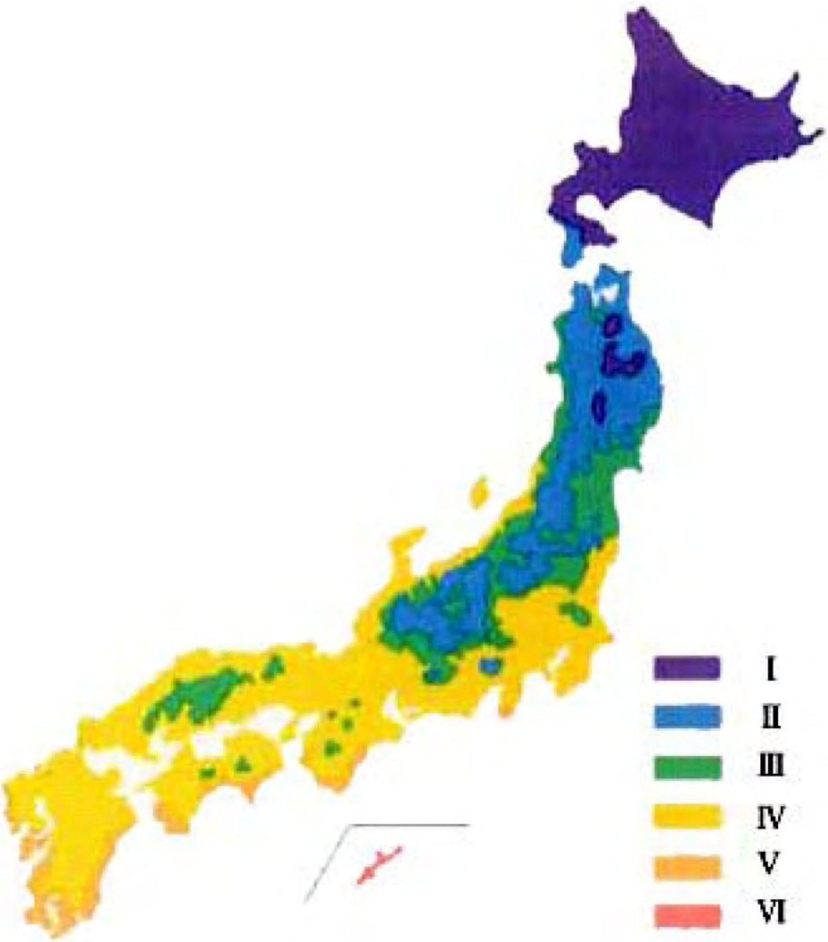


Figure 4.15: Climatic classification based on the Next-Generation Energy Conservation Standard (Source: Institute for Building Environment and Energy Conservation)

Applicable climatic zones for GSHP installation

Table 4.7 shows the classification of 124 GSHP systems in Japan. These systems were installed by 2005 and their installation sites are recorded. From the table, most of the snow melting systems are adapted in areas of a heavy snowfall. The total installation number has tended to be larger in the area which has colder winter season so far. At the first stage to promote the GSHPs in Japan, it is predicted that the GSHP systems will be applicable in the cold climate region where air source heat pumps have their intrinsic disadvantages in heating performances under low outdoor air temperatures, even though they can be basically applied everywhere. The southern area with much more cooling demand than heating one also has potential for the GSHP installation in the near future, if the demand balance between heating and cooling is kept by effective heat utilization, such as hot water supply in swimming pools and spas.

Table 4.7: GSHP installation numbers for each climatic zone as of June, 2005 (Source: Study Group on Geothermal & Heat Pump Systems in the Heat pump & Thermal Storage Technology Center of Japan)

Zone	Climatic features		System		Total
	Summer	Winter	Heating/cooling	Snow melting	
I	Cool	Very cold, much snow	42	10	52
II	Slightly warm	Cold, much snow	19	11	30
III		Slightly cold, snow	4	3	7
IV	Warm	Moderate	31	3	34
V	Hot		1	0	1
VI		Hot	0	0	0
Total			97	27	124

Geological features in Japan

Rock type

The geology in Japan shows quite complicated characteristics because of the volcanic activities from the Mesozoic period downward. Isoyama et al. investigated the distributed ratio of rocks in Japan. The result shows sedimentary rock of 58%, volcanic rock of 26%, plutonic rock of 12% and metamorphic rock of 4%. The Geological Survey of Japan in the National Institute of Advanced Industrial Science and Technology (AIST) has also developed the seamless digital geological maps of Japan.

Existence of aquifers

Many aquifers in Japan were formed in the Quaternary period. The rest were made in the Neocene period or by the volcanic ejecta from the Tertiary to the Quaternary period. The complicated soil-structure and the abundance of groundwater with high fluidity sometimes make it difficult to realize actual utilization of underground thermal energy in Japan.

Ground temperature

Ground temperature is stable throughout a year below a depth of 10 m from the ground level. Previous surveys have reported the temperature is 1 to 2 ºC higher than average annual air temperatures shown in Figure 4.14 except for special geological regions such as volcanic ones. For example, the temperature in Sapporo is known as around 9.5ºC.

Soil condition

Mountains in Japan usually have been affected by weathering because of the steep shape and a lot of rain. On the other hand, soil in plains mainly consists of gravel layers, which were formed by pile of earth and sand through flow of rivers such as diluvial soil or alluvial soil. Thermal conductivity is an important factor for heat extraction in the GSHP system, which is influenced by the soil condition, such as kind, formation, moisture content and density. Effective thermal conductivity was observed around 1.4 W/(m·K) in a typical sand layer with a moisture content of 0.4 by a previous study in Japan. Similarly, a volcanic ash soil and a clay layers showed 0.9 W/(m·K) and 1.2 W/(m·K) respectively. Although the results don't include the effect of ground water flow, these are relatively smaller than that observed in Europe, which can reach 4 W/(m·K) or more due to the rock layers.

4.2.4 Norway

Groundwater and bedrock data – digital maps
Groundwater

In Norway, the temperature in groundwater reservoirs 10 to 15 meters below ground level is typically 1 to 2 K higher than the average annual air temperature at the site, and the temperature is practically constant during the year. A rough overview of the groundwater temperatures in Norway, Sweden and Finland is shown in Figure 4.16. The map is based on data from the Nordic groundwater grid (NGU, 2004).

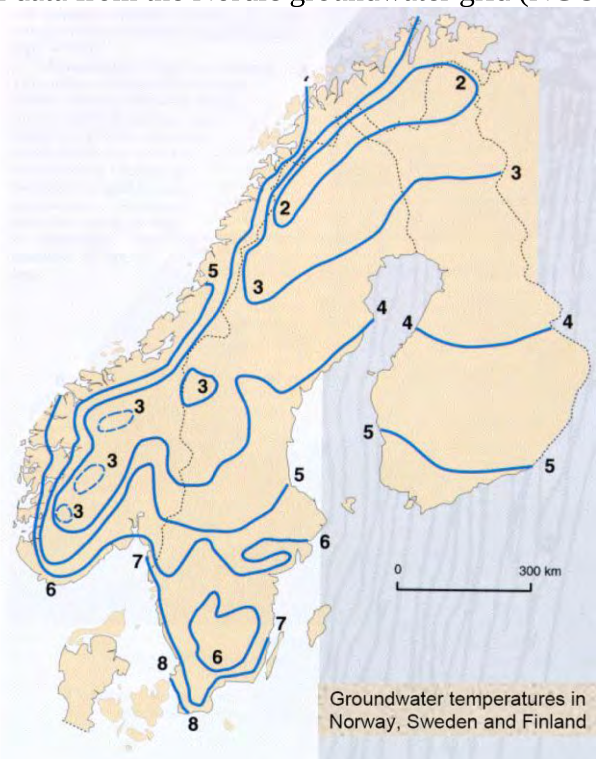


Figure 4.16: Groundwater temperature map for the Nordic countries (NGU, 2004).

Figure 4.17 presents, as an example, weekly temperature variations during one year (1983/84) for air, river water and groundwater at Elverum, Norway – inland climate

(NGU, 2004). During the winter the air temperature fluctuates between -25ºC and +10ºC, the temperature of the river water is more or less at the freezing point, whereas the groundwater temperature remains more or less constant at 5ºC. This clearly demonstrates the great advantage of using groundwater as a heat source for heat pumps in Norway.

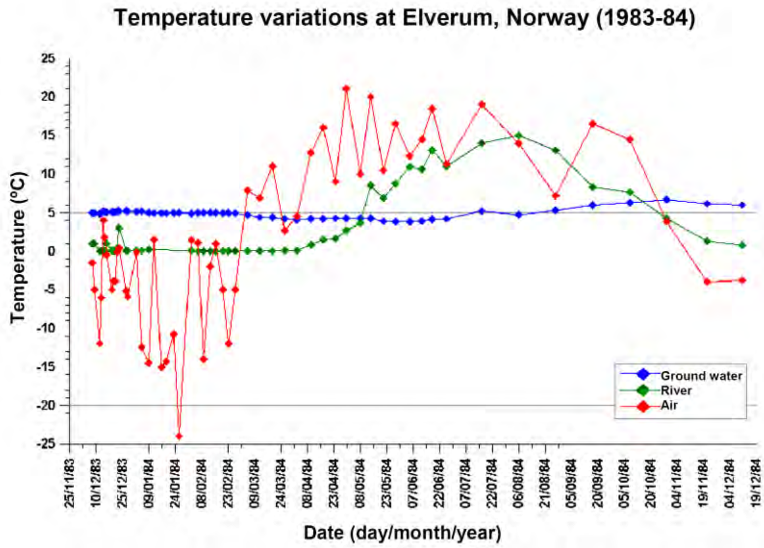


Figure 4.17: Weekly temperature variations during one year (1984/85) for air, river water and groundwater at Elverum, Norway – inland climate (NGU, 2004).

The Geological Survey of Norway (NGU) has developed digital web-based groundwater maps. The borehole database contains information from roughly 23,000 groundwater wells in bedrock, 2500 wells in sand/gravel and 1,500 energy wells (NGU, 2004), and the information includes location of the well (coordinates, municipality), well data (diameter, depth, application) and water flow rate. The borehole maps can be combined with detailed digital bedrock maps or quaternary geological maps (uncompacted material).

Figure 4.18 shows a printout example from the digital borehole database displaying the area around the city of Trondheim. The different well types are represented by colored circles, and the topographical background map can be replaced by a bedrock map or a quaternary geological map.

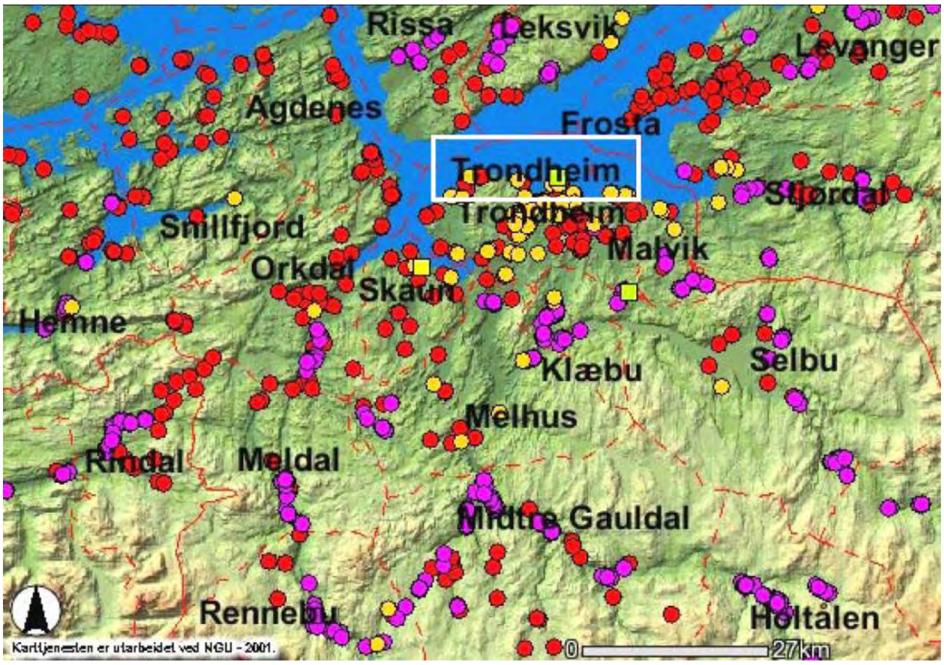


Figure 4.18: Printout example from the Norwegian borehole database. Red circles – groundwater wells in bedrock, violet circles - wells in sand/gravel, yellow circles - energy wells in bedrock (NGU, 2004).

Bedrock and Uncompacted Material

Thermal Conductivity of Bedrock

Figure 4.19 shows measured ranges for thermal conductivity of different rock types in Norway (NGU, 2004). For GSHP systems, fewer energy wells will be required in sandstone than in volcanic rock, limestone or syenite due to the considerably higher thermal conductivity.

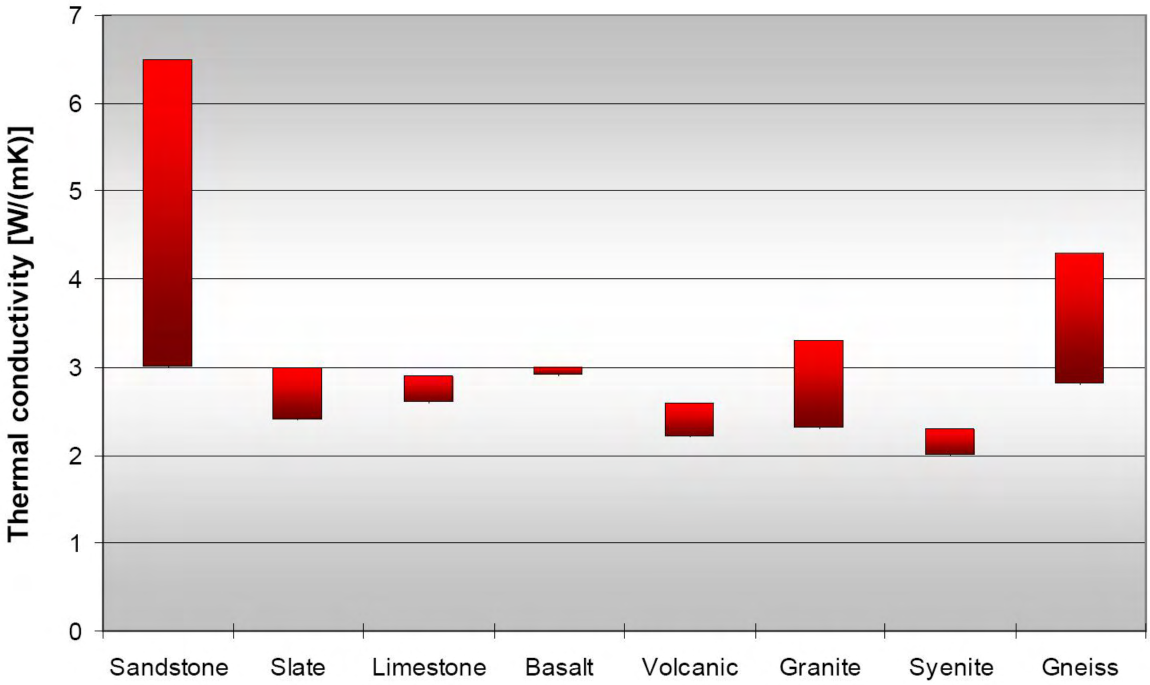


Figure 4.19: Measured thermal conductivity of different rock types in Norway (NGU, 2004).

Figure 4.20 shows, as an example, measured thermal conductivity of bedrock (average values) for the Asker/Bærum municipality south of Oslo (NGU, 2004).

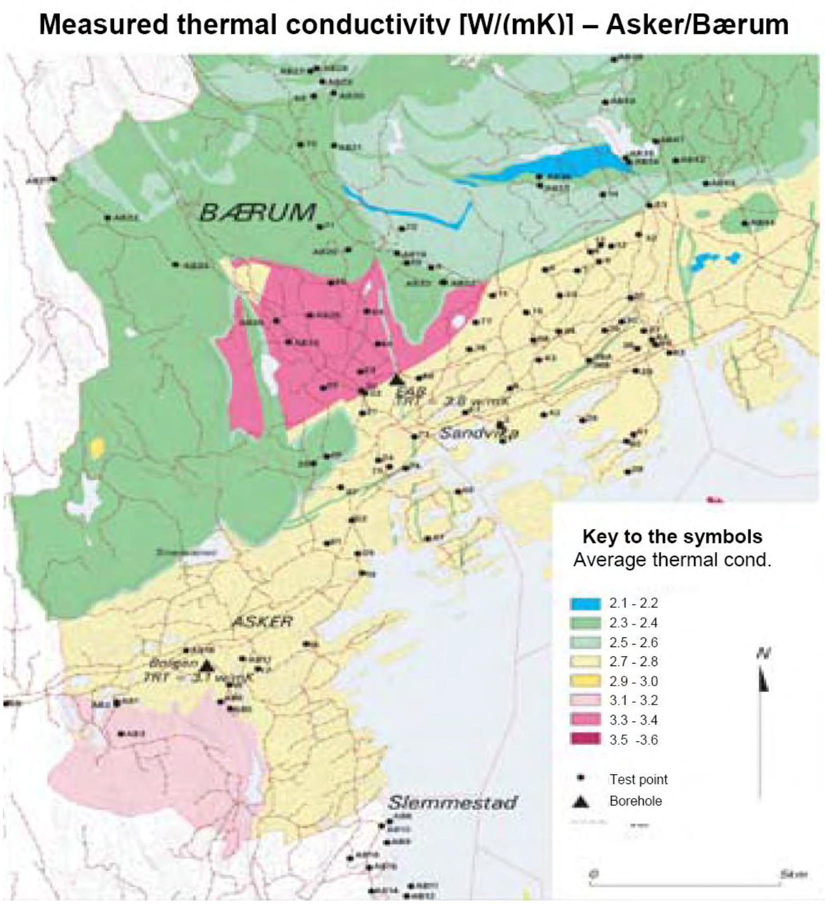


Figure 4.20: Measured thermal conductivity in bedrock for Asker/Bærum (NGU, 2004).

