COUNTRY RESEARCH REPORT GERMANY

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Abstract: Outgoing from the energetic and environmental requirements for future refrigeration and heat pump systems the Country Report for Germany describes various research projects in this field. Mainly, the projects are sponsored by the German Ministery of Economy and Technology (BMWi) and coordinated by PTJ Jülich dealing with adsorption and compression heat pump systems. Also the German Federal Foundation Environment (DBU), Osnabrück sponsores further projects in this field. Especially, the research in this field is performed on the one hand by the Fraunhofer-ISE, Freiburg on adsorption systems together with the SorTech AG, Halle/Saale and on the other hand by the Viessmann Company, Allendorf. Concerning compression systems research projects are under way also at the Fraunhofer-ISE in Freiburg, the Viessmann Company in Allendorf together with the Copeland Company in Berlin and the FKW Research Institute in Hanover, as well as at the Stiebel-Eltron Company in Holzminden and at the Technical University in Braunschweig.

The sorption heat pump research concerns in both cases adsorption systems whereas the compression research is directed towards field tests for seasonal performance measurements, development of CO_2 heat pumps for space heating and water heating, as well as concerning CO_2 heat pipes as earth probes.

Key words: ***adsorption heat pump, compression heat pump, heat pump efficiency, field tests in Germany, CO_2 heat pump for retrofit market. CO_2 scroll compressor, CO_2 heat pipe***

1 INTRODUCTION

The environmental issues of Ozone Depletion covered by the Montreal Protocol 1987 and Greenhouse Gas Emissions as dealt with in the Kyoto Protocol 1997 have led to a big change in all refrigeration and heat pump applications because the mainly used CFC- and HCFC- refrigerants contributed remarkably to ozone depleting and also like HFC refrigerants to global warming.
Since the old CFCs and HCFCs and the new HFCs all have a remarkable Global Warming Potential an important task for the future is to reduce leakages and tighten refrigerant systems and heat pumps.
Another solution of the problem could be to use natural fluids as refrigerants with negligible Global Warming Potential (GWP) like the old refrigerants ammonia, hydrocarbons or carbon dioxide.
Between these fluids ammonia has a zero Global Warming Potential due to its short lifetime in the atmosphere whereas hydrocarbons and carbon dioxide have a small but negligible Global Warming Potential.
Since refrigeration systems need energy supply they cause carbon dioxide emissions from fossil fuel power generation and therefore they also contribute indirectly to the greenhouse effect.
The sum of both effects per system, the direct from refrigerant emissions and the indirect caused by the energy to drive the refrigeration system is called Total Equivalent Warming

Impact TEWI. The relationship between the direct and the indirect greenhouse effect is different for various applications of refrigeration systems and heat pumps as shown in Figure 1 (DOE 1991).

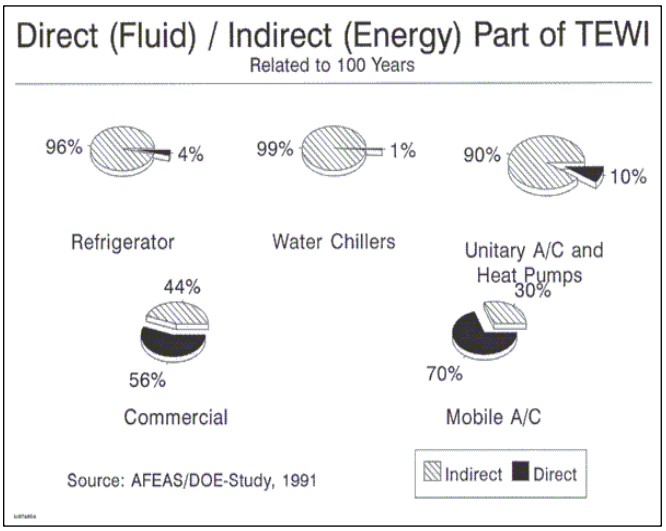


Figure 1: Direct and indirect TEWI effect for various applications

As can be seen in Figure 1 the medium size unitary equipment of Air conditioning and Heat Pumps in 1991 still showed a remarkable part of 70% direct emissions and, considering the whole refrigerant consumption at that time this application was the second one according to Figure 2 because of the large numbers of those systems in field world wide.

