FIELD HEATING AND SPACE COOLING AT "GELREDOME" MULTIFUNCTIONAL STADIUM IN ARNHEM; AN EXAMPLE OF HEAT-PUMP APPLICATION IN THE NETHERLANDS

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1. INTRODUCTION

American football is one of the most popular sporting events on the North-American continent. The rest of the world is more interested in soccer. Yet the ambience in which football is played in America was the source of inspiration for the new multifunctional stadium of soccer club Vitesse in Arnhem. This is reflected by the name of the stadium: "Gelredome".

The new stadium is equipped with several novel facilities such as a mobile playing field, solar collectors and a sliding roof. The nicest piece of technology, however, has been there for tens of thousands of years: the aquifer, a water-bearing layer in the subsoil. This sand layer will be used to temporarily store the thermal-energy surplus that remains after heating and cooling by means of a heat pump. This specific application of energy storage will be discussed later in this article. First, a general overview is given of the state of the art in the Netherlands as regards heat pumps and more in particular the combination with energy storage.

2. HEAT PUMPS IN THE NETHERLANDS

Since the discovery in 1960 of one of the world's largest natural gas fields, heating in the Netherlands is mainly obtained by means of gas-fired boilers. Recently, however, the monopoly position of natural gas has come under pressure owing to the re-introduction of heat pumps.

The renewed interest in heat pumps has several reasons. First of all, technological developments have brought about major improvements in heat-pump efficiency. Secondly, the newest power plants have increased efficiency in electricity generation up to a remarkable 56% (Voorter, 1996). Furthermore, electric power utilities consider heat-pump technology a means to strengthening their control of the heating market, which to date was mainly in control of the gas industry. Finally, in its attempts to maximize the efficiency of non-renewable energy sources, the government is also interested in using the heat pump. This interest is substantiated not only by a large number of research projects carried out by government institutes, but first of all by the 20% subsidies granted to such projects.

3. GROUND SOURCE HEAT-PUMPS

It is remarkable that heat-pump system studies pay almost no attention to the heat source. First of all one tends to think of using outside air or ventilation air. But it is soon recognized that there is little recoverable heat in outside air at -5°C and that the amount of ventilation air is so small that its total heat content is generally insufficient. So, in most cases the final option is to use the subsoil.

3.1 Groundwater

In the Netherlands, 95% of the shallow subsoil (<200 m below surface level) consists of aquifers. It is relatively easy and consequently not very expensive to extract groundwater from these layers. Because of the relatively high temperature of approx. 12°C, this groundwater is most suited for use as a heat source for a heat pump. An additional advantage is the constant temperature throughout the year, which is unlike other heat sources, such as outside air or a ground heat-exchanger system. Several methods are available for a heat pump to use this groundwater.

1. *Extraction and disposal (figure 1).* This system is based on groundwater extraction from wells, recovery of thermal energy from it by means of the heat pump, and disposing of it into a sewer or surface water. The Dutch government, however, does not grant licences for such systems, mainly because groundwater is relatively scarce in the Netherlands, which one would not expect from a country with a rather low altitude. For that reason, groundwater may only be used for high-grade applications such as the production of drinking water and for the food product industry. Using it as a heat source is considered a very low-grade application.

