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A VERY LARGE DISTRIBUTED GROUND SOURCE HEAT PUMP PROJECT FOR DOMESTIC HEATING: SCHOENMAKERSHOEK, ETTEN-LEUR (THE NETHERLANDS).

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ABSTRACT

Schoenmakershoek is a new development, of about 1400 houses, located in the southwest Netherlands (province of Brabant) to the north of the municipality of Etten-Leur. An Energy Vision was developed by the municipality from the onset of the project, and heat pumps are an integral part of this "all electric" energy-neutral vision. Etten-Leur has a high ambition level with respect to the use of renewable energy: the long-term policy of Etten-Leur is to achieve energy-neutral building for new developments by 2020. Within the framework of this long-term policy the goal is to attain 40% energy neutral housing projects by 2010.

To successfully realize such a large scale, high density ground source heat pump project, it is paramount to pay special attention to the feasibility, performance, long-term sustainability and installation quality. The conditions for the design and implementation of individual heat pump systems (typically consisting of 50 - 100 units each) within the total plan project needs to be well defined. Therefore, after the preliminary general feasibility study had been carried out, a second phase was entered where especially the feasibility of long-term use of ground source closed loop heat pump technology was evaluated.

Principal questions included how the large number of heat exchangers affect each other within the plan area, if - given the configuration - cold zones would develop and if ground water flow would play any role in heat transport on the location. To address these questions a large scale simulation was carried out using the 2D simulation code HST2D, with a realistic heat exchanger geometry consisting of two submodels of about 1000 heat exchangers each and incorporating heat conduction as well as ground water flow as a heat transport mechanism. Several energy scenarios were evaluated and finally the conditions for sustainable use of the ground for heating were defined using this study. Subsequently three trial boreholes were drilled and ground water observation wells were installed at depth of the two main aquifers to allow ground water measurements. A heat exchanger installed was in two of the boreholes as well. In addition to the detailed soil stratigraphy and depth of aquitards, two In Situ Response Tests yielded high-quality information on the thermal characteristics of the soil. Measurements of ground water gradient led to an accurate assessment of ground water flow on the location.

These technical data now form the backbone for the implementation phase of the project, allowing clearly defined design conditions in terms of minimum temperature levels that must not be exceeded as well as thermal balance that need to be achieved.

Within the feasibility and technical studies it has been shown that very large scale and high density (in total about 2500 heat exchangers will be installed) ground source heat pump projects are feasible when the design takes into

account proper design conditions. When clear goals are set, and specifications concerning the thermal performance as well as mechanical installation quality are defined, an environmentally friendly and sustainable use of the ground can be made for heating and cooling applications. In addition to achieving significant savings on primary energy use and greenhouse gas emissions, these systems will provide a high level of comfort and are expected to last for a long time into the future.

1. INTRODUCTION

The project "Schoenmakershoek", being realized in the municipality of Etten-Leur in the Netherlands (figure 1), is nominated for the National Energy Future Trophy 2006. Awarded by the ministry of VROM (Ministry of Housing, Spatial Planning and the Environment), the Trophy aims to stimulate initiatives within the scope of energy-conscious living and working. The project Schoenmakershoek is the first to apply heat pumps on a very large scale (1,400 dwellings) and is part of the energy ambition of the municipality, which aims to have only fully energy balanced new developments by 2020.

In view of the need for reducing the use of primary energy sources and greenhouse gas emissions and of the fact that a significant proportion of energy-use concerns space heating and cooling, the energy-efficiency of buildings is a "hot" theme. One of the technologies to reduce primary energy use in buildings is the application of Ground Source Heat Pumps (GSHP). As the electrical energy needed to drive the heat pump is only a fraction of the thermal energy exchanged, GSHP's can contribute significantly to the reduction of primary energy use. GSHP systems are quite successful, as is shown by the numbers of installed units in the USA (more than 900,000 units installed), Sweden (± 275,000 heat pumps installed for residential houses), Germany (over 50,000 units), Switzerland (more than 40,000 units installed) and for instance Austria (over 35,000 units).