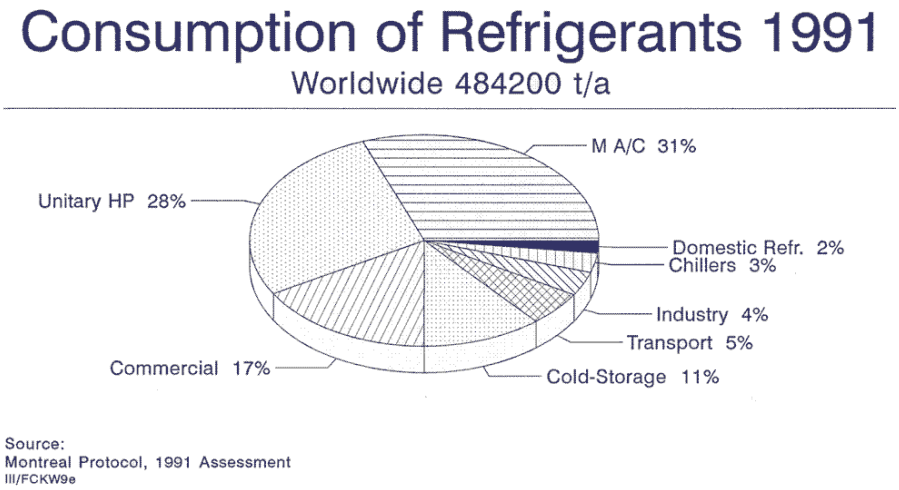


Figure 2: Worldwide Consumption 1991 of fluorinated Refrigerants

When considering this TEWI evaluation of refrigeration systems and heat pumps the question is if hereby the goal of real sustainability for the future will be approached.
The United Nations Conference on Environment and Development 1992 in Rio de Janeiro, well known as “Earth Summit“ or ”Rio Conference” based on the 1972 report of the Club of Rome “Limits to Growth” and the Brundland-Report “Environment and Development” established in its “Agenda 21” and the “Climate Convention” the request for a sustainable development, namely a stabilisation of the greenhouse gas concentration on a level to ensure a natural adaptation of the ecosystems to the climate change without endangering the food production and with an economic development in a sustainable manner”.
Sustainable Development therefore means a permanent improvement of the quality of life of mankind within the possibilities of the natural environment.

Although 1992 at the Rio Conference the Montreal Protocol had already been signed 5 years ago and the Kyoto Protocol has been signed 5 years later the principle of a" Sustainability" should be applied when applying energy consuming refrigeration and heat pump technologies with synthetic or natural fluids as refrigerant and at different running and investment costs. Therefore, the principle of "Eco-Efficiency" should be addressed when evaluating different refrigerating systems concerning their sustainability

2 CURRENT PUBLIC SPONSORED RESEARCH PROJECTS ON HEAT PUMPS IN GERMANY

2.1 The German Ministery of Economy and Techology (BMWi) with its **Project leader PTJ Jülich** is responsible for the Federal Heat Pump Research Projects currently performed by various research organisations and companies in the field of sorption and compression heat pumps.

2.1.1 Adsorption Heat Pumps

The Fraunhofer ISE-Institut in Freiburg together with the company SorTech AG in Halle/Saale works jointly on a project concerning adsorption heat pumps with the working pair water/zeolite.
Further on Viessmann, Allendorf also works on the development of an innovative gas driven zeolite heating system.

2.1.2 Compression Heat Pumps

The other systems guided by the Projektträger Jülich for the Ministery of Economy concern the compression heat pumps in various projects, namely at the
Fraunhofer Institute of Solar Energy in Freiburg concerning the heat pump efficiency by field tests regarding the seasonal energy performance, further on by
Stiebel Eltron GmbH, Holzminden concerning a CO_2 refrigerant cycle with ejector for heat pumps for heating buildings, and by
Viessmann, Allendorf, concerning the development of a heat pump for the retrofit market with high efficiency on the basis of natural refrigerants.
The FKW Research Centre for Refrigeration and Heat Pumps, Hannover works on a special pump less not groundwater affecting heat pipe with carbon dioxide as earth probe for heat pumps.

