# Non-skid winter road, Investigation of deicing system by considering different Road profiles

## Sensitive analysis and Simulation of deicing systems for two different climates; HalvorsLänk in Gothenburg and Hällabacken in Orebro

Master of Science Thesis in the Master´s Programme Infrastructure and Environmental Engineering

**MARYAM ABBASI**

**Department of Civil and Environmental Engineering**

**Division of Water Environment Technology and Geoengineering**

**CHALMERS UNIVERSITY OF TECHNOLOGY**

**Gothenburg, Sweden 2013**

**Master’s Thesis 2014:60**

# Non-skid winter road, Investigation of deicing system by considering different Road profiles

## Sensitive analysis and Simulation of deicing systems for two different climates; HalvorsLänk in Gothenburg and Hällabacken in Orebro

Master of Science Thesis in the Master´s Programme Infrastructure and Environmental Engineering

Department of Civil and Environmental Engineering

Division of Water Environment Technology and Geoengineering

CHALMERS UNIVERSITY OF TECHNOLOGY

Gothenburg, Sweden 2013

# Abstract

Road maintenance and make the roads safer during winter is one of the challenging issue for a while. There are some conventional ways to remove the snow and ice from the road surface. Salting and sanding are the most common ways to achieve winter road maintenance.

By increasing the number of roads and environmental side effects of conventional ways, new methods, such as district heating system, were suggested.
In this project different effects of the system is studied and solar energy is considered as the environmentally friendly and cost-effective source. The system contains of a water pipe network under the surface which absorb the heat from sun radiation during hot summer days and store it in some storages. This stored warm water will warm up the surface in order to prevent ice making.

The major part of this study is simulation of two different roads; HalvorsLänk in Gothenburg and Hällabacken in Orebro. The effects of different parameters which affect the district heating system such as power, pipe depth, and thermal conductivity are surveyed. To sum up, by considering the efficiency and the energy consumption, some efficient design models are suggested.

## Acknowledgements

I would like to thank my supervisors Jan Sundberg and Peter Liden.

They are highly appreciated for their motivation, inspiration and guidance during this study.

I gratefully acknowledge the support for this work from Vectura/Sweco.

# Table of contants

Abstract ........................................ III
Acknowledgements ........................................ IV
1. Introduction ........................................ 1
  1.1. Aim and Purpose ........................................ 2
  1.2. Methods ........................................ 2
  1.3. Limitations ........................................ 2
2. Background ........................................ 3
  2.1. Previous Work ........................................ 5
  2.2. The impact ........................................ 7
3. Deicing System ........................................ 9
  3.1. Ice formation ........................................ 9
    3.1.1. Static control ........................................ 11
    3.1.2. Dynamic control ........................................ 11
  3.2. Soil properties ........................................ 12
    3.2.1. Thermal conductivity: ........................................ 13
    3.2.2. Heat Capacity ........................................ 13
  3.3. Piping properties ........................................ 15
4. Modeling ........................................ 17
  4.1. Uncertainties ........................................ 17
  4.2. Simulation and the results: ........................................ 18
    4.2.1. Heat Power Effect ........................................ 20
    4.2.1.1. Static control ........................................ 21
    4.2.1.2. Dynamic pipe Control ........................................ 23
    4.2.2. Depth of the heat source ........................................ 25
    4.2.2.1. The Effect of depth in static model ........................................ 25
    4.2.2.2. The effect of depth in dynamic simulation ........................................ 29
    4.2.3. Effect of different material by different thermal conductivity ........................................ 31
    4.2.3.1. The effect of thermal conductivity in static simulation ........................................ 31
    4.2.3.2. The effect of thermal conductivity in dynamic simulation ........................................ 33
    4.2.4. Insulation layer ........................................ 34
    4.2.5. Some other simulations ........................................ 35
5. Discussion ........................................ 39

6. Conclusion ........................................................................................................49
7. References........................................................................................................51
- Appendix ........................................................................................................54

# 1. Introduction

The roads can be more dangerous during winter time especially when they are slippery. The number of road accident decrease dramatically by winter road maintenance. There are different methods to remove ice and snow from the roads. Salting and sanding are the most common ways to accomplish winter road maintenance.

District heating system is another way which can be used to make the roads safer during the winter. In district heating systems, pipes contain warm water and warm up the road surface and melt the ice or snow. This system is not very common and is used only in small scale. In this system different kind of energy sources can be used.

For example, in some projects fossil fuels is used as the source of energy. In some projects the excess heat from the district heating from the return pipes are used. Using solar energy is one of the possible sources, which is free and environmental friendly.

This project is an investigation and simulation of ice free roads by using solar energy. The software that has been used for simulations is CoupModel. Meteorological data can be imported and used for simulations. Also some information about the radiation, soil properties and water situation in the soil can be adjusted in this software.

In the simulations, effects of heat power and soil properties are studied. The pipes are implanted in different depths to see which depth can give the best results. Also different thermal conductivities of asphalts are used to show the effect of thermal conductivity on the project efficiency.

The master thesis is carried out as a part of the project Non-skid winter roads, performed by Vectura at the request of Trafikverket. The project Non-skid winter roads is divided into 3 parts, a pre study, case studies (in progress) and finally a pilot project where the technique is demonstrated (Sundberg, J & Lidén, P. In progress).

Two roads are investigated in this project, HalvorsLänk in Gothenburg and Hällabacken in Orebro. The aim is to study the effect of the climate on the system performance and to investigate the effect of changing the road profiles, like depth, thermal conductivity and the different energy demand for different road profiles.

## 1.1.Aim and Purpose

Ice or snow on the road causes a lot of problems for the drivers and also citizens. Less speed, more traffic and more accidents cost a lot for people and society. The aim of ice free roads is to increase the road safety and try to have a better mobility and comfort driving during the winter times.

The aim of this project is to investigate and simulate a snow melting system which has more efficient functionality. Also some factors which can effect operation of the system were studied. Consequently, the simulation results for different designs were compared together by efficiency and energy consumption.

## 1.2.Methods

In this project, solar energy is used as the energy source. Different parameters which can have an effect on the system efficiency are considered. Simulations are done dynamic and static which are described later.

The simulations are done by considering different power, depth of the pipes, thermal conductivity of the asphalt and insulation layer.

At the end, the results are discussed base on the efficiency and the energy consumption of the system in different situation.

## 1.3.Limitations

This project focuses on the heat transfer between the pipes, the soil surface and the parameters which can effect on that. There are some important factors which should be considered and calculated for having this system but they are not reflected on this study.

- The warm water flowing in the pipe is stored in storage. The dimensions and the material of the storage should be designed and calculated. During the storing process some energy is lost. This energy lost effects on the total consumed energy in the system.
- Since the water flows in the pipes, design a water-network is needed in the system.
- The water pumps which are used to pump up the water from the storage should be designed.

- Since the energy of the system is gained by cooling the road, some more consideration can be done in this context.

## 2. Background

Using district heating in order to melt the ice and snow on the road is almost common. This system can be worked by different kind of energy sources. For example fossil fuels or electricity can be used as an energy source. The problem is that they are quite expensive, not environmental-needed; they are limited and cannot be used for ever.

Recently some other sort of energy are introduced which are cheaper and environmental friendly for example using the biofuels, geothermal energy or solar energy. Changing the heat source to environmental friendly sources reduce carbon dioxide emissions and emissions of Sulfur, Nitrous Oxide and particles. It leads a reduction of the pollution in the area (Svesnk Fjärvärme, 2013).

There are some successful experiences of these projects all over the world. These systems can keep the roads ice free during the winter and cool down the surface during the summer which helps to prolong the pavement lifespan and prevent the heat island effect.

Heat island effect may occur both on the surface and air. This is phenomenon in metropolitan area where it is considerably warmer than surrounded area. This phenomenon can affect the climate, health, nearby water and etc. (EPA, 2013).

During the winter time, icy and slippery roads are the most hazardous situation which threats the road safety and the comfort of driving. In Sweden, 74% of the total accidents in 2005-2006 happened when the roads were in slippery conditions, mostly when it was snowing or had snowed. Figure 1, illustrates the relation between the total number of accidents and the number of accidents when the road was slippery. According to figure 1, 60% of all accidents in January 2005 and 90% of all accidents during January 2006 occurred in slippery conditions (Andersson, 2010).

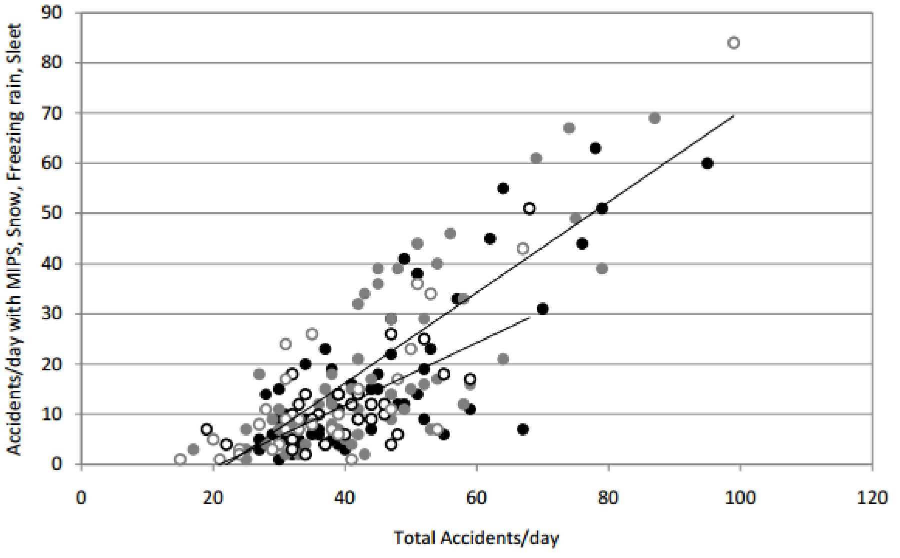

Figure 6. Accidents *per* day during MIPS/Snow/Freezing rain/Sleet vs. total amount of accidents *per* day ● 2004-2005, ○ Jan 2005 (short trend line), ● 2005-2006, ○ Jan 2006 (long trend line).