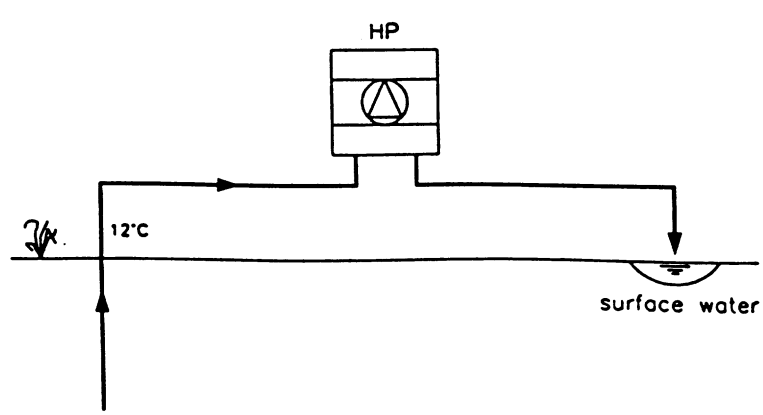

Fig 1: Extraction and disposal

2. Extraction and injection (figure 2). A major objection of the authorities can be overcome when the groundwater is re-injected into the subsoil after its thermal energy has been absorbed. This means that groundwater is no longer consumed but merely used. An important drawback of the system is a strong cooling of the subsoil surrounding the injection well. Though this does not have any direct physical and chemical consequences for the subsoil system, certain disadvantages are still involved. First, injected groundwater may flow towards the extraction well, lowering the temperature of extracted water and reducing the heat-pump efficiency. Continuously lowering the extraction temperature may eventually result in the groundwater freezing. A second disadvantage is that potential groundwater users in the immediate surroundings of systems that have already been installed, will be confronted with groundwater that is less suitable as a heat source. In a densely populated country like the Netherlands, in contrast to the USA, this disadvantage should not be underestimated.

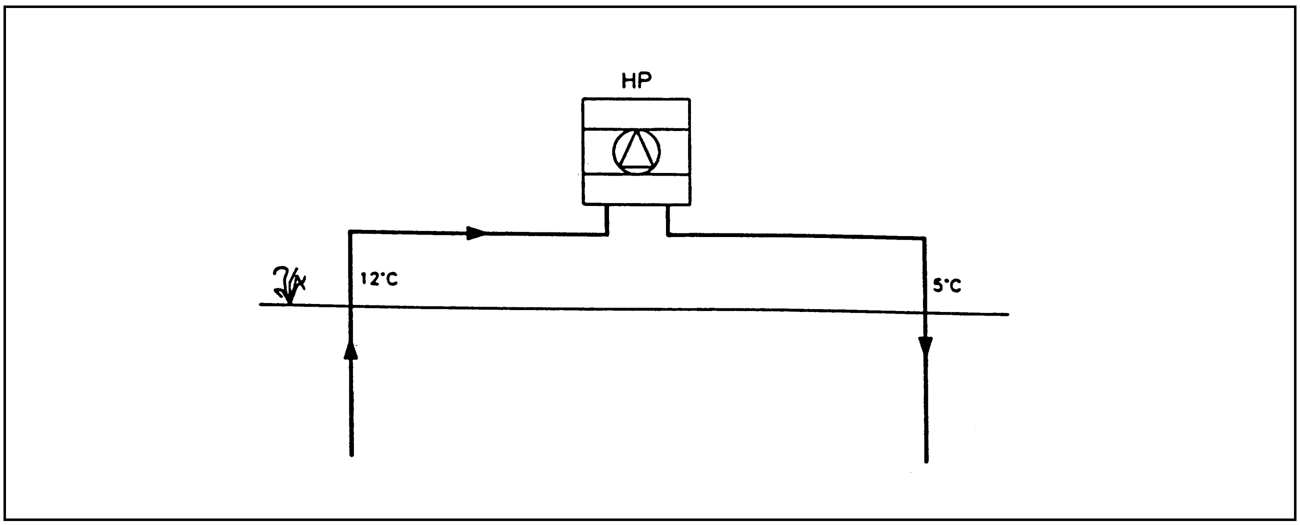

Fig 2: Extraction and injection

3. Extraction and injection with thermal equilibrium (Figure 3). Though re-injection of groundwater does dispel the main objection of the authorities, they are still very reticent when licences are requested for the systems described above. Within the framework of "sustainable utilization" of groundwater (which means that present utilization shall not be a barrier to future utilization) they would prefer the restoration of the thermal equilibrium in the subsoil. This can be achieved by extracting groundwater from the extraction well in summer, heating it by means of outside air (dry heaters), the sun (solar collectors), surface water or surplus heat from buildings. The groundwater with raised temperature is then re-injected and mixes in the subsoil with the cold groundwater from the previous winter season.

