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2005 SOLAR WORLD CONGRESS: COMBINATION OF SOLAR COLLECTORS AND GROUND-SOURCE HEAT PUMP FOR SMALL BUILDINGS

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ABSTRACT

The combination of solar heat and ground-source heat pumps in dwellings gives opportunities for optimising the use of renewable energy sources and minimize the share of bought energy. Solar collectors in the system may give advantages for the operational conditions both for the solar collectors and for the heat pump. The aim of this project was to analyse different variables such as energy demand, building types, climate, geological conditions, system design and control. The study has been carried out with TRNSYS simulations for Swedish climate and building conditions.

The results from the computer simulations so far, shows that there is an obvious risk that the use of electricity for the circulation pumps is larger than the decrease of electricity use for the heat pump and the auxiliary heater. It is most important that the system is optimised in order to restrict the total use of electricity.

1. INTRODUCTION

In Sweden, the interest both for ground-source heat pumps and solar collectors has steadily increased in the dwelling sector during the last years. In 1999 there were about 100,000 ground-source heat pumps installed, a figure that has reached about 250,000 at the end of 2004. Every year about 30,000 ground-source heat pumps are now installed.

The combination with solar collectors gives several advantages depending on system design and type of

collectors. Several systems from different contractors are already on the Swedish market.

The combination of ground-source heat pumps and solar collectors can be assembled in many ways, with different components and designs. An example is shown in figure 1. The benefit of the system may therefore vary considerably and close analysis has not yet been undertaken.

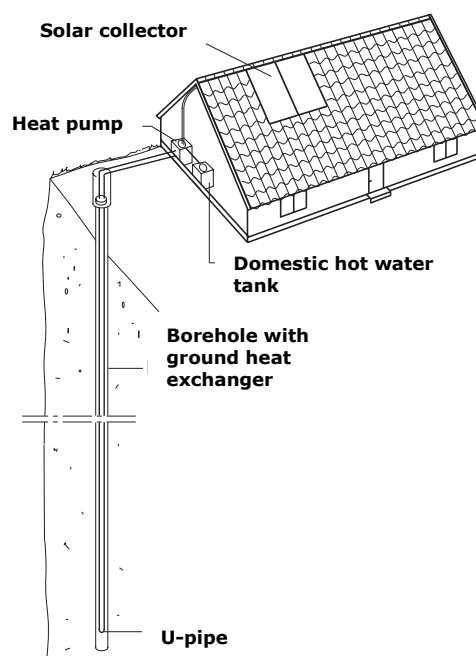


Fig. 1: Single-family dwelling with solar collectors and ground-source heat pump.

A project is ongoing at Lund University in Sweden, and the first part has been reported (ref. 1). The first part includes an extensive reference list. In the project, simulation studies are made for different components, systems and energy balances in different climate and geological conditions.

2. BACKGROUND

Ground-source heat pumps, in combination with solar heat, have been tested with different system design during the last 25 years in several countries. Many projects were realised in Europe during the 80's and the 90's.

In Sweden the performance of small solar-assisted ground-source heat pump systems was tested by the Swedish State Power Board. Experiences from 1984/85 from operation of 19 heat pump plants are reported. Fourteen of these installations included equipment like simple solar collectors or air collectors to recharge heat into the ground. The system performance was considered to be satisfactory regarding operating time, energy performance, coefficient of performance (COP) etc. However, it was concluded to be more cost-effective to achieve a higher source temperature and thus an improvement in performance by drilling a deeper borehole. The source temperature increase, due to recharging, only reached about 2°C.

The differences since these projects were realised are that the components have improved in performance and costs have decreased. The heat pumps have a higher COP and the manufacturing of the solar collectors are more industrialised. The control system has, by the microprocessor technique, opened new possibilities for the operation strategies and makes it possible to design and optimize systems for different applications, according to solar radiation and heat demand. The drawback is that the complexity in these systems may cause difficulties in control of the operation and optimisation. Economic conditions have also changed, e.g. the alternative energy costs, which in Sweden in the late 80's were assumed to be about 0.30 SEK/kWh for electricity and about the same for oil. Today these prices are more than three times higher and this indicates that other solutions might be more cost-effective today.