2.2 The German Federal Foundation Environment (DBU), Osnabrück

The DBU also sponsors heat pump research whereby a project on small heat pumps for low-energy-houses at the Technical University Braunschweig can be mentioned.
The description of the individual projects shall be made in the following chapter according to the various systems, namely sorption systems, compression systems and earth probe systems.
Hereby always the before mentioned guidelines should be taken into consideration concerning the TEWI effect, the Eco-Efficiency, the energy supply for operating the systems renewable or exhaustive energy and their reliability every time and general availability in the future.

3 DESCRIPTION OF THE RESEARCH PROJECTS

3.1 Adsorption systems

3.1.1 a) SorTech AG, Halle/Saale

Project No. 0327423A:"Development of Heat Pump and Refrigeration Systems based on crystallized Adsorber"

3.1.1 b) Fraunhofer-ISE, Freiburg

Project No.0327423B: “Evaporator and Heat Pipes”
This joint research project is divided into two parts, whereby the company SorTech AG in Halle works on the heat pump and refrigeration system development based on crystallised zeolite absorber and the Fraunhofer Society in its Institute for Solar Energy in Freiburg works especially on the subsystem evaporator and heat pipes.
The public sponsored project concerns the optimization and improvement of evaporators with the refrigerant water at low pressures of 7 mbar to 23 mbar in a temperature range of +5°C to 20°C. The advantages of water are the environmental benign and non toxic behavior, as well as a high specific refrigeration capacity with disadvantages of low density, operation at vacuum conditions and possibility of ice formation.
The fundamental investigations concern different surface structures and geometries in relation to the boiling characteristic of water in order to gain lower temperature differences for bubble boiling behavior.
Also the application of heat pipes will be studied regarding the optimum design for the application and realization at evaporators.
This project is part of Annex 34 of the IEA Heat Pump Programme which contains the market analysis, the standardization of the energetic evaluation of thermal heat pump systems as well as the overiew about system technologies and components.

3.1.2 Viessmann, Allendorf

Project No. 0327435A: “Development of an Innovative gas driven Zeolite Heating System”

3.2 Compression Systems

3.2.1 Fraunhofer Gesellschaft, Institute for Solar Energy (ISE)

(Project No. 0327401A) Heat Pump Efficiency, Field Tests Two large Field Test in Germany
Under the direction of the ISE two large field tests on newly installed heat pumps have been launched in 2006, namely two metering projects of a large number of heat pumps in field under real operating conditions in one-family or multi-family houses in Germany according to Figure 3:



Figure 3: Distribution of Monitored Heat Pumps in Germany

The topics in both projects are:
The heat pump efficiency of heat pumps with small heating capacity of 5 kW to 10 kW with outdoor air or earth heat sources. 75 heat pumps of 7 manufacturers are being monitored. In spring and summer 2008 another 35 units will be installed. The aim of the project is the assessment of the efficiencies under varying operating conditions and different system configurations.
In addition the refrigerant leakages will be monitored at some units over a period of 4 years.
The project is part of the Annex 32 of the IEA Heat Pump Programme and is co-financed by 7 heat pump manufacturers and the electric utilities EnBW Energie Baden-Württemberg and E.ON Energie AG together with the German Federal Ministry of Economy and Technology (BMWi) and guided by its Project Leader Jülich (PTJ).
A directly by E.ON sponsored project concerns the " Replacement of Central Oil Boilers with Heat Pumps" whereby 75 heat pumps particularly suitable for un-refurbished existing buildings are monitored with emphasis on the comparison of both systems regarding the financial feasibility and the greenhouse gas emissions.

