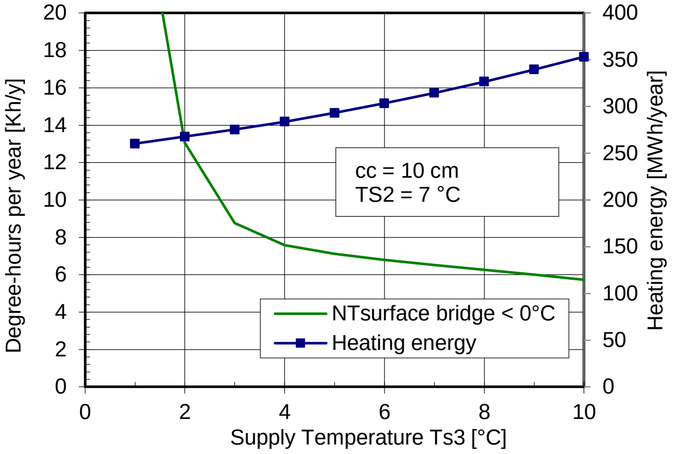

Figure 6: Variations of TS3 for fixed value of TS2 = 7 ℃, cc = 10 cm.

### 4.1.2 Variation of TS2 with different pipe spacing

The distance between pipes in the road (cc) is one of the major parameters in a HP system. In Figure 8 it could be seen how the spacing of pipes effects the value of NT for varying TS2. The simulation was done at a fixed fluid flow per square meter namely 77 (l/(h m$^2$)), as a way of keeping the temperature drop low between the supply and return flows. The results indicates that by decreasing the spacing of pipes, the value of NT will decrease. Decreasing the cc from 10 cm to 5 cm, the TS2 could be lowered by one degree to 6 °C with equal or better system performance. However, even for a spacing of 5 cm, lower values of TS2 than 5 °C would increase the value of NT substantially. Pipe spacing of 10 cm was chosen for further investigations due to the easier construction.

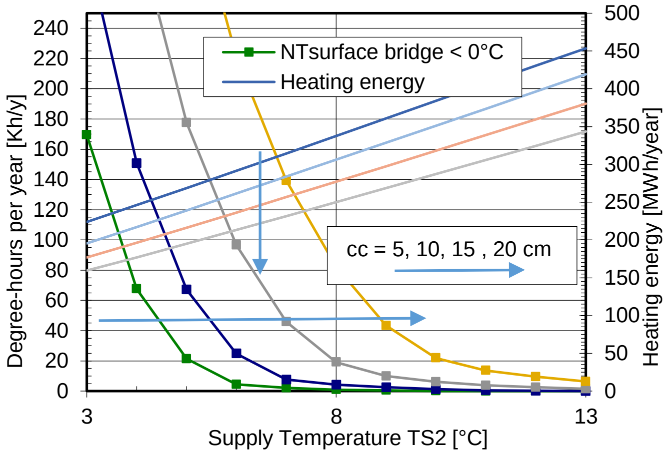


Figure 7: Varying pipe spacing for different TS2, fixed TS3 = 4 ℃.

### 4.1.3 Varying TS2 for different ground temperature $T_2$

The temperature under the road $T_2$ could either act in a positive or negative way for the system depending on the temperature $T_2$ and TS2. The simulations presented previously was made using a road model with insulation. However the influence of the ground temperature was studied by removing the insulation layer and varying $T_2$ for different TS2. Results from simulations with and without insulation is combined and they are presented in Figure 9. It could be seen that the effect of the ground temperature $T_2$ is limited and for temperatures of TS2 around 7 ℃ the effect on NT is neglect able. However, it could be seen that the required energy for an insulated ground, compared to uninsulated, is decreasing with increasing temperatures of TS2. That is, since more energy is required to heat the ground. From the results it could be recommended to avoid using insulation if the supply temperature is less than the ground temperature plus 2 °C. However further simulations with different thickness and placement of the insulation should be done to verify this conclusion.

