

## De-Icing and Snow Melting System with Innovative Heat Pipe Technology

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### ABSTRACT

This is the first time that a self-operating, CO<sub>2</sub> heat pipe system has been used with a direct surface heat condensing system to melt snow and ice on an asphalt street. This snow and ice melting system is completely controlled by on-site weather conditions. Evaporated warm CO<sub>2</sub> rises to the top of the heat pipe because of geothermal heat sources. At the surface, the CO<sub>2</sub> condenses through simultaneously occurring heat release and returns to the vaporization zone of the heat pipe as a cool liquid. This results in an automatic heat pipe cycle and heats the street surface without using any external energy.

An intelligent de-icing and snow melting system based on the heat pipe principle is in use at a fire station in Bad Waldsee, Germany, as part of an EIFER/EnBW demonstration project. Specially designed register systems with varying diameter and distances are used to cover a 150m<sup>2</sup> area at the entrance to the fire station. A new theoretical model was developed for this project to take into account all coupled processes. With this model, it is now possible to conduct a complete heat balance of a coupled heat pipe solution. All relevant parameters (required pipe dimensions, filling rates, heat pipe designs of the surface and underground systems) as well as meteorological conditions were taken into consideration. A monitoring system consisting of fiber optic cable, PT100-sensors, a weather station and an infrared camera system was installed on site. Through the sophisticated monitoring system at Bad Waldsee, it is possible to check and validate theoretical calculations, the description of the snow-melting process, the model of pavement temperature distribution, as well as the heat and mass transfer on the pavement, the snow layer and ambient conditions. This heat pipe system installation has already proven that cooling loads can be transported into the underground and that the street can be heated through geothermal resources, even under very low surface temperatures. Measured and modeled values in this project are consistent and detailed theoretical calculations based on these findings will enable planning for new de-icing and snow melting systems. These may be made possible through using heat pipes and borehole heat exchangers and could be applied to airports and helicopter landing sites, parking areas, and garage entrances, for example.

### 1. INTRODUCTION

The use of geothermal energy from shallow depths (up to ~400 meter) is gaining importance world-wide with respect to energy efficiency in both heating and cooling operations. The ground acting as a heat storage zone offers the possibility of damping the effects of the outside air temperature fluctuations, in colder climates it enables monovalent operation of a heat pump (there is no need of an additional operation system like, for example, a gas boiler). The geothermal energy can be used in different ways, direct use with no changing of the source temperature and an indirect use with a Ground-Coupled Heat Pumps (GCHP). With a heat pump the source temperature can be adjusted as desired to higher or lower values. The extraction of heat from underground and its transfer to a heat pump or for a direct use is usually done with borehole heat exchangers (BHE). BHE are normally filled with a calorific medium that extracts energy from the underground to the surface.

An innovative alternative to brine BHE is the use of gravitational heat pipes. In this case, there is no need for a circulating pump (the phase change of an internal medium makes it circulate). This leads to higher efficiencies and lower costs. Heat pipes are currently used to heat roadways and bridges to remove snow and ice, to cool soil in permafrost locations to improve its mechanical strength (Nydahl et. al. 1987, Vasilew 1988, Fukada et al. 1990, Kovalev et al. 1992, Tanaka et al. 1992). Results from an 18 meter deep CO<sub>2</sub> ground coupled heat pipe are given in Kruse (2004). Feldmann (2004) suggests applications of heat pipes for heating of rail switches and platforms. Theoretical calculations for heat pipes are described e.g. in Hegab and Colwell (1994). Commercially applied heat pipe solutions for house heating purposes are described, for example, in Mittermayer (2007). Zorn et al. (2008) have also realized successfully a 250 meter deep CO<sub>2</sub> heat pipe solution. An intelligent de-icing and snow melting system based on the heat pipe principle for a part of the entrance of the fire engine building is used in Bad Waldsee, Germany (Zorn et al. 2010). Such a system is especially sustainable because,

- Minimizing application of de-icing salt.
- Self-acting operation without any additional input of energy.
- CO<sub>2</sub> heat pipes are totally harmless for groundwater.
- No manual or mechanical removal of snow and ice, etc.

A schematic principle of a heat pipe based de-icing and snow melting system is given in Figure 1.