3.2.2 Viessmann, Allendorf

Project No. 0327367A: "Development of a CO_2 Heat Pump for the Retrofit Market".
The aim of the research project concerns a development of an electrically driven heat pump with the refrigerant carbon dioxide for he retrofit market in order to fulfill the requirements of the existing one- and two-familiy-homes. The segment of the retrofit market for heat pumps is covered up to now only occasionally. The problem when substituting old burner heating systems by heat pumps are the hydronic water supply temperatures of 70 to 90 ^{o}C as compared to the low temperatures for new buildings.
Another motivation of this research project is the possibility to change to the environmentally friendly refrigerant CO_2.
The heat pump design was made for a normal heating capacity of around 20 kW in mono-energetically conception. A seasonal energy performance factor over the year of at minimum 3.0 should be achieved.
The heat pump for heating and hot water production (90 % heating, 10 % hot water supply) will be realized by a refrigerant cycle with economizer and intermediate vapour injection into the scroll compressor. The bivalence point is at -7 ^{o}C with a heating capacity of 13 kW. The additional direct electrical heating energy below this point amouts up to 5 %.
As calculated, in this project a CO_2-scroll compressor will be developed for the mentioned capacities and for high temperatures on the high pressure side whereby a high compressor efficiency is required, as well capacity modulation as low production costs and long life time.
The project is part of the international IEA Annex 30 of the International Energy Agency Heat Pump Programme which is guided by the IZW Information Centre Heat Pumps and Refrigeration e.V. Hannover.
The Viessmann Company, Allendorf is responsible for the whole research project with subcontracts to the Copeland Corporation, Berlin for the CO_2 scroll compressor and to FKW, Hannover for evaluating the subsystems gas cooler and evaporator as well as the final whole heat pump system under various environmental conditions in a calorimetric chamber. The heat pump is an air to water heat pump with water supply temperatures up to 70 ^{o}C whereby the heat pump works partly in a subcritical manner.
The theoretical preliminary evaluation of such a cycle was made at FKW, Hannover by a subcontract of Viessmann in order to show if at high water supply temperatures to hydronic systems the same seasonal energy performance can be reached by the heat pump as with the most efficient condensing gas burners. This can be achieved at an isentropic compressor efficiency of 65 % which is the goal of the compressor development at Copeland Corporation.
The evaluation of the component measurements have shown the possibility of optimisation of the evaporator under the influence of humiditiy leading to remarkable lower air volume flow.

As gas cooler three different designs were tested, namely a plate heat exchanger, a coaxial heat exchanger and a shell and tube heat exchanger whereby the best results were gained with the coaxial heat exchanger which will be used for further heat pump design.

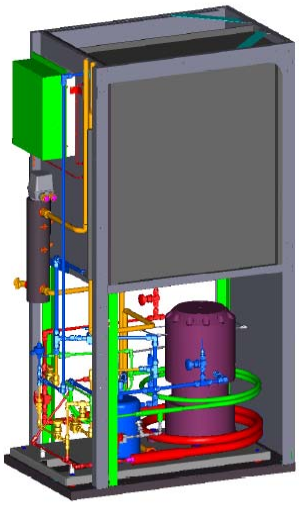


Figure 4: Design of CO_2 Heat Pump

The prototype of the second generation CO_2 scroll compressor has achieved an isentropic efficiency of more than 65 % already so that the seasonal energy performance of condensing gas boilers can be reached at high temperatures whereby still the high pressure control at supercritical gas cooling shall be developed further on to achieve an optimization of the efficiency. In order to reach high seasonal performance factor of more than 3 it is necessary also to run the heat pump in subcritical conditions over a part of the heating season where the outside air temperatures in Germany are sufficiently moderate.

The design of the heat pump is shown in the next Figure 4 and is done that way that standard housings of the HFC heat pumps of Viessmann can be used.

Copeland CO_2 scroll compressor for transcritical carbondioxide heat pumps.

The higher pressures for transcritical operation imply remarkable higher forces on bearings and scroll elements whereby Figure 5 shows how different the scroll elements look when designing a compressor for supercritical or subcritical CO_2 running conditions, respectively. In order to resist the bending of the scroll elements large wall thicknesses are necessary. Only by this way of design the leakages at the axial sealing gaps can be kept to a reasonable amount for a high efficiency.



Figure 5: Super- and Subcritical Scroll Elements

Concerning the scroll element a flat design as been chosen which leads to a rather high radial extension and hence a large diameter.

Figure 6 shows the cross section of the CO_2 heat pump compressor.

As far as the housing is concerned the solution at the very high pressure discharge gas is to lead the discharge line directly from the scroll exit to the discharge valve outside of the compressor. Therefore, the design of the compressor head which at subcritical compressors contain the discharge gas, does not need to be designed for the highest discharge pressure here, according to Figure 6.