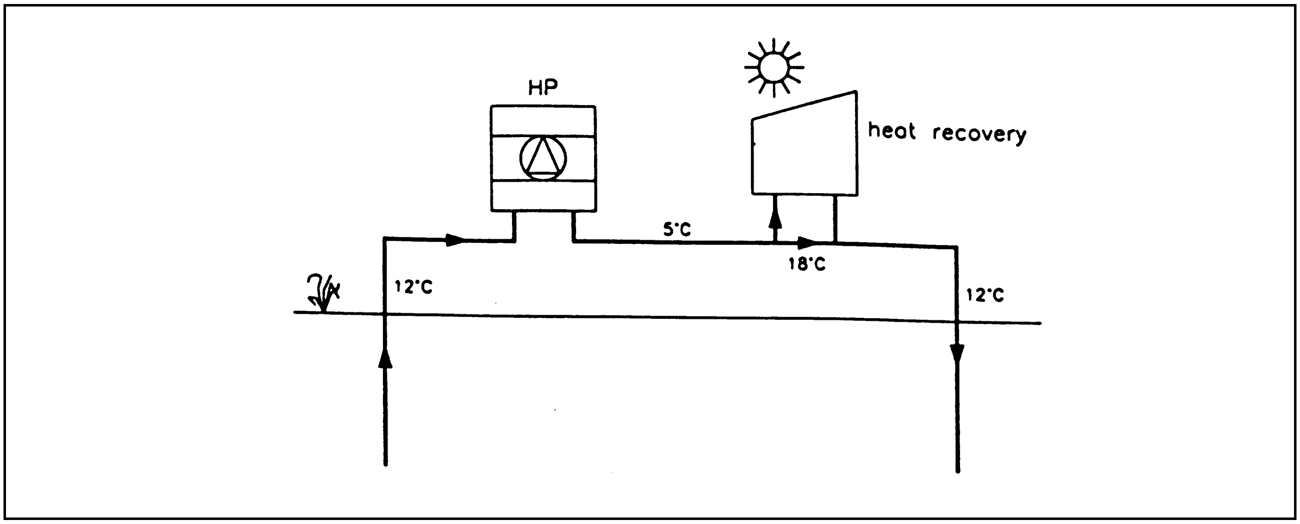

Fig 3: Extraction and injection with thermal equilibrium

4. Energy storage (figure 4). From the energy point of view, restoration of the thermal equilibrium is less interesting than a system whereby this does not take place. This may be improved in summer by utilizing cold energy which had been injected in winter. To achieve this, groundwater can be extracted from the injection well used in winter (the "cold well") and then be brought into the air-handling unit. Here, the groundwater absorbs heat from the ventilation air. The then warmer groundwater is injected into the well used for extraction in winter (the "warm well"). This system is called an Underground Thermal Energy Storage (UTES) (see also chapter 4, Energy storage in the Netherlands).