**Figure 1: The relationship between the total number of accident and the number of accidents that occurred during the slippery conditions (Andersson, 2010).**

There are some alternatives to reduce the risk of accident when the roads are slippery. The traditional ways are based of removing the ice and snow of the road surface mechanically. Additionally using sand and salt to increase friction and reduce freezing point and make snow melting faster. These solutions can make the roads safer but costs a lot and are not environmentally-friendly. In Sweden, during 2007-2008, 184 000 tons of salt is consumed in order to winter road maintenance (Andersson, 2010).

Another way to remove ice and snow from the road is warming up the road surface to melt the ice. The oldest recorded of these snow melting systems was built in 1948. That system used geothermal water to heat up the surface (Lund, 2000).

For the snow melting systems, different heating source can be used. Some examples are using the heat of geothermal, sewage, electricity and solar energy. Since providing a heating source is one expensive process, using the sun is a great free source of energy and it is economical.

In this system, roads can act as a solar-collector to absorb the heat and warm up the water pipes which have been implanted under the road. The water can be stored under the ground and .use again during the cold winter days, when the roads are in slippery conditions.

## 2.1.Previous Work

A number of successful snow melting projects are operating all over the world where they used geothermal or solar energy as the main energy source. One of the well-known project in this issue is SERSO pilot plant in Switzerland, it can be called the mother of geothermal bridge. It has worked from 1994 without interruption until now. The aim of the project was to prevent the ice formation on the highway bridge (Eugster, 2007).

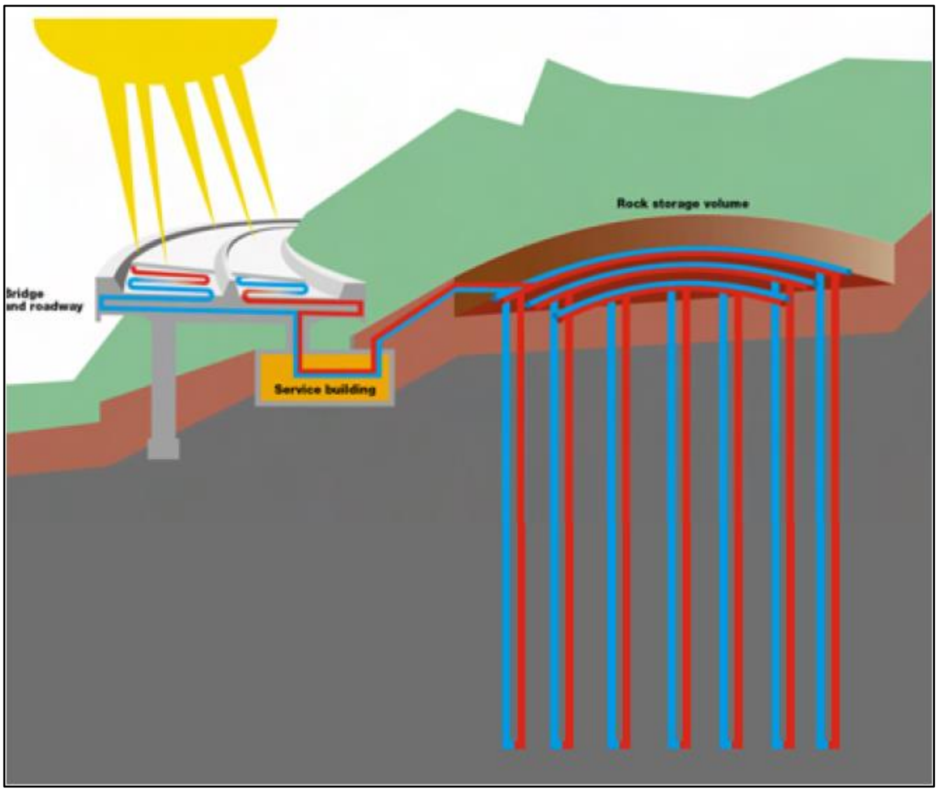

Figure 2: SERSO system, a basic scheme of the road de-icing system (Eugster, 2007)

In this system, the surface temperature should not go under zero °C. To fulfill the requirement, SERSO system works about 1000 hours/year to warm up the road during the winter and almost 1000 h/year to cooling down the surface during the hot summer times. The energy demand is dependent on the severity of the winter and can be vary from 30 MWh to more than 100 MWh (Eugster, 2007).

Another successful project is Gaia in Japan. This system is working by vertical ground heat exchangers, a heat pump and heating pipes which are buried under the surface. This system uses both geothermal and solar heat to melt ice and snow. The system tries to keep the temperature higher than the temperature of ice formation.

**Figure 3: Gaia snow-melting system on the side walk. Aomori City-Japan 2002-12-28 (Morita & Tago, 2005)**

This system contains:

- Heat source which is solar energy during the summer and geothermal during the winter.
- Heat exchanging pipes which are embedded in the pavement
- A Sensor to measure the actual weather
- A Control system

The system is illustrated in the figure 4; the road is warmed up by a hydronic heating system. The heat will be transferred from water pipes to the surface.

In some small areas electrically resistance heater are used. Different heat power is needed in different projects; depending on the snow-fall rate, de-icing, climate and the purpose of the project. For example the power for a commercial building in Boston is 729 W/m$^2$ and for residential application in Albuquerque is 224 W/m$^2$ (Eugster, 2007).

The initial costs of these kinds of projects are high but it does not necessarily mean it is uneconomical. Actually the social and macro-economic benefits may cover the cost during the time.

## 2.2.The impact

As it mentioned before the initial cost for this project would be high. But in the other hand it helps to prevent cost in some aspect in society and environment. It is not easy to estimate the exact cost of a frozen road or to evaluate the environmental cost of common ways of winter maintenance. Here it is tried to show the positive effect of using green energy in order to have ice free roads.

Frozen and slippery roads cause to spend lots of time in the heavy traffics. It is estimated that every jam hour cost almost 10 Euros per vehicle (Eugster, 2007).

The cost of traffic accident can be stated as a percentage of the gross national product GNP . In the most cases, the total cost of the road accident in a national economy is about 2.5% of (GNP) by including an economic valuation of lost quality of life. It would be 1.3% of the GNP without counting the valuation of lost quality of life. The total cost of the road accident would be 0.5% to 5.7% of GNP by considering the valuation of lost quality and 0.3% to 2.8 without counting the valuation of lost quality of life. The approximations of GNP are taken from OECD publications (Elvik, 2000). GNP in Sweden has been 539.7 billion (THE WORLD BANK, 2011). Table 1 shows the costs of road accident in different countries as a percentage of GNP. Values are in national currencies, amounts are in millions.

One of the most common ways for winter maintenance is using the mechanical snow cleaners or snowplow with a combination of using sand and salt on the road. Using some new technology for example sensor-controlled spreading salt could reduce 50% of the salt usage. The most common salt which used is NaCl.

Salt affects the nearby plants and the ground. High level of sodium causes loss of vital plant nutrients and chloride impact on leaf and shoots. It causes marginal scorching (Groundwater pollution primer, 1998). It is estimated that the yearly salt usage cost about 450 million Euro in Germany (Eugster, 2007).

When the snow and ice are melted the salt can easily be absorbed by the vegetation’s root. Both high level of sodium and chloride will affect the plants in the surrounded area.

**Table 1: Cost of road accident in different countries as a percentage of GNP**

| Country | Year | Total costs of road accidents | | Gross national product (GNP) | Costs as percent of GNP | |
|---|---|---|---|---|---|---|
| | | Lost quality of life included | Lost quality of life excluded | National currency | Lost quality of life included | Lost quality of life excluded |
| Bangladesh | 1997 | 7495 | 5519 | 1 616 309 | 0.5 | 0.3 |
| Denmark | 1997 | 14 145 | 11 281 | 1 080 550 | 1.3 | 1.0 |
| Finland | 1990 | 9487 | 5417 | 501 734 | 1.9 | 1.1 |
| Germany | 1994 | 43 380 | 39 150 | 3 368 689 | 1.3 | 1.2 |
| Italy | 1997 | 36 968 | 32 497 | 1 143 875 | 3.2 | 2.8 |
| Korea | 1996 | 10 986 | 7142 | 422 540 | 2.6 | 1.7 |
| Netherlands | 1993 | 12 353 | 9527 | 614 165 | 2.0 | 1.6 |
| New Zealand | 1991 | 3691 | 764 | 83 072 | 4.4 | 0.9 |
| Norway | 1995 | 21 540 | 10 975 | 928 700 | 2.3 | 1.2 |
| Sweden | 1995 | 44 672 | 14 519 | 1 649 900 | 2.7 | 0.9 |
| UK | 1990 | 11 193 | 2726 | 550 273 | 2.0 | 0.5 |
| US | 1988 | 334 011 | 116 597 | 5 820 336 | 5.7 | 2.0 |
| Mean value (unweighted) | | | | | 2.5 | 1.3 |
| Mean value (weighted by GNP) | | | | | 3.1 | 1.4 |

High level of sodium causes loss of vital plant nutrients and chloride impact on leaf and shoots. It causes marginal scorching (Groundwater pollution primer, 1998).

In Sweden, the road administration uses almost 200 000 tons salt every year for winter maintenances. This amount of salt can effect on the surrounding environment and have impact on the plants life. The salt can reach the groundwater or water surface and increase the salt concentration in the drinking water (Nordin, 2011).