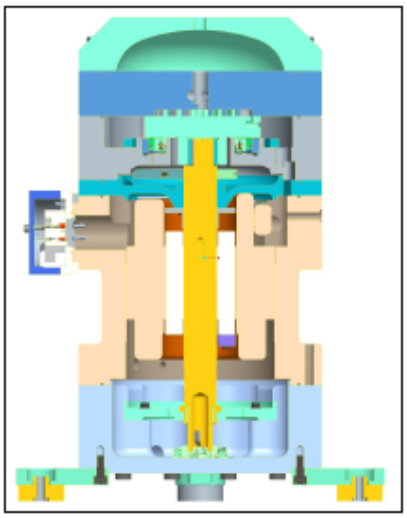


Figure 6: CO_2 Scroll Compressor

3.2.3. Stiebel-Eltron, Holzminden

Project No. 0327393A: " CO_2-Refrigerant Cycle with Ejector for Heating Heat Pumps".

3.2.4. Technical University Braunschweig

DBU Project: "CO_2-Heat Pump for Low Energy House".

3.2.5 FKW Research Centre for Refrigeration and Heat Pumps, Hannover

Project No.0327424 "CO2 Heat Pipe of High Efficiency".
FKW has performed R&D work since 1998 on a CO_2 earth heat pipe system with patent application on December 24, 1998 (No. DE 19860328.2-15).
Initial results of this R&D work have been published at the 8th IEA Heat Pump Conference 2005 in Las Vegas, USA , (Kruse 2005).
That work as described there led to the development of a special CO_2 earth heat pipe with corrugated flexible stainless steel pipes (Figure 7).



Figure 7: Corrugated stainless steel pipe

Corrugated stainless steel pipes of this type, (Figure 7), are produced by the Brugg Pipe Systems GmbH, the German subsidiary of the Swiss Brugg AG Holding, for various applications like flexible and rigid pipe systems for district and local heating industry, filling stations and system packages.

The whole R&D work led up to now to the development of the "Brugg-FKW-CO_2 Earth Heat Pipe," covered by the German Patent No. DE 10327602.

Theoretical comparisons of the annual Seasonal Performance Factors (SPF) of earth coupled heat pumps have been performed theoretically by A. Peterlunger and Professor Ehrbar [2] from the Buchs Technical Institute based on some otherwise measured results in a project of the Swiss Federal Office of Energy according to Figure 8 [2].

Figure 8 shows the results for CO_2 heat pipe systems, the ground water systems and brine systems in various configurations. The study predicted the optimized CO_2 system to be the best compared to the ground water and brine systems, whereby the latter one running with pure water is very close in the SPF to the CO_2 system but needs much longer earth probes.