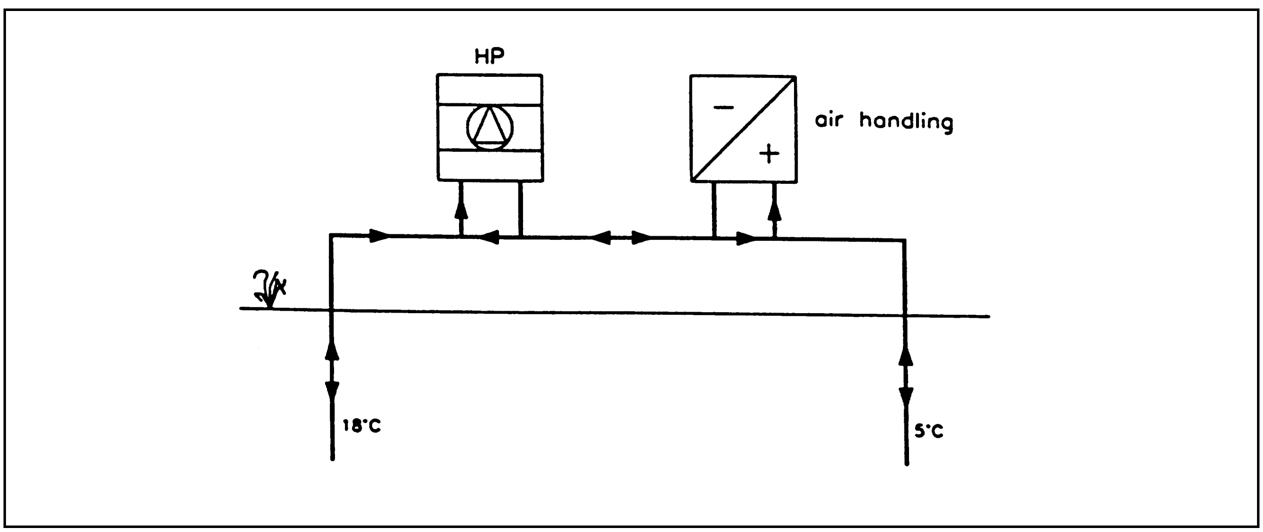

Fig 4: Energy storage

In addition to the advantages for the subsoil system, such storage systems improve the heat-pump efficiency. This is caused by the raised supply temperature from the warm well (18°C instead of

12°C). It should be noted here that such systems supply cold energy in summer without using the heat pump. If the cold groundwater were only used to cool the condensor of the chiller (heat pump), a considerable part of the energy saving that can be achieved with such systems, would not be realized.

The heat pump with energy-storage system is especially practicable in situations with a clear demand for cold energy. For the Dutch situation this implies that it is mainly suitable for offices and buildings and less so for houses.

3.2 Ground heat exchangers

Where aquifers are absent in practicable depths, it is possible to extract energy from the subsoil by means of conduction. This is done by means of a ground heat exchanger consisting of a number of vertical boreholes accommodating a PVC tube system. The most common practice is that an antifreezing mixture (e.g. glycol) is pumped through the tube system. This liquid flows through the heat pump where it delivers the heat it has absorbed from the subsoil. In addition to situations where no groundwater is available in the subsoil, such systems are often used for relatively small heat-pump systems (<100 kW) for which a groundwater system is likely to be too expensive. In practice, this means that individual houses or small offices are equipped with ground heat exchangers.
A specific group of users are new residential areas in the Netherlands, where each house is equipped with a system of its own consisting of a heat pump and ground heat exchanger with generally four boreholes to a depth of 40 m below surface level. The large density of houses per unit area (approx. 40 per hectare) in these new housing estates demands that the subsoil be regenerated in summer. If this is omitted, the temperature around the ground heat exchanger may drop to such an extent that the heat-pump coefficient of performance (C.O.P.) becomes very low or the subsoil freezes under peak-load conditions. As the behaviour of a frozen ground heat exchanger is still unknown, this is still an undesirable situation. Regeneration of the ground heat-exchanger system is achieved by means of solar collectors or surface water.

Apart from the possible problems from the energy point of view, ground heat exchangers are also the subject of discussion because of environmental risks. These include the possible leakage of glycol and the danger that impervious clay layers between aquifers are perforated.

4. ENERGY STORAGE IN THE NETHERLANDS

For further market penetration, the technology of Groundwater source heat pumps can take advantage of the knowledge and experience collected with thermal-energy storage in the Netherlands over the last 15 years. Aquifer thermal-energy storage has been a frequently used technique since 1985 to provide buildings and/or manufacturing processes with cooling and/or heating in a sustainable way. The most frequently used concept is that of cold storage, which is considered a low-energy alternative to chillers. The principle of this technique is that cooling is performed in summer using cold energy that was stored in winter. This means that groundwater is extracted from a warm well in winter and cooled with outside air by means of air-handling units, or dry or wet cooling towers. The groundwater temperature is lowered to approx. 7°C and injected into the cold well. The system is reversed in summer, with the stored cold groundwater being extracted from the cold well. After the cold energy has been recovered by means of an air-handling system, the slightly warmer groundwater is injected into the warm well. A remarkable aspect of this system is that cold energy is supplied without the need for a chiller.