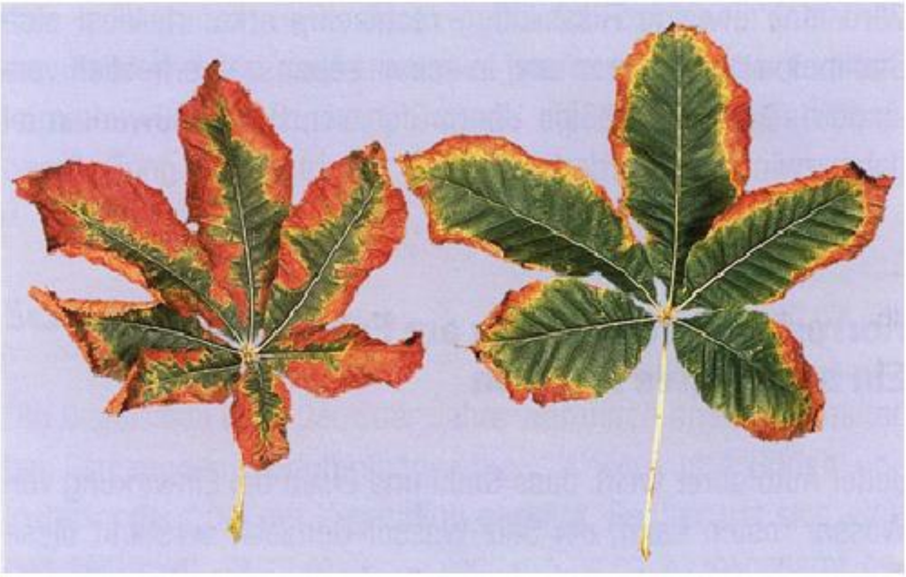

Figure 4: The effect of salt on the leaf and shoot (Eugster, 2007)

## 3. Deicing System

The deicing system works by spiral pipes which are implanted under the road surface. The asphalt works as an energy collector and during the summer absorb energy from the sun radiation. By conduction the energy transfer to the pipes and the water pipes become warmer. This warm water will store in storage under the ground and used again during the winter when the road is frozen. Figure 5 illustrate the direction of heat transfer in this system.

By considering the process of this system, all the parameters which can affect the solar energy absorption, heat transfer and ice formation would be important.

In this project, this kind of deicing system is studied. It is tried to simulate and calculate the efficiency and the energy consumption of the system. This project works similar to the one which is explained in the chapter one as the previous work.

To model the system CoupModel software has been used. It is a software which was made by KTH University (CoupModel, 2013).

### 3.1.Ice formation

There are three important parameters which cause the ice making. The first one is temperature and the others are humidity and pressure. Since the ice is the solid form of water, no ice is made in the dry cold weather.

Dew point is defined as a temperature which dew or water droplets are formed. Dew point is varying according to the pressure and humidity. If the surface temperature is under zero and below the dew point, ice will be formed on the surface (The weather prediction, n.d.).

By considering the dew point, it is easier to recognize when the road surface is frozen. The CoupModel has the ability to model the system by considering this point. The model can be run as static or dynamic. The dynamic control considers the dew point. Figure 5 illustrate a conceptual model of the system when it is set by dynamic and static control. It shows that when the system stats to work.

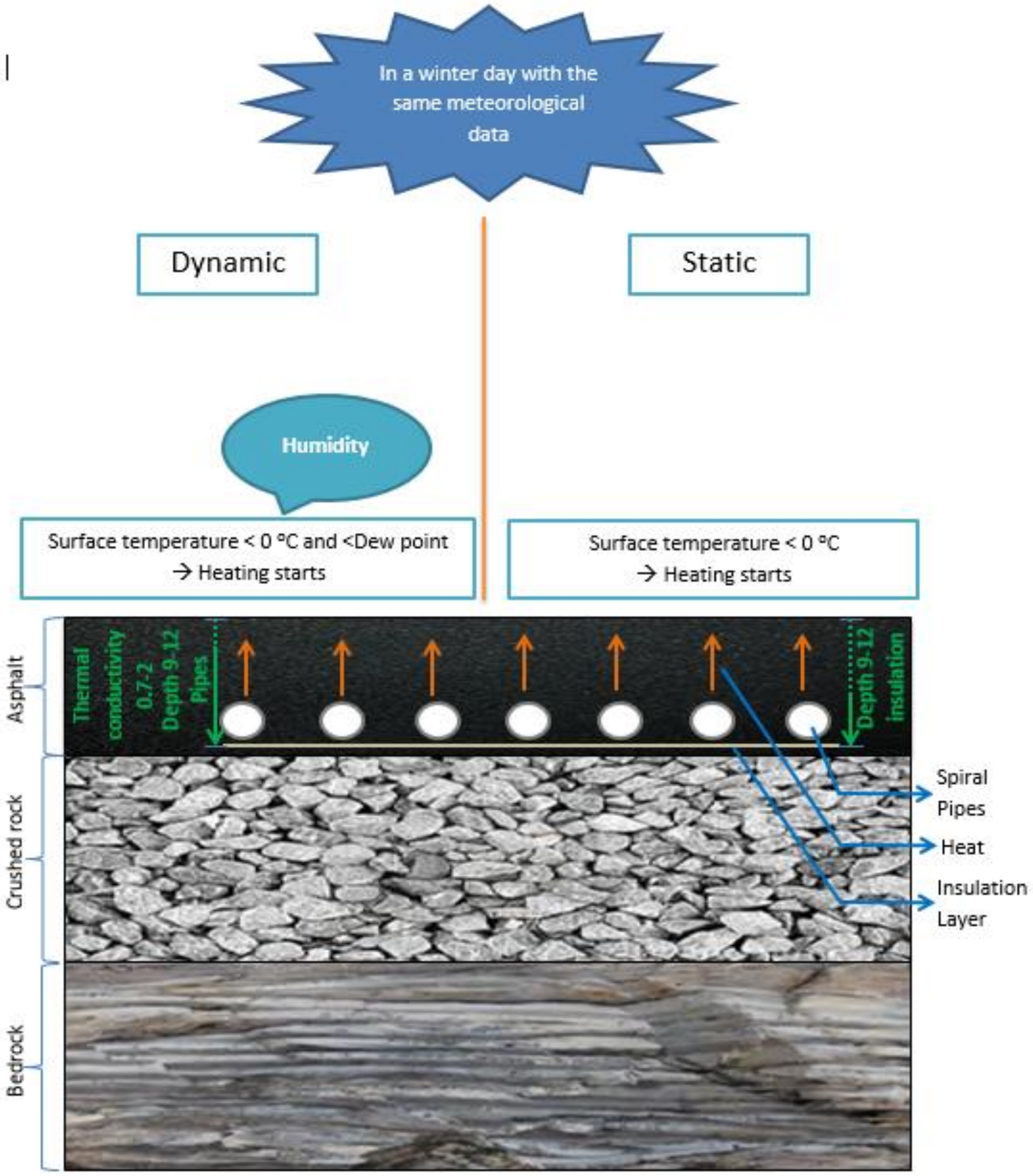

**Figure 5 the conceptual model for the road heating system, when it is set by dynamic or static control. To see the effect of different parameter the power (W/m2), thermal conductivity (W/m ºC), pipe depth (cm) and the depth of insulation layer (cm) are changed and the system is modeled.**

### 3.1.1. Static control

In the Static control the system start to warm up the road when the temperature becomes zero and then continues to warm it with the full effect until the surface temperature becomes 3 °C. Then it is stopped to work until the next time that the surface temperature becomes zero again.

The duty of the system during the hot summer days is to absorb the energy to use it during the winter. Thus the system starts to work when the temperature is more than 30 centigrade. In this way the system can save the warmest water with lower volume instead of saving more water with a lower temperature. It may effect on the dimension of the storage.

### 3.1.2. Dynamic control

It is possible during a cold winter day, when the temperature is under zero but the weather is sunny and there is not any ice or snow on the road. Actually the process of ice making on the road is dependent to the moisture on the road. Considering the dew point can help to understand when the ice is formed. If the weather is under zero and the surface temperature is under the dew point, the road would be frozen. Figure 6 illustrates how the system works in the dynamic form of control.

In this type of situation, there is no need to warm up the road when the temperature is under zero. The system starts to warm up only when the ice formation occur. The cooling system of this method is the same as the static one.

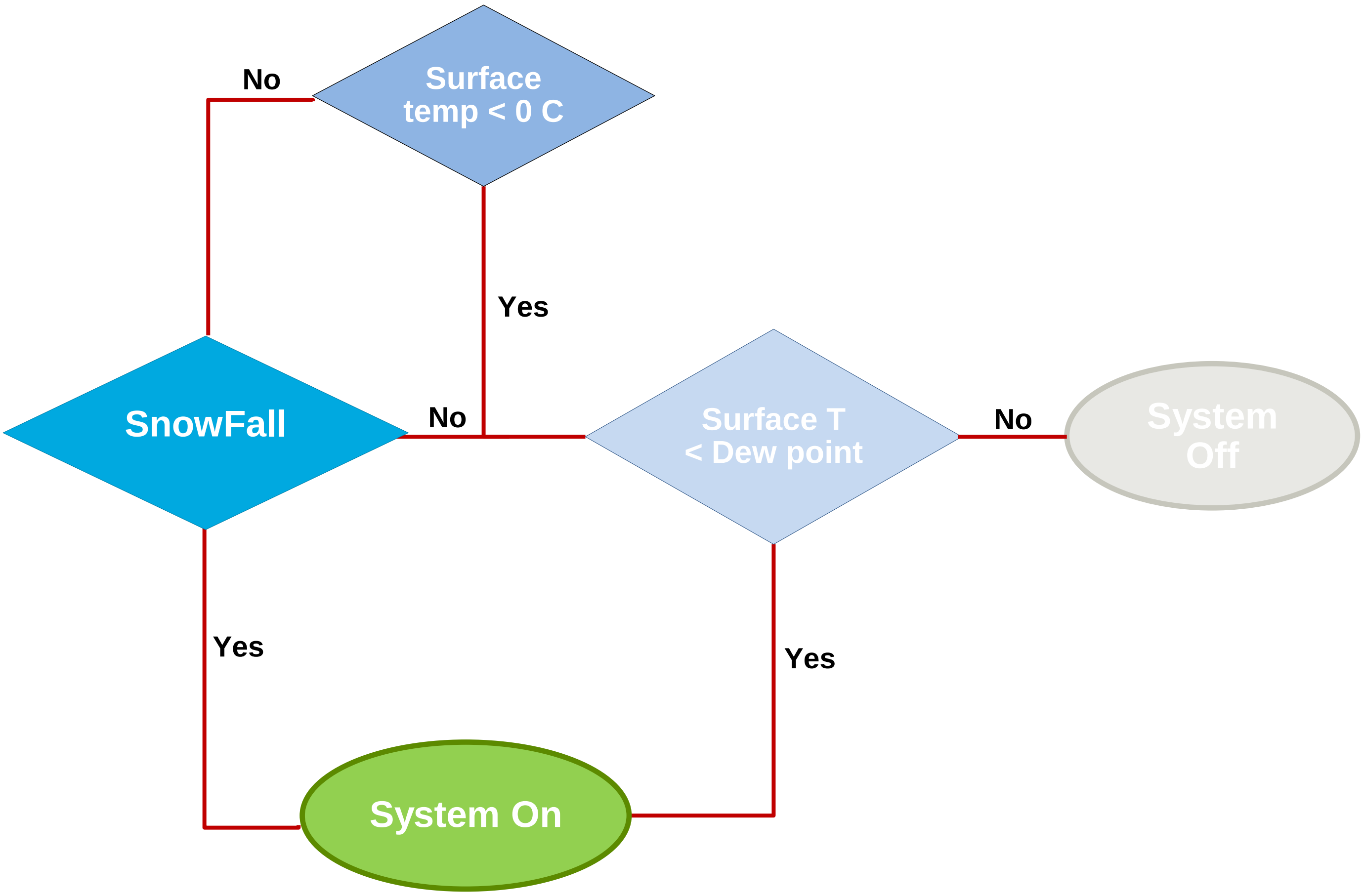

**Figure 6: A flowchart of Dynamic system, it illustrates how the system warm up the road only when it is frozen**

### 3.2.Soil properties

The heat flow in the soil is calculated by the sum of conduction and convection, according to:

