CASE STUDY OF A BTES AND ENERGY PILES APPLICATION FOR A BELGIAN HOSPITAL

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1. INTRODUCTION

The European Parliament has recently adopted a directive on energy efficiency in public buildings with the objective to control and reduce the energy consumption of public buildings by 20% by the year 2020 (European commission 2005). One example of such public buildings is the health sector (hospitals, rest homes, etc.). The energy use in the Belgian health sector amounts to 1,505 GWh/year electricity (8% of service sector electricity consumption) and 16.3 PJ/year fuel (10% of service sector fuel consumption) (Aernouts 2005).

To reduce greenhouse gases (GHG) emitted by heating and cooling plants the health sector needs to shift away from the use of conventional techniques towards more ecological, renewable energy sources. With the use of renewable energy sources the consumption of “classical” energy sources can be reduced and these sources can be maintained for other more energy-intensive applications where renewable energy sources are less suitable. To meet the requirements of the European Parliament and to meet the Kyoto protocol the Flemish government has adopted several energy saving recommendations for new and renovation projects in the health sector. One of these measures is that a COP _cooling_ of at least 5 has to be reached when new cooling installations are placed in hospitals. BHEs and GSHPs can achieve easily these recommendations.

In recent years VITO carried out several case studies in the health and commercial building sector on GSHPs with vertical BHEs (Desmedt 2005, Hoes 2005). In the present situation, only a few demonstration BTES systems are planned in Belgium (2006) resulting out of these case studies. A high temperature (> 50°C) BTES with 144 BHEs (depth 30 m) is in operation and demonstrated at the site of VITO (Belgium) and is monitored in a 5th European framework research project TESSAS (Hoes 2004).

This paper provides an overview of the results from a case study for a Belgian hospital concerning the energy savings, economic savings and environmental benefits offered by using vertical BHEs and energy piles (EPs) in combination with GSHPs.

2. DESCRIPTION OF CASE STUDY

The health sector in Belgium is characterized by a high, continuous and simultaneous heating/cooling demand. Furthermore the energy costs take an increasing part of the operational costs. Hospitals are large consumers of electricity, heating and especially cooling energy. Since recent years the demand for cooling in patient rooms has tremendously increased due to the higher internal heat production of medical equipment and (higher) comfort requirements of patients and staff. Therefore the health sector is continuously searching for techniques to produce on an energy-efficient way cooling and heating. The use of BHEs in combination with GSHPs gives possibility’s to reduce operational costs of the hospitals.

For a hospital at the coast region of Belgium with 600 beds and a net floor area of 59,000 m² a case study was made (Hoes 2005). The hospital has made a master plan with a description of future building plans. In the framework of this master plan a new hospital will be build in 2006 where a part of the heating and cooling demand are supplied by
BHEs, EPs and GSHPs. When using the underground for cooling purposes the focus lies on top cooling, the delivered temperature regime in the summer period of the BHEs is too high (14/18°C) for deep cooling purposes such as cooling of surgery rooms. For deep cooling a typical temperature regime of 6/12°C is needed and can be delivered by compression chillers. In the case study the focus lies on top cooling.

**Temperature data analysis**

The heating and cooling plants in hospitals are for a large part operating primarily dependent on climatic conditions. The annual mean temperature in the coast region is about 10.2°C with a standard deviation of about 6.5°C. The distribution of minimum, maximum and average monthly outside temperatures for a reference year are shown in Figure 1. Figure 2 shows the annual outside temperature duration curve at the location for the reference year.

![Figure 1: Minimum, maximum and mean outside temperature at the location (reference year)](image1)

![Figure 2: Annual outside temperature duration curve at the location (reference year)](image2)
Analysis of heating and cooling power

From the engineering company the maximum heating and cooling powers were obtained. The maximum predicted heating power amounts to 4.5 MW. The low temperature power demand of the air handling units (AHUs) amounts to 2.3 MW (51%) and the high temperature demand (radiators) amounts to 2.2 MW (49%). The heat in the patient rooms, consultation rooms, kitchen, etc. is distributed by radiators designed at a temperature regime of 80/50°C and supported by the AHUs. The heat pump cannot be used for the high temperature regime, gas-fired boilers needs to cover this demand. The low temperature heat is used in the ventilation installations and is typically suitable for use with the heat pump.

The predicted cooling power for the total hospital is 2.6 MW; 2.0 MW (77%) is used for top cooling (high temperature cooling) at a temperature regime of 14/18°C and 0.6 MW (33%) for deep cooling demands at a temperature regime of 6/12°C. The top cooling is used in patient rooms, kitchen, consultation rooms, etc. The deep cooling demand is especially needed in surgery rooms. Cooling air is delivered by the AHUs.