Bedrock Data and Bedrock Maps

Figure 4.21 shows examples of stratigraphy (rock type layers), geothermal gradients and groundwater levels for 475 m deep boreholes drilled at Arnestad and Gullhaug in Norway (NGU, 2004). Figure 4.21 clearly demonstrates that there are considerable variations in the stratigraphy, geothermal gradient and groundwater levels for different boreholes, and that detailed information about the local conditions for the bedrock and the groundwater is required when dimensioning and drilling energy wells for GSHP systems.

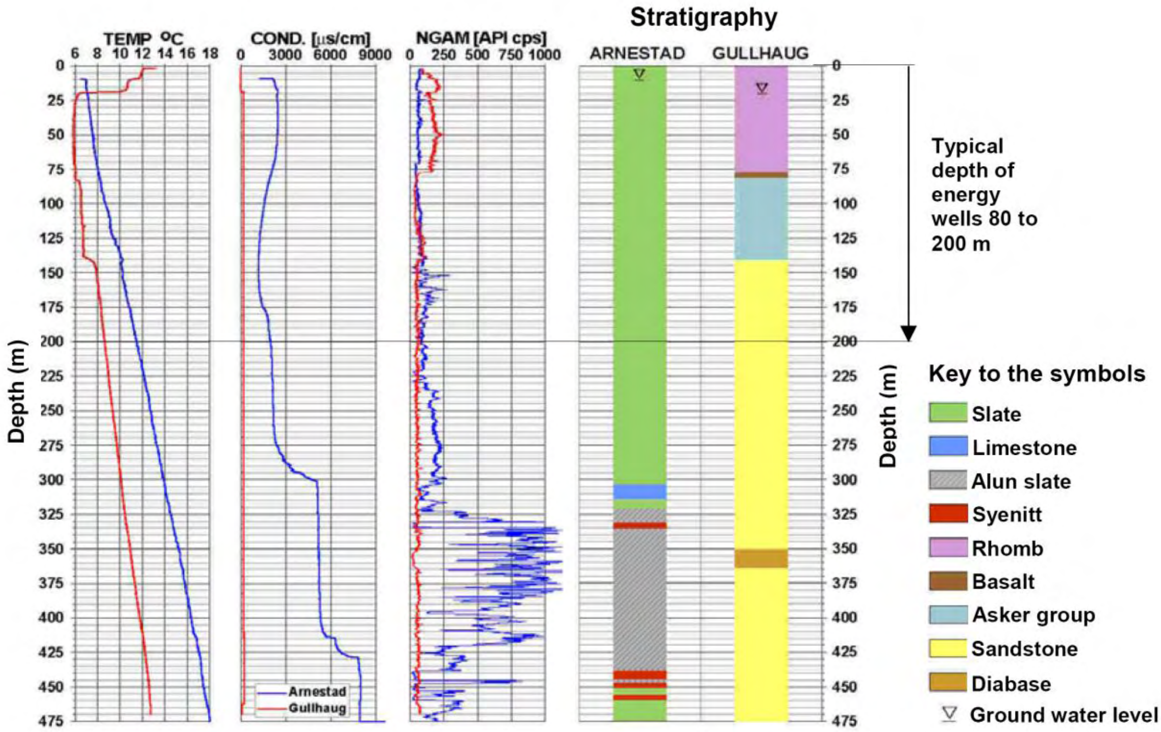


Figure 4.21: Example of stratigraphy, geothermal gradients and groundwater level for boreholes drilled at Arnestad and Gullhaug, Norway (NGU, 2004).

The Geological Survey of Norway (NGU) has developed digital bedrock maps (1:250,000) and quarternary geological maps (1:1,000,000). The latter database includes information about uncompacted material such as sand, gravel and clay (NGU, 2004). As pointed out in the previous chapter, the maps can be combined with digital groundwater maps.

Figure 4.22 shows a printout example of digital bedrock maps displaying the areas around the two largest cities in Norway, Oslo and Bergen. Although the geological bedrock maps are essential tools when planning and designing GSHP installations, geological expertise is always required in order to obtain competent dimensioning and drilling of energy wells and thermal energy storages in bedrock. For larger installation with more than 15 to 20 energy wells, the utilization of thermal response testing (TRT) will lead to a more precise dimensioning and design of the borehole system.

An advanced high-resolution digital map system comprising e.g. bedrock maps (N250), quaternary geological maps (N1000) and groundwater wells is under development. A prototype version can be found at the Internet site: http://www.ngu.no/kart/arealis.

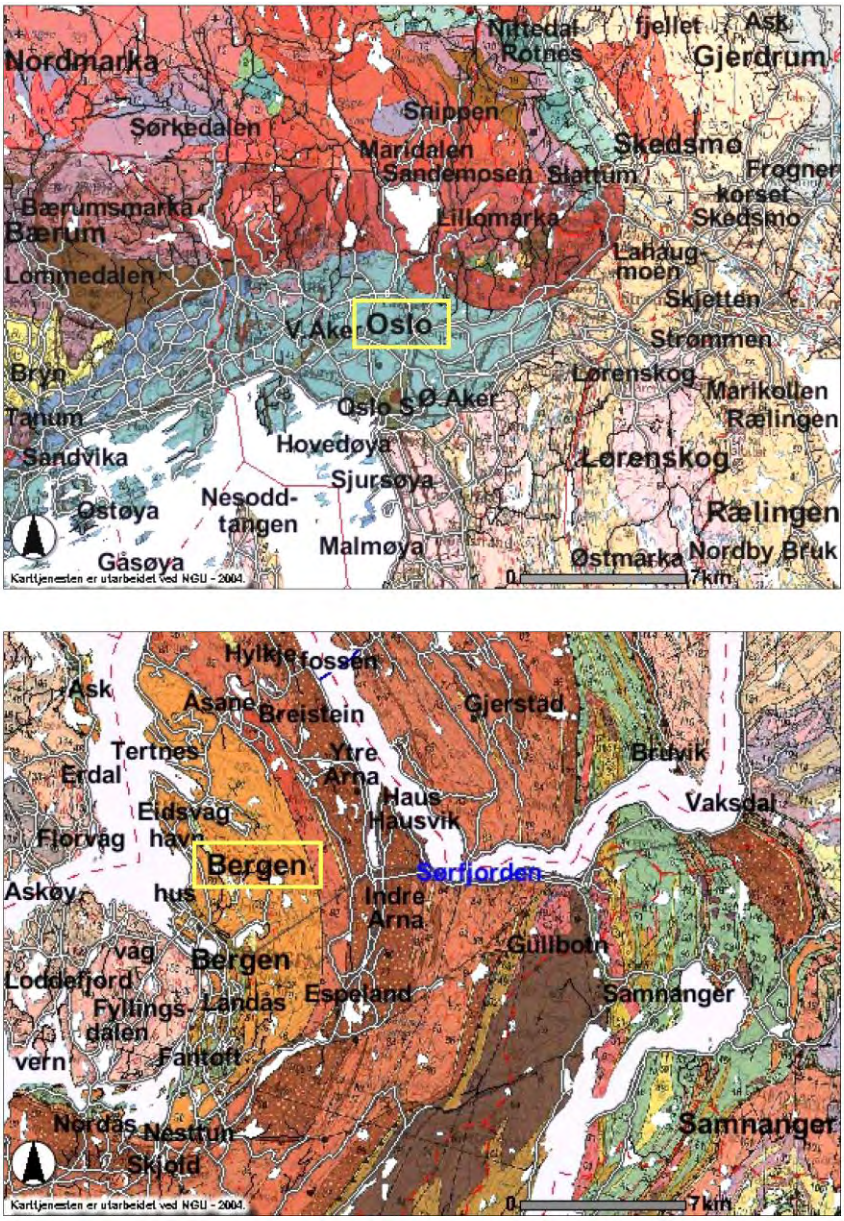


Figure 4.22: Printout examples from the Norwegian digital bedrock database (NGU, 2004).

4.2.5 Sweden

There are large variations in climate from Southern Sweden to Northern Sweden. The ground conditions are to a large extent crystalline rock, which simplifies drilling for vertical GSHP significantly. Certain areas do have other types of ground.

Climatic conditions
The climatic conditions can be described in several ways using for example Degree Days, extremes or monthly averages. For air/air heat pumps information on relative humidity at temperatures slightly above 0°C is relevant. The annual variation of the monthly mean temperatures is given in Figure 4.23 for three Swedish cities: Lund (Southern Sweden), Stockholm (Central Sweden), and Luleå (Northern Sweden).

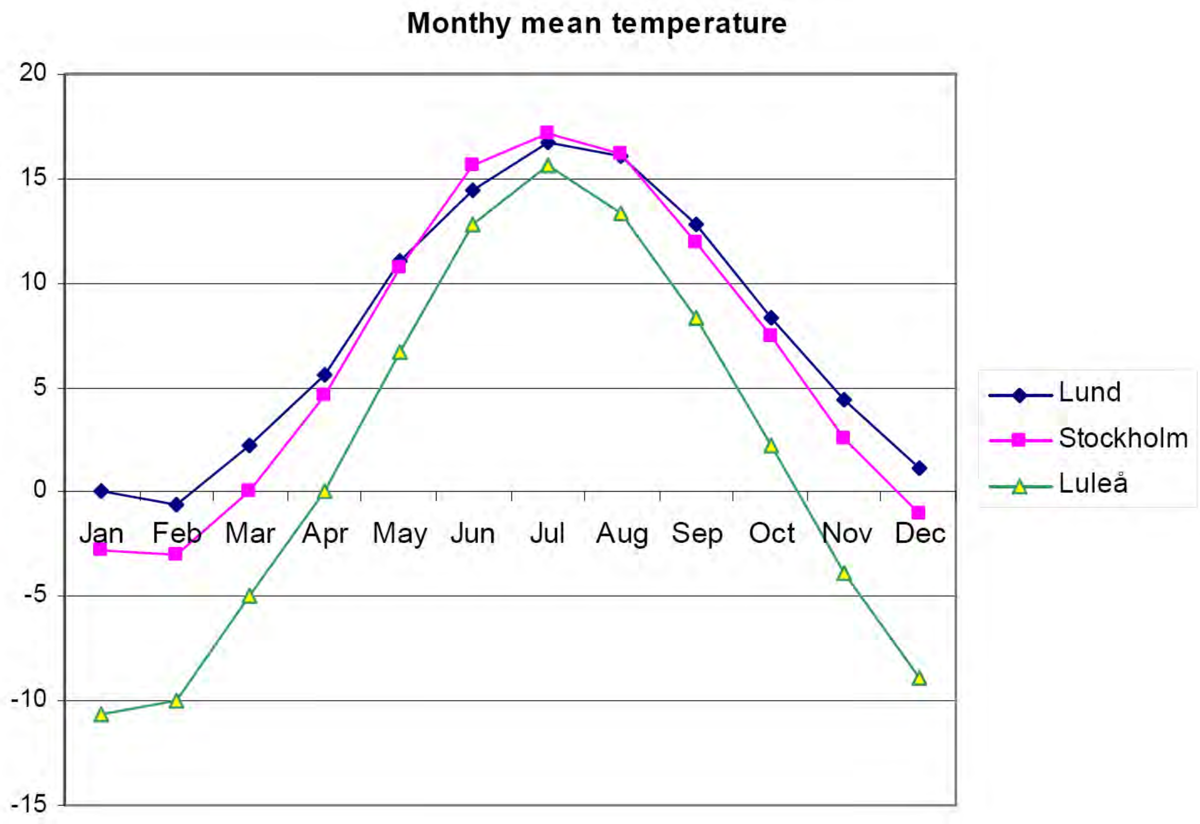


Figure 4.23: Average monthly temperature in three cities, Lund, Stockholm and Luleå.

The climatic conditions determine the ground-source temperatures. In addition to the air temperature also information on snow coverage may required since the snow layer through its insulating effect hinders the solar energy stored during the summer to escape from the ground.

For ground-source heat pumps using vertical boreholes the average undisturbed ground temperature along the borehole depth is relevant information. Figure 4.24 shows the estimated ground temperature at 100 m depth, which may be used as a reference value for the design. In urban areas, the ground temperature is often somewhat increased down to 50-100 m due to heat losses from buildings. It should be noted that the annual average of the ground surface temperature is slightly higher than the annual mean air temperature due to the insulating effect of the snow cover. In Sweden, this difference varies from about 1 ºC in the South to about 4 ºC in the North. The ground temperature increases downwards due to the geothermal heat flux by 10-17 ºC per km in crystalline rock and by 20-30 ºC per km in sedimentary rock.

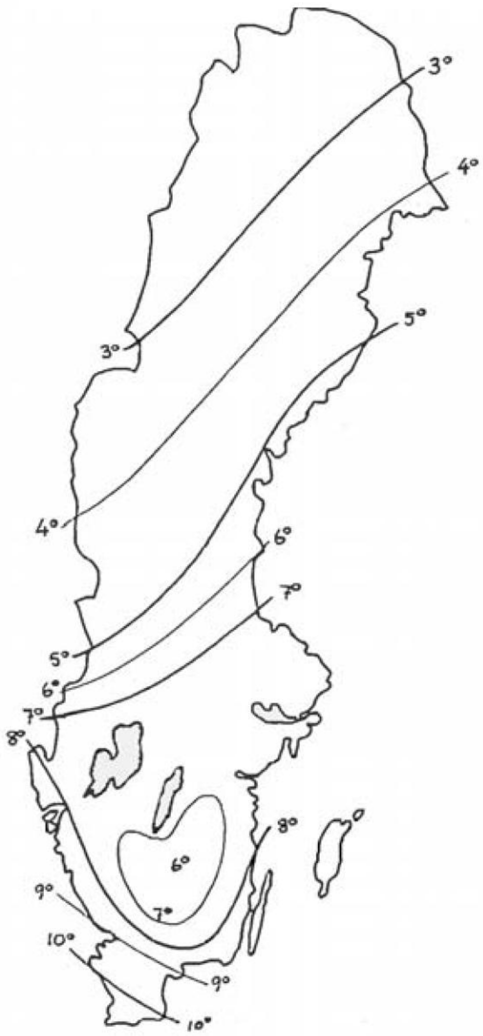


Figure 4.24: Estimated ground temperature at a depth of 100 m below ground surface.

The seasonal temperature variations close to the ground surface are attenuated with depth. Field measurements for typical Swedish conditions show that an annual amplitude of 20 ºC at ground surface is reduced to 12 ºC at 1 m depth, 7 ºC at 2 m depth and 4 ºC at 3 m depth. The amplitude is less than 1 ºC below the depth 6 m. For shallow horizontal systems, the progression and depth of natural frost penetration is crucial and linked to winter air temperatures, ground conditions (mainly water-saturation level), depth of snow cover, and how early an insulating snow cover builds up in the winter season.

Ground conditions

The ground conditions in Sweden are in general especially favorable for vertical ground source systems. Most areas have crystalline rocks, which feature high thermal conductivities and good drilling properties that are covered with a thin soil layer. One exception is areas with a thick covering soil layer that necessitate expensive cased soil drilling. Another exception is the very Southwest tip of Sweden that has sedimentary rock with lower thermal conductivity and more complicated drilling conditions. However, the sedimentary rock can sometimes be favorable for groundwater source systems (Aquifer Thermal Energy Systems). Such systems are used on a large scale in the city of Malmö. Shallow horizontal ground-source systems can be used almost anywhere where there is a covering soil layer without too many embedded stones. The main obstacle is to find a suitable and sufficiently large land area.

4.2.6 USA

Figure 4.25 gives an overview on ground temperatures in the USA.

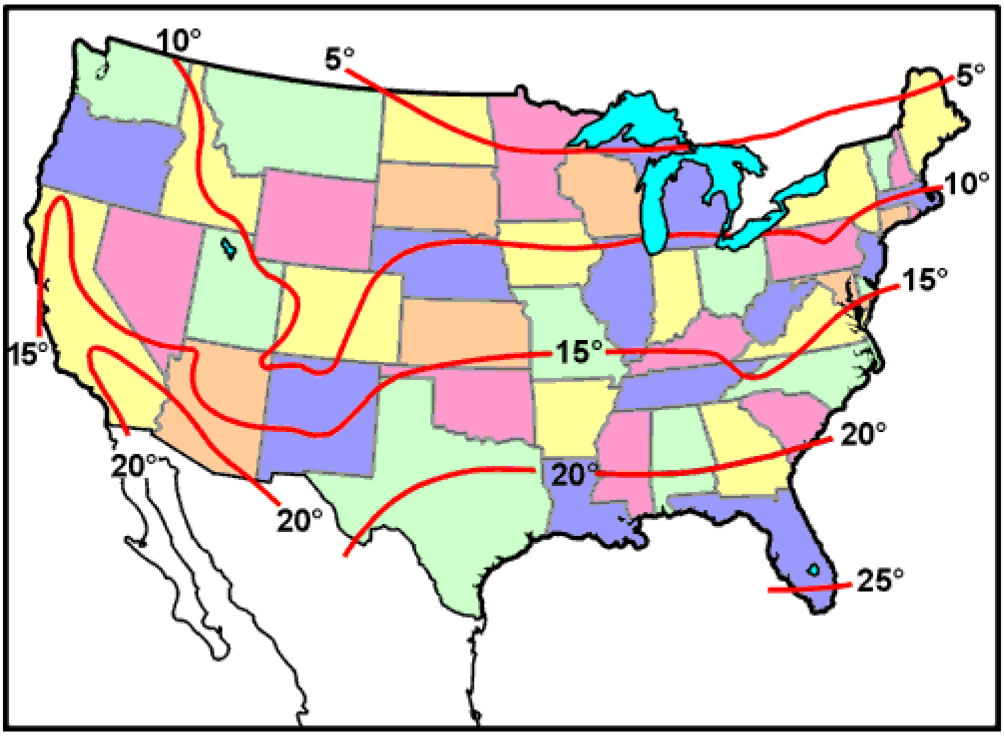


Figure 4.25: Ground temperature in the USA

5 IMPROVEMENT OF COMPONENTS AND SYSTEMS

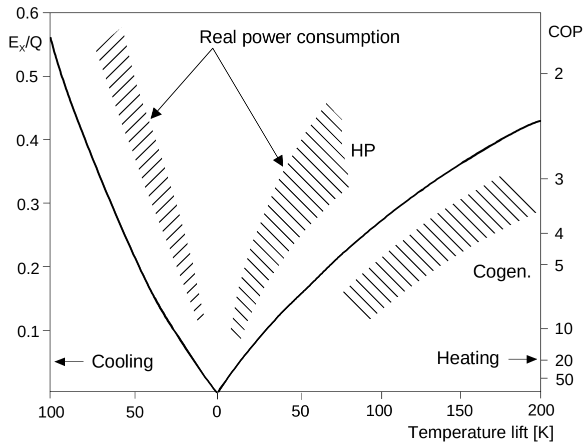
Heat pumps offer the possibility of reducing energy consumption significantly, mainly in the building sector, but also in industry. The second law of thermodynamics shows the advantages: While a condensing boiler can reach a primary energy ratio (PER) of at best 105 % (i.e. the boiler efficiency; the theoretical maximum would be 110 %, based on the lower calorific value), heat pumps achieve 200 % and more.