$$q_h = -k_h \frac{\partial T}{\partial z} + C_w T q_w + L_v q_v$$

Where *h* is heat, *v* is vapor and *w* means liquid water, *q* is flux, *k* is conductivity, *T* is soil temperature, *C* is heat capacity, *L* is latent heat and *z* is depth.

The first Convection flow which is calculated by (*CwTqw)* is important during the heavy snow and when the melting snow is infiltrated and the flow rate is high. And the other convection term is calculated by *Lvqv* which consider the latent heat flow by water vapor (Coupmanual).

### 3.2.1. Thermal conductivity:

Since the most part of the heat transfer is done by conduction, thermal conductivity of the soil is very important. When the thermal conductivity is higher the heat can be transferred better.

The thermal conductivity is depended on the soil aggregates, material and atomic structure. Different layers of the soil have different thermal conductivities. In the nature, since there is more humus in the top layers and more mineral in the lower layers, often the thermal conductivity is increased by the soil depth (Coupmanual).

The thermal conductivity of different types of the soil can be measured by the laboratory experiments. The thermal conductivity of a soil layer is improved by adding aggregation with higher thermal conductivity. For example Quartzite can increase the thermal conductivity of the soil (Mallick, Chen & Bhowmick, 2009). The thermal conductivity can also be increased by adding graphite powder or short carbon filler (CF) (ASCE, 2011).

There are different types of asphalt with different thermal conductivity. The thermal conductivity of normal Asphalt is 0.7 W/m ºC. Asphalt Concrete (AC) has higher thermal conductivity and it is 1.3 W/m ºC. For the higher thermal conductivity, Conductive Asphalt Concrete (CAC) can be used. The thermal conductivity of CAC is varied between 2-5 W/m ºC (Chen, Wang & Zhang, 2011).

### 3.2.2. Heat Capacity

The heat capacity of soil can be described as the total heat capacities of soil components. Heat capacity can be defined as a number of heat units which can increase the temperature of a body by one degree. Solid components of soil are assumed as a volumetric basis. Since the air heat capacity is insignificant, in this model it is ignored. The heat capacity is calculated based on this formula (Jansson , 2012).

$$C = f_s \Delta z C_s + \theta C_w + \theta_i C_I$$

In this equation $f_s$ is the volumetric fraction of solid material such as mineral and organic matter. $f_s$ is derived from $\Theta_m$, the porosity of the soil. $\Delta z$ is the thickness of the layer $\Theta$ is soil water contents and $\Theta_i$ is soil ice content. $C_s$, $C_w$ and $C_i$ are respectively specific heat capacities for solid material, water and ice (Jansson , 2012).

The soil heat capacity can also be calculated as a function of depth. There are two alternatives which can be assumed. The first one is uniform when the soil heat capacity is assumed to be constant and the other is *f(z)* when the soil capacity can vary with depth according to $C_{bulk}$ ,the solid soil heat capacity in different layer. In this project uniform alternative is used.

## 3.3.Piping properties

The pipe material can be either metal or plastic. Cooper and steel iron pipes have been used widely in snow melting projects in the past. The problem of these pipes is that they can be corroded rapidly if they are not protected by coating. The salt usage in order to deice the roads together with raised temperature accelerates corrosion of these metal pipes. For every 8 increase in temperature the corrosion speed rate is doubled. As a consequence, this corruption causes that the snow melting system collapse after almost 50 years of operation (Lund, 2000).

In some projects in USA, iron pipe has been used for the header pipes and plastic pipes for the rest. One of the typical plastic pipes is cross linked polyethylene or PEX. It can handle 82° C water at 100 psi. These pipes are lightweight, easy to handle and bend as little as 30 cm thus there is no need for expansion loops and other mechanical connections. These pipes are not corroded so their life time is more than 50 years. To protect the pipes from freezing during cold winter, ethylene or propylene glycol is used in the pipe (Lund, 2000).

The price is another reason which makes the plastic pipes as a proper choice. The plastic pipes are cheaper than the steel pipes ( Mallick, Chen & Bhowmick, 2009).

In order to use warm water pipes to melting the ice and snow, pipes with diameter between 2 to 2,5 cm can be placed about 5 cm under the surface.(Lund, 2000)

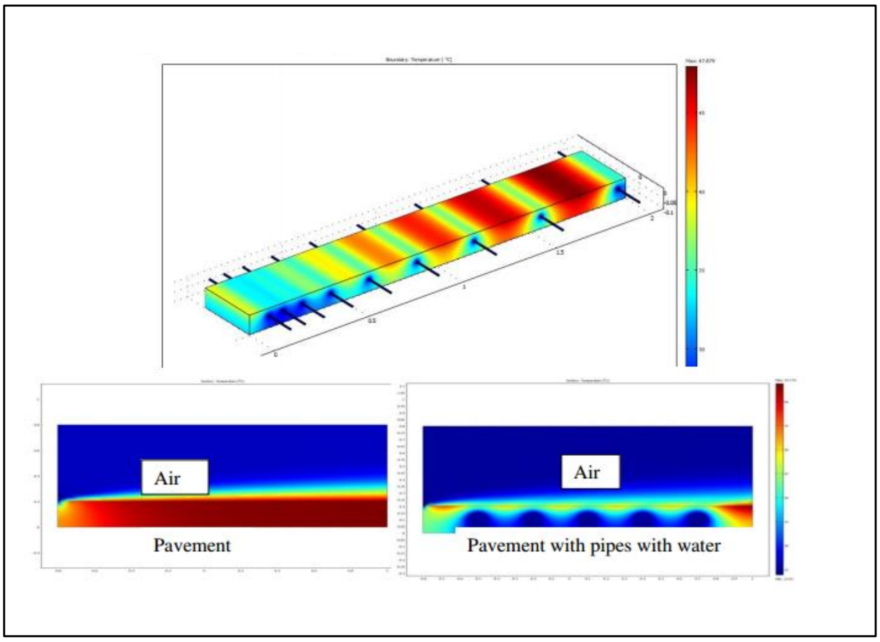

**Figure 7: The impact of pipe spacing on reduction of surface and near surface air (Mallick, Chen & Bhowmick, 2009)**

The pipe spacing is also important when this system is designed. The pipe spacing effects the temperature reduction during the process. In the figure 7 the different temperature distribution of hot mixed asphalt with different pipe spacing has been illustrated. As it can be seen the efficiency of the system is much better when pipes are implied nearer to each other and there is a better reduction of temperature in this situation.

## 4. Modeling

To simulate the effects of heating ‘CoupModel’ software have been used. Coupmodel is originally developed to model condition in forest soil. It has been upgraded now and is able to simulate water and heat processes in a different kind of soil independent plant cover.

The model is based on some well-known physical equations which lets the model can be adapted to different ecosystems. The model also includes nitrogen and carbon cycle. It provide an active interaction between the abiotic and plants in the environment. This part is not used in this project.

In this project, Coupmodel is used to simulate the heat transfer between the pipes and the surface to see how the system works in summer to gather the heat and how it works during the winter to keep it warm to prevent ice forming.

All meteorological data derives from the weather stations of SMHI close to the roads of this project. The data include information about humidity, air and surface temperature, wind, sun radiation, dew point and precipitation.

### 4.1.Uncertainties

The most important uncertainties in the Coupmodel are:

a. Convection: Vertical transference properties for heat and water in the soil and air for example, soil hydraulics properties.

b. Advection: Horizontal heat transport in the atmosphere.

c. Resistances: Reaction, resistance and friction between soil, atmosphere and canopy (when there are vegetable on the surface) for example, aerodynamic resistance (Jansson,n.d.).

d. Global radiation: Slope surface, correction measured radiation parameters, turbidity, humidity and cloudiness during the sunshine. These parameters influence the Global radiation and short wave net radiation which consequently influence on the Total Net Radiation.

e. Thermal conductivity: the value of thermal conductivity differs with different material and the atomic shape of them.

f. It is assumed that the road is completely impervious and 100% of precipitation becomes the runoff surface or evaporate.

g. Regulation: There are some pre-defined temperatures when the system starts to work. Always it takes some times from the moment that the temperature reaches to a special number and the system start to warm up the road, and the time that the road is warmed up. It is one of the reasons that the system efficiency never can be 100%.

In order to simulate the project lots of setting and regulation of the CoupModel is done. Some of the most important settings are written in the appendix II.

### 4.2.Simulation and the results:

In the first step, it is tried to simulate the models for the both roads (HalvorsLänk in Gothenburg and Hällabacken in Orebro) as they are on the real situation as they are without a deicing system.

In this project, parameters were given different values for the soil and surface in order to make the models as close as possible to the reality. Three kinds of soil layers are considered. First layer is the 15cm thickness of asphalt and the second 40 cm crushed rock. And the last layer is considered as a bed rock and the thickness is entered 7m to get the best result.