### 2. THEORETICAL PLANING

The maximum heat demand for a de-icing and snow melting system at the given surface area (asphalt layer, etc.) has to be calculated by taking into account extreme weather conditions (highest possible wind forces (12 Beaufort), lowest possible temperature, highest amount of snowfall per hour, etc.). The requirement of energy is also depended on the dimension of the area for de-icing and the snow melting as well as on the characteristics of the area (asphalt, etc.). Furthermore the performance limits of the used heat pipe system (material, dimensions, etc.) and the underground conditions (thermal conductivity, underground heat

flow, etc.) have to be considered. Thus a new theoretical model was developed to take into account all coupled processes. With this model, it is now possible to conduct a complete heat balance of a coupled heat pipe solution. All relevant parameters as well as meteorological conditions are taken into consideration (Figure 2, more details see in Zorn et al. 2011).

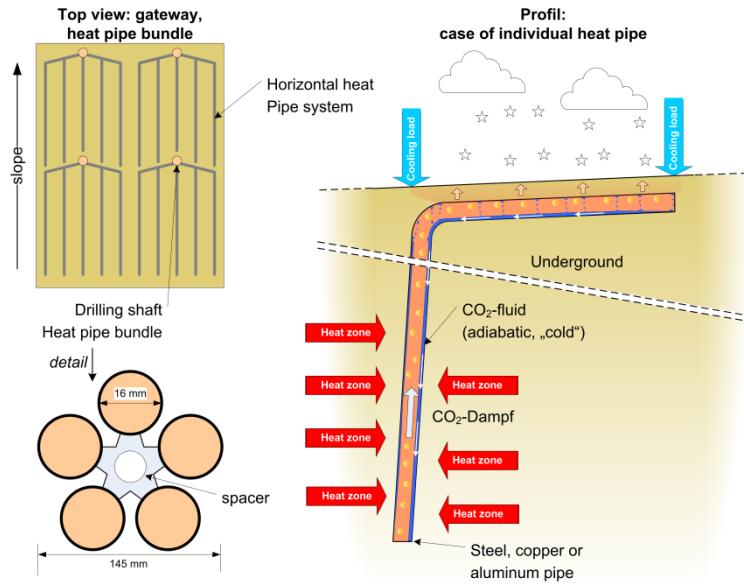


Figure 1: Schematic principle of a heat pipe based de-icing and snow melting system.