In the Netherlands, Ground Source Heat Pumps for heating and domestic hot water production are currently gaining wider acceptance. Although the total number of heat pumps sold each year is still far less than in e.g. Austria or Sweden, the projects realized are often of a considerable size. Projects of 50 - 100 dwellings, all in a compact space, are becoming more and more common and a number of projects comprising 200 - 300 houses have been realized as well. In principle two types of GSHP systems can be distinguished: projects using ground water (aquifer thermal energy store, ATES) as a source for the heat pump and projects using ground heat exchangers installed in vertical boreholes (borehole heat exchanger thermal energy store, BTES). Due to space limitations horizontal heat exchangers are not very common in the Netherlands. During two workshops organized by the SenterNovem (2004/2005) an international panel of experts discussed both the long-term performance of heat pumps and the specific experience with ground source heat pumps. The main conclusions from these workshops were that heat pumps, if properly designed and installed, "function reliably and show enduring performance" and that the main bottlenecks are not of a technical nature but due to "an inadequate development of the market infrastructure".
Municipalities can play a major role in the definition of new developments, especially with regard to policies of climate change, energy savings and sustainable project-development. The municipality of Etten-Leur (Netherlands) was among the first to define very ambitious goals for energy consumption. In fact, the goal set by the municipality is to achieve fully energy-balanced new developments by 2020. Already in 2010 40% of all new construction needs to be energy-balanced. Schoenmakershoek is a new development currently being realized, of about 1400 houses, to the north of the municipality of Etten-Leur. From the onset of the project an Energy Vision was developed by the municipality, and heat pumps are an integral part of this "all electric" energy-neutral vision.

Figure 1. Location of Etten-Leur and the development "Schoenmakershoek".

To successfully realize such a large scale, high density ground source heat pump project, it is paramount to pay special attention to the feasibility, performance, long-term sustainability and installation quality. One of the principle questions was what boundary-conditions should be defined for the individual heat pump installations to ensure that at the project level all systems will achieve a specified Seasonal Performance Factor. Groenholland was contracted to conduct this feasibility study for the municipality.

The goal of the study was to investigate the large-scale and long-term effects of the application of ground source heat pumps, to provide information on thermal soil conditions as well as guidelines for individual system design and to provide a general framework for evaluation of the individual system designs.

2. METHODS

The feasibility study has been mainly based on two types of model calculations. First of all, a general design study of a number of reference dwelling types using state of the art borehole heat exchanger design software Earth Energy Designer (Eskilson et al 2000), mainly used for the evaluation of different energy-usage profiles. This software facilitates rapid calculation and evaluation of different scenarios of borehole heat exchangers systems consisting of a maximum of 120 individual heat exchangers. Borehole heat exchanger construction was chosen in such a way as to be representative both of low-resistance boreholes (borehole resistance 0.08 - 0.10 K/(W/m) and for high-resistance boreholes (e.g. with a complete bentonite filling, borehole resistance 0.17 0 0.19 K/(W/m)). Average borehole resistance was 0.13 K/(W/m). Both the average and peak-load behaviour of the system was considered.

The large-scale thermal response of the system and possible effects of groundwater flow were investigated using the 2- and 3Dimensional numerical finite difference (FD) code HST2D/HST3D (Heat and Solute Transport Program), developed by the US Geological survey (Kipp 1986).
Principal questions included how the large number of heat exchangers affect each other within the plan area, if - given the configuration - cold zones would develop and if groundwater flow would play any role in heat transport on the location.

For a borehole heat exchanger design calculation information is needed on the geology and thermal properties of the soil at the location, of the borehole heat exchanger construction, of the energy-use profiles and of the heat pump characteristics. All information was taken form existing literature sources. The energy-use profiles were obtained first from a previous study (Ecofys, 2002), later augmented by monitoring data (Dubotechniek, 2005).

During a later stage three test boreholes were drilled on the location. One of these boreholes was drilled using a cable tool technique, yielding a high quality description and samples of the geological profile. A borehole heat exchanger was installed in two of the boreholes and a Geothermal Response Test (van Gelder et al 1999, Witte et al 2002) was performed on each of those. In all three boreholes observation wells were installed to measure the hydraulic gradient on the location. The findings of this investigation were used to evaluate the conclusions from the feasibility study.