Whereas the thermodynamic principle of the heat pumping process was found at the beginning of the 19th century (by Carnot, Kelvin, and others), it was realized about 1834 (by Perkins and Evans) for refrigeration, and not before 1855 for producing heat: In this year, Peter Ritter von Rittinger put into operation the first heat pump, an open-cycle mechanical vapour recompression (MVR) unit, directly driven by hydro energy, in the saltern of Ebensee, Upper Austria. Much later, also the closed vapour process was used for generating useful heat. Essentially after World War II, heat pumping units for air conditioning of homes and individual rooms became common, somewhat later the "reversible" units for cooling/dehumidifying as well as heating, and after the oil price crisis of 1973 also the heating-only heat pumps for moderate and cold climates were introduced.

The general term heat pumping technologies is used for processes in which the natural heat flow from a higher to a lower temperature level is reversed by adding high value energy, i.e. exergy. The term heat pump is used for a unit producing useful heat.

5.1 Efficiencies

Figure 5.1 demonstrates the efficiencies of thermodynamic heating/cooling.



Over the (positive or negative) effective temperature lift ΔT from ambient, the relative exergy E_x/Q is plotted for the ideal process (Carnot process, second law of thermodynamics) and for real processes. For the ideal process:

$$Ex/Q = 1 - Ta/T = (T - Ta)/T = \Delta T/T = \eta c$$

where

Ex	Exergy
Q	Heat transferred
T_a	Ambient temperature, K
T	Process temperature, K
η_c	Ideal (Carnot) efficiency

Figure 5.1: Ideal and real power consumption E_x/Q for cooling (freezing, refrigeration, air conditioning) and space heating by heat pumps and by cogeneration district heating

The coefficient of performance (COP) is shown at the right-hand scale: COP = Q/E_x. The internal efficiency is given by the ratio η = COP/COP_{ideal} at ΔT. The left-hand area refers to cooling: freezing, refrigeration and air conditioning including dehumidification, the right-hand area refers to heating: The heat pump area shows a temperature lift of 5 to 70 K, E_x/Q is between 0.08 and 0.45 and COP therefore between 2.2 and 12.5, the efficiency η is about 0.4...0.7. The important term for the COP is ΔT, the temperature lift in the heat pump.

This ΔT depends on the temperature of the heat source, which can be increased by using the ground as heat source instead of ambient air, and by the temperature required by the heat sink. In highly insulated buildings with floor heating systems this temperature can be reduced to values below 30°C, so ΔT can be reduced to 20 K. The coefficiant of performance of the area “Cogeneration” is different: Here the real exergy loss is smaller than the theoretical one because of reduced turbine losses and condenser losses.

Performance Factors

The drive energy of heat pumps is most commonly electricity, and for the future improved power generation systems based on renewable and fossil fuels have to be taken into consideration. The power plant efficiency, η_{PP}, is up to 58 % for gas-fired combined-cycle power plants available on the market; with oil as fuel similar values are possible. The power plant efficiency η_{PP} depends, of course, on the kind of fuel (primary energy source).

Table 5.1 shows the relations for the more important primary energy sources and for heat pump SPFs of 4 and 5. PER is highest for direct power generation from renewable sources such as hydro, wind or solar, for which η_{PP} = 1.0 by definition. PER gives an absolute measure of the units of useful heat obtained from one unit of primary energy at power plant input, neglecting for the moment losses upstream of the power plant such as in production, cleaning, transmission, and distribution losses between power plant and heat pumps.

Table 5.1: Typical Primary and Useful Energy Ratios

	Coal, Biomass	Gas	Renewables	Nuclear
Efficiencies				
Power plant, η_{PP}	0.4	0.55	1.0	0.33
Boiler (local conversion), η_B	0.8	0.98	1.0	1.0
PER for SPF = 4				
PER = SPF. η_{PP}	1.6	2.20	4.0	1.33
UER = PER/η_B	2.0	2.24	4.0	1.33
PER for SPF = 5				
PER = SPF. η_{PP}	2.0	2.75	5.0	1.67
UER = PER/η_B	2.5	2.81	5.0	1.67

More information than by PER is, however, given by comparing, for a given fuel (primary energy source), the efficiency of the indirect path via power plant and heat pump (PER) to the efficiency of the direct path of conversion (η_B), e.g. in a heating boiler. The ratio may be called Useful Energy Ratio UER = PER/η_B. Comparing the same fuel means that all upstream effects cancel each other out. The downstream effects, i.e. the local distribution losses, also cancel each other out in the case of electric heating from hydro, wind, or nuclear plants whereas they may be considered of equal value as a first approximation when comparing electricity for the heat pump, and fuel for the boiler. If, in the latter case, the distribution efficiencies η_d should be markedly different, a more exact formulation would be:

$$UER = (PER/\eta_B)(\eta_{d,,el}/\eta_{d,fuel})$$

$\eta_{d,,el}$ relates to electricity, and $\eta_{d,fuel}$ to the fuel distribution efficiency. The data of Table 1 show that

- UER is larger or – for η_B = 1.0, as for electric heating – equal to PER. Only for η_B somewhat higher than 1.0 – as may be the case for very efficient gas-fired condensing boilers – or for $\eta_{d,el} < \eta_{d,fuel}$ could UER become lower than PER.

- For direct electricity from renewables, the efficiencies are 1.0, and UER = PER = SPF.
- For the basic data of Table 1, UER ranges from 1.33 to 5.0.

- Boiler efficiencies near 1.0 are close to the theoretical limit (i.e. for the gas-fired condensing boiler). A SPFs of around 5.0 is far below the theoretical limit of heat pumps; SPFs of 6 or more may be possible and will be economic in the future.

For absorption heat pumps, PER is the ratio of heat output to primary energy input (not to the power plant but to the heat pump).

Renewable energy gain by heat pumps
It should be noted that the heat pump, which in most cases grades up free heat from the environment (air, water, ground) and from waste heat, is a major source of renewable energy. The renewable heat R gained by the heat pump is the difference between the thermal output Q and the drive energy E_x (in the case of electricity, $E = E_x$):

$$R = Q – E = Q – Q/SPF = Q(1 – 1/SPF)$$

Obviously, if the drive energy is electricity from renewable sources, all the energy used for the heat pump is renewable energy.

5.2 Heat Pump Applications

Taking different applications of heat pumping technologies several items have to be taken into consideration like drive energy, design of the unit, integration into a system and control strategy:

1. The drive energy of heat pumps is most commonly electricity, and for the future improved power generation systems based on renewable and fossil fuels have to be taken into consideration. The power plant efficiency is up to 58 % for gas-fired combined-cycle power plants available on the market; with oil as fuel similar values are possible. The power plant efficiency depends, of course, on the kind of fuel (primary energy source). PER, the primary energy ration, is highest for direct power generation from renewable sources such as hydro or wind, for

which the power plant efficiency η_{PP} = 1.0 by definition. PER gives an absolute measure of the units of useful cold/heat obtained from one unit of primary energy at power plant input, neglecting for the moment losses upstream of the power plant such as in production, cleaning, transmission, and distribution losses between power plant and heat pumping equipment. For absorption heat pumping units, PER is the ratio of cold/heat output to primary energy input (not to the power plant but to the heat pumping units).

2. The second item is the efficiency of the unit, which is most commonly expressed by the COP, the coefficient of performance. This COP depends on the refrigerant selected and on the components used like the compressor, the size and the design of condenser and evaporator, the flow sheet – single stage, two stage, economiser or cascade – and the internal cycle control. The choice of the refrigerant is most commonly a compromise between efficiency and cost, smaller equipment using a high-pressure working fluid can reduce the cost, a working fluid with low discharge temperatures can avoid a two-stage system.

3. The third item is the integration of a unit into a system, and again the choice of the refrigerant may have a large influence on this integration. The most efficient way of heat absorption/heat dissipation is direct evaporation/direct condensation; the alternative are secondary loop systems. Secondary loop systems require an additional temperature lift to transport heat to the evaporator and from the condenser, and most commonly they require circulation pumps with an additional power consumption. Especially in low-temperature applications this may cause problems. This means that secondary loop systems are less efficient than direct evaporation/condensation systems.

   However, the unit itself can be designed as a compact unit and the refrigerant content can be minimised. Additionally, if heat absorption/heat dissipation happens in spaces with public access, the working fluid has to be a safety refrigerant, flammable and/or toxic fluids cannot be used. But there are lot of applications, where the secondary loop system already exists, for example hydronic heating systems or cold water based air conditioning systems. In large cold stores the use of direct systems with flammable and/or toxic working fluids is also possible.

4. The fourth item is now the real operation of the system combined with the control strategy selected, and the operation of the system shows not only full-load, but mainly part-load: many systems loose a lot of efficiency operated in part-load, and taking this part-load operation one will get the SPF, the seasonal performance factor, which includes the cold/heat output, the drive energy at the different operating conditions, and the parasitic energy consumers like fans and circulation pumps. This is the value which has to be taken into account when specifying the TEWI; such a figure is too complicated for a politician and for an environmentalist. But this figure is a basis for the right selection of the whole system (Halozan 2002).

5.3 Ongoing Developments

The future development will be characterised by the improvement of components, probably other refrigerants, and advanced systems.

5.3.1 Components of Heat Pumps

In the small to medium size capacity range the reciprocating compressor has been practically replaced by the rotary compressor and the scroll compressor (Fig. 5.2).

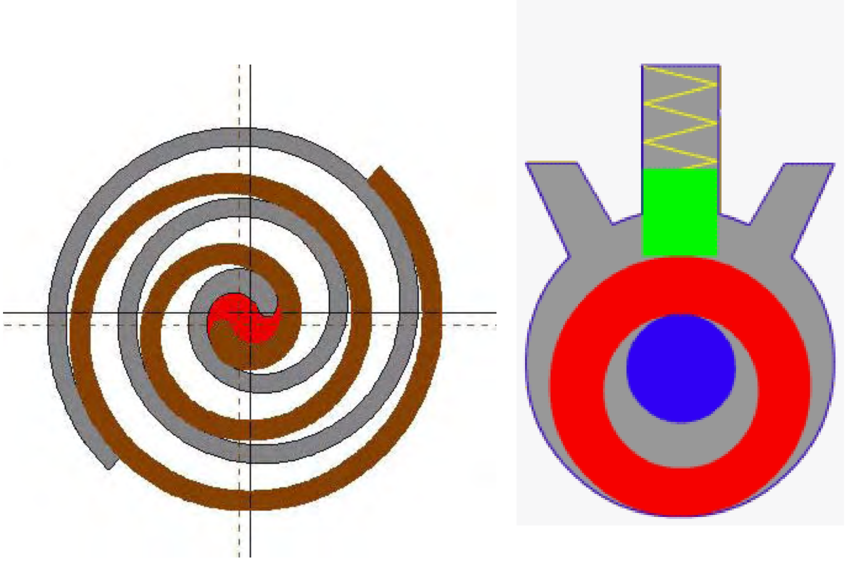


Fig. 5.2: Scroll Compressor and Rotary Compressor

These two compressors have some advantages,

- a minimum of moving parts,
- highly suitable for variable speed operation or variable capacity operation, respectively, and
- in the case of the scroll compressor a simple way to realise the economiser flow sheet which means two-stage compression with one compressor.

Considering the heating and the cooling season, the vast majority of the operating time only part load is required. In the case of ground source heat pumps the temperature drop from the source to the evaporator can be reduced significantly.
The economiser flow sheet shows its advantages at higher temperature lists required, which most commonly happens in the case of retrofitting existing buildings equipped with hydronic heat distribution systems.

A new development are small centrifugal compressors with high-speed drives and magnetic bearings for oil-free operation (Fig. 5.3).

Fig. 5.3: High-Speed Centrifugal Compressor with Magnetic Bearings (Turbocor)

Liquid/refrigerant heat exchangers have changed to welded flat plate heat exchangers, and gaseous/refrigerant heat exchangers are changing to multi port micro channel heat exchangers, both with the aim to reduce size and temperature drop at the heat transfer from one medium to the other (see Fig. 5.4).

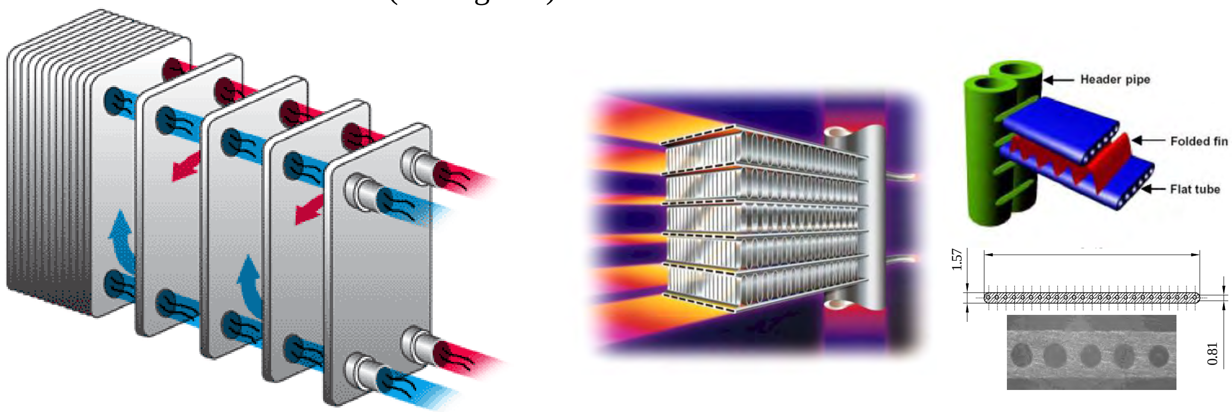


Fig. 5.4: Flat Plate Heat Exchanger and multi port micro channel heat exchanger.

Another important device are electronic expansion valves, especially in the case of changing operation temperatures and in the case of variable speed operation. With such newly developed valves it is possible to reduce suction gas superheating significantly.

5.3.2 Refrigerants

The refrigerants (working fluids) from 1834 up to the 1930s were ammonia, carbon dioxide and other fluids, most commonly toxic and/or flammable; later on the “safety refrigerants” (chlorofluorocarbons, CFCs, and hydrochlorofluorocarbons, HCFCs) quickly occupied the market, and the old refrigerants disappeared from the market.

The only exception was ammonia, it was and still is in use for large applications. This situation remained so until at the Vienna Convention of 1986 and the Agreement of Montreal 1997 the future production of CFCs was limited and in the end essentially banned, for reasons of depleting the stratospheric ozone layer (Fig. 5.5). A few years later (Kopenhagen, 1992) also an agreement for limiting the HCFCs was concluded, a phase-out schedule until 2030 - in the EU until 2015 – already exists.

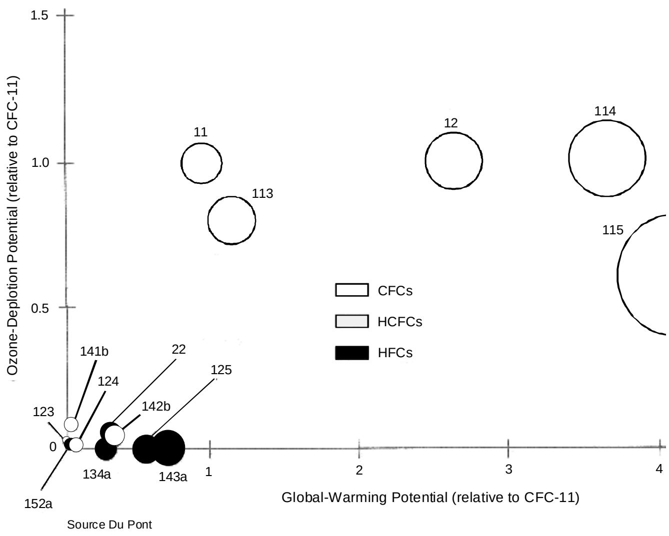


Fig. 5.5: ODP versus GWP of some CFCs, HCFCs and HFCs

The HCFCs presently in use are R-134a, R-404A, R-704C, and R-410A. The new pure fluid and these mixtures require changes in the manufacture of components, new sealing materials and especially new lubricants. It was a change from mineral oils to synthetic oils like alkylbenzol, polyalphaolefine (PAO), polyolester (POE), and polyglykole (PAG) oils. Decomposition problems of the non-azeotropic mixtures within the cycle are not yet fully solved. The main synthetic refrigerants and mixtures, respectively, presently used in the market are

R-134a

R-134a is the only new pure fluid which can be directly used as refrigerant. It is an alternative of R-12 in the temperature range of –10°C in refrigeration up to 84°C for heat pumps, i.e. worse than R-12 in the low-temperature regime and better in the medium-temperature regime and in the high-temperature range.