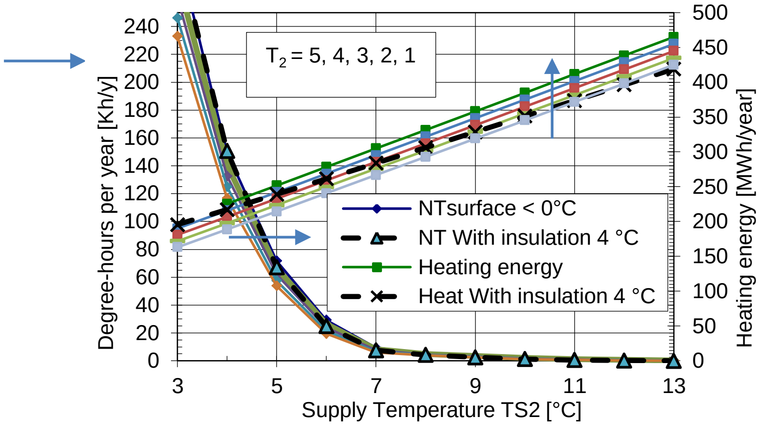


Figure 8: Varying ground temperatures $T_2$ for different TS2, fixed TS3 = 4 ℃, $cc = 10$ cm.

## 4.2 Design of BTES

The second design task was to design the borehole storage together with the controls for harnessing solar energy.

### 4.2.1 Varying Nbore for different thermal conductivity of the ground

The number of boreholes would directly affect the total borehole length, considering a fixed length of 200 meters for each borehole. The thermal conductivity of

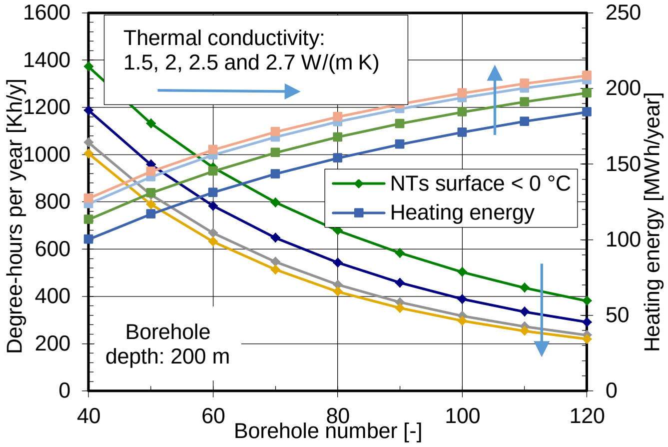


Figure 9: Varying thermal conductivity of the ground for different NBore, fixed NSerie = 3.

the ground in the area of the test site was rather low, 2 W/mK compared to the average for Sweden, about 3 W/mK. This is due to the rock type at the test site limestone and shale which have generally lower thermal conductivity than the crystalline rocks that dominate the bedrock of Sweden. However, the thermal conductivity was varied in the simulation to investigate the importance of that parameter. The results are presented in Figure 10.

The results presented in Figure 10 was done with 3 boreholes connected in series, DT1CST = 8 °C and DT0CST =4 °C. The results indicates the effect of the thermal conductivity on the value of NT, the degree-hours that the system fails to meet the demand. However, with a thermal conductivity of 2 W/m K at the test site and with these settings the required number of boreholes is approximately 100.

4.2.2 Harnessing control

The amount of solar energy stored into the BTES was controlled by the harnessing control settings. The simulations was done for a case with the borehole depth fixed to 200 m, ground thermal conductivity of 2 W/m K, NBore arbitrary selected to 90. The results of simulations are presented in Figure 11.

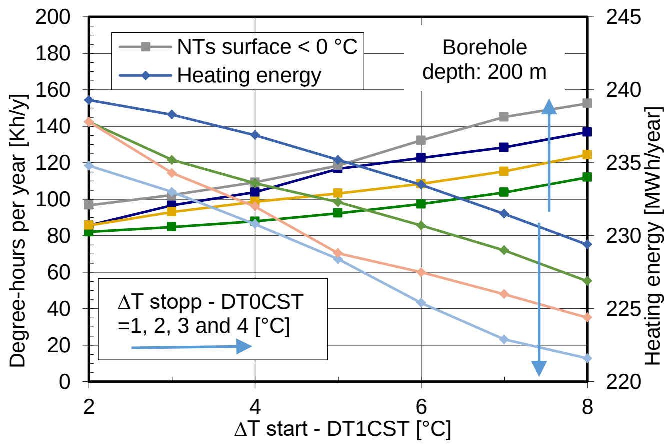


Figure 10: Varying settings for the harness control.