3. RESULTS

The geology of the location consists of two aquifers separated by a impermeable layer at depths around 100 meters. The aquifers consist of medium fine to coarse sands, sometimes with some intercalated clayey layers. At greater depth the geohydrological base, consisting of impermeable clays, is found. Groundwater movement was estimated to be around 5 - 10 meters/year in the freatic zone and around 5 meters per year in the first aquifer. A soil conductivity value ranging between 1.96 - 2.37 W/mK was estimated based on the geological information. The heat capacity was estimated to range between 2.06 - 2.50 MJ/m^3/K and the soil temperature range between 8,0 - 11,0 ^{o}C. Results form the Geothermal Response Test performed later were a conductivity of 2.23 W/mK in the first and 2.0 W/mK in the second borehole, average soil temperature at depths below 10 meters was 9.3 ^{o}C.

Results from the Ecofys study identified thee dwelling types, apartment building, terraced houses and semi-detached houses, each with several possible standards of energy-efficient construction. In the final analysis however, information on the energy usage profiles of a number of monitored houses was used, especially as variations in occupants behaviour is better represented in that dataset (data made available by Dubotechniek, 2005). Monitoring of all these houses was done based on the monitoring protocol for heat pump systems developed by TNO (Traversari & Geelen 2001). The type "apartments" was excluded as the use of individual heat pumps is not considered for that building type, and a type "detached house" was included. As both the Ecofys study as well as the monitored houses have no or very little cooling demand, the dataset was extended by defining three levels of recharge load: no recharge load, 50% recharge and 70% recharge load. This is important, as the recharge load will compensate the thermal extraction done during the heating season and thereby help to prevent thermal depletion. Recharge can be provided by "free cooling" at very high COP (only circulation pump active) or by a heat recovery unit in the ventilation shaft, the complete recharge load is therefore directly transferred to the ground. Thermal loads are presented in table 1.

Based on general heat pump capacities and specification, temperature design limits were set at 0 ^{o}C minimum average circulation fluid temperature. The principal design parameters are summarized in table 2.

Dwelling type	Peak capacity (kW)	Heating (MWh)	Recharge 0% (MWh)	Recharge 50% (MWh)	Recharge 70% (MWh)
Detached	8	13.42	0	6.71	9.39
Semi-detached	6	8.49	0	4.25	5.94

Terraced	4	6.84	0	3.42	4.79

Table 1 Total heating and recharge demand and peak capacity for three different dwelling types. Heating loads based on monitoring data, recharge loads defined for the purpose of this study as a percentage from the heating load.

PARAMETER	Detached	Semi-detached	Terraced
Peak capacity heat pump (kW)	8	6	4
COP heat pump (heating)	4.5	4.2	4.0
System flow (m^3/hour)	1.15	1.14	1.05
ΔT borehole heat exchanger (K)	4.75	3.5	2.5
Number of houses in calculation	1	2	10