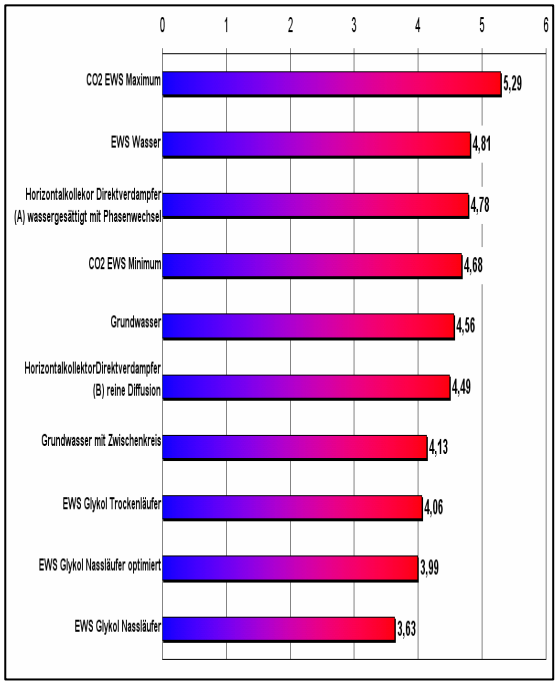


Figure 8: SPF of Earth Coupled Heat Pumps

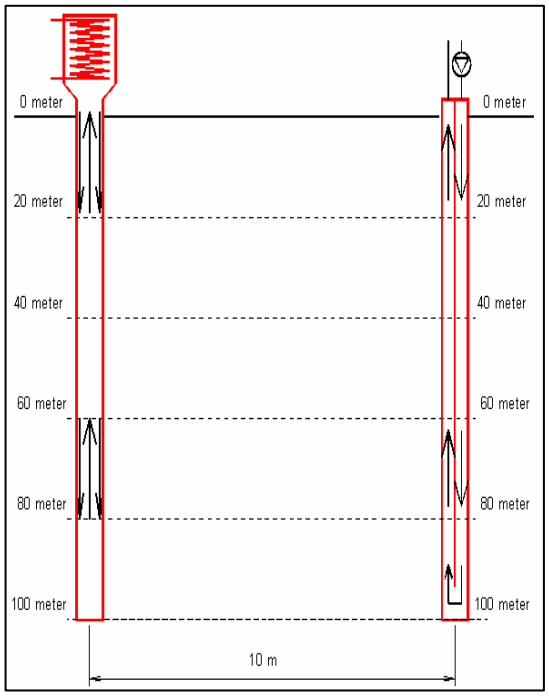


Figure 9: Tests with CO_2 versus Brine

After the end of the R&D work in 2004 which had been sponsored by the DBU (German Federal Foundation Environment) to FKW and its Partners Aetna Wildau and Kaeltro Berlin, and as presented at the IEA Heat Pump Conference in Las Vegas, field tests have been performed with 100 m long corrugated heat pipes in order to investigate the feasibility of handling and inserting them into the earth and to measure the performance together with a conventional brine earth probe for comparison (Figure 9). Various tests with the CO_2 heat pipe were performed in May and June 2005 and March 2006 by Kaeltro in Berlin according to Table 1.

Table 1: Results of measurements

Period	Brine Inlet Temp [°C]	Evaporating Temp. t_o R407C [°C]* at dew line	Condensing Temp. t_c R407C [°C]* at dew line	Heat extraction rate of brine earth probe [W/m]	CO_2 Inlet Temp. [°C]	Evaporating Temp. t_o R407C [°C]* at dew line	Cond. Temp. t_c R407C [°C]* at dew line	Heat extraction rate of CO_2 earth probe [W/m]
20.-23.5.05: 60 h	-	-	-	-	-1.4	-6.4	44.4	56.5
1.-2.6.05: 24 h	-	-	-	-	-3.3	-8.3	26.9	60.4
4.-6.6.05: 48 h	-1.4	-13.9	37.6	42.4	-3.9	-9.1	37.5	60.0
7.-8.6.05: 18 h	-0.5	-13.5	51.9	43.4	-3.6	-8.8	51.0	61.7
27.-30.6.05: 60 h	-	-	-	-	-0.1	-7.1	39.4	59.8
7.-7.3.06: 7 h	-	-	-	42.2	-2.0	-8.7	47.1	52.9

The test heat pump system consisted of two identical systems each for one probe, running continuously. Only the CO2 and brine heat exchangers each of 5 kW cooling capacity were different of the shell and coil or plate design, respectively.

First, according to Table 1, the R407C system for the brine earth probe system showed an evaporator brine outlet temperature i.e. an earth probe brine inlet temperature of -1.4°C, a R407C dew line evaporation temperature of -13.9°C, a dew line condensing temperature of +37.6°C at an earth heat extraction rate of 42.4 W per meter depth of the brine earth probe. Secondly, the CO_2 liquid inlet temperature into the heat pipe, i.e. at the outlet of the R407C evaporator CO_2 condenser vessel was -3.9°C at a R407C dew line evaporation temperature of -9.1°C, a dew line condensing temperature of +37.5°C and an earth heat extraction rate of 60.0 W per meter depth of the CO_2 heat pipe.
This different behaviour caused for the CO_2 heat pipe a higher heat extraction rate of 60 W/m because of the higher temperature difference between CO_2 liquid at the inner heat pipe wall and the undisturbed earth, as compared to the brine earth probe with 42.4 W/m with a lower temperature difference to the earth.
For testing both earth probes with the same heat extraction rate it would have been advisable to run the compressor of the CO_2 heat pipe system with an adequate lower speed in order to achieve also 42.4 W/m as the brine earth probe. This test regrettably had not been performed due to lacking of an inverter control for the compressor.
Regarding the COP a higher value can be expected for the CO_2 heat pipe system due to the higher R407C evaporation temperature than for the brine earth probe caused by the lower R407C evaporation temperature, in each heat pump, respectively.
An approximate theoretical comparison of the COP had been done using the FKW Refcycle Programme for both R407C systems based on the measured mean evaporating and condensing temperatures resulting in the COP_c of cooling or COP_h of heating, respectively, according to Table 2:

Table 2: Test results and calculated COP values.