By increasing DT1CST from two to eight degrees Celsius it was found that the value of NT is increasing while the amount of energy for heating was decreasing. This means that less solar energy would be harnessed by increasing DT1CST. By studying the different values for DT0CST, it was found that a lower DT0CST would result in a

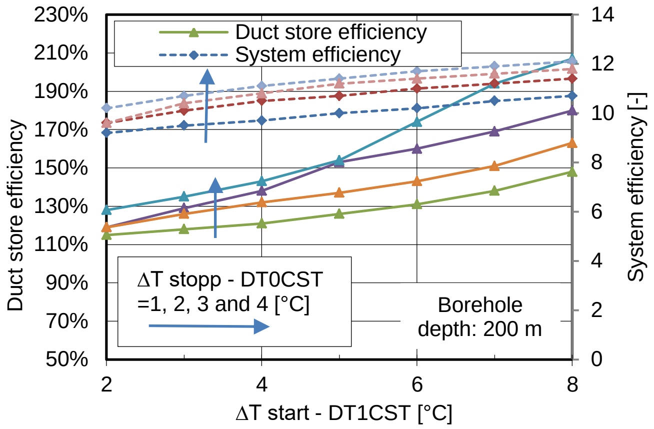


Figure 11: Efficiency for varying harness control settings.

lower value of NT and that more solar energy would be harnessed. However, by decreasing the control temperatures for harnessing, the efficiency of the system was reduced, see Figure 12. For the simulated system, DT1CST was selected to 4 ℃ and DT0CST to 2 ℃.

The duct store efficiency was calculated by dividing the energy extracted from the storage by the energy injected into the storage. The system efficiency was calculated by the energy used for heating the road surface divided by the energy need for the circulation pumps. Since increasing the starting temperature DT1CST, would decrease the number of hours that the pumps will be in operation thus, the system efficiency increases. Furthermore, by increasing the starting temperature, less energy would be harnessed from the sun which leads to more energy would be coming from the surrounding ground, thus increasing the duct store efficiency. For a system with a high content of harnessed solar energy the duct store efficiency should be less than 100 %.

### 4.2.3 Number of borehole in series and size of water tank

The results of the simulations of increasing the number of boreholes connected in series, NSerie, was low. There was a difference on the value of NT of about 10 when changing from one borehole in series to two boreholes. Further increase of the boreholes connected in series did not decrease the value of NT. From this results it could be concluded that at the simulated fluid flows there is no need to use more than 2 boreholes in series. Furthermore, when investigating the effect of altering the volume of the short term thermal energy storage tank it was found that it had a limited effect on the value of NT. Thus, for the case study of Östersund a small water tank of about 4.4 $m^3$ would be sufficient.

## 4.3 Summary of system design parameters

The results and conclusions from the simulations above are presented as parameter values in Table 3. Results from one simulation with the parameter values presented in Table 3 are shown in Figure 13. Results in Figure 13 indicates that in order to reach low values of NT more than 120 boreholes would be needed. That is equivalent of having 24 meters of borehole for each square meter of road. The drilling cost would be in the range of 610 000 € which would be more than most projects could

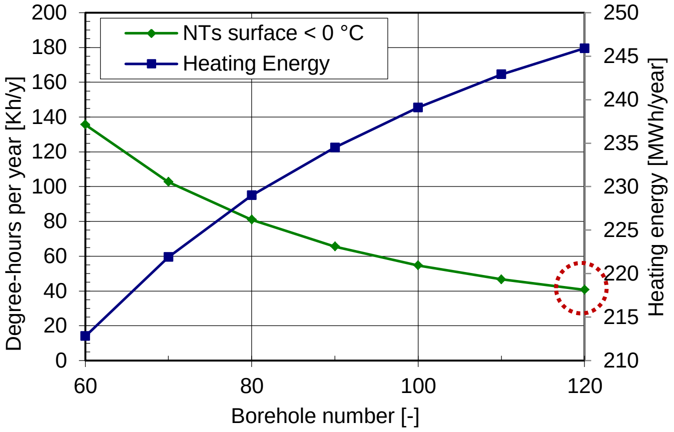


Figure 12: Varying number of boreholes for suggested system design.

support considering that the road surface is only 1000 $m^2$. However, the importance of designing the system could be seen by comparing Figure 10 and Figure 13. The adjustments made to the control system reduced the number of NTs from 290 to 40 for 120 bore holes.