3. COMPONENTS AND SYSTEMS

The solar heat may be used in different ways in systems with ground-source heat pumps, depending on the choice of components and system. In the most flexible systems, solar heat can be used in several ways depending on demand and temperature levels, see table 1:

1. directly to the domestic hot water
2. directly for heating the building
3. heating the evaporator in the heat pump
4. recharging the borehole

TABLE 1: DIFFERENT POSSIBILITIES TO USE SOLAR HEAT IN COMBINATION WITH GROUND-SOURCE HEAT PUMP AND THE EFFECTS ON THE SYSTEM

| Mode of operation | Solar collector | Heat pump | Borehole |
|---|--|---|---|
| 1. Solar collector is used to produce domestic hot water | Heat production at "high" temperatures (>50°C) | Heat pump not in operation | Natural recharging of borehole from the surrounding |
| 2. Solar collector is used to produce heat for the heating system | Heat production at lower temperatures (about 20-50°C) gives increased efficiency and longer operation time | Heat pump not in operation | Natural recharging of borehole from the surrounding |
| 3. Solar collector is used to increase the entering evaporator temperature to the heat pump | Heat production at lower temperatures (about 5-20°C) gives increased efficiency and longer operation time | Heat pump in operation, increased COP because of high temperature to the evaporator, which increases the heat production and decreases the operation time | Heat extraction from borehole, possible recharging the borehole with solar heat |
| 4. Solar collector is used to produce heat for recharging of the borehole | Heat production at lower temperatures, gives increased efficiency and longer operation time | Heat pump is not in operation – no other heat demand The operation conditions for the heat pump is improved for the season | The temperature in the borehole increases and shorter borehole may be used |

The advantages of recharging the borehole may be:

- increased seasonal performance factor of the heat pump
- possibility to use shorter boreholes
- possibility for a higher extraction of heat from the borehole
- reduction of the thermal influence of neighbouring boreholes with heat extraction
- solar collectors and boreholes may be designed for seasonal heat storage in a system with a group of houses with a common heat distribution network

The reduction of the thermal influence is of special interest in densely populated dwelling areas, where a concern for long-term thermal influence between adjacent boreholes might lead to restrictions on the use of ground heat sources.

The solar recharge may also be used to:

- increase the evaporator temperature when the active borehole depth is undersized e.g. because of
 - higher heat demand than assumed
 - the ground thermal conductivity was lower than assumed
 - the ground water level was lower than assumed
- counteract freezing of boreholes

The drawback with the combination is that the investment cost as well as the operation cost, increases with the complexity of the system. Depending on sizes and equipment, the cost for a ground source heat pump to a single family dwelling in Sweden is between € 3000 and 6000 (incl. VAT) and the cost for drilling € 2000 to 6000 (incl. VAT, installation cost not included). The additional cost for the solar collector is € 2000 to 5000 (incl. VAT). The operation cost increases as there are more circulation pumps in operation, compared to a not combined system. Depending on operation strategy, pump size and pump efficiency, the operation cost of these pumps can exceed the advantages with the combination. This has to be optimised carefully.

3.1 The Borehole

The heat to a conventional ground-source heat pump is taken from boreholes. For single family dwellings it is normally enough with one borehole, but for larger demand several boreholes can be linked together. The depth of the borehole varies from 60 to 180 m. A rule of thumb is that in the Stockholm area in Sweden, the need of borehole is about 20 m for each kW thermal output of the heat pump. The depth depends on:

- heat load for the building
- thermal output for the heat pump

- thermal conductivity in the ground
- natural temperature in the ground
- distance to other ground-source heat pump systems
- depth of covering soil layer (down to the rock)
- ground water level and the ground water flow in the borehole
- geological conditions and drilling costs

In the borehole there is normally a collector consisting of a U-pipe heat exchanger with a circulating heat carrier fluid. In ground-source heat pump systems without solar collectors, the heat carrier fluid is normally an antifreeze solution with ethanol/water. If the system is connected to solar collectors with high temperatures, this antifreeze liquid can not be used due to explosion risks and a glycol based rape oil is normally used instead.



Fig. 2: Drilling a borehole to a single family dwelling

In Sweden, the borehole (outside the U-pipes) is often filled with ground water. When sizing the depth, the required *active* borehole is calculated. The *active* borehole is the part of the borehole which is filled with a material with acceptable heat conduction, such as water or solid material. The heat transfer between the heat carrier fluid and the rock is negligible in the airfilled part of the borehole. The distance between the ground surface and the ground water level can be large on hills or near tunnels.

3.2 The Heat Pump

The most preferable to use in combination with solar collectors, is the ground-source heat pump system with vertical boreholes, see example in figure 3. The natural ground temperature is also relatively constant over the year, which increases the possibilities for the solar collectors to recharge the borehole during the summer. For the heat pumps with horizontal pipes or connected to lakes, the

temperature varies over the year, depending on the depth of the collectors.