In this study, the efficiency is calculated based on the reduction percent of the frozen hours by the system. Here the efficiency is independent of the energy consumption or cost.

Simulated surface temperature is the temperature which is simulated by CoupModel according to the software setting. Measured surface temperature is the temperature which is measured by some sensors under the road surface.

By changing the setting of the software and simulate the different situation, the number of frozen hours are changed. The numbers of frozen hours are calculated by a summation of the time when the simulated surface temperature is less than zero.

For example in Gothenburg the total number of frozen hours would be 2200 when there is no deicing system. By using the deicing system this value decreases. If the number of frozen hours decreases from 2200 to 220, the efficiency of the system would be 90%.

When there is not any deicing system, the numbers of frozen hours are 2200 hours/ year in Gothenburg and 3200 hours/year in Orebro. These numbers are calculated by the times when the temperature is under zero and the dew point is not considered. Regardless which kind of system control is used, in order to calculate the efficiency these two numbers are used.

The most accurate diagram is when the simulated surface temperature is the same as the measured surface temperature. It is not easy to have exactly the same curves for simulated and measured temperature.

Figure 8 and 9 show the base diagram for Gothenburg and Orebro. The green lines are the temperature of the soil surface (two cm below the surface) and the blue lines are the temperature that is simulated by CoupModel. As it can be seen they are not exactly match but almost reasonable to continue the simulation.

Figure 8: Measured and simulated surface temperature without using the heat source –Gothenburg

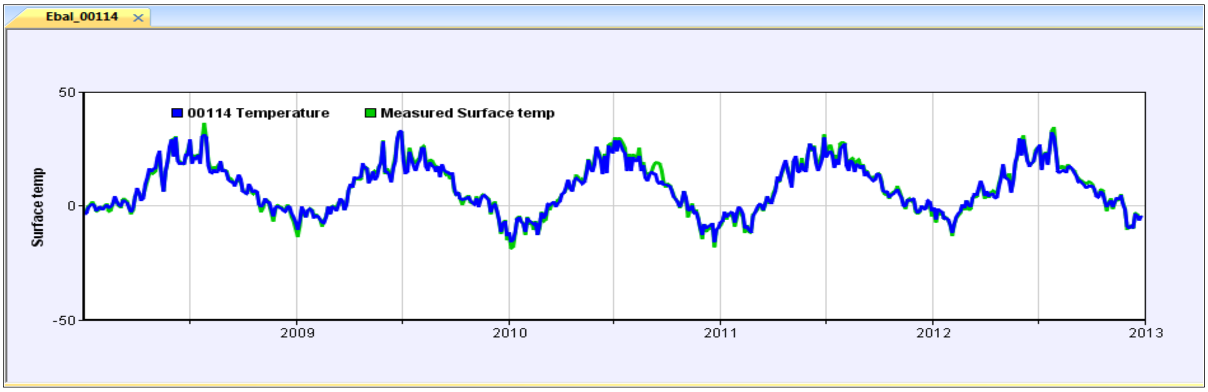

Figure 9: Measured and simulated surface temperature without using the heat source -Orebro

The next step is to simulate the situation when there is warming pipes under the road. The aim is to have the blue line always above zero temperature in order to prevent frost-making. Then the model can be simulated by different soil profile properties.

As we know, there are four different parameters which can effect on the heat transfer by conduction.

- The difference in temperature (here can be translate as the heat source power)
- Distance or the length
- Cross sectional area
- The material

Here these parameters are changed to see how they effect on the result and to find the most proper situation (The physics hypertextbook, n.d.)

### 4.2.1. Heat Power Effect

Here the model is set by using a single layer (pipe) as a heat source. The system assumes that there is a coherence heating layer like a heating plate.

The model is simulated by considering a pipe as a heat source. The annual heat power for Orebro is 8 286 300 J/m$^2$/day and for Gothenburg is 8 249 040 J/m$^2$/day. These power values can be gained during the summer by the system. It is not huge difference between the total energy of these cities.

For both cities the power is rounded to 8 000 000 J/m$^2$/day or 93 W/m$^2$. Actually we ignore all the heat lost during the storing process of hot water and assume all the heats can be absorbed by the pipes and reused again without energy lost.

Another power which is used in this project is 347 W/m$^2$. 347 W/m$^2$ is a power that can be achieved with a heat pump through external energy. Thus attempts are made to make a comparison between this power (347 W/m$^2$) and the power that can be absorbed in this system by the pipes during the summer (93 W/m$^2$).

There are two ways to control the heat pipes. The first one is the static control and the other is dynamic. When the system is simulated by the static control, it means that the system start to work at a pre-defined temperature to cool down or warm up the system and stop working at the other pre-defined temperature. In this project the starting point is at the 0 ºC to warm up and 25 ºC to cool down and the stop points are respectively 3 ºC and 35 ºC.

The other form of controlling the pipe or the heat pipes are the dynamic control. In the dynamic control, the system is run when there is a probability of frost making on the road but not every time that the temperature is under zero. Frost making is depend on the humidity and the temperature. For example in a sunny winter day the temperature can be even -20 ºC but the road was dry and ice free. By using the dynamic system more energy can be saved and the system warm up the road whenever it is needed.

### 4.2.1.1.Static control

The static control tries to keep the roads temperature above zero degrees to prevent ice making. In this part the model is simulated when the system is set by static control. At first, the models are simulated by the power of 93 W/m$^2$ which can be absorbed by sun and then they are simulated by the power of 347 W/m$^2$.

Figure10 and 11 illustrate the static simulation when the power is 93 W/m$^2$ and the heating pipes are implanted at the depth of 4cm under the surface.

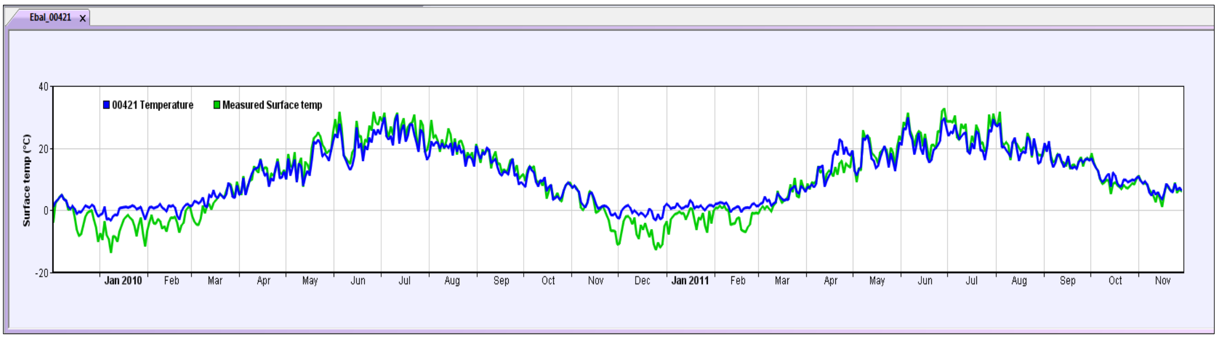

**Figure 10: Heating pipes are in the depth of 4 cm and the power is 93 W/m2, the pipe control is set by statistic temperature (Gothenburg).**

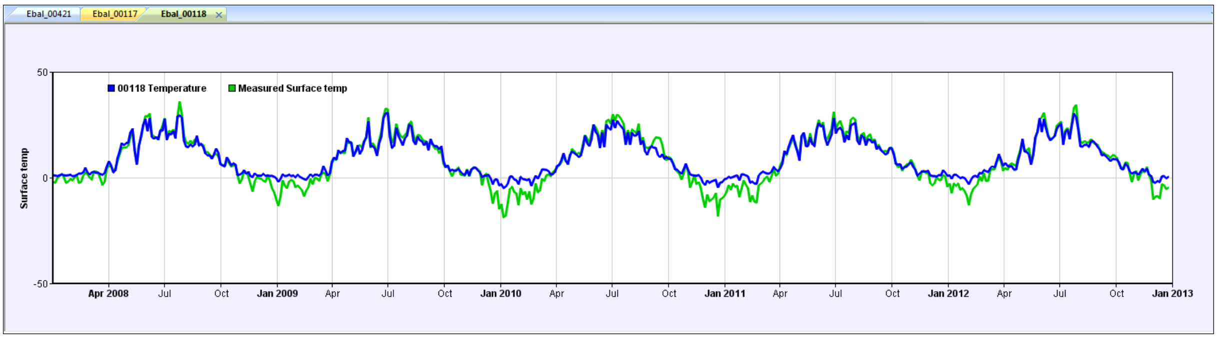

**Figure 11: Heating pipes are in the depth of 4 cm and the power is 93 W/m2, the pipe control is set by statistic temperature (Orebro).**

As it can be seen for the most days with the temperature under zero the heating pipe can cover the systems but still there are many days (hours) when the blue line is under the zero.

In order to better understand, the simulation's data are extracted from the software for analysis. In the both cities, the numbers of frozen hours are reduced dramatically.

When the power is set by 93 W/m$^2$, the number of frozen hours decreases from 2 200 to 750 hours in Gothenburg and from 3200 to 1195 in Orebro.

Although the system can decrease the number but the number of frozen hours is still high. The result can be improved in some different ways for example increasing the power.

As it can be expected, by increasing the power to 348 W/m$^2$, the reduction of frozen hours will be more. In this situation the number of frozen hours would be 32 and 79 hours respectively in Gothenburg and Orebro.

The maximum energy which can be put on the Coupmodel is 5E+7 J/m$^2$/day or 578 W/m$^2$. Even by using this power, still 17 hours/year in Gothenburg and 41 hours/year in Orebro, would be frozen.  The values of energy consumption in different conditions are also extracted from the software. By increasing the power, more energy consume by the system.