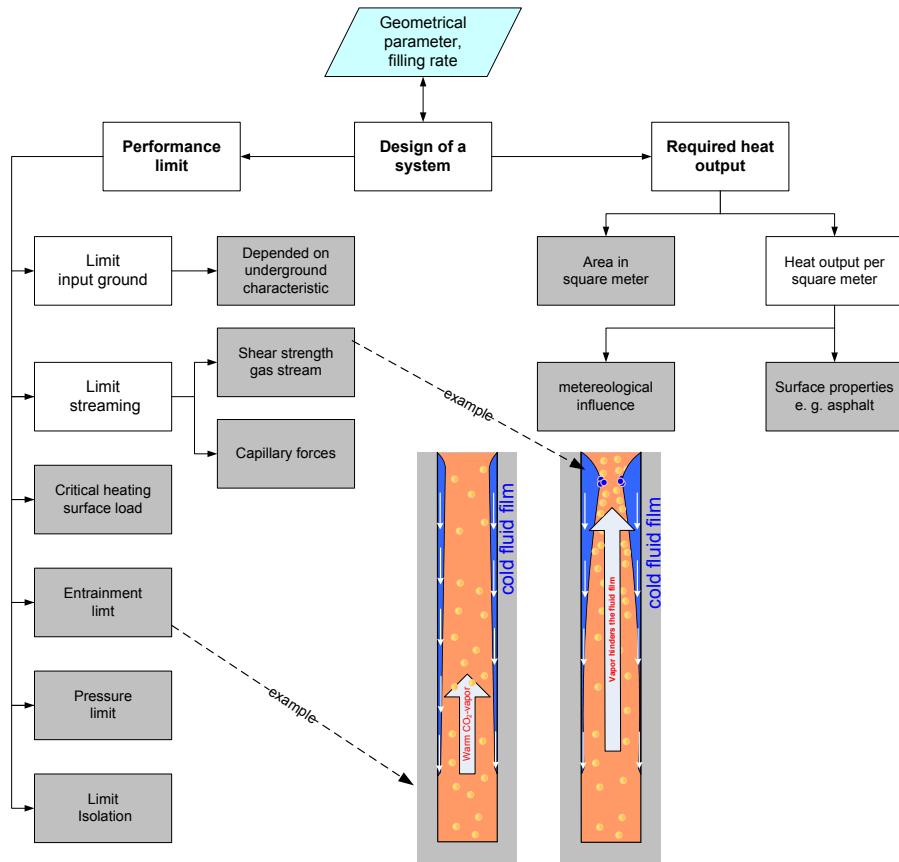
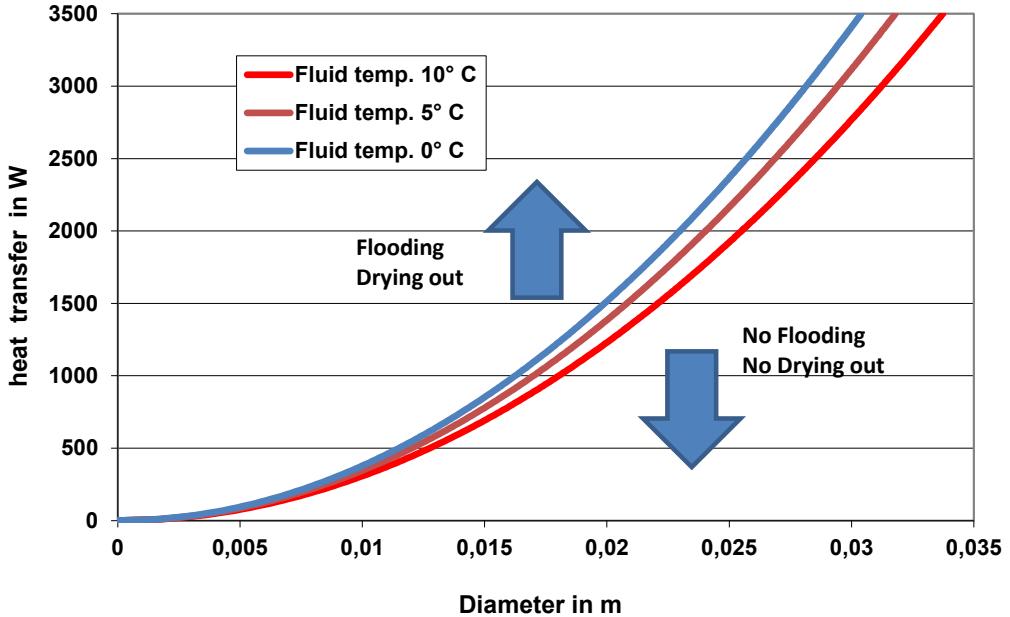


Figure 2: theoretical planning and modeling (after Zorn et al. 2011).

One challenge of a heat pipe installation in the underground is the fact that there is relatively long evaporation zone in the underground. A limit of performance could occur if too high filling rates are used and high axial and radial heat fluxes could be expected. High axial heat flux leads to high relative velocities between the downwards flowing condensate film and the upwards streaming vapor phase. Thus the shearing strengths increase at the interface between the vapor and liquid phase. The shearing strengths cause waves and turbulences in the condensate film and leads to an accumulation of the liquid phase. Under such

conditions the condensation zone is flooded and lower parts of the evaporation zone are dried out. A limit of performance could also happen if for example too low filling rates are used and the liquid film is not completely flowing down to the lower parts of the heat pipe. In such a case the liquid evaporates totally before reaching the lower end of the heat pipe. The calculation of entrainment limit in dependency on the heat transfer and inner heat pipe diameter is given in Figure 3. The calculations are made for a copper as a heat pipe material and  $\text{CO}_2$  as heat pipe medium. This means that there is risk of flooding if high amounts of heat has to be transported at a given heat pipe diameter. In contrast this also means that the diameter limits the maximum possible heat transfer. Thus the heat pipe diameter dimensioning is one of the most important steps for planning of a self-acting de-icing and snow melting system.



**Figure 3: Entrainment performance limit in dependency on the inner heat pipe diameter (case of  $\text{CO}_2$  as heat pipe medium and copper as heat pipe material).**

### 3 TEST FIELD AT BAD WALDSEE

Specially designed register systems with varying diameter and distances are used to cover an area of  $165\text{m}^2$  at the entrance to the fire station, Bad Waldsee (Germany, Figure 4).