R-404A

R-404A - 125/134a/143a (44/4/52) and R-507 - 125/143a (50/50), both are used as alternatives for R-502, where R-404A is almost an azeotropic mixture with a negligible temperature glide, R-507 is an azeotropic mixture. The disadvantage of both is the high GWP.

R-407C

R-407C - 32/125/134a (23/25/52) is used as alternative for R-22. The problem of this refrigerant is the high temperature glide of about 7 K, which can only be utilised in some applications. Decomposition in the cycle is an additional problem.

R-410A

R-410A - 32/125 (50/50) is a very efficient working fluid, it promises a higher efficiency than R-22 and R-407C, but it requires a 40 bar technology. After the modification of compressors this fluid starts replacing R-22, but also R-407C in small air conditioning and heat pump equipment. COPs are increased, the cost should be decreased to a more compact design of the units.

In some countries even more rigid phase-out schedules have been decided, the EU will phase out R134a for automotive air conditioning, Denmark, Switzerland, and Austria want to phase out HFCs due to their global warming potential (see Fig. 5.5). Alternatives are ammonia (R-717), the hydrocarbons propane (R-290), sometimes propylene (R-1270) or isobutane (R-600a), water (R-718) and CO_2 (R-744) as shown in Table 5.2.

Ammonia and the hydrocarbons do not match the requirements of a "safety" refrigerant caused by toxicity and/or flammability; water and CO_2 keep it (Halozan, Rieberer 2006).

Table 5.2: Old "Natural" Working Fluids

Refrigerant	ASHRAE	Composition	Boiling Point °C	ODP	HGWP
Ammonia	R-717	NH_3	-33,6	0	0
Propane	R-290	C_3H_8	-42,0	0	0
Isobutane	R-600a	C_4H_{10}	-11,9	0	0
Water	R-718	H_2O	100,0	0	0
Carbon Dioxide	R-744	CO_2	-78,4	0	0

Ammonia – R-717
The technology used for ammonia systems is different from the technology used in systems with fluorocarbons: Copper is not compatible with ammonia, one has to use steel or aluminium, and steel has to be welded, aluminium welded or soldered, but soldering aluminium is more difficult than soldering copper. The problem of ammonia units is the combination of all these differences. For large systems within an industrial process, mostly in the chemical, food and lumber industries, this is not a serious problem. The real problem are medium sized and small applications, where ammonia is in competition with direct evaporation/condensation systems. Nevertheless, ammonia has an increasing share in new equipment, developments are going on to develop hermetic compressors.

Other developments are to reduce the refrigerant charge of the systems. The one change was from flooded evaporation to dry evaporation, the second was in the case of small systems the change from non-soluble oil to a soluble oil. Combined with flat-plate heat exchangers the refrigerant charge has been reduced significantly (0.1 to 0.05 kg/kW heating capacity). Such units are used for cold stores as well as for retail refrigeration, direct evaporation systems have been changed to systems with a secondary loop. For higher temperatures 40-bar compressors with maximum condensing temperatures of more than 74°C have been developed (Halozan 2005).

Propane – R-290
Compared with existing units using R-22 as refrigerant, only a few changes have to be made to adapt the unit for the operation with propane, to improve the performance of the unit an internal heat exchanger has to be added, and the COP of the unit becomes

significantly higher. Furthermore, the condensing temperature can be increased from 57°C of a R-22 unit to 65°C of the propane unit.

CO_2 – R-744

Presently CO_2 is being used as heat carrier in commercial secondary loop systems. But with CO_2 it is also possible to realise again direct evaporation systems by using it as refrigerant in the low-temperature stage of a refrigeration cascade.
For applications with condensing temperatures exceeding 30°C the trans-critical cycle, also proposed by the late Prof. Lorentzen (Lorentzen 1995), with pressures up to 140 bar has to be used. This cycle is characterised by evaporation taking place in the sub-critical region, whereas heat rejection takes place in the super-critical region. Taking the temperature-entropy-diagram this happens near the critical point. This means a heat rejection characteristic similar to the Joule-Brayton cycle, but in a region with strong deviations from ideal gas conditions; the maximum of the specific heat - infinite in the two-phase region and at the critical point - is still existing (Rieberer 1998).

Highly efficient solutions using CO_2 are hot water heaters, air heating systems and exhaust air heat recovery systems suitable for being the only heating devices for ultra low energy and passive houses, respectively (Halozan, Rieberer 1999).

H2O – R-718

Water has been and is being used successfully in MVR systems; but nowadays it is also used for chillers where the water is both refrigerant and heat carrier. Due to the low volumetric cooling capacity centrifugals have to be used, and the smallest capacity presently realised in prototype installations is about 800 kW.

5.4 Buildings

The most important item is the development of systems. The interaction of the user, the building, the heating/cooling equipment and the control has to be considered very carefully, and only such a system approach can achieve highly efficient systems.

During the last decades a lot of changes occurred in the building sector, mainly initiated by the two oil price shocks in 1973 and 1978. In this time the main goals were substitution of oil and reducing the energy consumption of buildings. Technical developments were supported by governmental regulations, and the achievements in this direction were remarkable (Fig. 5.6).

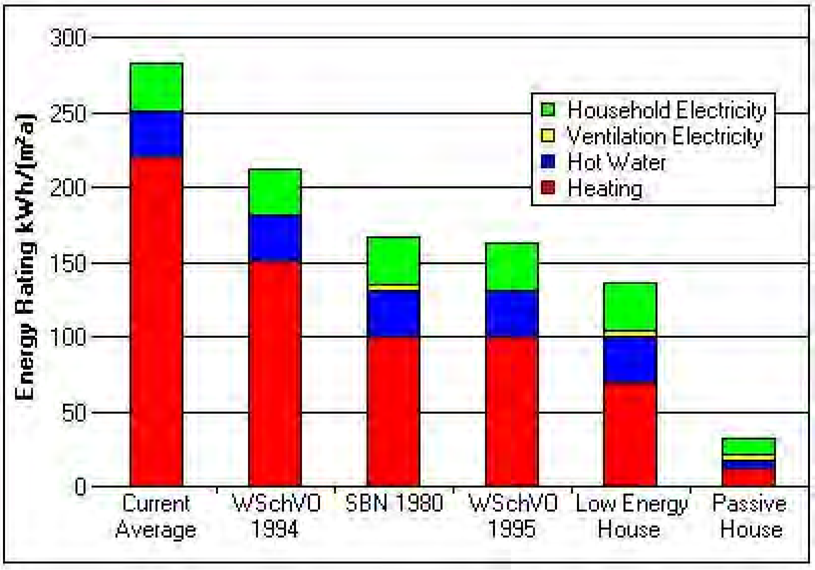


Fig. 5.6: Energy consumption of different buildings

The first step was the improvement of the building envelope.

- Bricks have been improved significantly, and presently with a 0.38 m brick wall U-values of 0.32 W/m^{2}K can be achieved compared with 1 W/m^{2}K before these improvements have been started.

- For getting lower U-values additional thermal insulation materials like mineral wool or foams like polystyrene have been used. Presently U-values in passive houses are in the range of 0.1 W/m^{2}K.

- The glazing of windows through an interesting development. Starting with an U-value of 5.4 W/m^{2}K for single glazing it went down to 2.8 W/m^{2}K for double glazing and 2.2 W/m^{2}K for triple glazing. This was the development for simple glass. Using coatings reflecting infra red radiation the U-value for double glazing went down to 1.8 W/m^{2}K, using argon instead of air between the two glass layers it went down to 1.1 W/m^{2}K. In the case of triple glazing an U-value of 0.7 W/m^{2}K is presently state of the art; the better solution using Xenon instead of Argon with an U-value of 0.5 W/m^{2}K became too expensive when the cart industry started with Xenon lamps.

- The problem now are the frames of the windows: in the case of single glazed windows the most commonly used wooden frame was always better then the glazing, but now with double glazing with U-values of 1.1 W/m^{2}K and triple glazing with U-values of 0.7 W/m^{2}K the frame is most commonly worth compared with the glazing.

Another development was to tighten windows, and an important step was the introduction of lip seals. This measure reduced the air exchange rate significantly, however, in naturally ventilated buildings – and more or less all residential buildings have been ventilated naturally – the air exchange rate became too small to allow to cover hygienic requirements by natural ventilation, which is caused by temperature differences and wind pressure.

People started to remember the requirements of ventilation – 0.4 to 1.0 air changes per hour – and in some countries like Sweden mechanical ventilation systems were regulated. Additionally these mechanical ventilation systems have to be combined with an exhaust air heat recovery system. Such a system combines now both hygienic conditions and energy efficiency.

Taking all these developments together we come to concepts like

- low energy houses,
- the German passive house,
- the Swiss minergiehouses (minergie, minergie P, minergie eco),
- net zero energy houses, and
- energy plus houses.

Low energy houses are characterised by a heat consumption of 40 to 80 kWh/m^{2}a, the passive house by a heat consumption of 15 kWh/m^{2}a, minergie has similar values, net zero energy means that the photovoltaic system of the house produces the annual electricity consumption of the house and energy plus means that the house produces on an annual basis more electricity than it needs.

Passive house and minergie are trademarks, and especially in the case of passive houses one has to be careful if the building really keeps the rules of the trade mark. The heating system of a passive house has to be a fresh air heating system with preheating the outside air in a ground coil with the fresh air as heat carrier, heating it by means of heat recovery from the exhaust air and end heating by a heat pump or another heating device (Fig. 5.7 and Fig. 5.8).

Due to comfort reasons – and bad installations of ventilation systems – many people prefer

- conventional hydronic heating systems like floor heating systems, and for
- preheating the outside air they use secondary loop ground coupled systems due to hygienic reasons, i.e. condensation in the air coil in the ground.

So, the main criterium which remains is the heat consumption of 15 kWh/m^{2}a.

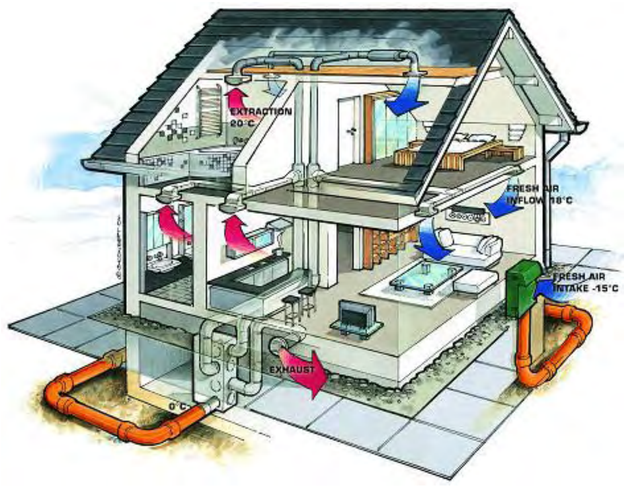


Fig. 5.7: Concept of a Passive House

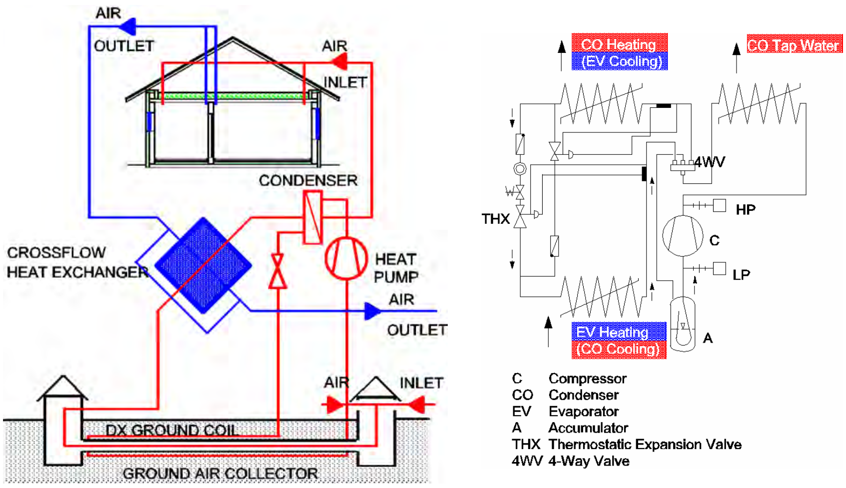


Fig. 5.8: Concept of a Passive House with Fresh Air Heating System with Ground Coil, Heat Recovery Heat Exchanger and Reversible Ground Source Heat Pump with Tap Water Condenser.

The step to a zero net energy house is now relatively simple: a passive house is equipped with photovoltaic panels which produce during the year the amount of electricity required for the operation of the house (Fig. 5.9). This does not mean that a self sufficient operation is possible is possible. During night time or in the cold region during winter time electricity is taken from the grid, when the sun is shining electricity is supplied to the grid.

Fig. 5.9: Net Zero Energy House

In the case of a energy plus house the photovoltaic panels deliver on an annual basis even more electricity than used by the house. The funny thing is that nobody asks where the electricity during night time or in winter time comes. This is the common problem of solar and also wind power generation systems.

The design of large commercial buildings has changed significantly during the last decades. Besides their original task of providing space for offices, stores or shopping centres they got as an additional task representation, representation of the city, representation of the company, and very often the owners of large commercial buildings are bank, insurance companies or head quarters of large international companies. The building has to be higher than the building of the competitor, which can be another country, another city or another company. The task of representation becomes sometimes more important than the original one, creating space for working or living, and very often the functionality of the building is lost (Fig. 5.10).

Fig 5.10: High Rise Buildings

This development in the building sector is not very new: the church has used this principle, emperors have used this principle for their palaces and castles; nowadays the multinational companies are obviously the emperors of the world.

Another development happened in architecture. The old large buildings like castles and palaces had inner courtyards, the depth of the buildings was therefore not larger than 12 to 15 m. This design offered the possibility of efficient natural ventilation, it offered also the possibility of day-lighting. Air conditioning was not available in former days, so the height of the rooms was larger than now, the windows had the size which was necessary for lighting, shading equipment was part of the building, sometimes it was integrated in the building structure. The mass of the building structure has been used as a store to stabilise the indoor temperature and to damp the influence of outside air temperature fluctuation as well as solar radiation.

Nowadays things have changed significantly: buildings become higher and higher, presently we have reached more than 500 m, and the limitation for the height is no longer the building material available as it was in the past, it is more the capacity of the elevators. After facades of bricks, concrete, natural stones and later steel or aluminium, glass became the main material for the envelope of large commercial buildings (Fig. 5.11). Glass has excellent properties concerning corrosion and cleaning. The problem is, that glass is not only used as cover, very often the whole building becomes transparent. Additionally some architects have introduced double glass façade to offer the possibility of opening the windows for natural ventilation and for increasing the comfort even in high-rise buildings in regions with strong winds. The natural circulation within the shell and the building envelope is used for cooling and as an additional thermal insulation; as an additional advantage noise protection is mentioned.

Fig. 5.11: Office Building with Transparent Glass Façade

The result of such designs are large cold surfaces in winter time and problems with overheating in summer time, especially on western oriented facades; surfaces below the height of a table cannot be used for lighting. Such buildings require cooling on the side with solar radiation and heating on the opposite side – without sunshine – even at temperatures significantly below 0°C at the same time. Additionally the mass for damping outdoor effects no longer exists in modern buildings.

The real problem is the solar radiation through the windows: it means an increase of the room temperature, which cannot be compensated by a lower room air temperature and surface temperature; the only solution is shading the glass façade and using artificial lighting, which increases the power requirement of the air conditioning system.

5.5 Heat Distribution Systems

As heat distribution systems in Europe hydronic systems are most commonly used, in Japan and in the USA air based systems. The reason for this variation is the need for cooling.

Hydronic systems are in principle secondary loop systems with water as heat carrier and radiators, fan coils or parts of the room like the floor, the wall or even the ceiling as heat transfer surface.

Floor heating systems

Nowadays the most common solution are floor heating systems. The heating water flows through pipes embedded in the cast plaster floor, and the supply temperature required depends on the specific heat load in W/m^2 floor area, the pitch of the pipes in the cast plaster floor, and the flooring material: tiles are ideal due to their excellent heat conductivity, wood as flooring material is acceptable, high-pile carpets should be avoided (Fig. 5.12).

Floor heating systems have a limitation, and this limitation is a specific heat load higher than 80 W/m^2: in such a case the surface temperature of the floor becomes more than 28°C; that is too high to guarantee the heat removal from the feet and can result in health problems. However, at lower specific heat loads – in modern buildings the specific heat load is below 60 W/m^2 , in passive houses below 20 W/m^2 - no problems will occur, in contrast, the heat transfer from the floor – about 50 % by radiation and 50 % by convection – guarantees high comfort.

If in one room the heating capacity of the floor is not sufficient to cover the heat load, thew floor heating system can be combined with a wall heating system. This happens relatively often in the case of the bath room (Fig. 5.13)

Fig. 5.12: Single-Family House with a Floor Heating System

Fig. 5.13: Wall Heating System Supporting the Floor Heating System

Taking a small pitch of the pipes ion such highly insulated houses maximum supply temperatures of 30°C – that means condensation temperatures of about 32°C - can be achieved. And this means a highly efficient heat pump operation, especially in the case of a ground source heat pump system.

Floor heating systems can be also used for cooling, if the specific heat load is lower than 40 W/m^2 and the humidity is not to high. The moisture condensing temperature has to be controlled carefully. The 40 W/m^2 are caused by the effect, that the heat transfer of the floor heating system in cooling mode only takes place by radiation.

Overhead cooling systems
For cooling operation the better solution is overhead cooling. The heat transfer of the cooling ceiling is about 50 % by radiation and 50 % by convection (Fig. 5.14).

These are about the same values as for the floor heating system in heating mode. However, using a floor heating system for cooling purpose means that the convective part no longer exists. With cooling ceilings the specific cooling load can go up to 80 W/m^2. Again, the moisture condensing temperature has to be controlled carefully.