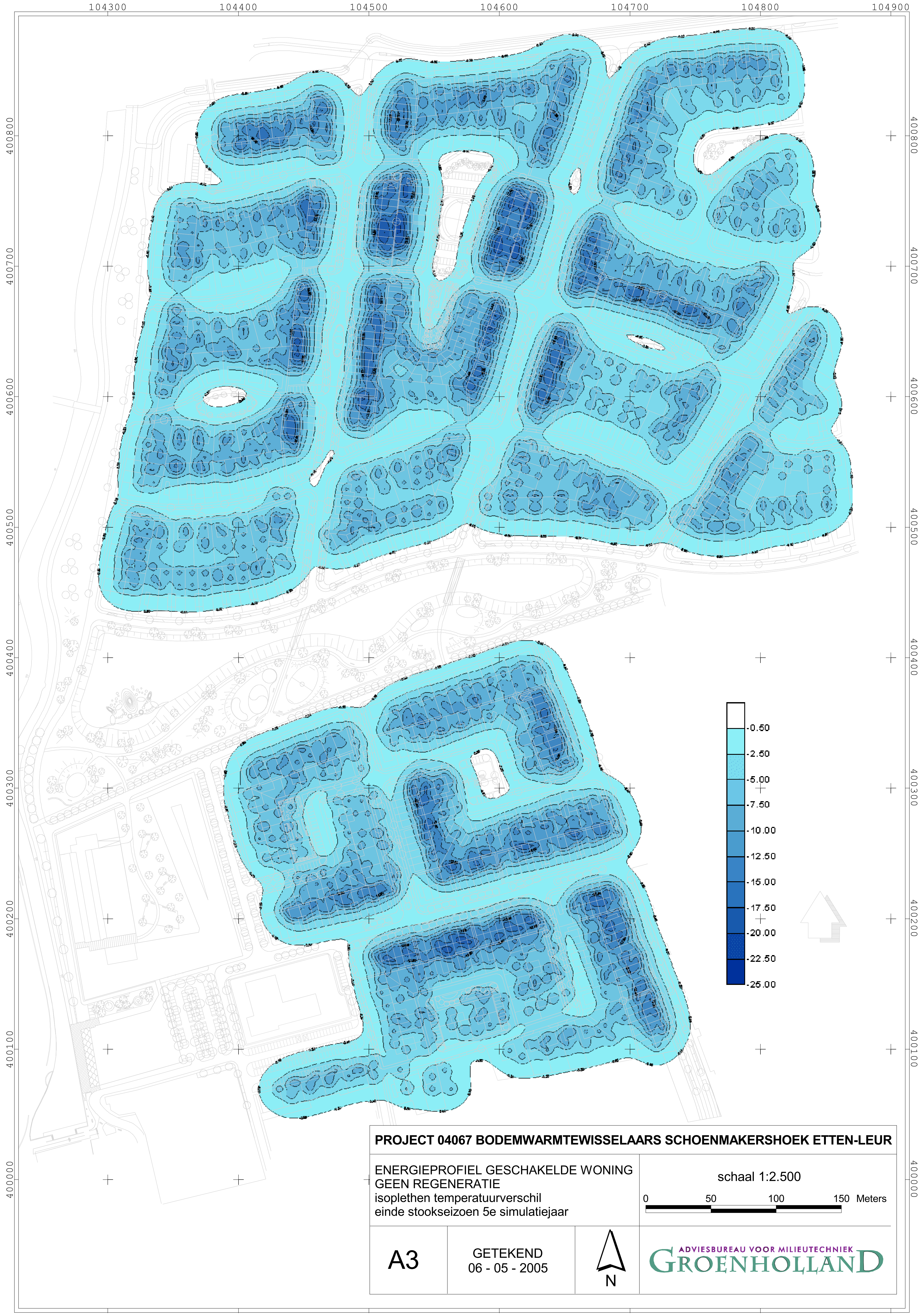
Table 2 Heat pump data and temperature design limits. Recharge is provided at very high COP (only circulation pump active), recharge loads are translated directly to the ground.

Using this information a general design of the borehole heat exchangers was made using the program EED where the maximum drilling depth was set at 120 meters, results are given in table 3. Clearly, any recharge load will significantly reduce the total length of heat exchanger needed. Especially in the terraced dwelling type, where the heat exchangers are relatively close together, the effect is large (33% and 45% reduction in size). However, this general design does not take into account any large-scale effects. Based on the results obtained with EED all heat exchangers were 100 meters long, with three heat exchangers for the detached houses and two for the semi-detached type and terraced houses type. All heat exchangers are located in the gardens of the houses, situated towards the rear of the house. As it was not practically possible to enter different load profiles for the individual heat exchangers in the numerical model, several runs were preformed with all heat exchangers experiencing the same load profile. The load profiles simulated were limited to detached (biggest heat extraction) and terraced house types (smallest heat extraction).

Dwelling type	Recharge 0% (bww m)	Recharge 50% (bww m)	Recharge 70% (bww m)
Detached	3 x 108 (324)	3 x 97 (291)	3 x 92 (276)
Semi-detached	2 x 115 (230)	2 x 98 (196)	2 x 92 (184)
Terraced	2 x 87 (174)	2 x 58 (116)	2 x 48 (96)

Table 3 General design borehole heat exchanger for all three dwelling types and recharge-load scenario's. Number of borehole heat exchangers and depth of individual heat exchangers is given. Total length required is indicated between parentheses.

Figure 2 Change in temperature after 5 years of simulation, energy use profile terraced house type with 0% recharge load (6.84 MWh heating, 0 MWh recharge load).