Each individual underground heat pipe (16x1 mm diameter plain pipes and special designed finned ~10 diameter pipes) is connected with the surface heating system over a shaft distribution system. The shafts are located directly over the boreholes of the underground heat pipes. In every borehole individual bundles of 4 or 5 heat pipes are installed. Four boreholes were drilled to a depth of 50m and one borehole was drilled up to 75m to have the possibility to see the difference of performance between different heat pipe lengths. The central connection pipe between the surface heating and the underground heating system is made with 16x1 mm diameter plain pipe.

A comb-shaped pipe distribution solution is installed at the street surface. The asphalt layer was already there before installing the surface heating system. Thus the boreholes were drilled at the side of the street considering the minimal distance of 5 m between the boreholes. That configuration causes also the used comb-shaped pipe distribution solution and the heat pipe connection system.

#### 3.1 Monitoring system

A monitoring system consisting of fiber optic cable, PT100-sensors, a weather station and an infrared camera system are installed on site. Due to the sophisticated monitoring system at Bad Waldsee, it is possible to check and validate theoretical calculations, the description of the snow-melting process, the model of pavement temperature distribution, as well as the heat and mass transfer on the pavement, the snow layer and ambient conditions.

#### 3.2 Results

This heat pipe system installation has already proven that cooling loads can be transported in the underground and that the street can be heated through geothermal resources, even under very low surface temperatures. The cooling loads are transported to the underground and are compensating the cold asphalt and soil temperatures (example for the pipe system B2, Figure 5).

The temperatures along the heat pipe remain always over  $0^\circ\text{C}$  despite very cold ambient air temperatures. The cold is transported to the underground according to the surface cooling of the collector systems. Thus the temperature traces in the underground are reflecting the air and the asphalt temperatures. A fluid film transport is evident up to 50m in depth. Logically the temperature decrease is higher in the upper parts than in greater depths of the underground. In greater depths the decrease is lower because the heat transport in the underground causes a successive increasing evaporation of  $\text{CO}_2$  and large amounts of the fluid film is already evaporated during the downwards transport. The feed pipes from the shaft to the street surface register system are not isolated. Thus

parts of the CO<sub>2</sub> are condensing in the feed pipes before reaching the surface heating system. The shorter the distance from the shaft the more efficient the heating system is working (Figure 6).