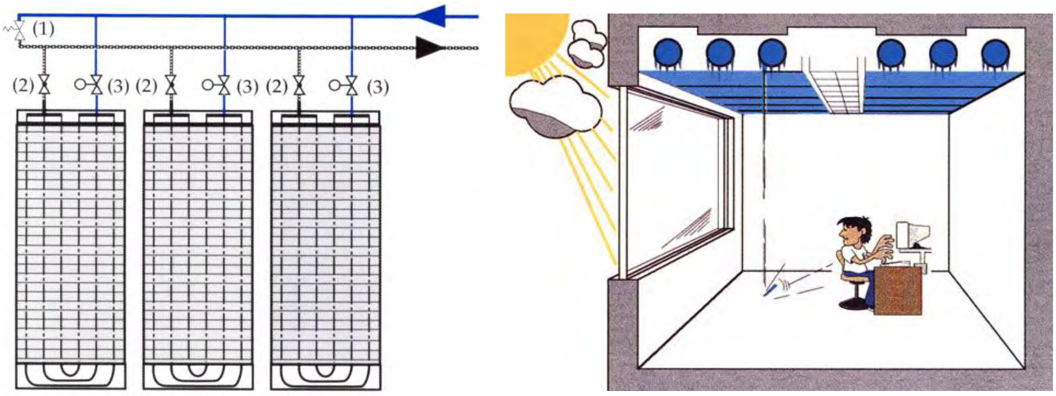


Fig. 5.14: Overhead Cooling System

The cooling ceiling can also be used for heating purposes. However, in this operation mode the specific cooling load drops to 40 W/m^2.

Taking the two systems, floor heating systems are mainly used in residential building with mainly heating loads and no or small cooling loads, cooling ceilings are mainly used in commercial buildings, where cooling operation dominates. In such buildings cooling ceilings are most commonly combined with mechanical ventilation systems with air handling units, where besides filtering humidification and dehumidification, respectively, is carried out.

Activation of the Building Structure

In the case of modern commercial buildings base-load heating and base-load cooling is carried out by activating the building structure, mainly concrete ceilings (Fig. 5.15).

Fig. 5.15: Activation of the Building Structure

In such a case plastic coils are embedded in the concrete ceiling, and the ceiling can be used for heating or cooling. The ceiling has the properties of a floor heating/overhead cooling system, additionally it acts as a store, which can be charged during night time and used during day time. The temperatures required are low for heating operation and high for cooling operation. Such a concept is an integral part of so called low-ex systems.

In the case of large buildings or in the case of humid climates additionally to the activation of the building structure air handling units for providing the air exchange and also to control the temperatures needed are required.

5.6 Systems for Heat Extraction from and Heat Removal to the Ground

For ground source systems, i.e. heat extraction from and heat removal to the ground, we have a variety of systems in use (Fig.5 16).

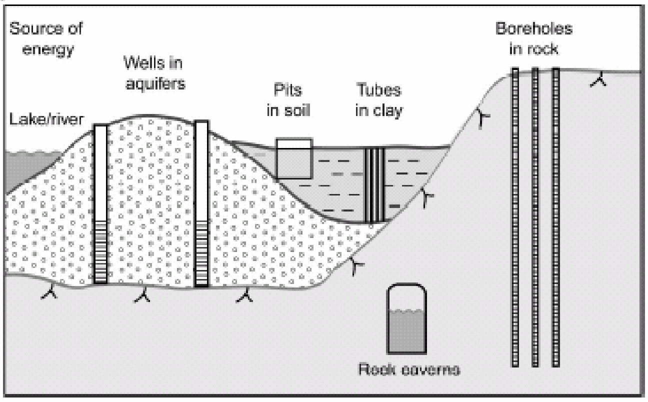


Fig. 5.16: Possible Ground Source Systems

Open loop systems
In the case of open loop systems, ground water, water from stores, water from rivers, ponds, lakes or the sea are used directly for heat extraction or heat removal. In the case of ground water two well systems, one for ground water extraction and one for ground water removal, and single well systems are in use.

Closed loop systems
In the case of closed loop systems coils are installed in the ground. It is also possible to install coils in ponds, lakes, rivers or in the sea. In the case of closed loop systems heat extraction/heat removal can happen by

- direct exchange ground source systems – direct expansion systems – or by
- secondary loop systems.

In the case of secondary loop systems a heat carrier – most commonly brine, sometimes water or recently CO_2 - are used as heat carrier.

Ground-coupled systems
The ground acts as a seasonal storage. At a depth of about 10 m the undisturbed ground temperature remains constant over the year; the value of this temperature corresponds to the annual average outside air temperature. Between the table where the constant temperature occurs and the surface, the ground temperature changes due to the outside conditions; depending on the depth, these changes are damped and delayed. Eliminating peaks of the outside air temperature, the ground is an efficient heat source for heat pumps.

The installation of the coils in the ground can be horizontally, most commonly in a depth of about 1 m – frosting depth + 0.3 m - or vertically in bore holes down to 30 m in the case of DX systems for both heating and cooling, to 100 m in the case of DX systems for heating only operation or secondary loop systems (100 m is often caused by the legal situation, down to 100 m it is the responsibility of the water authority, below 100 m it is the responsibility of the mining authority), to 240 m and more.

In the case of horizontally installed systems, heat recovery after a heating season happens via the surface by means of solar radiation, precipitation and wind. The influence of the surface goes down to depth of 10 to 15 m depending on the properties of the ground. The tempertaure of the ground is also dependant on the climate.

In the case of vertically installed systems with depths greater then 15 m heat recovery happens by heat delivery from the centre of our globe, which still has a temperature of about 5,000°C (Fig. 5.17).

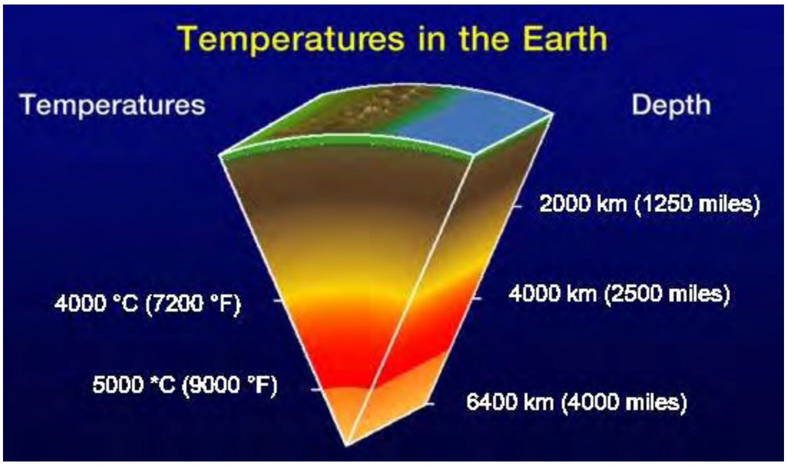


Fig. 5.17: Temperatures in the Earth

This temperature results in an average heat flux near the surface of about 0.14 W/m^2, which means a temperature increase of 3 K/100 m depth. This value varies in different regions of the world: in volcanic areas the temperature just below the surface can be 100°C and more.

In the case of a vertically installed system heat recovery is a result of the heat stored in the ground and the heat delivered from the centre of our globe, it is mainly geothermal energy. But this means also that in the case of a vertically installed system the temperature drops during the first years of operation, until the system is balanced again (Fig. 5.18).

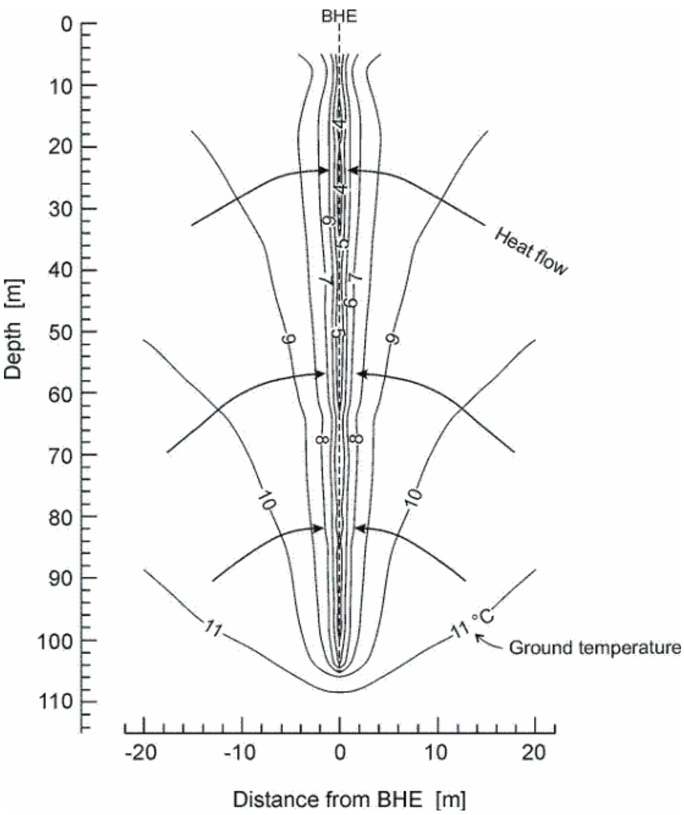


Fig. 5.18: Temperature and Heat Flux around a Borehole Heat Exchanger

5.6.1 Small Systems

The common characteristic of small systems is natural recovery of the ground, mainly by solar radiation collected by the ground surface. Small systems are in use for heating as well as heating and cooling, they can be used, depending on the climate and the distribution system, for direct cooling (without heat pump operation), at least at the beginning of the cooling season (Fig. 5.19).

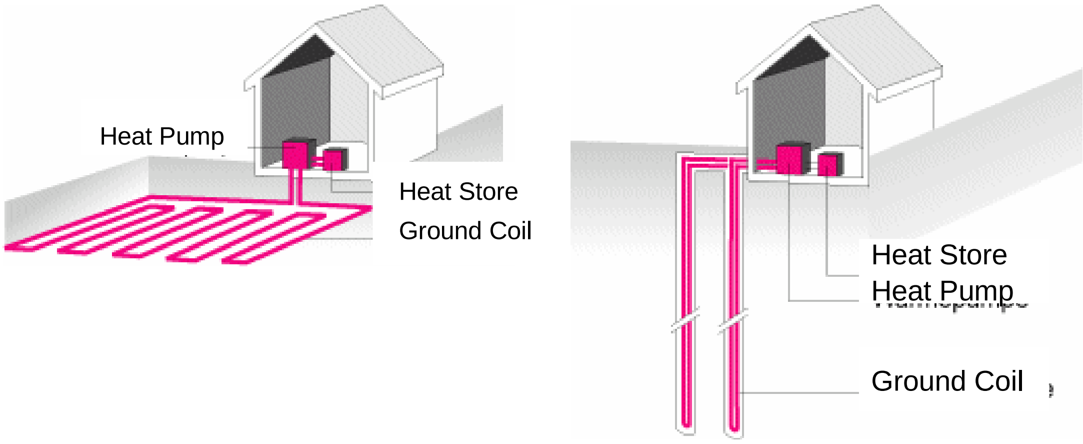


Fig. 5.19: Small Ground-Coupled Systems

Horizontal ground coils are most commonly installed at a depth of about 0.3 m below frosting depth, i.e. in the populated regions of Austria at a depth of about 0.8 - 1.2 m. At such a depth, the ground temperature changes during the year: At the beginning of the heating season it is higher than the undisturbed ground temperature (15 to 17°C instead of 10 to 12°C); during the heating season it drops below 0°C caused by heat extraction, but moisture migration to and frost formation around the coil increase heat conductivity and help to stabilise the temperature where heat extraction takes place. At the end of the heating season natural recharging starts and heat is delivered from the surface to the coil; if the system design is correct vegetation above the coil is hardly influenced at all, if the correct design data are used (see VDI, 1998).

Secondary Loop Systems

In the case of secondary loop systems the heat pump unit and the heat extraction system are separated.

- The heat pump unit is being designed as a compact brine/water unit, where the refrigerant content can be minimised and which can be manufactured and tested in the factory to fulfil the requirements of leak tightness. Leak tightness means that – taking the present technology – no greenhouse gases are emitted directly to the environment.

- The problem of this concept is the secondary loop system: The heat carrier, most commonly a glycol/water mixture, has to be circulated through the ground coil by means of a circulation pump. Compared with water the properties of these mixtures are worse, the density is slightly higher, but the specific heat capacity is lower, and the viscosity is higher with a tendency to increase significantly at decreasing temperatures. This results in a circulation pump which has to be sized for the lowest temperature which may occur, because in the case of a transition to laminar flow the heat transfer coefficients drop and at the same time also the brine temperature.

Each temperature drop has a negative influence on the COP, i.e. the power requirement rises and increases the indirect greenhouse gas emissions due to increased drive energy generation. Under-sizing the ground coil or the circulation pump can result in a male function of the system.

Direct Expansion Systems

Direct expansion systems have some advantages compared with secondary loop systems:

- The evaporator of the heat pump unit is directly installed in the ground, which means that the heat transfer from the ground to the refrigerant takes place directly, i.e. one heat transfer loss can be avoided.

- The drive energy for the circulation of the refrigerant in the evaporator comes from the compressor and from the throttling loss, respectively; this means that no additional power for a circulation pump is needed.

- Additionally, heat transfer conditions of copper tubes (with a diameter of 12 to 14 mm coated with a thin plastic film to avoid corrosion) used in direct-expansion coils are better than those of plastic tubes used for secondary loop systems. The heat conductivity of the plastic material used for the tubes of secondary loop coil is relatively low.

- This means that in the case of an appropriate design direct evaporation systems are more efficient than secondary loop systems. The SPFs of direct evaporation systems in new well insulated buildings with specific heat loads below 60 W/m2 equipped with low-temperature floor heating systems are in the range of 4 to 5 and higher!

To achieve such high SPFs the design of the heat pump unit and the construction of the whole system have to be carried out very carefully:

- The refrigerant velocity in the evaporator has to be kept as small as possible to minimize the pressure drop, which means also a drop in the evaporation temperature: but it has to be high enough to ensure oil return. In horizontally installed collectors the required velocity at the evaporator outlet has to be about 5 m/s, in vertical systems it has to be about 7 m/s. To achieve this velocity and to make a sufficient mass of ground accessible, the diameter of the evaporator tubes has to be smaller than that of secondary loop systems; this means that the temperature drop from the ground to the tube surface becomes larger or the heat transfer area has to be increased.

- The refrigerant cycle control cannot be carried out using a conventional thermostatic expansion valve due to the fact that the length of the tubes used is 60 m and 75 m, respectively, and the run-through time is in the range of more than 30 seconds. Possible solutions are capillary tubes or thermostatic expansion valves based on liquid sub-cooling, which seems to be the best solution (see Fig. 5.20).

- The design of the coils of vertical systems has to be carried out very carefully (Fig. 5.21). In horizontally installed systems the pressure decreases from the inlet to the outlet, and with the pressure the evaporation temperature decreases as well. In the case of vertical systems one has to consider the pressure gains in the down comer. Without evaporation in this section systems with a depth of 50 m to 60 m cannot be realised, because the evaporation temperature will rise significantly, and it may become higher than the ground temperature. Evaporation in the down comer has to be used to compensate pressure wins caused by gravity. The riser has to be sized to guarantee oil return to the compressor. Using pressure gains in the down comer and pressure losses in the riser, it is possible to size a vertical coil in a way that externally, between inlet and outlet, no pressure loss exists.

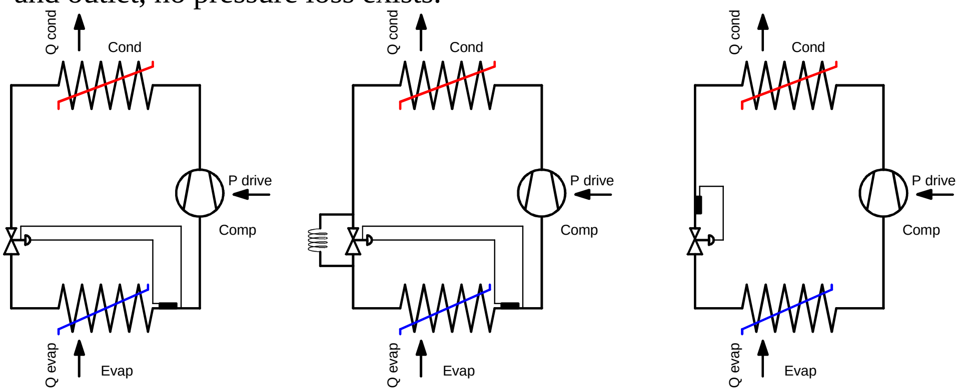
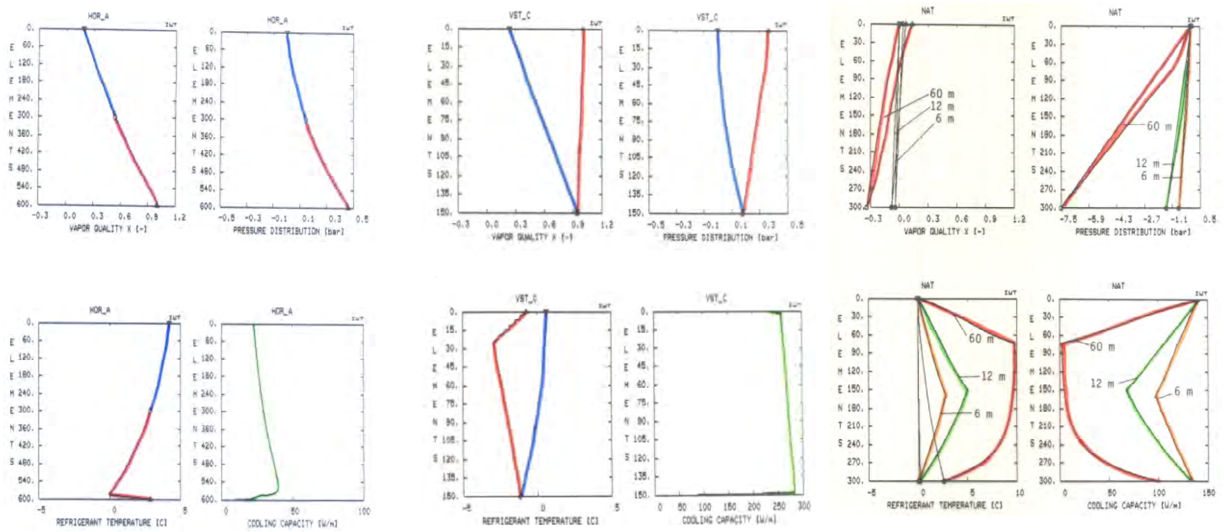


Fig. 5.20: Refrigerant Flow Control with Suction Gas Superheating Control and Liquid Subcooling Control



Once-Through Horizontal | Once-Through Vertical | Natural Circulation

Fig. 5.22: Refrigerant Flow Through Possible Direct-Evaporation Concepts

- However, these pressure gains in the down comer avoid the design of natural circulation systems, which would result in a perfect cycle control. But due to the variation of pressure and evaporation temperature only shallow systems can be realised.