The heat pump is, for single family dwellings, normally sized to cover 50-70 % of the maximum designed heat load. This means that the heat pump covers 85-95 % of the annual heat demand in the building. If the demand changes, the operation conditions for the heat pump is also changed.

Depending on the thermal characteristics of the building, auxiliary heating will normally be needed when the outdoor temperature is less than about 0° to - 5°C.

The size of conventional heat pumps for single family dwellings with a heat demand of about 20.000 kWh/year for heating and domestic hot water, is around 1,6 kW_{el} (correspondent to about 5 kW_h thermal output). For larger heat demand, up to 35.000 kWh/year, the normal size is around 2,8 kW_{el} (correspondent to 9,0 kW_h thermal output). The figures assume a temperature of the heat carrier fluid entering the evaporator of 0°C and a temperature of 50°C from the condenser to the heating system in the building respectively.

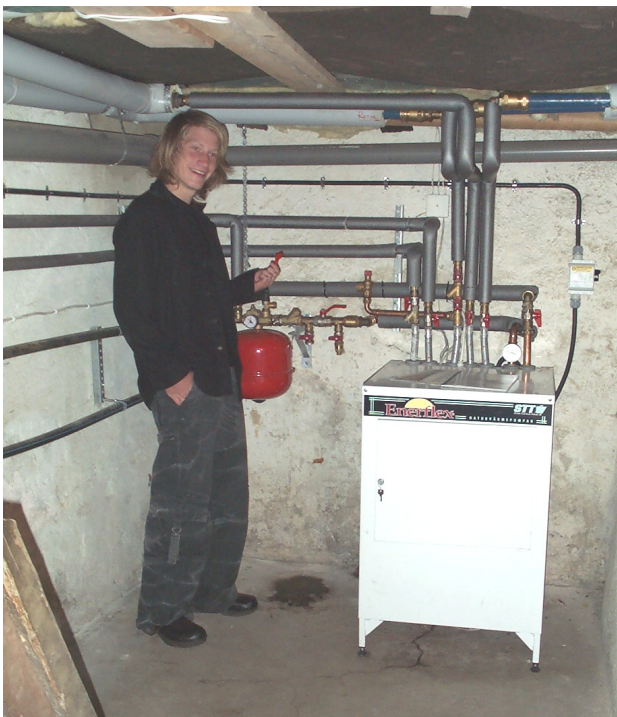


Fig. 3: Heat pump for a single family dwelling, where the connection for the systems, with the solar collector and the borehole respectively, are integrated within the cover of the heat pump.

3.3 The Building and the Heat Demand

The sizing of the heat pump depends on if it is included in an existing heating system or if it makes its own system. In the latter, the heat pump system also includes a hot water heater and an electric booster, which provides the auxiliary heat when the load is larger than the heat pump can provide during cold days. If there is already another boiler, this can be used for the auxiliary heat.

What is most important to consider for installations with heat pumps in older buildings, is that modern heat pumps for single family dwellings are designed for a low temperature system in the building. This means that the maximum outlet temperature from the condenser is often about 55°C with a return temperature of 45°C, compared to older systems with 80/60°C in forward and return pipes respectively. The result can be that the radiators in the building have an undersized heat transmission capacity, and cannot maintain the desired value for the indoor temperature during cold days.

3.4 Unglazed and Glazed Solar Collectors

Depending on the type of solar collectors used in the system, the solar heat can be used in several ways. For unglazed solar collectors, the heat can be used either to increase the temperature to the evaporator or for recharging the borehole. The simplest way is to connect the solar collector to the return pipe from the evaporator back to the borehole. Figure 4 shows one system available on the market.

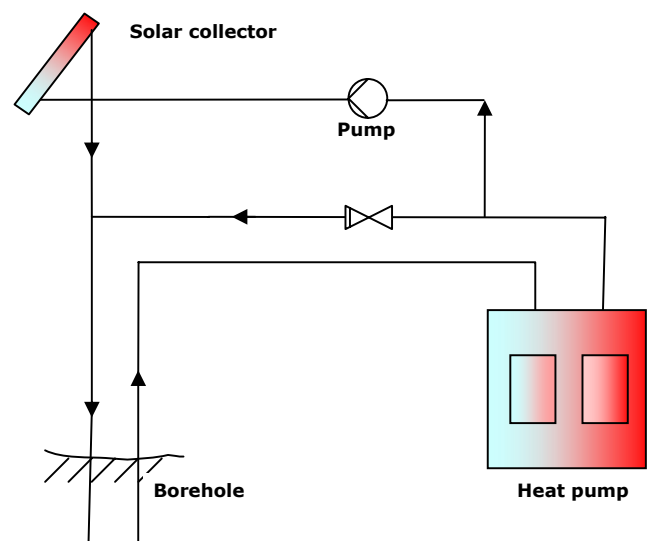


Fig. 4: Unglazed solar collector recharging the borehole.