Description of soil characteristics

When designing BHEs with GSHPs the knowledge of ground thermal properties (thermal conductivity, borehole thermal resistance, undisturbed soil temperature, specific heat capacity, etc.) are important for correct functioning of the system. Due to the higher investments costs, over-sizing of BHEs and GSHPs pays a higher penalty than in conventional applications. Obtaining accurate values for thermal ground properties requires detailed survey on site by a thermal response test (Hoes 2004, Pahud 2001, Gehlin 1997). However in this case study, analytical equations were used instead of physical measurements to calculate the thermal properties of the soil (Hoes 2004). Parameters that can have an influence on the result are the building load, borehole spacing, borehole fill material and the on-site characteristics (Zeng 2003).

At the site of the hospital the soil consists mainly of heavy clay with minor parts of sand and silt and this at a maximum depth of 150 m. In the western part of Flanders the content of heavy clay is more present then sand layers. Based on our former experiences the thermal conductivity amounts to 1.7 W/m.K and the specific heat capacity to 2.45 MJ/m³.K. The undisturbed soil temperature is 11°C. The ground water level is at -1.41 m to 2.89 m reference.

3. RESULTS OF CASE STUDY

Designing values, assumptions and data

With energy storage systems determination of energy load and energy consumption of heating and cooling is much more crucial in conjunction with other conventional applications (boilers, compression chillers). Therefore an energy simulation in this case study was carried out. The hourly heating and cooling demand was simulated based on the assumptions made.

For the energy simulation the following numerical assumptions are made:

- compression chiller efficiency \(\text{COP}_c = 3.2\);
- heat pump efficiency \(\text{COP}_h = 4.1\);
- gas-fired seasonal thermal efficiency \(\eta_{\text{fb}} = 85\%\).

BHEs system design

Knowing the thermal ground properties one can start at designing BHEs and EPs. In this case study we used common simulation models for BHEs, EPs and GSHPs such as EED, Pilesim and TRNSYS. Based on the energy simulations a total of 688 EPs at a depth of 12 m and 60 BHEs at a depth of 120 m can be installed. The BHE storage is formed by 6 rows of 10 boreholes arranged in a rectangular pattern. The borehole spacing is 5 m and the borehole diameter is 160 mm. The polyethylene (PE) double U-tubes have an inside/outside diameter of 26/32 mm.
and a wall thickness of 3 mm. The EPs have an outside borehole diameter of 550 mm and are placed under the basement of the building. Just 4 of the 5 EPs are thermally activated. The lowest level of the hospital's basement is -4 m depth ensuring that the EPs are fully surrounded by water.

**Energy balance**

Figure 3 shows the predicted yearly duration cooling curve. Figure 4 shows the heating duration curve.

Based on the energy simulation the total (low and high temperature) heating demand of the hospital is calculated at 8,190 MWh per year, the total (low and high temperature) cooling demand is 559 MWh per year. By considering the heating and cooling demands the GSHPs and BHEs were chosen to cover a part of the cooling and heating

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**Figure 3: Yearly cooling duration curve**

**Figure 4: Yearly heating duration curve**
powers. A heat pump with a thermal heat power of 650 kW, (only 14% of the total heating power) can deliver 18% of the total heating energy demand of the hospital. When only considering the low temperature demand 36% is covered by the heat pump with only 29% of the total heating power. The EPs and BHEs deliver 78% of the total cooling energy demand of the hospital with only 30% of the total cooling power. The cooling by the BHEs and EPs is delivered at very high efficiency (only circulation pump in operation, no heat pump). For the total hospital an electricity saving on cooling of 56% can be reached. There is a change on focus from heating with natural gas towards electricity used by the heat pump. By using the heat pump a cost saving of 50% can be realized. On the total gas consumption of the hospital 18% saving is possible.

4. ECONOMIC ANALYSIS

Initially, the feasibility of each option has been assessed in terms of annual return, simple pay-back period, net present value and internal rate of return (IRR). Both the investment, maintenance and energy costs (electricity and natural gas) were calculated according to information obtained from the manufacturers and the owner of the hospital. The cost of electricity and fuel (natural gas) is a function of different parameters as consumption, daily/night use, etc. Prices of electricity and fuel are calculated from the actual energy costs of the hospital. The annual interest rate has been assumed to be 6% while Belgian taxes and/or fiscal/financial incentives were not considered. The net present value is calculated with 20 years of operating life. The installation of BHEs, EPs and GSHPs is evaluated against a reference installation with conventional technologies. Heating (and also sanitary hot water) is supplied by gas-fired boilers. Compression chillers satisfy cooling needs. This situation is what we call the “reference” installation. For the economic analysis, table 1 gives the adopted energy prices. The results of the economic analysis of case study 1 are shown in table 2.