Table 1: Some long-running cold-storage projects (Bakema, 1995)

Name	Location	Sector	Realization	Task	Storage volume	Temp. warm	Temp. cold	Flow
			year		m^3	° C	° C	m^3/s
Province Hall	Zwolle	office buildings	1985	cooling	70,000	20	9	$1.7*10^{-2}$
Perscombinatie	Amsterdam	press	1987	cooling	250,000	14	9	$3.3*10^{-2}$
RU	Utrecht	university	1990	heating	100,000	90	40	$2.7*10^{-2}$
Heuvelgalerie	Eindhoven	mall	1992	heating/ cooling	200,000	32	18	$2.7*10^{-2}$
Office block	Schiedam	office building	1992	cooling	20,000	15	6	$3.4*10^{-2}$
Groene Hart	Gouda	hospital	1992	cooling	40,000	15	8	$1.7*10^{-2}$
BAM	Bunnik	office building	1993	cooling	15,000	16	6	$0.8*10^{-2}$
IBM	Zoetermeer	office building	1993	cooling	150,000	15	5	$2.7*10^{-2}$
Freesia plant nursery	Gameren	greenhouse	1993	cooling	80,000	12	12	$1.4*10^{-2}$
Museonder	Hoge Veluwe	museum	1993	cooling	5,000	12	12	$0.1*10^{-2}$
Hedera plant nursery	Luttelgeest	greenhouse	1993	cooling	40,000	12	12	$1.4*10^{-2}$
Jaarbeurs	Utrecht	events hall	1993	cooling	70,000	14	7	$11.1*10^{-2}$

So far, about 50 office blocks, hospitals, museums etc. have been equipped with this cooling system. Table 1 contains examples of several long-running projects. At present, cold-energy storage is considered a "proven" technique. In years to come, the number of cold-storage projects will further increase, partly because of an increasing environmental awareness. The expected growth rate is between 20 and 30 new projects per annum.

The number of cold-storage systems with heat pumps is on the increase. A major reason for this is that the temperature level of the heating system in modern offices is less than 50°C. Additionally, it is important aspect that the heat pump produces cold energy as a by-product of heating. With this cold energy the cold-storage system can be charged in a relatively simple way with low energy requirements. A further advantage is the fact that heat injected into the subsoil in summer, can improve the heat-pump C.O.P. in winter. Finally, the heat pump has the option of serving as a chiller in case of insufficient cold-energy supply from the subsoil.

5. THE GELREDOME STADIUM

The Gelredome stadium - a 70 million dollar project - will accommodate 27,000 visitors. Apart from soccer games, concerts and other sporting events will be organized here. In winter, the stadium will need heating for the playing ground and base floor, and in summer it will need cooling for offices and congress facilities. The cold and warm energy will be supplied by NUON, the energy utility for the provinces of Gelderland, Friesland and Flevoland. NUON considers the Gelredome project an opportunity to test several renewable energy systems. By doing so they hope to gain sufficient knowledge to apply these systems in other large-scale building projects. For that reason, using a heat pump for heating purposes was included right from the start of the development of the energy concept. The energy-storage item was added later.