With the system shown in figure 4, the risk of getting high temperatures from the solar collector to the evaporator inlet is low, as the solar heat always passes the borehole before the heat pump. There is normally a maximum limit on the evaporator inlet temperature around 20°C. The heat pump operation will stop if this limit exceeds. When using glazed solar collectors, one possible system is to only use the solar collectors for domestic hot water, see figure 5.

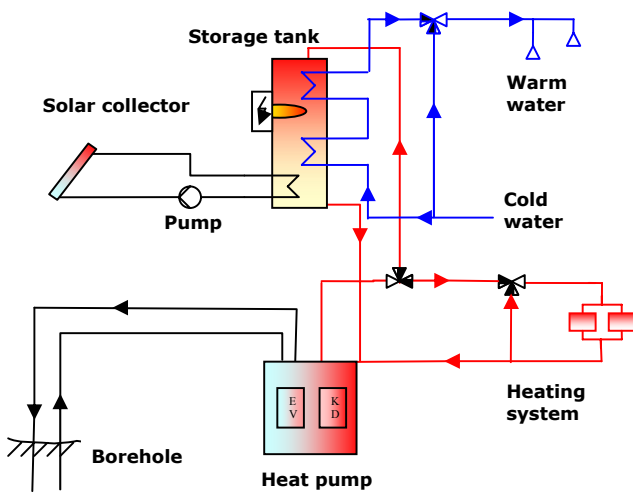


Fig. 5: System with a heat pump and glazed solar collectors, only used for heating domestic hot water.

In the system in figure 5, the heat pump is used for all of the heating and as auxiliary heating for the domestic hot water, when the solar collector is not able to cover to total demand. The operation time of the heat pump decreases as the solar collector produces the hot water during the summer and the heat pump can be shut off. This gives the borehole a natural recharging and may give the heat pump a longer life time, as the summer operation with many starts and stops is reduced to a minimum. The seasonal performance factor (SPF) of the system is also increased, as the heat pump has a shorter operation time and that the temperature in the borehole is higher, compared to a conventional system without solar collectors.

3.5 System with Flexibility

With glazed solar collectors, the solar heat can be used also for more than heating domestic hot water, either when there is no demand for hot water, or when the irradiation is not high enough to reach the needed temperature. With a system

as in figure 6, there are possibilities to use solar heat also to heat the building, the evaporator or the borehole.

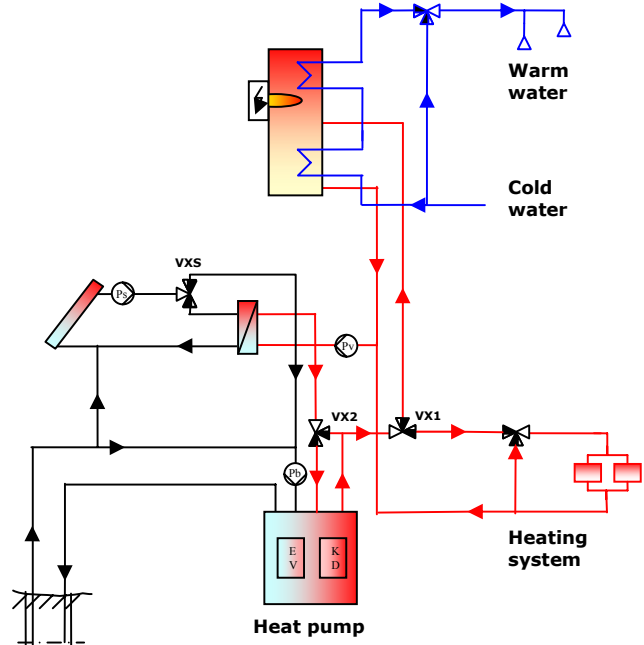


Fig. 6: System with a heat pump and glazed solar collectors with possibilities to use solar heat for heating domestic hot water, the heating system in the building, the evaporator in the heat pump or recharging the borehole.

The solar collector circuit and the borehole circuit in the system in figure 6, are linked together with an antifreeze liquid with an external heat exchanger for the water in the heating system.