- In the case of part-load operation by means of two-speed (variable-speed) compressors or two compressors arranged in parallel, which is an efficient measure to increase the SPF, the speed drops. Thus for the oil return, maximum capacity operation at the beginning of a cycle or after a defined time interval has to be implemented.

If these preconditions are fulfilled no problems for an efficient and reliable operation are missing. However, there are also some disadvantages of direct-evaporation systems:

- Soldering at the site is (was!) necessary to connect the ground collector and the heat pump unit, refrigerant losses and pollution of the ground water can occur.

- The ground coil evaporator becomes much larger than the evaporator of a compact heat pump unit, thus the refrigerant charge increases.

These disadvantages have been solved by manufacturers and installers of direct-expansion systems (Halozan, 1997). These manufacturers are small companies with employees highly skilled in both refrigeration systems and heating systems, they are designers and constructors and not only heat pump manufacturers or heating system installers, and that is the reason why direct expansion systems are so successful in Austria and why the SPFs are significantly higher than those of secondary loop systems.

In principle, these small system designers and constructors safe first cost by investing their knowledge and experience into these systems. It is possible to achieve such high SPFs also with secondary loop systems, and some companies are successful in almost achieving these values. However, the systems become more expensive due to a larger ground coil, which results in an increase of the secondary fluid temperature and the evaporation temperature, respectively, and this increase has to be utilised for reducing and compensating the electric power consumption of the circulation pump.

5.6.2 Further Developments

But the development of heat pumping technologies goes on, and heat pumps are strongly influenced by advancements in refrigeration technology - positively - and by regulations, which are sometimes an obstacle.

Packaged Direct Evaporation Heat Pump with Propane as Working Fluid

Propane is an excellent substitute for R-22, practically a drop-in, and using an internal heat exchanger it becomes even more efficient than R-22 with about the same cooling capacity; additionally, the refrigerant charge can be reduced by about 50 % compared with R-22. One problem of propane are restrictions due to existing regulations and restrictions introduced by compressor manufacturers, and it seems that at least one large compressor manufacturer in the USA wants to prevent the use of the hydrocarbons in Europe. Nevertheless, some manufacturers still use hydrocarbons like propane as refrigerants (Halozan, 1995).

One of the small heat pump manufacturer in Austria has developed a packaged direct-expansion heat pump using propane as refrigerant. The heat pump unit – designed for outdoor installation due to Austrian regulations – connected with the ground evaporator is prefabricated, filled with the refrigerant charge required, and proven in the factory. The complete unit is transported to the site on a pallet, the heat pump part is mounted on a small foundation, the evaporator coil, folded on the pallet, is being laid out into the excavated ground, covered with sand and than filled up with the excavated ground material. The connection to the heating system in the building consists of the supply and the return pipe and cables for power supply and control. The control itself and the heating water circulation pump are mounted in the building (Fig. 5.22:).

Fig. 5.22: Packaged DX Heat Pump with Propane as Refrigerant

CO_2 Heat Pipe Based Ground Probe

A very interesting refrigerant is CO_2: The "natural" working fluid CO_2 (R-744), in Europe introduced by Linde already in the year 1881, became an important refrigerant: It has been used until the end of the Thirties as refrigerant for marine cooling and for air conditioning systems in buildings, both applications where a "safety" refrigerant was required. Difficulties have been caused by the thermodynamic properties, the critical data are about 31°C and 74 bar. This resulted at high ambient temperatures in a trans-critical operation where both capacity and efficiency dropped significantly. G. Lorentzen initiated the revival of this interesting high-pressure refrigerant again (Lorentzen, 1993).

An interesting development has been carried out by K. Mittermayr of the M-tec company, who developed a heat-pipe based ground probe with CO_2 as working fluid for vertical wells down to a depth of about 70 m (Rieberer and Mittermayr, 2001) (see Fig. 5.23).

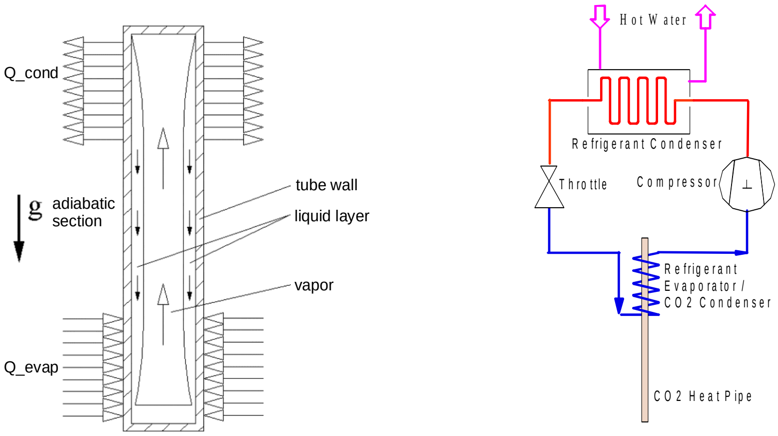


Fig. 5.23: Working principle of a heat pipe (two-phase thermosyphon) and heat pump system layout

This self-circulating system is environmentally fully acceptable – the probe works oil-free – and it has the advantage that no circulation pump is required. The working principle of a heat pipe can be described as follows (compare left chart of Fig. 3): due to gravity the liquid working fluid (CO_2) flows along the tube wall to the 'heated' section of the probe where it becomes evaporated, thus the liquid film becomes thinner and thinner while the vapour rises to the top due to the buoyancy. In the “cooled” section – at the top of the heat pipe – the vapour becomes condensed and the cycle starts again.

The system design leads to a heat pump cycle that is physically de-coupled from the heat source cycle, the CO_2 cycle (compare right chart of Fig. 3). The refrigeration cascade consists of the earth probe in which CO_2 is evaporated, and the “probe-head” which is both the CO_2-condenser and the refrigerant-evaporator of the conventional heat pump using R-410A as refrigerant. The experimental analysis confirms that the proposed CO_2 heat pipe is a reliable and a highly efficient as well as environmentally friendly alternative to common ground-coupled systems. With a prototype heat pump a system SPF of higher than 5 has been measured.

5.6.3 Large Systems

If large systems can be realized as groundwater systems or as horizontally installed systems all remains the same: natural heat recovery is still possible (Fig.5.24).

If due to the local situation vertically installed systems are required, things start to change: natural heat recovery is no longer possible. The coil matrix forms a store, and the heat flow from the surrounding cannot reach the centre of this store. Heat recovery has to be carried out using other sources like air-based or solar-based systems. Waste heat from industry is another a possibility to recover the ground around the coils (Fig. 5.25).

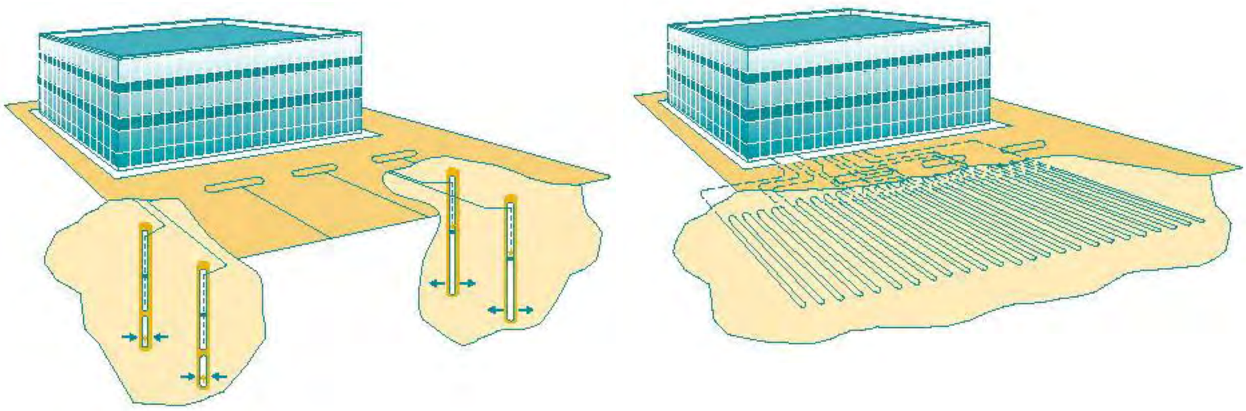


Fig. 5.24: Large Systems with groundwater and horizontally installed coils

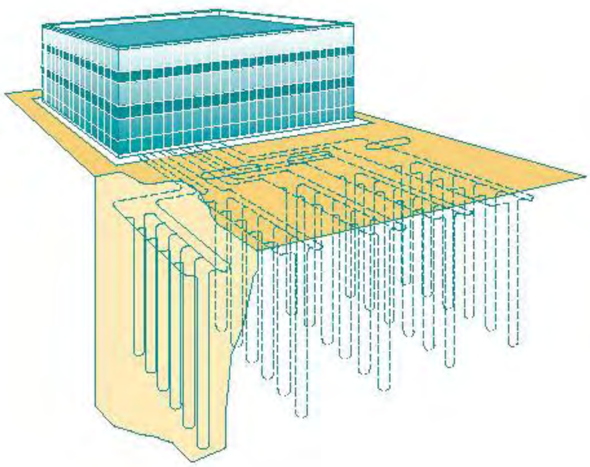


Fig. 5.25: Large System with Vertically installed coils

But there is another possibility of restoring the ground, it is the possibility to utilise excess heat from cooling operation. The need for air conditioning depends not only on the climate, it also depends on the size of the building and the utilisation of a building; an additional point is architecture, glass is modern, and solar gains can become very fast solar loads, which have to be removed by an air conditioning system.

There are three types of climates which require air conditioning, climates with daily average temperatures higher than 24, climates with a humidity higher than 65 %, and climates, which combine both.

But there are additional reasons for air conditioning: If the depth of a building is more than 20 m transverse ventilation becomes difficult do to strong air movement, if the depth is larger besides ventilation internal gains have to be removed, and if a building becomes high in many regions windows cannot be opened due to wind forces. In large commercial buildings high internal loads due to people, lighting, computer equipment etc. occur; these loads have to be removed also. And an improved building envelope moves the border for air conditioning to the north (in the southern hemisphere to the south).

This means that the ground around the coils becomes a store, more or less independent from the surrounding, which is charged during the cooling season discharged during the heating season. And there are different systems to realise such a store:

- Aquifers
- Borehole heat exchangers
- Foundation piles

An aquifer is a formation, group of formations, or part of a formation that contains sufficient saturated, permeable material to yield significant quantities of water to wells and springs. Such aquifers are the basis for ground water heat pump systems. But there are also special aquifers with no or almost no water movement, and such aquifers can be used as a store (Fig 5.26).

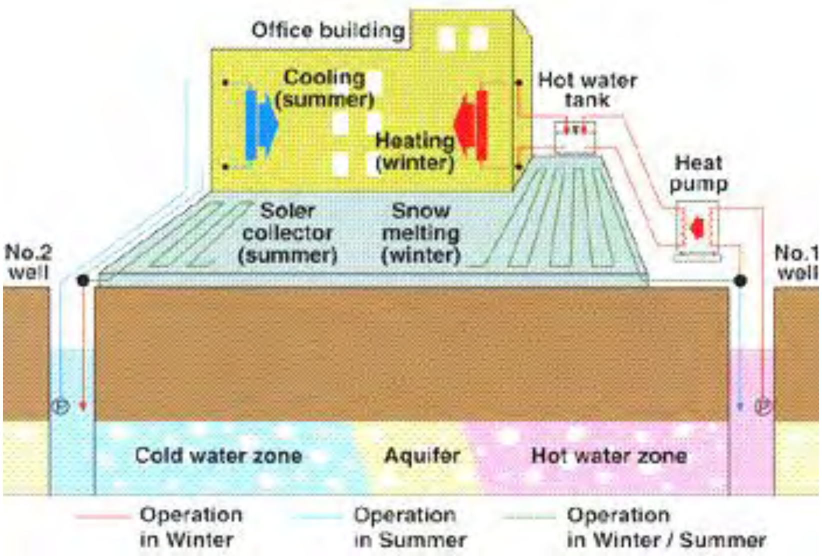


Fig. 5.26: Aquifer Storage System

One of the most famous systems with two aquifer stores, a cold and a hot store, is the Reichstag-Building in Berlin (Fig.5.27)

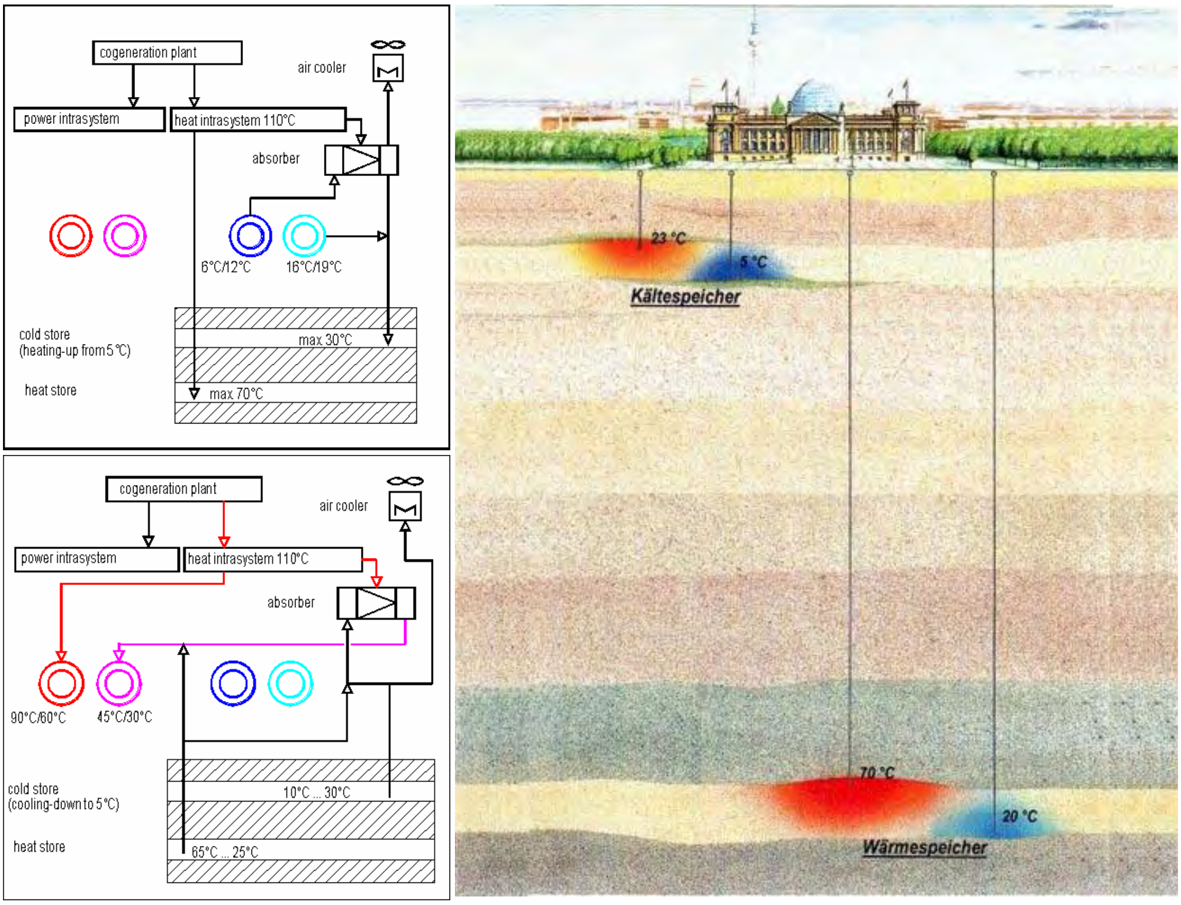


Fig. 5.27:Reichstag Building in Berlin- Heating and Cooling using Aquifer Stores

Another concept are UTES – underground thermal energy storage systems – where a matrix of boreholes is drilled into the ground and equipped with heat exchanger coils (Fig. 5.28). Possibilities are U-tubes, double U-tubes or coaxial tubes.