PROJECT 04067 BODEMWARMTEWISSELAARS SCHOENMAKERSHOEK ETTEN-LEUR

ENERGIEPROFIEL GESCHAKELDE WONING
GEEN REGENERATIE
isoplethen temperatuurverschil
einde stookseizoen 5e simulatiejaar

schaal 1:2.500

0 50 100 150 Meters

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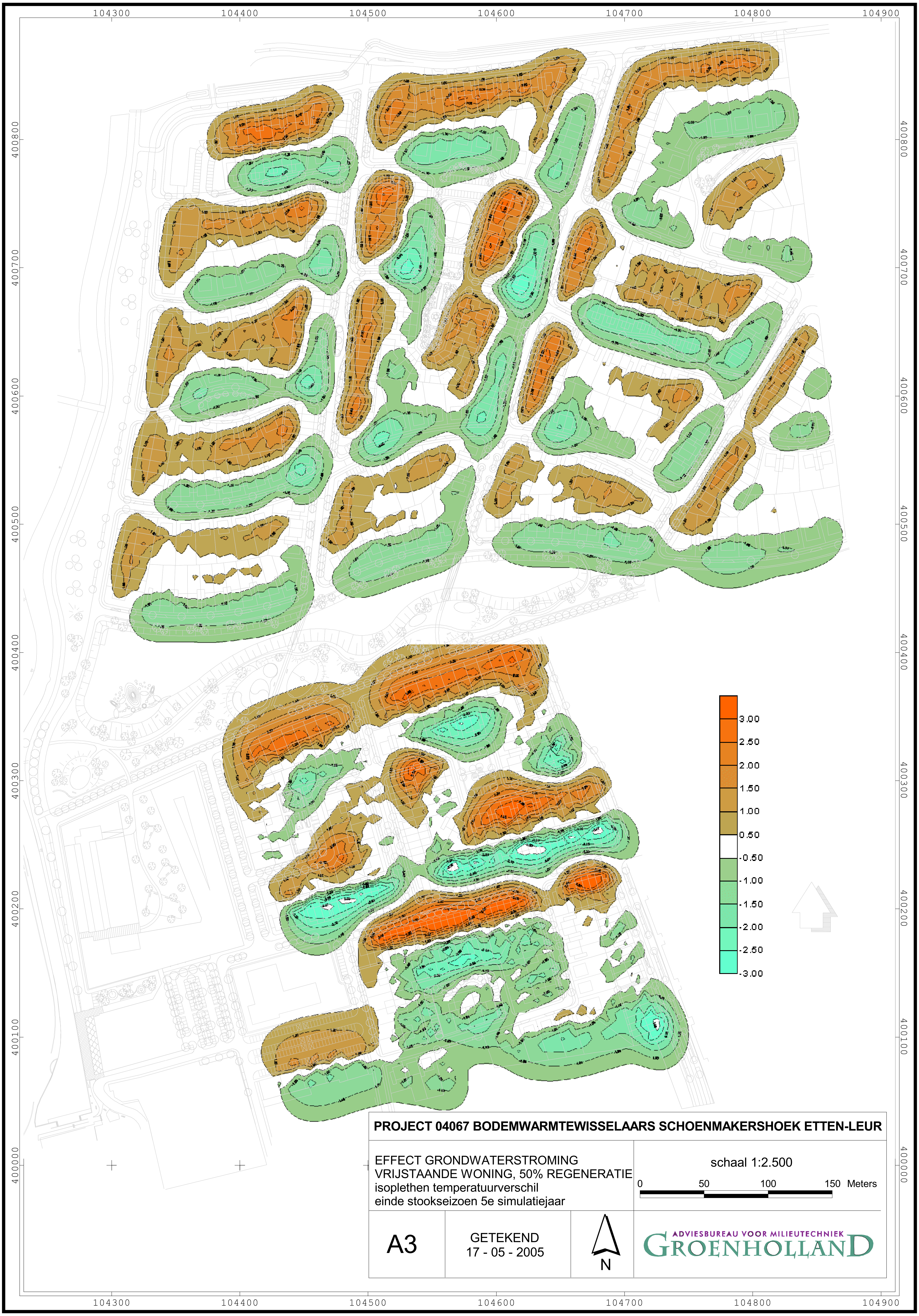
Figure 3 Effect of groundwater flow, temperature difference between simulation with and without groundwater flow. Energy usage profile detached, 50% recharge.



PROJECT 04067 BODEMWARMTEWISSELAARS SCHOENMAKERSHOEK ETTEN-LEUR

EFFECT GRONDWATERSTROMING
VRIJSTAANDE WONING, 50% REGENERATIE
isoplethen temperatuurverschil
einde stookseizoen 5e simulatiejaar

schaal 1:2.500

0 50 100 150 Meters

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From the analysis (figure 2) it was clear that large scale effects are present even for the energy-usage profile with the lowest load, especially in regions where the local density of heat exchangers is high for instance due to the fact that the houses where the back yards face each other and are relatively close together. When no heat is restored to the ground in summer, temperatures in a five-year simulation decline in some places by 20K. Given an undisturbed ground temperature of 9.3 ^{o}C the temperature drop should not be larger than about 10K, this is achieved only for simulations with a recharge of at least 70% of the heating demand. As the heating is generated with a COP between 4.5 and 4, while the recharge load is transferred directly to the ground, in practice this means that in the ground there is an almost complete energy-balance.