**Table 2: Static control with different power in Gothenburg**

| | Without heating source | Power 93 W/m$^2$ | Power 347 W/m$^2$ | Power 578 W/m$^2$ |
|---|---|---|---|---|
| **Frozen hours (h/year)** | 2200 | 750 | 32 | 17 |
| **Efficiency (%)** | - | 65.9% | 98.5% | 99.2% |
| **Energy consumption (kWh/m$^2$/year)** | - | 130 | 160 | 163 |

**Table 3: Static control with different power in Orebro**

| | Without heating source | Power 93 W/m$^2$ | Power 347 W/m$^2$ | Power 578 W/m$^2$ |
|---|---|---|---|---|
| **Frozen hours (h/year)** | 3200 | 1195 | 79 | 41 |
| **Efficiency (%)** | - | 62.6% | 97.5% | 98.7% |
| **Energy consumption (kWh/m$^2$/year)** | - | 224 | 284 | 289 |

Figure 12 and 13 show the models when the power of 348 W/m$^2$ is used. As it can be seen, the system works better by the higher power.

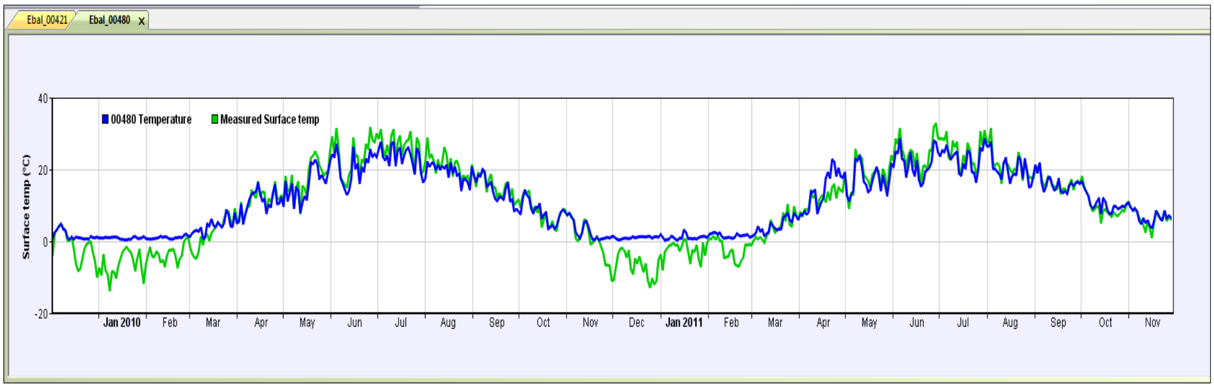

**Figure 12: Static simulation with the power of 348 W/m$^2$ and in the depth of 4 cm -Gothenburg**

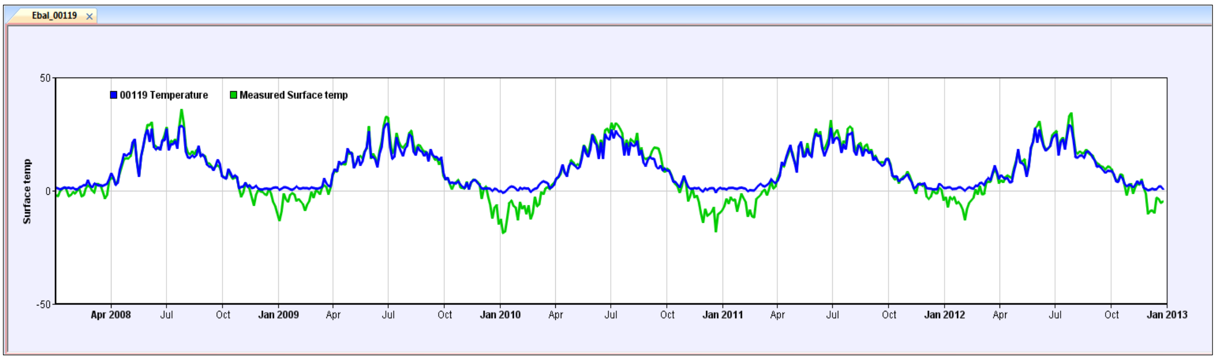

**Figure 13 : Static simulation with the power of 348 W/m$^2$ and in the depth of 4 cm -Orebro**

### 4.2.1.2.Dynamic pipe Control

In the reality it can happen that the temperature is below zero but there is any frost on the road. Actually if the temperature is under zero and the surface temperature is less than dew point, ice can be made on the road surface. Thus considering only the surface temperature is not enough and gives more frozen hours than it can happen in reality.

Since the aim of this project is to warm up the road when there is frost on it, it would be better to warm it whenever it is needed. In this way, more energy will be saved.

To make this simulation, dew point is used. When the surface temperature is under the dew point, there will be water or ice on the road. Thus if the temperature is below zero but the surface temperature is more than the dew point, the road will not have any layer of frost. Figure 14 shows when the pump starts working. It can be seen that there are some days when the temperature is under zero but the heat pipe is not working.

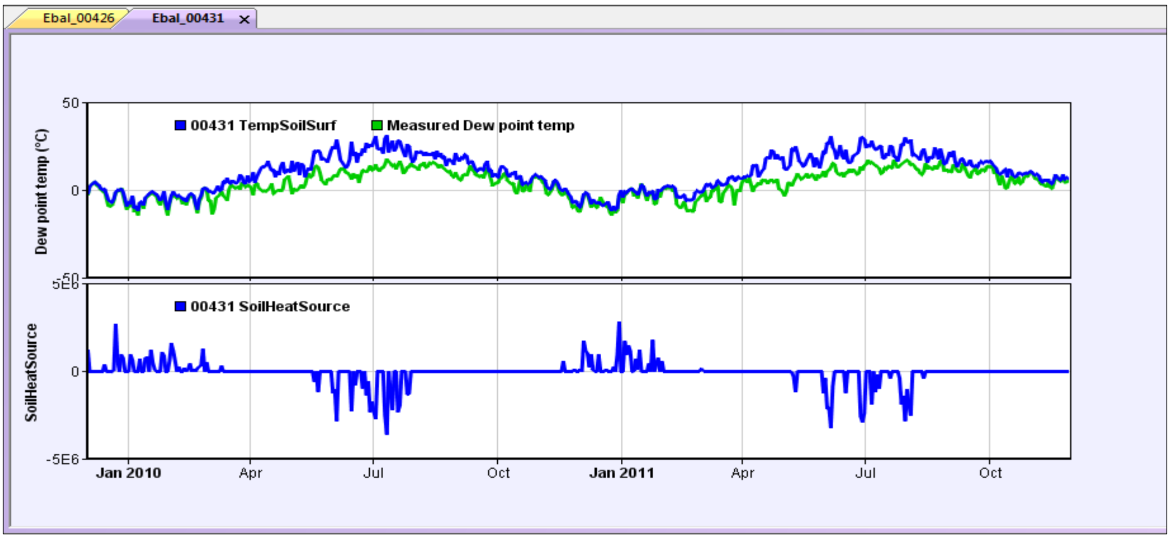

**Figure 14: The dynamic simulation when the pipes are in the depth of 4 cm and the power is 93 W/m$^2$**

In the Dynamic simulation for Gothenburg, when the pipes are in the depth of 4 cm, there are 95 hours in a year when there is frost on the road. For about 19 hours, the heat pipes cannot cover the system and for 76 hours the system does not start to work. These can happen because of the system regulation.

These numbers for Orebro respectively are 80, 24 and 54.

In the next step the power is increased to 347 W/m$^2$. The results of these changes are in the table below. In the dynamic simulation, changing the power does not make a huge different. In general the dynamic system can work better than the static one.

As it can be seen in the table the value of the energy consumption is much lower in a comparison by the static simulations. For example, when the power is 93 W/m$^2$ in Gothenburg, the asphalt is normal and the depth of pipe is 4 cm, the energy consumption in a static simulation is 130 kWh/m$^2$/year but in the dynamic 14 kWh/m$^2$/year. The static values are in table 2 and 3 beside the dynamic one are in table 4.

**Table 4: The camparison when the power increases to 347 W/m$^2$**

| City | Power | Number of frozen hours No heat system | Total fail | Heat is not enough | System does not work | Efficiency | Energy consumption |
|---|---|---|---|---|---|---|---|
| | W/m2 | h/year | h/year | h/year | h/year | Percentage | kWh/m2/year |
| Gothenburg | 93 | 2200 | 95 | 19 | 76 | 95.7 % | 14 |
| Gothenburg | 347 | 2200 | 82 | 10 | 72 | 96.3 % | 18 |
| Orebro | 93 | 3200 | 80 | 24 | 54 | 97.5 % | 23 |
| Orebro | 347 | 3200 | 71 | 11 | 60 | 97.8 % | 26 |

### 4.2.2. Depth of the heat source

The effect of depth of the heat source is considered both in static and dynamic simulation.

#### 4.2.2.1.The Effect of depth in static model

In this part, it is tried to find the best depth to implant the pipes when the system is by Static control. The pipes are modeled in different depths of the soil. The first three figures respectively show when the pipes are in the depth of 2, 4 and 12 cm. As it can be expected when the pipes are nearer to the surface, the system works better.

There is a direct relation between the pipes placement towards the surface and the number of frozen hours. The number or frozen hours are less when the pipes are in the depth of 2 than 4 and so on. According to the metrological data, the number of the frozen hours during a year in Gothenburg is 2 200 h/year and in Orebro is 3 200 h/year when there are no heating pipes.

By using the heat pipe the number of frozen hours decreases, and this reduction is related to the depth of the pipes. The corresponding diagrams are shown in the figures 15-17 for Gothenburg and 18-20 for Orebro.

Since the diagrams are drawn for 2 years in Gothenburg and 4 years in Orebro and the changes considered as hours, it is not easy to see the changes in different diagrams.

To see the effect of depth, the number of freezing hours can be found in the table 5-8.

In general by increasing the depth of the pipe, the energy consumption is increased. The reason can be the heat needs to be transferred longer way thus some energy can be lost.