System	t_{B1}	t_{B2}	Δt_{Brine}	t_o	t_c	COPc	COP_h	Δt_{om}	Δt_{Earth}	Q_o	l
	[°C]	[°C]	[K]	[°C]	[°C]	-	-	[K]	[K]	[W/m]	m
Brine	-1.4	+0.2	1.6	-13.9	37.6	2.81	3.81	13.3	12.3	42.4	100
CO_2	-3.9	-3.9	0	-9.1	37.5	3.23	4.23	5.2	15.4	60	100
CO_2	+0.6	+0.6	0	-4.6	37.5	3.71	4.71	5.2	10.9	42.4	100
Brine	-3.6	-2.0	1.6	-16.1	37.6	2.65	3.65	13.3	14.3	50	100
CO_2	-1.3	-1.3	0	-6.5	37.5	3.50	4.50	5.2	12.8	50	100

This table shows for the different above mentioned cases of comparison for both earth probes their inlet and outlet temperatures and temperature differences, the dew line evaporating and condensing temperatures of R 407C in the heat pump cycles, the calculated Coefficients of Performance (COP) for Cooling and Heating, the mean temperature differences in the individual evaporators and further on between the earth and the earth probe liquid, as well as the heat extraction rate from the earth and finally the earth probe length.
The COP values in Table 2 show the better energetic performance of the heat pump with a CO_2 earth heat pipe than with a brine earth probe. The COP for cooling is around 15% better at the tests with different heat extraction rates of 42,4 or 60,0 W/m, respectively, and 32% better at equal heat extraction rates of 42,4 W/m or 50 W/m with both probes.
The COP for heating is under the same test conditions 11% better with different heat extraction rates of 42,4 or 60,0 W/m, respectively, and 24% or 25% with equal heat extraction rates of 42,4 or 50 W/m with both probes, respectively. No brine pump power has been taken into consideration.
This improvement is based on the better heat exchange behaviour in the CO_2 condensing evaporator than in the brine cooler of the individual systems, indicated by the smaller

temperature differences. Also the better heat transfer in the heat pipe itself contributes to the better energetic performance of this system as compared to the brine earth probe.

4 PILOT SYSTEMS

Since 2005 around a dozen pilot heat pump systems with FKW-CO_2- Earth Heat Pipes have been installed in Germany and Austria in order to gain experience in real applications at one-family houses. They have now been operated for up to three heating seasons without problems.

5 RESEARCH PROJECTS

EIfER – Research-Project

During the year 2005 the EIfER, European Institute for Energy Research in Karlsruhe, initiated a research project which was sponsored by the both utilities EnBW, Energie Baden-Württemberg, Karlsruhe and EDF, Éléctricité de France, Paris, in order to investigate a 250 m deep FKW-CO_2-earth heat pipe for providing earth heat to an old existing building from only one individual deep borehole.
Partners in this project were the University of Karlsruhe, FKW Hannover, Kaeltro Berlin, and the “systherma planning bureau for earth heat systems” in Starzach-Felldorf which performed the coordination, FKW the lay out of this first very deep heat pipe system, Kaeltro the installation between the heat pipe, the heat pump and the heating system, as well as the Institute for Applied Geology of the University Karlsruhe which provided the installation of the devices for measurements in order to evaluate together with FKW the operation of the whole system.
The drilling of the borehole at Triberg (Black Forest) was done in December 2006, the heat pipe was placed into the borehole in March 2007 and, after several preliminary tests with the whole heat pump system and the CO_2-earth heat pipe, the official starting of operation had been on January 23, 2008 [3, 4].