Subsequently the possible effects of groundwater flow were evaluated, the maximum temperature changes were calculated by using the detached energy-usage profile with 50% (figure 3) and 70% recharge. In the energy-usage profiles with 50% recharge load effects were on the order of ± 3K while in the scenario's with 70% recharge load (energy balance in the ground) the effect was reduced to ± 1K. From the figure 3 it is evident that there is an interaction between the seasonal operation of the store and the groundwater flow, creating alternating bands of areas with higher and lower temperatures. Because the effects in the scenario with 70% recharge are small, the groundwater effects were not investigated in more detail.

Results from the two Geothermal Response Test's carried out on the location showed that there is a considerable variation in the conductivity, a soil thermal conductivity of 2.00 W/mK was found in one test while the second test showed a conductivity of 2.23 W/mK. Due to the very high density of the borehole heat exchangers and the need for achieving some level of energy-balance in the ground, the conductivity values do not affect so much the total length required for each individual heat exchanger system, but do affect the minimal and optimum distance between adjacent heat exchangers. The effects of the different conductivities were investigated in a sensitivity study. The conclusion was that for the scenarios with recharge loads the effects were small enough (< 1K) to be ignored when the average conductivity value is used in the calculations.

4. DISCUSSION AND CONCLUSIONS

The Dutch government has set a goal for the sustainable use of energy in the Netherlands of 10% by 2020. The ground is recognized as one of the sustainable energy sources that are available for space heating and cooling. The municipality of Etten-Leur has set as a goal that all newly constructed buildings and houses should be completely energy-balanced by 2020, by 2010 already 40% of the new constructions should comply with this ambitious goal.

The feasibility and technical studies have shown that very large scale and high density (in total about 2500 heat exchangers will be installed) ground source heat pump projects are feasible when correct design conditions are taken into account. Important in this respect is the realization of sufficient recharge or regenerative heat production during summer to offset winter extraction and prevent any trend of long term cooling. Experience has shown that using the under floor heating system for passive cooling during summer is very effective. In addition heat recovery units can be installed in the central ventilation shaft. Finally, there is an option of applying thermal solar panels to generate heat for recharging.

Although a number of environmental issues were raised with respect to the large number of boreholes drilled and the use of anti-freeze mixtures, especially as there is as yet no clear legislation or policy guideline, these questions could be adequately addressed by referring to the pertinent technical quality guidelines, such as the Quality Guideline Vertical Ground Heat Exchangers (Novem 2003), guidelines for Subterranean Energy Storage (NVOE 2001) or the Evaluation guideline for Environmental Soil Studies (SIKB 2000). Moreover, the municipality of Etten-Leur defined a number of specific pre-requisites for the practical implementation of the project by commercial parties, these included:

- Clear guidelines for the implementation of balanced ventilation with heat recovery.
- Use of a heat pump for space heating and domestic hot water, that has been quality-certified by the Dutch Heat Pump association
- Noise emissions better than 45 dB(A
- COP for space heating at least 4.9 at design conditions, at least 2.1 for DHW production
- Free cooling option standard, including control system to prevent condensation on the floor
- Borehole Heat Exchanger designed and constructed according to the 2DEN-03.24 Quality Guideline
- Average fluid temperature should not drop below 0 ^{o}C.
- At least between 50 - 60% of the heating demand of the house needs to be recharged to the ground, in practice this means there will virtually be a seasonal thermal energy balance in the ground.

To ensure that the individual projects comply with the requirements a certificate based on a qualitative checklist is currently being developed.

When clear goals are set, and specifications concerning the thermal performance as well as mechanical installation quality are defined, an environmentally friendly and sustainable use of the ground can be made for heating and cooling applications even for very large scale projects. In addition to achieving significant savings on primary energy use and greenhouse gas emissions, these systems will provide a high level of comfort and are expected to last for a long time(50-100 years) into the future.

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