**Table 5: Changing the depth in static control when the power is 93 W/m$^2$ in Gothenburg**

| | Without heating source | Depth of 2 cm | Depth of 4 cm | Depth of 12 cm |
|---|---|---|---|---|
| **Frozen hours (h/year)** | 2200 | 700 | 750 | 988 |
| **Efficiency (%)** | - | 68.2 % | 65.9% | 54.5 % |
| **Energy consumption (kWh/m$^2$/year)** | - | 131 | 130 | 131 |

**Table 6: Changing the depth in static control when the power is 93 W/m$^2$ in Orebro**

| | Without heating source | Depth of 2 cm | Depth of 4 cm | Depth of 12 cm |
|---|---|---|---|---|
| **Frozen hours (h/year)** | 3200 | 1100 | 1195 | 1650 |
| **Efficiency (%)** | - | 65.6 % | 60.9 % | 48.4 % |
| **Energy consumption (kWh/m$^2$/year)** | - | 223 | 224 | 223 |

**Table 7: Changing the depth in static control when the power is 347 W/m$^2$ in Gothenburg**

| | Without heating source | Depth of 2 cm | Depth of 4 cm | Depth of 12 cm |
|---|---|---|---|---|
| **Frozen hours (h/year)** | 2200 | 9 | 32 | 154 |
| **Efficiency (%)** | - | 99.6 % | 98.5 % | 93 % |
| **Energy consumption (kWh/m$^2$/year)** | - | 170 | 178 | 198 |

**Table 8: Changing the depth in static control when the power is 347 W/m$^2$ in Orebro**

| | Without heating source | Depth of 2 cm | Depth of 4 cm | Depth of 12 cm |
|---|---|---|---|---|
| **Frozen hours (h/year)** | 3200 | 6 | 79 | 454 |
| **Efficiency (%)** | - | 99.8 % | 97.4 % | 85.8 % |
| **Energy consumption (kWh/m$^2$/year)** | - | 283 | 300 | 343 |

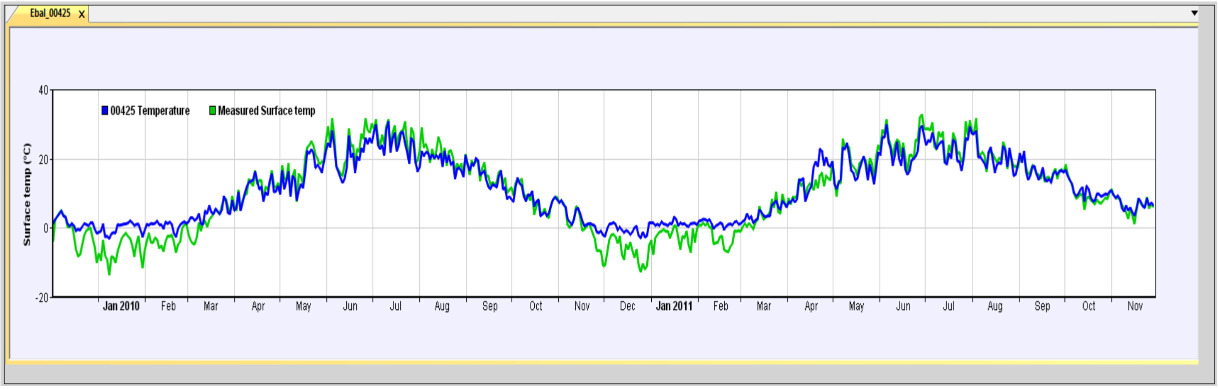

Figure 15: The pipe power is 93 W/m$^2$ and it is implanted in the depth of 2 cm -Gothenburg

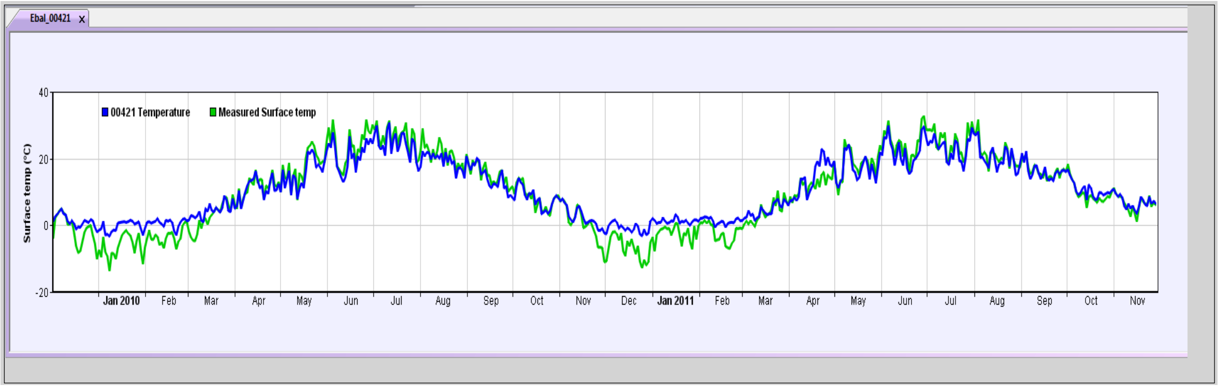

Figure 16: The pipe power is 93 W/m$^2$ and it is implanted in the depth of 4 cm -Gothenburg

Figure 17: The pipe power is 93 W/m$^2$ and it is implanted in the depth of 12 cm -Gothenburg

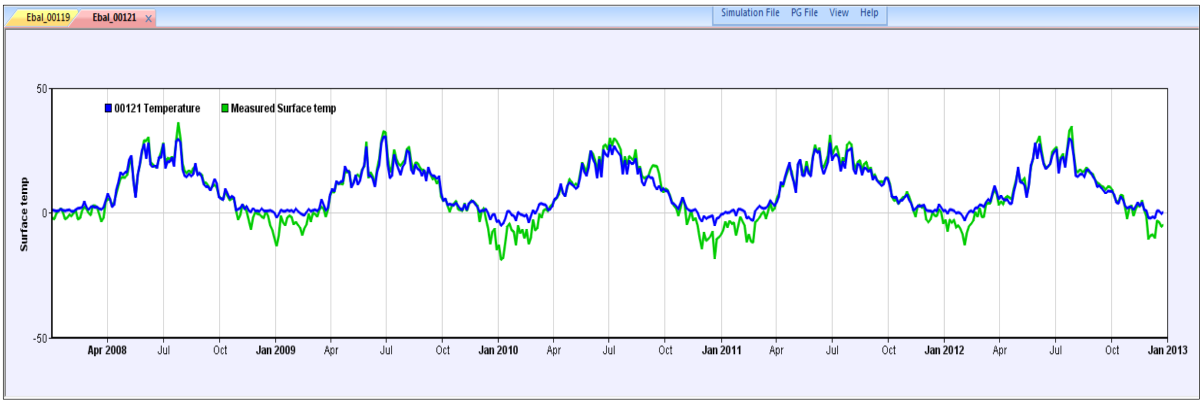

Figure 18: The pipe power is 93 W/m$^2$ and it is implanted in the depth of 2 cm -Orebro

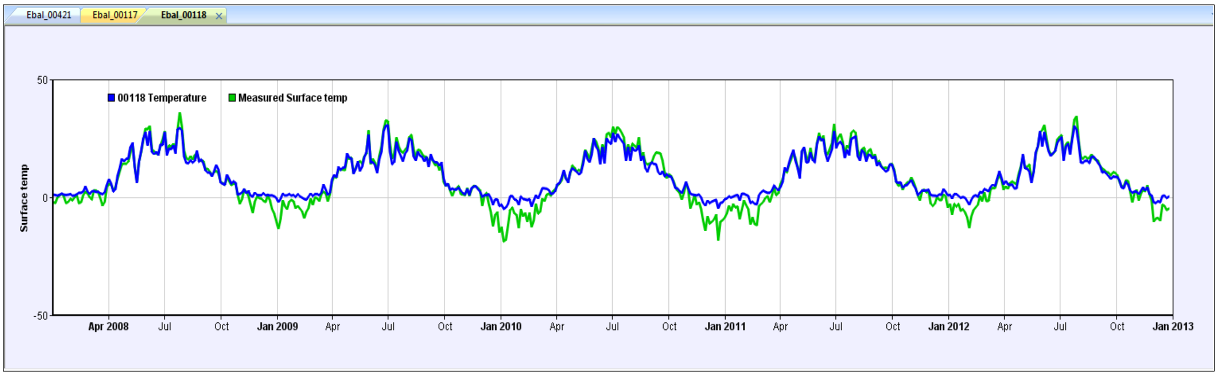

Figure 19: The pipe power is 347 W/m$^2$ and it is implanted in the depth of 4 cm -Orebro

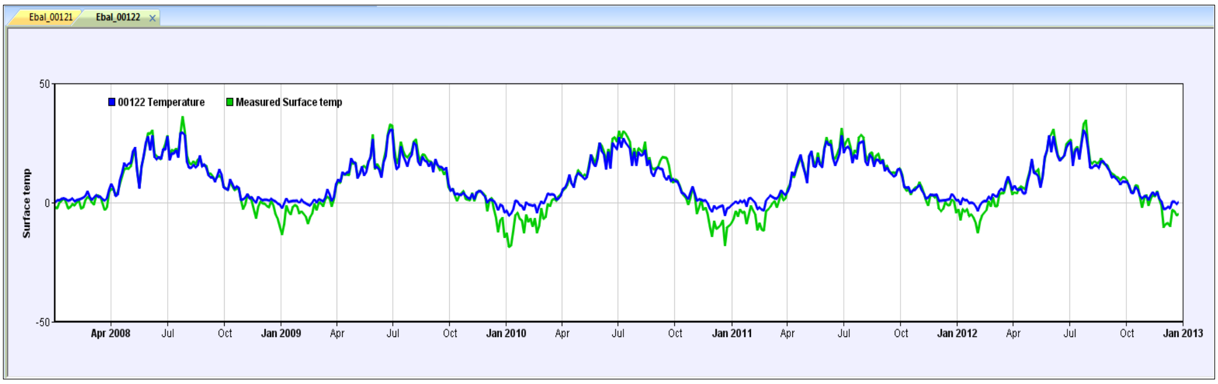

Figure 20: The pipe power is 347 W/m$^2$ and it is implanted in the depth of 12 cm -Orebro

To choose the place of the pipes, the construction of the pipes should be considered. The stress caused by the traffic loads can damage the pipes. Although putting the pipes near the surface can give the better result but on the other hand can reduce the pipes life time. To prevent this problem relatively soft asphalt mix can be used. Also interlocking grids are useful to protect the pipes. In the figure 21 one example of interlocking grids is shown.