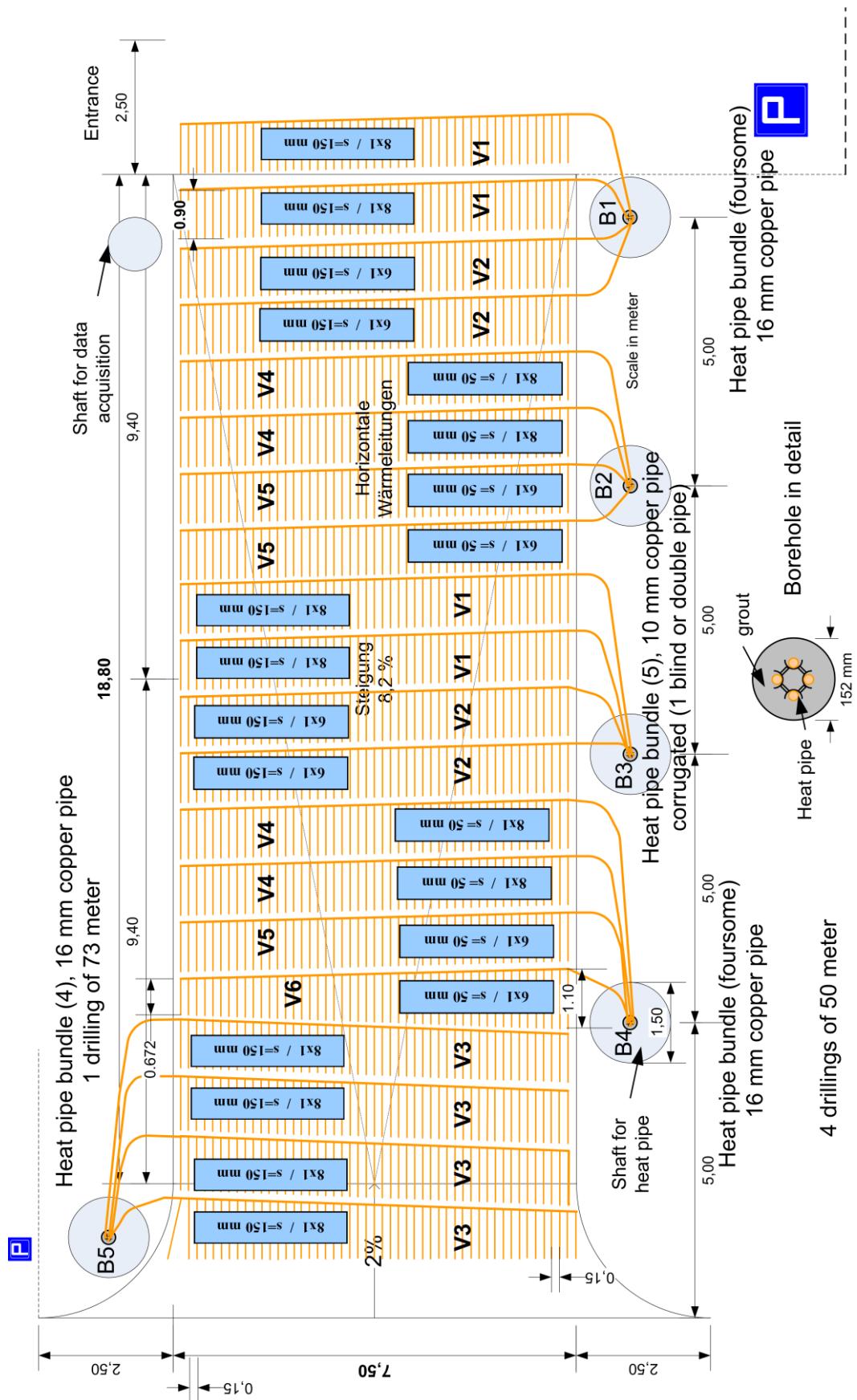
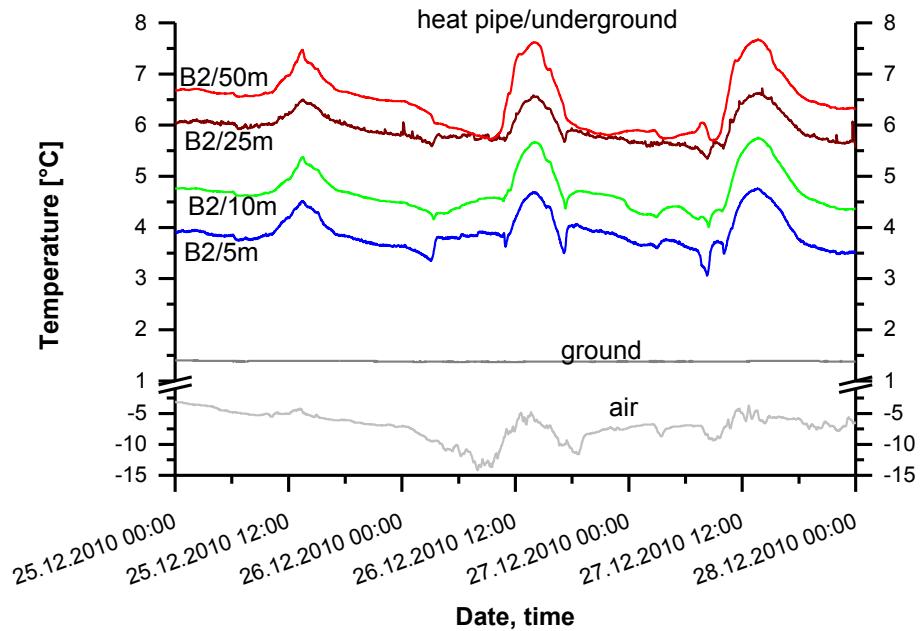
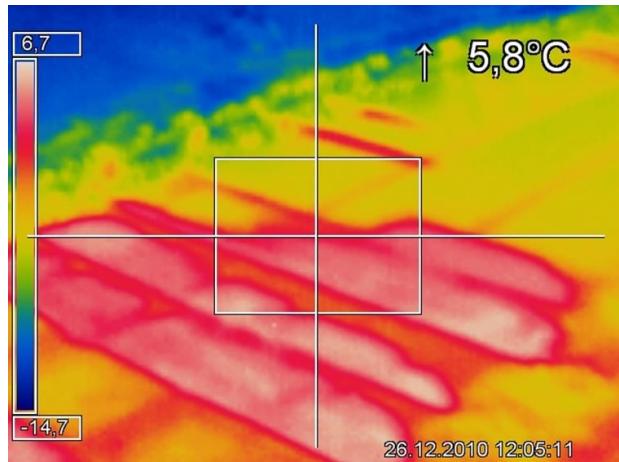