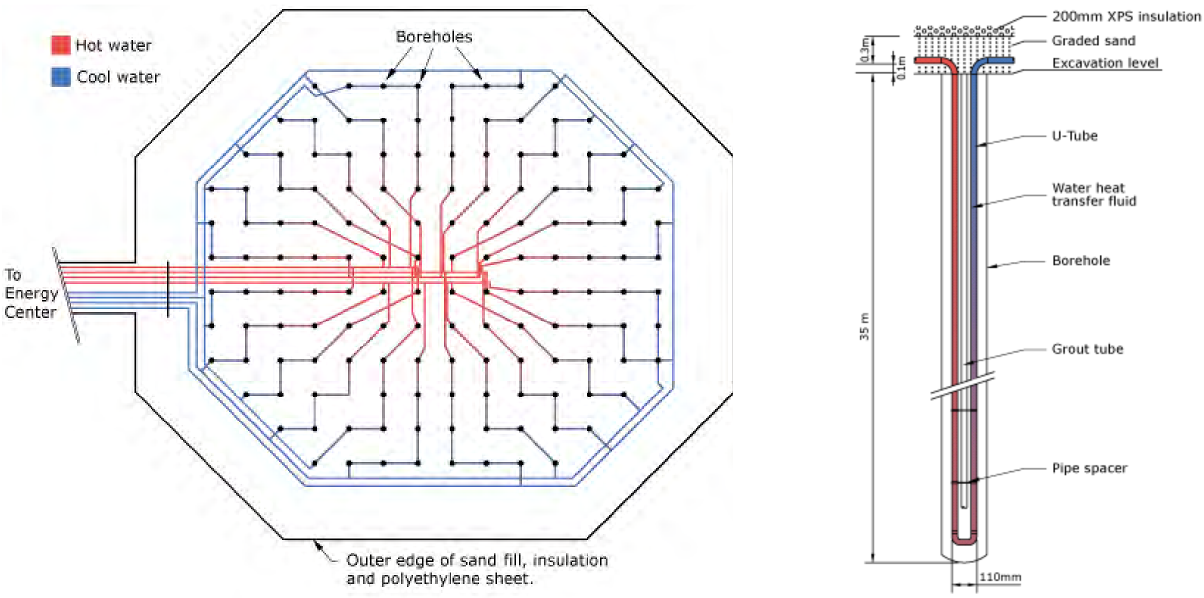


Fig. 5.28: UTES – Underground Thermal Energy Storage

A third concept is using piles necessary for the foundation of a building, equipped with plastic tubes, as heat exchangers. If for the foundation of the building enough piles are necessary – this is very often the case in cities built on alluvial land near a river or lake – this type of energy store is very cost effective (Fig. 5.29, Fig. 5.30).

Fig. 5.29: Foundation piles as underground energy storage

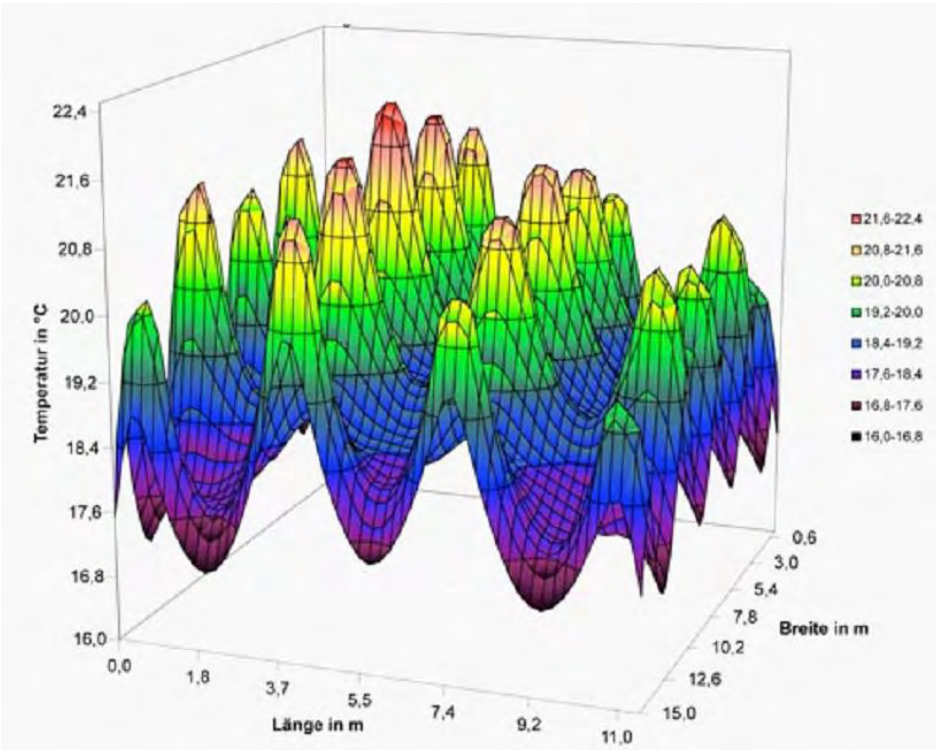


Fig. 5.30: Temperature distribution in the store

Depending on the climate such a store can be used at the beginning of the cooling season

- for direct cooling without chiller operation,
- for cooling the building using the chiller, and
- for heating the building.

Additionally with the chiller the energy of rooms or parts of the building with cooling demand (caused by computer equipment or insolation) can be shifted to rooms with a heating demand (Fig. 5.31).

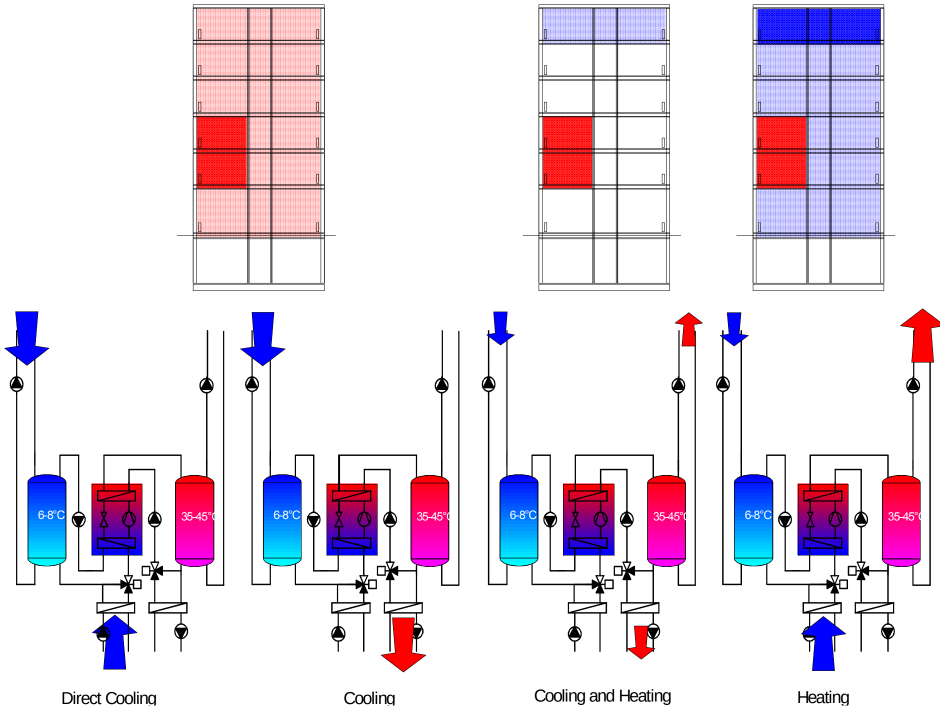


Fig. 5.31: Ground-Source System for Direct Cooling, Cooling, Heating, and Shifting Energy within the Building

The problem of all these systems is that they have to be balanced, i.e. heat delivery to the store and heat extraction from the store have to be approximately the same, otherwise the temperature increases or decreases. So sometimes it is necessary to install an additional system, mainly for removing heat to the environment. Such systems are called hybrid systems (Fig. 5.32).

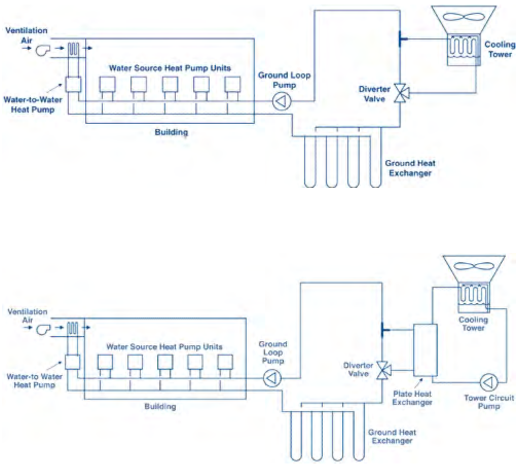
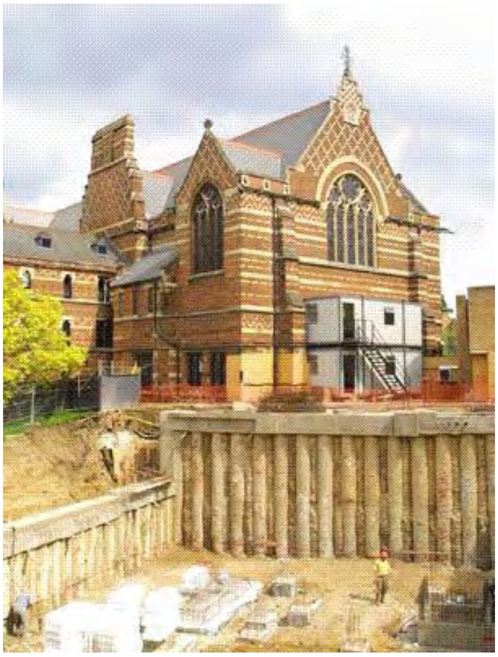
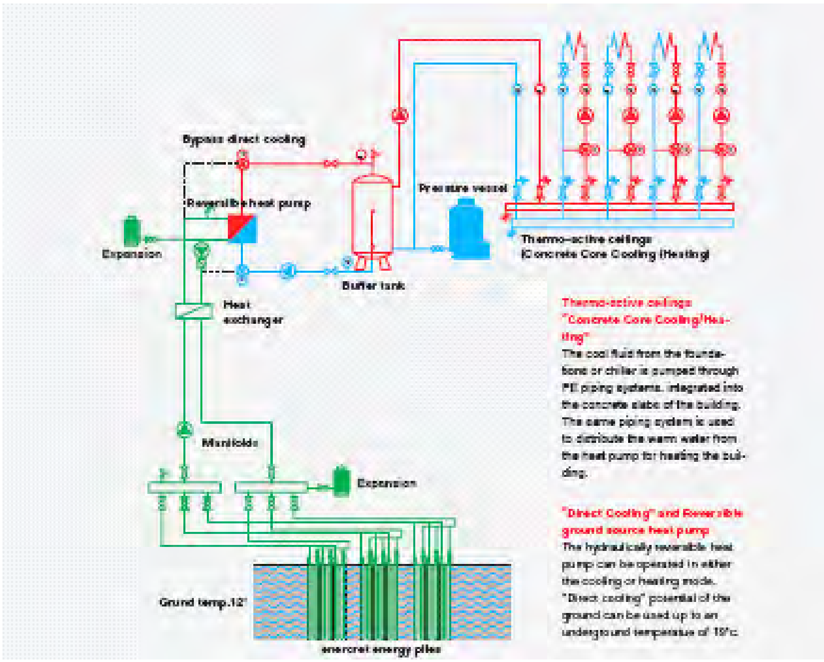


Fig. 5.32: Example of a Hybrid system Ground – Air

But ground source heat pump systems cannot be used only in new buildings, they can be also used in the case ofretrofitting buildings, even historical buildings like the Keble College in Oxford. In this case diaphragm walls equipped with coils are used as heat source/heat sink (Fig. 5.33).





ig. 5.33: Keble College, Oxford

5.7 Drilling Methods

Drilling is the most expensive part of ground source heat pump systems. Therefore, the selection of the optimum and most cost effective method of drilling is extremely important, and developments are going on to reduce this cost bourdon.

In **rotary drilling**, a drill bit is attached to a length of connected drill pipe. The drill bit will be made of tough metals such as tungsten, and as the drill is rotated, the bit acts to grind up the rock. The broken pieces (cuttings) are flushed upward and out of the hole by circulating a drilling fluid (sometime called drilling mud) down through the drill pipe and back to the surface. This drilling fluid also serves to cool and lubricate the drill bit, and by stabilizing the wall of the hole, it can prevent possible cave-in of unstable sands or crumbly rock before the well casing or well screen is installed. As the drill intersects water bearing rock formations water will flow into the hole. Most drillers carefully monitor the depth of water "strikes" and keep a note of the formations in which they occur (Fig. 5.34).

Fig. 5.34: Rotary Drilling

Auger drilling is done with a helical screw which is driven into the ground with rotation; the earth is lifted up the borehole by the blade of the screw. Hollow stem Auger drilling is used for environmental drilling, geotechnical drilling, soil engineering and geochemistry reconnaissance work in exploration for mineral deposits. Solid flight augers/bucket augers are used in construction drilling. In some cases, mine shafts are dug with auger drills. Small augers can be mounted on the back of a utility truck, with large augers used for sinking piles for bridge foundations (Fig. 5.35.

Auger drilling is restricted to generally soft unconsolidated material or weak weathered rock. It is cheap and fast.

In soft ground, diameter 63 - 350 mm, down to 15-20 m (max. 60 m) depth; ramming the ducts with pile driving equipment could also be done in soft ground.

Fig. 5.35: Auger Drilling Equipment

In areas of hard rocks many drillers prefer to use a well drilling technique that uses compressed air to operate a **down-hole air hammer** on the end of the drill string that helps to break up the hard rocks. The compressed air also blows the crushed rock fragments out of the hole to the surface along with any water that flows in the well during drilling. In medium to hard and very hard rock, the Down-Hole Hammer (DTH) is a good tool for high drilling velocity; a *percussing/rotating* hammer is mounted beneath the drill pipes and is operated by compressed air blown through the drill pipe, cuttings are flushed out of the hole by air pressure; diameter is 101-216 mm, depth 100 m and more. For drilling with DTH in hard rocks underlying soft layers, some special tools are on the market (ODEX, Overburden Drilling Equipment, or Tubex, etc.). A new option is a water driven DTH (G-Drill, Wassara),
allowing faster drilling and greater depth.

Air core drilling and related methods use hardened steel or tungsten blades to bore a hole into unconsolidated ground. The drill bit has three blades arranged around the bit head, which cut the unconsolidated ground. The rods are hollow and contain an inner tube which sits inside the hollow outer rod barrel. The drill cuttings are removed by injection of compressed air into the hole via the annular area between the innertube and the drill rod. The cuttings are then blown back to surface up the inner tube where they pass through the sample separating system and are collected if needed. Drilling continues with the addition of rods to the top of the drill string. Air core drilling can occasionally produce small chunks of cored rock.

This method of drilling is used to drill the weathered regolith, as the drill rig and steel or tungsten blades cannot penetrate fresh rock. Where possible, air core drilling is preferred over RAB drilling as it provides a more representative sample. Air core drilling can achieve depths approaching 300 meters in good conditions. As the cuttings are removed inside the rods and are less prone to contamination compared to conventional drilling where the cuttings pass to the surface via outside return between the outside of the drill rob and the walls of the hole. This method is more costly and slower than RAB.

Diamond core drilling (Exploration diamond drilling) utilises an annular diamond-impregnated drill bit attached to the end of hollow drill rods to cut a cylindrical core of solid rock. The diamonds used are fine to microfine industrial grade diamonds. They are set within a matrix of varying hardness, from brass to high-grade steel. Matrix hardness, diamond size and dosing can be varied according to the rock which must be cut. Holes within the bit allow water to be delivered to the cutting face. This provides three essential functions; lubrication, cooling, and removal of drill cuttings from the hole.

Diamond drilling is much slower than reverse circulation (RC) drilling due to the hardness of the ground being drilled. Drilling of 1200 to 1800 metres is common and at these depths, ground is mainly hard rock. Diamond rigs need to drill slowly to lengthen the life of drill bits and rods, which are very expensive.

Core samples are retrieved via the use of a lifter tube, a hollow tube lowered inside the rod string by a winch cable until it stops inside the core barrel. As the core is drilled, the core lifter slides over the core as it is cut. An overshot attached to the end of the winch cable is lowered inside the rod string and locks on to the backend, located on the top end of the lifter tube. The winch is retracted, pulling the lifter tube to the surface. The core does not drop out the inside of the lifter tube when lifted because a "core lifter spring," located at the bottom of the tube allows the core to move inside the tube but not fall out.

Diamond core drill bitsOnce a rod is removed from the hole, the core sample is then removed from the rod and catalogued. The Driller's offsider screws the rod apart using tube clamps, then each part of the rod is taken and the core is shaken out into core trays. The core is washed, measured and broken into smaller pieces using a hammer to make it fit into the sample trays. Once catalogued, the core trays are retrieved by geologists who then analyse the core and determine if the drill site is a good location to expand future mining operations.

Diamond rigs can also be part of a multi-combination rig. Multi-combination rigs are a dual setup rig capable of operating in either a reverse circulation (RC) and diamond drilling role (though not at the same time). This is a common scenario where exploration drilling is being performed in a very isolated location. The rig is first set up to drill as an RC rig and once the desired metres are drilled, the rig is set up for diamond drilling. This way the deeper metres of the hole can be drilled without moving the rig and waiting for a diamond rig to set up on the pad

Direct Push Rigs

Direct push technology includes several types of drilling rigs and drilling equipment which advances a drill string by pushing or hammering without rotating the drill string. While this does not meet the proper definition of drilling, it does achieve the same result - a borehole. Direct push rigs include both cone penetration testing (CPT) rigs and direct push sampling rigs such as a PowerProbe or Geoprobe. Direct push rigs typically are limited to drilling in unconsolidated soil materials and very soft rock.

CPT rigs advance specialized testing equipment (such as electronic cones), and soil samplers using large hydraulic rams. Most CPT rigs are heavily ballasted (20 metric tons is typical) as a counter force against the pushing force of the hydraulic rams which are often rated up to 20kn. Alternatively, small, light CPT rigs and offshore CPT rigs will use anchors such as screwed-in ground anchors to create the reactive force. In ideal conditions, CPT rigs can achieve production rates of up to 250-300 meters per day.

Direct Push Drilling rigs use hydraulic cylinders and a hydraulic hammer in advancing a hollow core sampler to gather soil and groundwater samples. The speed and depth of penetration is largely dependent on the soil type, the size of the sampler, and the weight and power the rig. Direct push techniques are generally limited to shallow soil sample recovery in unconsolidated soil materials. The advantage of direct push technology is that in the right soil type it can produce a large number of high quality samples quickly and cheaply, generally from 50 to 75 meters per day. Rather than hammering, direct push can also be combined with sonic (vibratory) methods to increase drill efficiency.

A new development for ground source heat pump applications is **GeoJetting**, where ater with a pressure of 1000 bar is used for breaking the ground (Fig. 5.35). The method is fast and environmental friendly.