Compared to conventional solar collector systems, mainly used for domestic hot water, the solar collectors used in combination with heat pumps, can be used with lower system temperatures. The advantages are that the solar collectors can produce more heat, due to longer operating time and reduced heat losses, because of the lower temperature in the collectors and the system. If the solar collectors are used for increasing the temperature to the evaporator, the efficiency is improved for the collectors, and at the same time, the coefficient of performance (COP) for the heat pump is also increased.

The disadvantage with the combination of solar collectors and ground-source heat pump is primarily the investment costs, which increases with the complexity. Also the cost for operating the circulation pumps increases, as the operating time is extended. The conventional circulation pumps in

both the solar collector circuit and the borehole circuit, have a low investment cost, but also a low efficiency. This means that the regulation of the pumps must be optimized for the overall system performance.

4. SIMULATIONS

Simulations for the combination of solar collectors and ground-source heat pump have been performed for a single family dwelling. The solar collector area varied between 0 and 14 m² and the borehole depths between 100-160 m. The simulations were carried out with the computer program TRNSYS 15 (with IISiBat) and about 20 TRNSYS Types were used to build up the system for simulation. So far only weather data from Stockholm has been used and the presented results are from the third year of operation.

One objective was to find out the benefits on the heat pump operation of solar recharge of the borehole. If all collected solar heat is delivered to the borehole circuit, the maximum increase of the inlet evaporator temperature is achieved. The result from the simulation, with a system as in figure 6, shows that the energy weighted temperature to the evaporator, for the whole year during the time when the heat pump is in operation, will increase about 2,5 – 3,5°C with 14 m² solar collector, compared to a system without solar collector. The highest increase is for the shortest boreholes, which have a lower temperature, compared to deeper boreholes, with the same load. This possibility can be used for undersized boreholes to compensate an increased load.

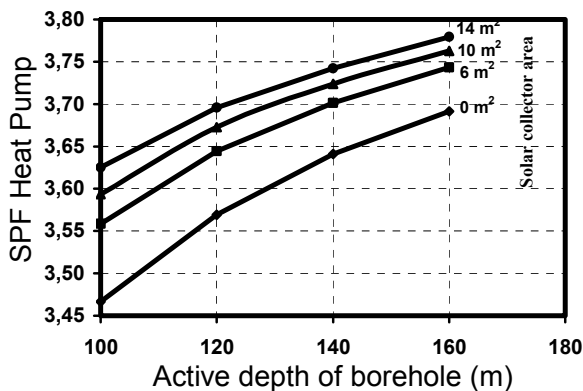


Fig. 7: Seasonal performance factor (SPF) for the heat pump, with and without solar heat (glazed solar collectors, m² collector area) for recharging the borehole, for different depth of boreholes (m), but the same load. The SPF is not including the use of electricity for circulation pumps and auxiliary heat.

For the type of heat pump used in conventional systems, the increase in the temperature to the evaporator gives a corresponding increase of the coefficient of performance (COP) for the heat pump, with about 1,5%/°C or for the thermal output about 3,5 %/°C. For the seasonal performance factor (SPF), the corresponding increase shows in figure 7. The seasonal performance factor in figure 7, is calculated as the ratio between the produced heat over the year and the used electricity in the compressor. This means that electricity for circulation pumps and auxiliary heat is not included. For the simulated systems, the increase in SPF is about 0,1 – 0,2 depending on different depths of the boreholes.

Calculations, also including the electricity use for the pumps and auxiliary, shows that the total use of electricity may exceed the advantage with recharging and gives a lower total system seasonal performance (SPF) compared to systems without solar collectors.

5. CONCLUSIONS

Recharging with solar heat is an alternative to improve the temperature to the evaporator in a system with ground-source heat pump, especially when the system is undersized with too short active boreholes. Recharging may also be necessary in areas where the ground-source heat pumps are so close that they influence each other.

With the systems available today on the market, there is a need for optimizing the energy flows for the whole system. Otherwise there are risks that the use of electricity for the circulation pumps will exceed the benefit of the recharging. Further simulations will be made, but it is already clear that the more efficient circulation pumps that now are being introduced into the market, seems to be definitely profitable within a few years in operation.

6. ACKNOWLEDGMENTS

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5. REFERENCE

1. E. Kjellsson, "Solar Heating in Dwellings with Analysis of Combined Solar Collectors and Ground-source Heat Pump" (in Swedish), Report TVBH 3047, Dept. of Building Physics, Lund University, Sweden, 2004. (Possible to download in pdf format from: www.byfy.lth.se/Publikationer/3000.htm)