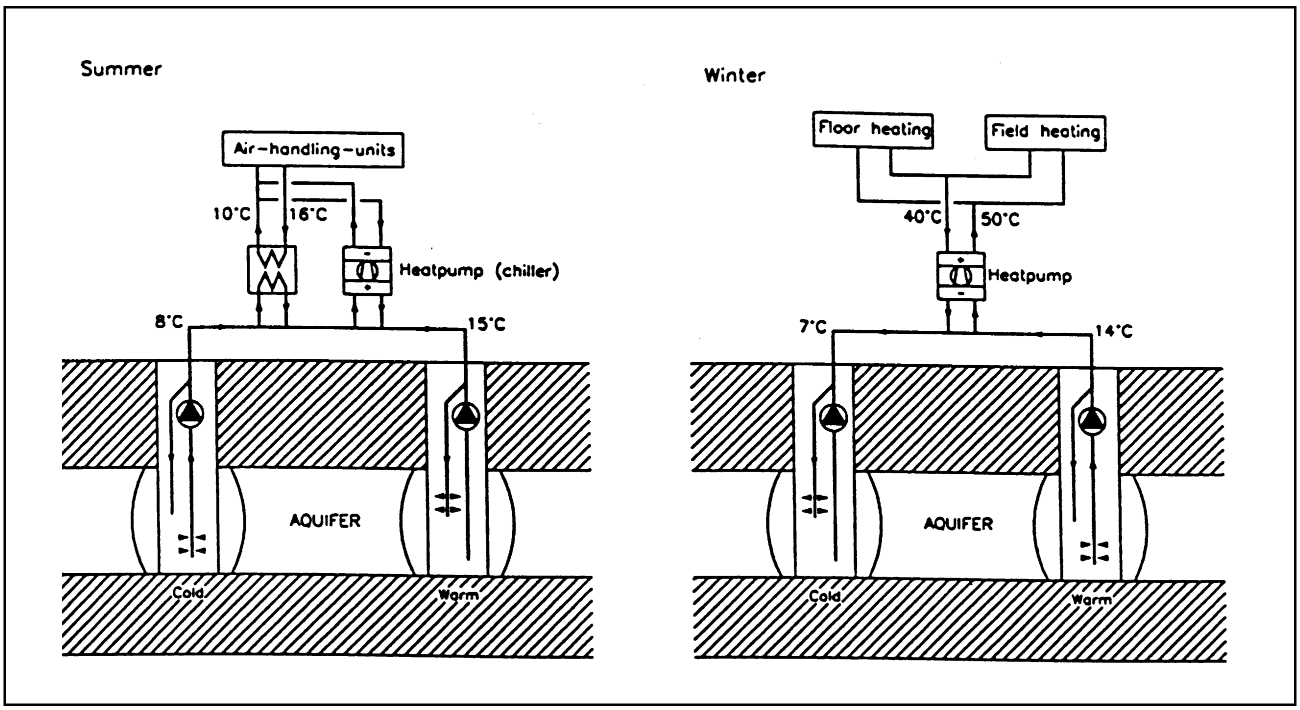

Fig 5: Energy storage at Gelredome

In winter, the heat pump with its capacity of 410 kW, will supply 70% of the required heat; the rest is taken care of by a gas-fired boiler. Groundwater extracted via two wells (figure 5) is used as the heat source for the heat pump. Once the groundwater has given off its heat, it is re-injected into the subsoil via a cold well. In summer, the cold-storage system can provide a cooling capacity of approx. 2,800 kW. This is achieved by extracting Groundwater at a rate of $6.9*10^{-2}$ m^3/s from the cold well and, after recovering its cold energy by the air-handling unit, injecting it into the warm wells. Under very extreme summer weather conditions, the stadium may demand an extra 10% more cold energy. If this situation arises, the heat pump will step in as a chiller. Then, the chiller condensor is cooled by means of the cold storage. The energy-storage system is to be realized in the second aquifer at a depth between 40 and 80 m below the surface.

Despite the fact that the cooling capacity in summer is much higher than the heating capacity in winter, the limited number of full-load hours makes that cooling demand is much less than heating demand. Consequently, much more cold energy is put into the subsoil in winter than is extracted in summer (table 2). But for the next 20 years the wells are prevented from affecting each other significantly by placing the two warm wells and the cold well far apart. The licensing authority in charge of thermal-energy storage does not object to the cold-energy surplus in the subsoil because there will be no other groundwater users in the immediate surroundings.

Table 2: Energy and water quantities at Gelredome stadium

Cooling capacity of heat pump	320 kW
Heating capacity of heat pump	410 kW
Heat production by heat pump	5400 GJ
Cold-energy production by heat pump	4320 GJ
Cold-energy demand in summer	1728 GJ
Cooling capacity of cold storage	2,800 kW
Groundwater flow rate in winter	$1.7*10^{-2}$ m^3/s
Groundwater flow rate in summer	$6.9*10^{-2}$ m^3/s
Pumped quantity in winter	175,000 m^3
Pumped quantity in summer	60,000 m^3
Injection temperature in winter	7°C
Injection temperature in summer	15°C

Compared with a conventional installation with chillers for cooling and a gas-fired boiler for heating, energy storage with the heat-pump system results in a 45% energy saving (table 4). Mainly in summer with energy storage a high percentage can be gained as the only energy consumer will be the submersible pump in the cold well. A further energy saving would have been possible if the cold-energy surplus in the subsoil could be made use of in summer.