Table 3: Input for suggested system design according to preliminary simulations.

| Parameter | Explanation | Values | Unit |
|---|---|---|---|
| TS2 | Max supply temperature | 7 | [°C] |
| TS3 | Min supply temperature | 4 | [°C] |
| $T_2$ | Lower temperature boundary road | 4 | [°C] |
| cc | Pipe spacing in road | 0.1 | [m] |
| NBore | Number of boreholes | 120 | [-] |
| $\lambda_{ground}$ | Thermal conductivity of the ground | 2 | [W/(m K)] |
| DT0CST | Harnessing stop temperature difference | 2 | [°C] |
| DT1CST | Harnessing start temperature difference | 4 | [°C] |
| Nserie | Number of boreholes connected in series | 2 | [-] |
| Wvol | Water volume in short term storage | 4.4 | [$m^3$] |

## 5 CONCLUSION

The methodology, presented in Pahud(2007) for using BRIDGESIM, to make a preliminary design of a hydronic pavement system have revealed that it is not feasible to design such a system for the location of Östersund; if only relying on harnessing solar energy and store the energy in a borehole thermal energy storage. It is possible to improve the model by adding other important physical phenomena's e.g. surface condensation and precipitation to the control system. Thus, decreasing the energy need. However, changes to the control system would most likely not be enough which means that supplementary energy from boilers or heat pumps would be needed.

The preliminary system design have however revealed that it is possible to design HP system for low supply temperatures of about 7 °C, considering a high thermal conductivity of the pavement. This temperature is far below the supply temperature that the manufacturers of HP system recommend, which is normally of about 35 °C. The prospect of utilizing low-temperature heat sources would make HP system more energy efficient which could make it an alternative to traditional winter maintenance methods. Usage of HP system would then be one way of making winter roads safer.

## REFERENCES

Fay, L., Shi, X., (2012). Environmental Impacts of Chemicals for Snow and Ice Control: State of the Knowledge. Water, Air, Soil Pollut. 223, 2751–2770. doi:10.1007/s11270-011-1064-6

Knudsen, F., Natanaelsson, K., Arvidsson, A., Kärki, O., Jacobsen, Á., Guðmundsson, G., Nonstad, B., Knut Magne Reitan, (2014). Statusrapport 2014 Vintertjeneste i Norden, NVF-rapporter 1/2014. NVF, Norge.

Koschenz, M., Dorer, V., (1996). Design of Air Systems with Concrete Slab Cooling, in: Murakami, S. (Ed.), 5th International Conference on Air Distribution in Rooms ROOMVENT 96. Yokohama, Japan.

Lysbakken, K.R., (2013). Salting of Winter Roads : The Quantity of Salt on Road Surfaces after Application. Norwegian University of Science and Technology.

Nordin, L., (2015). Energy Efficiency In Winter Road Maintenance A Road Climatological Perspective. Dep. Earth Sci. University of Gothenburg, Gothenburg.

Pahud, D., (2008). BRIDGESIM: Simulation Tool for the System Design of Bridge Heating for Ice Prevention with Solar Heat Stored in a Seasonal Ground Duct Store, User Manual. SUPSI, Lugano, Switzerland.

Pahud, D., (2007). Serso, stockage saisonnier solaire pour le dégivrage d’un pont, Rapport final. Bundesamt für Energie BFE, Bern.

Pan, P., Wu, S., Xiao, Y., Liu, G., (2015). A review on hydronic asphalt pavement for energy harvesting and snow melting. Renew. Sustain. Energy Rev. 48, 624–634. doi:10.1016/j.rser.2015.04.029

Sundberg, J., Lidén, P., (2014). Halkfria vägar – Etapp 2. Energi- och systemanalys med kostnader. Solvärme och värmelagring för miljöanpassad halkbekämpning, Rapport 2014:121. Trafikverket, Borlänge.

Uponor, (2013). Ytvärmesystem, in: VVS Handboken Edition 2. Uponor VVS AB, Västerås.

Ye, Z., Wu, J., Ferradi, N. El, Shi, X., (2013). Anti-icing for key highway locations: fixed automated spray technology. Can. J. Civ. Eng. 40, 11–18. doi:10.1139/cjce-2012-0226