Fig 5.35: GeoJetting Rig and Method

5.8 Thermal Response Test

To design borehole heat exchangers (BHE) for Ground Source Heat Pumps (GSHP) or Underground Thermal Energy Storage (UTES), the knowledge of underground thermal properties is paramount. In particular for larger plants (commercial GSHP or UTES), the thermal conductivity should be measured on site. A useful tool to do so is a thermal response test, carried out on a borehole heat exchanger in a pilot borehole (later to be part of the borehole field). For a thermal response test, basically a defined heat load is injected into the BHE, and the resulting temperature changes of the circulating fluid are measured (Fig. 5.36).

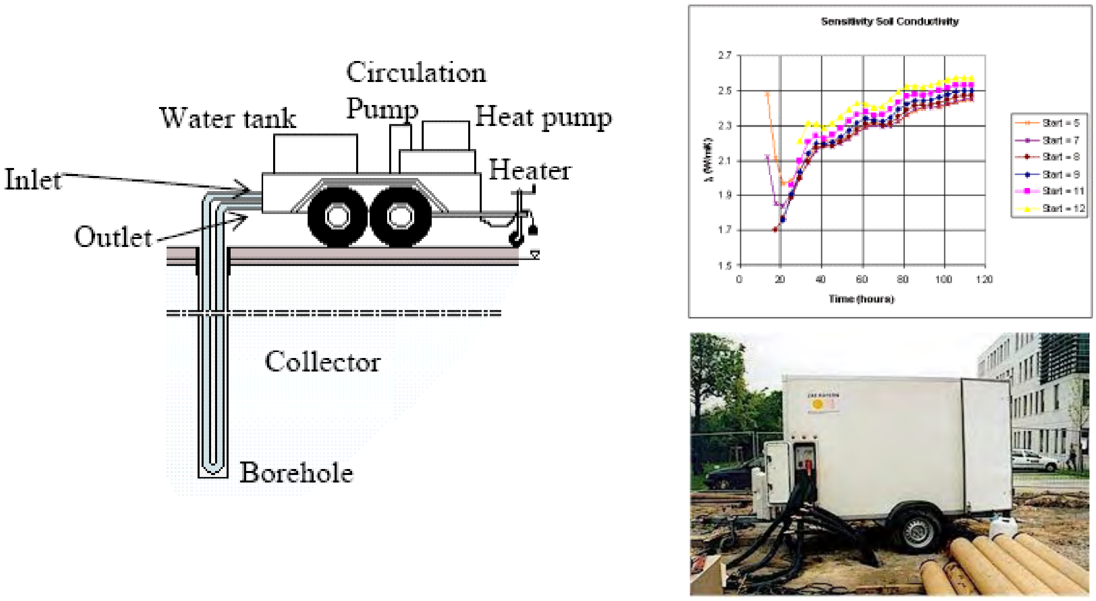


Fig. 5.36: Thermal response test equipment

The problem of the original thermal response test is that it gives only an answer on the average heat conductivity of the borehole, it cannot describe different layers with varying thermal properties along the borehole. This was the reason for improvements, i.e. measurements of the temperatures along the BHE. This method gives a much better overview on the situation along the borehole, and it can lead to the decision to optimise number and depth of the boreholes.

6 OVERCOMING BARRIERS FOR GROUND SOURCE HEAT PUMPS

Looking on ground source heat pump systems, we have the following barriers for a greater market share of this highly efficient technology. The barriers are

- legal barriers, which can be a serious hindrance for installing ground source heat pump systems,
- there is the first cost barrier, which can be overcome by
  - subsidies form the government and other public bodies,
  - tax incentives,
  - subsidies by utilities, and
  - contracting models,
- and there is the lack on awareness of this highly efficient technology and their impact on energy efficiency, utilization of renewable energy and the reduction of cost for heating, cooling and hot water production.

6.1 Legal barriers

Legal barriers in the case of ground source heat pump systems are most commonly connected with heat extraction from and heat removal into the ground, because the ground is also the source of groundwater, which is used as drinking water and has to be protected in the best way. Other legal barriers are the refrigerants used in the heat pump: the HFCs (hydrofluorocarbons) presently in use have a high global warming potential, propane and ammonia are flammable and/or toxic, CO_2 has not the best properties to be used in hydronic heat distribution systems.

Sources of polluting the ground water is drilling itself as well as leakages from ground coils. In the case of secondary loop systems that are leakages of brines with different additives protecting corrosion of the cycle, in the case of direct exchange systems leakages of refrigerants and oil for lubrication of the compressor.

Another source for polluting ground water is the drilling operation itself, and water authorities are not fully sure what is more dangerous leakages or drilling.

Measures against these barriers are

- working fluids without any toxic component like water and CO_2,
- certified heat pump installers and maintenance personnel,
- refrigerants without GWP,
- monitoring of systems to demonstrate leak tightness,
- use of endless pipes protected against corrosion in the ground,
- certified drilling companies.

6.2 First cost barrier

The main barrier for installing ground source heat pumps is most commonly the first cost barrier, and this first cost barrier is most commonly caused by the drilling cost.

Another first cost barrier can occur when other technologies like solar thermal or biomass are subsidized more than heat pumps. Customers will tend to take the technology with the lower investment not considering the final operation cost.

6.2.1 Energy Performance of Buildings Directive

A great help to increase the share of energy efficient and renewable energy technologies in buildings is the European Union Directive on the Energy Performance of Buildings. The Directive on the Energy Performance of Buildings (EPBD), which came into force in January 2003, intends to increase awareness of energy usage in buildings. It also aims at obtaining a substantial increase in investments in energy efficiency measures. Applying more stringent standards to new buildings and to renovations can help the EU reduce greenhouse gas emissions and realize an energy saving potential of over 20 percent by 2020.

Additionally the European Union has decided to

- reduce energy consumption,
- increase the share of renewables, and
- increase the efficiency by 20 % until 2020.

One of the problems in the past was that heat pumps have not been recognized as renewables, and until now there are problems with air source heat pumps, only "geothermal" heat pumps are fully accepted as renewables. In the IEA the share of renewable energy utilized by heat pumps is not yet considered in the statistics.

The problem is that the drive energy of heat pumps is usually electricity and that the electricity generation mix in Europe is not the best, about 400 g CO_2/kWh. However, some countries are much better.

People expect highly efficient products in the end-use sector, but they do not recognize that electricity generation will be also improved significantly in the future. The also do not recognize that the best use of biomass is not burning it to produce low-temperature heat but using it for electricity generation and produce low-temperature heat by means of heat pumps: that are savings of 50 % and more.

6.2.2 Renewable Energy Sources for Heating An Cooling

This project has analysed public policies supporting renewable heating and cooling (RES-H), It has identified best practice and it has developed concrete guidelines applicable at local, regional, national and European level.

The project had a cross-sectoral nature, as it has analysed a number of key issues, first it has looked in parallel at the different RES-H technologies: solar thermal, biomass and geothermal, and then it has integrated the results for policy guidelines applicable to RES-H in general.

Renewable energy technologies help

- decreasing import dependency,
- diversifying sources of production, and
- contribute to a sustainable development.

For the promotion of Renewable Energy for Heating and Cooling a current support framework has been established for RES-H consisting of

- Market Incentive Programme
- Two support elements:
    - Investment grants for smaller applications (e.g. solar collectors)
    - Soft loans with low interest rates for larger applications
- Extra payments for RES-H installations in efficient buildings

Fir achieving of RES-H targets measures are

- Setting incentives for
    - supporting technology diversification
    - structural changes in the heating market (DH grids!)
    - RES-H penetration in the building stock
- Securing stable and reliable support conditions in order to avoid stop-an-go development support should
    - either be independent from public budgets
    - or politically "stabilised"
- Minimising transaction costs and risk of windfall profits

The two options are

Option 1: Installation Obligation with Compensation Charge (1)

- Building owners are obliged to guarantee that a minimum share of their annual heat demand is supplied by RES (e.g. 15 % for new buildings, 10% for existing buildings)
- The obligation becomes effective when the boiler is replaced (incl. the building stock!
- Those who are not willing or are not in a position to fulfill the installation obligation have to pay a legally fixed compensation charge (which is also used to support RES-H appliances)

Option 2: Bonus Model (1)

- The bonus model concept involves major elements of a classic feed-in scheme (well known from the RES-E sector)
- RES-H operators are entitled to receive a legally fixed bonus payment per kWh of heat produced and used
- Bonus level can easily be adapted and periodically adjusted to the specific needs of the different RES-H technologies (e.g. special incentives for the implementation of grid based heating systems
- Key design element: Organisation of the relationship between the beneficiaries and the obliged parties (e.g. Which party to oblige?, Aggregation of bonus claims)

Using these options in a correct way could help ground source heat pumps a lot.

6.2.3 Governmental Subsidy Programmes

Governments have already some different possibility to subsidise energy efficient and renewable energies by tax models.

- Tax allowance
  A certain percentage of expenses for RES reduces the taxable income
- Tax reduction
  A certain percentage of expenses for RES reduces taxes
- Tax credit
  A certain percentage of expenses for RES reduces taxes. In the case of low incomes a payout (negative taxes) is possible.

In the near future the European countries have to fulfil the requests of the RES-H.

6.3 Contracting Models

The concept of energy contracting comprises different forms of energy services with main emphasis being energy supply by use of energy saving procedures and efficient technologies. With this focus given energy contracting can generally be described as an eco-efficient service, since the realisation of energy saving potentials also implies the saving of resources by using less primary energy sources and a decrease in emissions.

Innovative highly efficient technologies and an intelligent energy management allow a significant reduction of energy cost. The technologies required to achieve these goals are usually expensive an require a lot of know-how. To avoid high investment costs contracting can be utilised. Contracting is both an energy service and a financial service, which can be provided by contracting companies and also by utilities, which is in a liberalised market very interesting.

In context with ground source heat pumps the following types of contracting are possible:

- Loop Leasing: The contractor/utility owns the loop and leases it back to end-user for a flat monthly fee, based on energy extraction and/or energy removal to the loop.

- Chauffage: The contractor/utility owns the whole system consisting of the loop and the air conditioning and hot water production equipment, he is responsible for providing heat and cold as well as hot tap water, and he is also responsible for maintenance work. The end-user gets conditioned space and hot water at a flat monthly fee.

- Integrated Community Systems: The well or the loop field is owned and maintained by developer or by the home owners association, home owner pays a flat monthly fee.

- Loop Guarantee: Contractor guarantees for the loop performance. Normal drilling companies do not guarantee for the performance of the well or the loop.

- Performance Contracting: Contractor or Energy Services Company installs the system, guarantees system performance, leases it back to customer; payment comes out of the guaranteed savings

In Europe the share of ground source heat pump systems introduced on the market by contractors is increasing. This is an excellent way to overcome the first cost problem.

In order to increase the transparency of contracting and to reduce the confusion around this complex concept, information campaigns, standardisation and the creation of a simplified framework could be helpful. Information, consulting, and support can be offered by public institutions or private institutions supported by the government. As far as the private sector is concerned this role can be played by associations.

When looking at the effects on the whole economy, many positive features and potentials are usually attributed to energy contracting. This is normally justified by the fact that this sector is promoting the development of efficient technologies and their competitiveness on the market.

Moreover, these domestic tendencies are good conditions for the development of new export markets, which will gain in importance abroad as well due to climate goals and the increasing scarcity of resources. A more efficient use of primary energy sources prolongs the remaining exploitation period and therefore offers more time for a technological and energy-political change for example towards less dependence on energy imports. Finally environmental pollution will be reduced, so that the external costs which are a burden for the economy concerned as well as neighbour economies and not for the businesses causing them, will become less.

6.4 Lack of awareness

A problem of ground source heat pumps is the lack of awareness of this highly efficient technology, and this lack of awareness covers all groups between policy makers and end-users.

The best known renewable technologies, CO_2 free or at least CO_2 neutral, in the end-use sector are solar thermal, photovoltaic power systems and biomass as well as biofuels. A heat pump requires most commonly electricity as drive energy, and for policy makers, decision makers, architects, planners and the majority of the end-users this electricity comes from coal-fired power plants or from nuclear power plants, and many people do not like these types of electricity generation. That we also have electricity from renewable energy sources like hydro, wind, biomass and solar is more or less neglected, and that the electricity production energy mix has to be and will be improved significantly in the next future is still ignored.

When electric utilities have been owned by governments of countries and states, there reputation was not the best, and even after the liberalization and privatization of the market this situation has not really changed. The influence of the biomass people – agriculture – and of the solar people on politicians and decision makers is much higher than the influence of heat pump manufacturers – utilities take no influence on politicians and decision makers in context with heat pumps, in contrast, very often electric utilities are also suppliers of natural gas and district heat.

To create a successful market requires time and one has to get the acceptance of the end-user. In regions where in the past a successful marketing took place it is presently easy to sell heat pumps; in new market it is a hard job.

It is necessary to inform people on heat pumping technologies, and this information has to start in the primary school. It is nice to learn there about history and literature, but it is also necessary to inform the children on technologies they use every day like lighting, cooking and heating, and a refrigerator, and where the energy comes to operate such devices. Politicians who are proud that they have no understanding on energy technologies should not talk and decide in such technologies !

Policy Makers, Decision Makers, Planners, Architects, the Research Community, Installers and end-users should be informed how such systems work and what we can achieve utilizing them.

Planners, Architects and Installers have to be informed, and one has to consider that these people are most commonly not paid for thinking about innovative solutions, they are poorly paid for reliable solutions, and such solutions are usually old and they do not even cover the state of the art.

For Installers, Drilling Companies and Excavation Companies training and certification programmes have to be initiated, in some countries they already exist.

For the end-user, the customer, information and communication with end-users should be provided to demonstrated the reliability as well as the cost effectiveness of advanced systems like ground source heat pumps.

7 Conclusion

Heat pumps are an old technology, which has not been extensively used as long as both energy prices and the efficiency of electricity generation have been low. The oil crises have changed this situation, and now Kyoto is a further reason for the increasing market deployment of this technology. Based on recent developments, the following conclusions can be drawn:

- Heat pumps offer the possibility of reducing energy consumption significantly, mainly in the building sector, but also in industry. Basic second law thermodynamics show the advantages: while a condensing boiler can reach a primary energy ratio (PER) of 105 % (the theoretical maximum would be 110 % based on the lower calorific value), heat pumps achieve 200 % and more, with hydro or wind energy even 400 % and more.

- The drive energy is most commonly electricity, and for the future improved power generation systems based on renewables and fossil fuels have to be taken into consideration. The efficiency of gas-fired combined-cycle power plants available on the market is presently about 58 %, with oil as fuel similar values are possible. Ground-source (“geothermal”) heat pumps combined with low-temperature heat distribution systems achieve seasonal performance factors (SPFs) of 4 and higher, which means PERs of 220 to 280 %.

- Heat pumping technologies, i.e. refrigeration, air conditioning and heat pumps, have undergone and are undergoing several changes in working fluids and design. However, the efficiency today is generally better than before these changes and keeps rising. Thus, not only the environmental effects of the working fluids are being reduced, but also the effects of power plants producing the drive energy for the heat pumps – due to higher SPFs, higher power plant efficiencies, and an energy sources mix with lower CO_2 emissions. Therefore, the TEWI (Total Equivalent Warming Impact) is reduced significantly. Phasing out HFCs is not so much a problem of technology, it is a problem of efficiency. Applications will remain where "safety" refrigerants, i.e. non-toxic and non-flammable fluids, have to be used also in the future. But the natural refrigerants such as ammonia, propane, CO_2 and some others will get an increasing share. The question of environmental acceptability seems to be solved. The main point, however, is efficiency, and the energy requirement has to be minimized.

- Ground-coupled heat pumps gain importance world-wide with respect to energy efficiency in heating and cooling operation. The ground acting as a storage offers the possibility of damping the effects of the outside air temperature fluctuations, in colder climates it enables monovalent heating operation of the heat pump, and for utilities it is a tool for demand side management measures. New developments like improved heat pump units, advanced direct-expansion heat pumps or heat pumps combined with heat pipe based vertical probes show that there is still room for new ideas, which may be necessary for being competitive and successful in the future.

- Direct-expansion ground-source heat pumps already achieve SPFs between 4 and 5, if the building standards are being kept and the design of the overall system has been made carefully. Such high SPFs are the work of highly skilled system constructors; they do not sell heat pump units, they sell systems. The choice of the refrigerants they use, i.e. presently R-410A, propane and CO_2 for heat pipes, is motivated by efficiency, reliability, environmental considerations, safety and regulations. Direct-expansion systems, either with horizontally installed collectors or with bore holes down to 60 m, show increasing sales figures, and they dominate the Austrian market. But one has also to consider the building stock, and retrofitting this building stock will become the heat pump market of the future. New developments like improved heat pump units, advanced direct-expansion heat pumps or heat pumps combined with heat pipe based vertical probes show that there is still room for new ideas, which may be necessary for being competitive and successful in the future.

- The choice of an air conditioning systems for a commercial building depends on the climatic conditions, on the building and on the utilisation of the building. In the meantime the design of the building became the main factor concerning energy consumption. The air conditioning system has the task to compensate external and internal loads and to provide hygienic conditions and year round comfort for the customers. Additionally the air conditioning system offers possibilities to carry out this task with a minimum amount on energy by shifting heat from spaces, which have to be cooled to spaces, which have to be heated at the same time. Using the ground as a store additionally heat and cold can be stored to a certain extent and used for providing cold without additional energy input, i.e. for direct cooling, and for increasing the heat source temperature for heating. Using low-ex systems these effects can be further increased.

- Sorption systems - absorption, adsorption and DEC systems - also gain importance. The efficiency of sorption units has been improved significantly by introducing welded flat plate heat exchangers for reducing heat transfer losses.
- With highly efficient systems the advantages of thermodynamic heating and cooling can be demonstrated and used for reducing the energy demand significantly.

The potential for reducing CO_2 emissions assuming a 30 % share of heat pumps in the building sector using technology presently available is about 6 % of the total world-wide CO_2 emission. With advanced future technologies in power generation, in heat pumps and in integrated control strategies up to 16 % seem to be possible. Therefore, heat pumps are one of the key technologies for energy conservation and reducing CO_2 emissions.

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Report no. HPP-AN29-1