In addition to the lower energy consumption and subsequently the reduction in the emission of combustion gases, the system has several more obvious advantages. The advantages resulting from the fact that a chiller is not needed, include the lower use of CFCs, lower noise production, flatter electricity peak, increased operational safety and less space required for technical facilities.

Table 3: Energy saving

Conventional installation - cooling with chiller, C.O.P. 3 - heating with gas-fired boiler, efficiency 80% - total	 576 GJ 2700 GJ 3276 GJ
Energy storage with heat pump - cooling with energy storage - heating with heat pump and energy storage - total	 36 GJ 1764 GJ 1800 GJ
savings	45%

6. PROSPECTS FOR GROUND SOURCE HEAT PUMPS

The Gelredome heat-pump project shows that the heat pump in combination with energy storage is an attractive alternative from the energy point of view. It is unsure whether this also applies to the application of heat pumps used only for heating. In principle, a heat pump with a C.O.P. value of 3 to 4 uses less energy than a gas-fired boiler with a 90% efficiency. Research on the use of heat pumps in houses, however, has shown that particularly the ways in which warm tap water is prepared and heating energy enters the house, might adversely affect the eventual C.O.P. The C.O.P. is also strongly affected by the temperature of the heat source. In particular in ground heat-exchanger systems it may be that the temperature in the subsoil falls in winter.

Furthermore, at present the energy calculations on the use of heat pumps in the Netherlands are still strongly influenced by interests on the part of the electricity and gas utilities. The main issue to be clarified is whether future housing estates shall have both natural gas and electricity networks or whether one of the two will suffice. The heat pump might render the installation of a gas network redundant. The electricity utilities expect approx. 200,000 heat pumps to be installed up to the year 2005 in new houses in the Netherlands (Voorter, 1996).

Apart from the issue of whether the heat pump is efficient from the energy point of view, its success will largely depend on how it is connected to the subsoil. If suppliers and heat-pump researchers have inadequate knowledge of the hydrological and thermal behaviour of subsoils, there is a risk that poorly operating systems will be built. This may vary from groundwater systems with clogging wells or a thermal breakdown occurring between wells, to ground heat-exchanger systems with boreholes projected rather close to each other so that a strong temperature drop is brought about in winter.

For the moment, research on systems with Groundwater source heat pumps as well as the realization of such systems will continue in the Netherlands. In a few years' time it will become clear on the basis of the results of some long-term projects whether these systems can really contribute to the realization of a sustainable energy supply.

7. EPILOGUE

Soccer was introduced at the end of the 19th century as a simple ball game for 11 healthy chaps against another 11 healthy chaps with only one purpose: ticking a leather ball into a goal marked by wooden beams and defended by the opponent. Elements such as rain, frost and wind, all had a free hand. Nowadays, however, soccer has also become a game of commerce where the influence of the elements is not appropriate and where the stadium shall be able to meet several purposes. The question remains whether the game of soccer as such and witnessing it in such "domes" will make for so much more fun. Maybe we need time to learn something of the perception of Americans watching their football games.

8. REFERENCES

Bakema, G. & A.L. Snijders (1995). Underground Thermal Energy Storage, state of the art 1994. IF Technology, Arnhem, The Netherlands.

Voorter, P (1996). Electrical heat pump replacing gas-fired boilers in new residential areas (in Dutch). Energie- and Milieuspectrum 4-96.

9. BACKGROUND INFORMATION

This article is partly adopted from the article by G. Bakema & A.L Snijders "Groundwater source heat pump for field heating and space cooling at Gelredome multifunctional stadium" (in German) for the symposium on ground source heat pumps in Giessen, Germany, on 20th - 22nd November 1997.