Figure 4: Schematic principle of a heat pipe based de-icing and snow melting system.



**Figure 5:** temperature distribution in the underground heat pipe system of B2 in comparison to the soil and air temperatures.



**Figure 6:** infrared picture the asphalt street at Bad Waldsee, Germany.

But it has to be pointed that even during very long extremely weather conditions the installed system has been nearly reached a completely de-iced and snow melted street (Figure 6).



**Figure 6:** Demonstration of successful operation of the system at Bad Waldsee, Germany.

Measured and modeled values in this project are consistent and detailed theoretical calculations based on these findings will enable planning for new de-ice and snow melting systems (Figure 7).

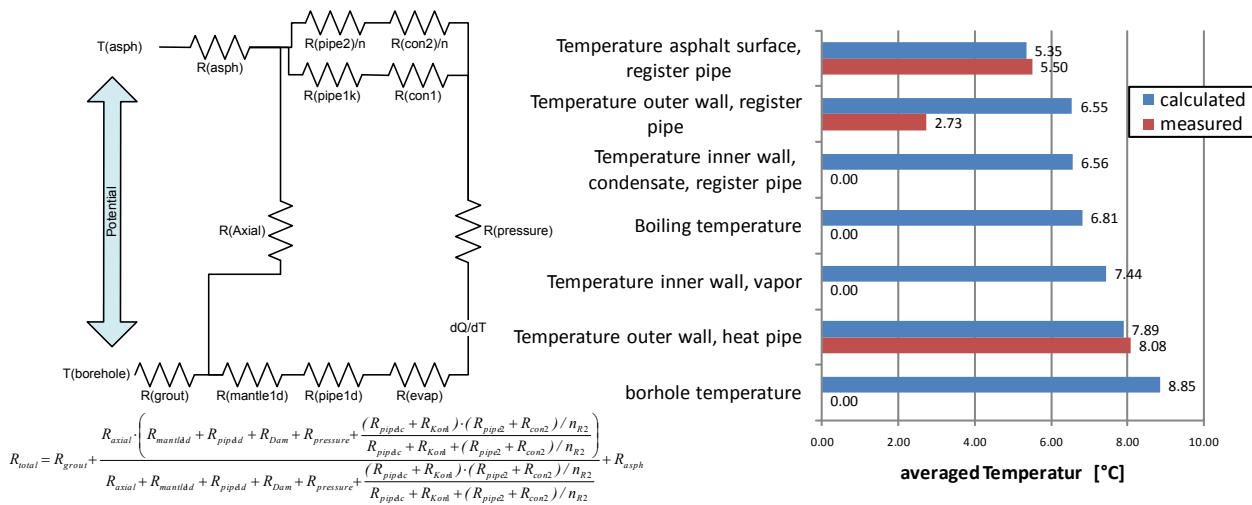


Figure 7: Measured and modeled temperatures at Bad Waldsee..

These may be made possible through using heat pipes and borehole heat exchangers and could be applied to airports and helicopter landing sites, parking areas, and garage entrances, for example.

#### 4. CONCLUSIONS

The aim of the project is to develop sustainable and innovative CO<sub>2</sub> heat pipe solutions for a self-operating de-icing and snow melting system. At the first time CO<sub>2</sub> heat pipes together with surface condensing system were used for a de-icing and snow melting of an asphalt layer. A theoretical model was developed considering all coupled processes. Now it is possible to carry out a complete heat supply balance of a coupled heat pipe system. All relevant parameter like e.g. the needed heat pipe diameters, heat pipe length and distances as well as the meteorological parameter could be considered and calculated. In the future also economic aspects will be also implemented in the model. Thus with the worked out model new projects of de-icing and snow melting system could be planned in every detail.

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