FKW – Research-Project

During the described former research work at the earth heat pipe of FKW and its partners the development of the heat pipe itself had been finished so far that the mentioned pilot systems could be installed. On the other hand, it was decided to start at FKW together with its new partners Viessmann, ThyssenKrupp, Brugg and Gea-WTT for the working period between May 1st , 2007 and April 30th, 2009 a development project for further improvement work before market introduction.
In 2006 such a project, sponsored by the German Federal Ministry of Economy and guided by PTJ ,Projektträger Jülich, was started at FKW together with Viessmann, ThyssenKrupp, Brugg and Gea-WTT. For performing the necessary research and development work as also further energetic measurements for comparisons to conventional systems, FKW had decided to install three earth probes at its parking lot close to the FKW building (Figure 10).
Here, three boreholes were drilled, each of 100 m depth, two with 160 mm diameter for a CO_2 earth pipe and a brine earth probe and another one with 180 mm diameter for a 100 m larger stainless steel flexible pipe to be filled with water or brine in order to be able to insert into this pipe different earth probes or heat pipes for further research or development investigations.

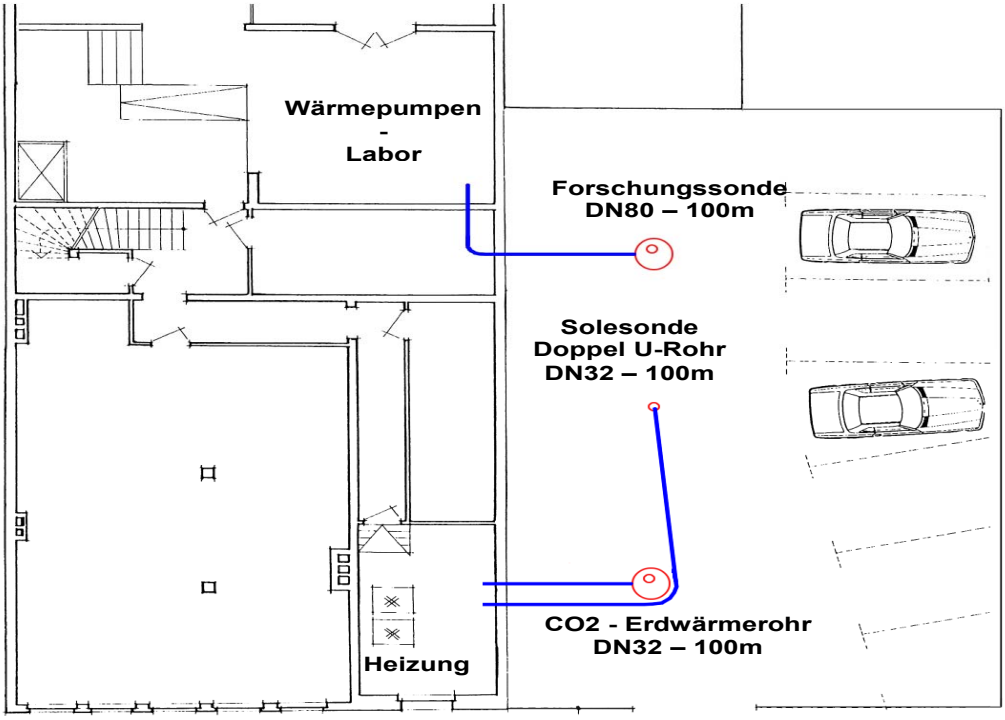


Figure 10: Map of the FKW- underground floor and the parking lot with the three earth probes and the connecting pipes to the heating system and the heat pump laboratory.

6 MARKET INTRODUCTION

After in 2006 the FKW-CO_2-earth heat pipe was covered by a patent No. DE10327602.5-15 FKW and Brugg convened a license agreement for manufacturing and marketing this novel type of CO_2 earth probe.
For the market introduction development work first had to be done for an industrial low cost production of the heat pipe system. This concerned mainly the heat exchanger on top of the heat pipe.
The first step for development was therefore a new design and calculation for lay out of heat exchangers for various capacities according to the different heat pipe lengths by applying computer calculations and tests at the FKW heat exchanger test rig.
After in 2007 some 10 newly designed Brugg-FKW-CO_2 Earth Heat pipes have been delivered already it is planned to start further market introduction in 2008.
More detailed information will be presented with the paper at the IEA Heat Pump Conference in Zürich.

7 LITERATURE

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