Table 1: Electricity and natural gas prices (excluding taxes)

<table>
<thead>
<tr>
<th>Energy prices</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Electricity price day (€/MWh)</td>
<td>64.70</td>
</tr>
<tr>
<td>Electricity price night (€/MWh)</td>
<td>41.50</td>
</tr>
<tr>
<td>Natural gas price (€/MWh)</td>
<td>18.25</td>
</tr>
</tbody>
</table>

Table 2: Economic evaluation of BHEs, EPs and GSHPs

<table>
<thead>
<tr>
<th></th>
<th>Reference Installation (1)</th>
<th>BHEs + EPs + GSHPs (2)</th>
<th>Difference (2) - (1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy costs</td>
<td>222,004 €/y</td>
<td>200,524 €/y</td>
<td>- 21,480 €/y</td>
</tr>
<tr>
<td>Maintenance costs</td>
<td>27,864 €/y</td>
<td>20,175 €/y</td>
<td>- 7,689 €/y</td>
</tr>
<tr>
<td>Annual costs</td>
<td>249,868 €/y</td>
<td>220,699 €/y</td>
<td>- 29,169 €/y</td>
</tr>
<tr>
<td>Investment costs</td>
<td>832,230 €</td>
<td>1,155,563 €</td>
<td>+ 323,333 €</td>
</tr>
<tr>
<td>SPB</td>
<td>-</td>
<td>11.1</td>
<td>-</td>
</tr>
<tr>
<td>IRR</td>
<td>-</td>
<td>7%</td>
<td>-</td>
</tr>
<tr>
<td>NPV</td>
<td>-</td>
<td>29,536 €</td>
<td>-</td>
</tr>
</tbody>
</table>

The total energy costs of the BHEs, EPs and GSHPs are € 21,480 (-10%) lower then in the reference installation mainly because of the reduction in natural gas (- € 31,240 per year). A part of the heat production is shifted from the gas-fired boilers to the heat pump and cooling energy is partly provided by the BHEs and EPs instead of classical chillers, saving a lot of electricity. Nevertheless the heat pump needs electricity (+ € 9,760 per year) but produces on the other hand cooling and heating at a higher efficiency. On the total exploitation costs (energy + maintenance costs) a reduction of € 29,169 per year or 12% can be realized in conjunction with the reference installation.

The BHEs and GSHPs needs a surplus investments of € 323,333 (+39%). A simple pay-back period (SPB) of 11.1 years, an internal rate of return of 7% and a net present value of € 29,536 can be realized with BHEs, EPs and GSHPs.
Sensitivity energy prices

A special attention is however needed towards the effect of increasing/decreasing electricity and gas prices in the near future. In the past year the gas price for hospitals in Belgium has increased with 20%. The electricity and gas prices have a large impact on the economic results. In the case study we have looked at 2 scenarios: one with electricity and gas prices increase/decrease with the same amount and a second scenario where only the gas price increased/decreased.

An increase of the gas- and electricity price with +15% moves down the SPB towards 10 years, a reduction of 1 year. If only the gas price amounts with +15% the SPB decreases to 9.6 year. The IRR amounts to 10% and NPV to € 83,283.

5. ENVIRONMENTAL BENEFITS

The CO$_2$ emission from each of the selected systems has been calculated in the case study. The following data were considered in the calculation of the environmental benefits:

- CO$_2$-emission factor electricity : 624 g/kWh,
- CO$_2$-emission factor natural gas: 181 g/kWh.

In the scenarios with BHEs, EPs and GSHPs the CO$_2$ emissions were lower compared to those from conventional installations. A CO$_2$ reduction of 152 tons per year can be realized or 7% in comparison with conventional applications.

6. CONCLUSIONS

This paper gives a look at the technical, economical and environmental benefits of BHEs, EPs and GSHPs for a Belgian hospital. Important factor of discussion is the calculation of the energy demand for heating and cooling. An over-estimation of the energy demand gives rather bad results, more expressively then with conventional installations (gas-fired boilers, compression chillers). The economic analysis showed that a reasonable pay-back period (< 10 years) can be achieved, CO$_2$ emissions can be saved compared to classic technologies.

BHEs, EPs and GSHPs are a promising technique for Belgian hospitals. The recent interest in renewable energies arouses this fact. In general one may conclude that application of BHEs, EPs and GSHPs in Belgian hospitals becomes a probably growing market.

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REFERENCES