Figure 21: Interlocking grids (Technology, 2008)

### 4.2.2.2. The effect of depth in dynamic simulation

In order to see the effect of heat pipe distance, the system is modeled by putting the pipe heat in different depths or in other words different layers.

In these simulations, when the pipes are in the depth of 4cm, the number of frozen hours is minimum. The energy consumption has the same trend as the static one. The energy consumption increases by increasing the pipe depth.

By increasing the depth, the energy consumption is increased. Table 9-12 shows the effect of depth of the number of frozen hours, system efficiency and also the energy consumption.

Table 9: Changing the depth in dynamic control when the power is 93 W/m2 in Gothenburg

| | Without heating source | the depth of 2 cm | the depth of 4 cm | the depth of 12 cm |
|---|---|---|---|---|
| **Frozen hours (h/year)** | 2200 | 114 | 95 | 88 |
| **Efficiency (%)** | - | 94.8% | 95.7 % | 96% |
| **Energy consumption (kWh/m$^2$/year)** | - | 11 | 14 | 25 |

**Table 10: Changing the depth in dynamic control when the power is 93 W/m$^2$ in Orebro**

| | Without heating source | the depth of 2 cm | the depth of 4 cm | the depth of 12 cm |
|---|---|---|---|---|
| **Frozen hours (h/year)** | 3200 | 106 | 80 | 63 |
| **Efficiency (%)** | - | 96.7% | 97.5 % | 98% |
| **Energy consumption (kWh/m$^2$/year)** | - | 14 | 23 | 34 |

**Table 11: Changing the depth in dynamic control when the power is 347 W/m$^2$ in Gothenburg**

| | Without heating source | the depth of 2 cm | the depth of 4 cm | the depth of 12 cm |
|---|---|---|---|---|
| **Frozen hours (h/year)** | 2200 | 120 | 82 | 75 |
| **Efficiency (%)** | - | 94.5% | 96.3 % | 96.6% |
| **Energy consumption (kWh/m$^2$/year)** | - | 11 | 18 | 37 |

**Table 12: Changing the depth in dynamic control when the power is 347 W/m2 in Orebro**

| | Without heating source | the depth of 2 cm | the depth of 4 cm | the depth of 12 cm |
|---|---|---|---|---|
| **Frozen hours (h/year)** | 3200 | 111 | 71 | 46 |
| **Efficiency (%)** | - | 96.5% | 97.8 % | 98.5% |
| **Energy consumption (kWh/m$^2$/year)** | - | 13 | 26 | 61 |

### 4.2.3. Effect of different material by different thermal conductivity

There are different asphalts with different thermal conductivity. The thermal conductivity can be changed by adding graphite powder to asphalt. In this part the model is simulated by assuming of using different kind of asphalt with different thermal conductivity in the road base course.

The thermal conductivity of normal Asphalt is 0.7 W/m ºC and Asphalt Concrete (AC) is 1.3 W/m ºC and the Conductive Asphalt Concrete (CAC) can be varied between 2-5 (Chen, Wang & Zhang, 2011).

Here the simulation is done by changing the first layer asphalt. Thermal conductivity of AC and CAC are used in order to see how the higher thermal conductivity effects on the result. The thermal conductivity can be changed by the scaling coefficient of soil thermal on the software (CoupModel). By putting different coefficients different thermal conductivity can be get. But the maximum thermal conductivity which the CoupModel can be simulated is 2 W/m ºC and for higher thermal conductivity like 3 or 5, the software errors.

The model is simulated by the dynamic and static form of pipe control and the power of 93 W/m$^2$ and 347 W/m$^2$ for the both cities.

#### 4.2.3.1.The effect of thermal conductivity in static simulation

The higher thermal conductivity causes heat to transfer more easily. The results of the simulations show that using a higher thermal conductivity, it decreases the numbers of frozen hours. Thus the system works better when CAC or CA is used.

Table 13-16 shows the effect of thermal conductivity in static simulation by the power of 93W/m$^2$ and 347 W/m$^2$ and the depth of 4cm.

**Table 13: Static simulation by different thermal conductivity of asphalt when the power is 93 W/m$^2$ Gothenburg**

| | Without heating source | Asphalt 0.7 W/m ºC | CA 1.3 W/m ºC | CAC 2 W/m ºC |
|---|---|---|---|---|
| **Frozen hours (h/year)** | 2200 | 750 | 841 | 889 |
| **Efficiency (%)** | - | 65.9% | 61.7% | 59.6% |
| **Energy consumption (kWh/m$^2$/year)** | - | 130 | 138 | 142 |

**Table 14: Static simulation by different thermal conductivity of asphalt when the power is 347 W/m$^2$ Gothenburg**

| | Without heating source | Asphalt 0.7 W/m ºC | CA 1.3 W/m ºC | CAC 2 W/m ºC |
|---|---|---|---|---|
| **Frozen hours (h/year)** | 2200 | 32 | 21 | 21 |
| **Efficiency (%)** | - | 98.5 % | 99 % | 99 % |
| **Energy consumption (kWh/m$^2$/year)** | - | 170 | 204 | 218 |

**Table 15: Static simulation by different thermal conductivity of asphalt when the power is 93 W/m$^2$ Orebro**

| | Without heating source | Asphalt 0.7 W/m ºC | CA 1.3 W/m ºC | CAC 2 W/m ºC |
|---|---|---|---|---|
| **Frozen hours (h/year)** | 3200 | 1195 | 1437 | 1541 |
| **Efficiency (%)** | - | 62.6% | 55.1% | 51.8% |
| **Energy consumption (kWh/m$^2$/year)** | - | 224 | 81 | 92 |

**Table 16: Static simulation by different thermal conductivity of asphalt when the power is 347 W/m$^2$ Orebro**

| | Without heating source | Asphalt 0.7 W/m ºC | CA 1.3 W/m ºC | CAC 2 W/m ºC |
|---|---|---|---|---|
| **Frozen hours (h/year)** | 3200 | 79 | 43 | 96 |
| **Efficiency (%)** | - | 97.5 % | 98.6 % | 97% |
| **Energy consumption (kWh/m$^2$/year)** | - | 283 | 353 | 376 |

#### 4.2.3.2.The effect of thermal conductivity in dynamic simulation

When the system is set by dynamic control, increasing the thermal conductivity gives also the better results.

Table 17 -20 show the results of simulations when the power is 93 and 347 W/m$^2$.

**Table 17: Dynamic simulation by different thermal conductivity of asphalt - Power 93 W/m$^2$ - Gothenburg**

| | Without heating source | Asphalt 0.7 W/m ºC | CA 1.3 W/m ºC | CAC 2 W/m ºC |
|---|---|---|---|---|
| **Frozen hours (h/year)** | 2200 | 95 | 86 | 74 |
| **Efficiency (%)** | - | 95.6 % | 96.1 % | 96.6 % |
| **Energy consumption (kWh/m$^2$/year)** | - | 14 | 16 | 18 |

**Table 18: Dynamic simulation by different thermal conductivity of asphalt - Power 93 W/m$^2$ - Orebro**

| | Without heating source | Asphalt 0.7 W/m ºC | CA 1.3 W/m ºC | CAC 2 W/m ºC |
|---|---|---|---|---|
| **Frozen hours (h/year)** | 3200 | 80 | 77 | 66 |
| **Efficiency (%)** | - | 97.5 % | 97.6 % | 97.9 % |
| **Energy consumption (kWh/m$^2$/year)** | - | 23 | 26 | 29 |

**Table 19: Dynamic simulation by different thermal conductivity of asphalt - Power 347 W/m$^2$ - Gothenburg**

| | Without heating source | Asphalt 0.7 W/m ºC | CA 1.3 W/m ºC | CAC 2 W/m ºC |
|---|---|---|---|---|
| **Frozen hours (h/year)** | 2200 | 82 | 79 | 78 |
| **Efficiency (%)** | - | 96.3 % | 96.4 % | 96.4 % |
| **Energy consumption (kWh/m$^2$/year)** | - | 18 | 18 | 19 |

**Table 20: Dynamic simulation by different thermal conductivity of asphalt - Power is 347 W/m$^2$ - Orebro**

| | Without heating source | Asphalt 0.7 W/m ºC | CA 1.3 W/m ºC | CAC 2 W/m ºC |
|---|---|---|---|---|
| **Frozen hours (h/year)** | 3200 | 71 | 69 | 69 |
| **Efficiency (%)** | - | 97.8 % | 97.8 % | 97.8 % |
| **Energy consumption (kWh/m$^2$/year)** | - | 26 | 28 | 30 |

### 4.2.4. Insulation layer

The only ideal direction of heat transfer in this project is from the pipe to the surface and vice versa. The heat transfer from the pipe to its lower layer is not suitable and causes wasted energy. Thus using an insulation layer can improve the situation.

The thermal conductivity of an insulation layer can be between 0.03-0.16 W/m ºC (The Engineering ToolBox, n.d.).

In CoupModel, the thermal conductivity for the insulation layer is assumed as 0.08 W/m ºC. Here the insulation layer is placed in different depths to see the effect on the results. As it can be seen there is not a huge different between the simulation with or without the insulation layer. The simulations are done when the system is set by dynamic control and the power is 93 W/m$^2$. Table 21 and 22 show the results of simulations when isolation layer is used. Also the simulations are done with different type of asphalt. E.C is Energy consumption, F.H. is frozen hours and E is Efficiency.

**Table 21: Insulation layer in different depth with different asphalt thermal conductivity in Gothenburg**

| Gothenburg | Asphalt 0.7 W/m ºC | | | CA 1.3 W/m ºC | | | CAC 2 W/m ºC | | |
|---|---|---|---|---|---|---|---|---|---|
| Insulation depth | F.H. | E | E.C. | F.H. | E | E.C. | F.H. | E | E.C. |
| cm | h/year | % | kWh/m$^2$/year | h/year | % | kWh/m$^2$/year | h/year | % | kWh/m$^2$/year |
| No insulation | 95 | 95.7 | 14 | 86 | 96.1 | 16 | 74 | 96.6 | 18 |
| 6 | 100 | 95.5 | 7 | 89 | 96 | 13 | 82 | 96.3 | 14 |
| 9 | 90 | 95.9 | 8 | 85 | 96.1 | 14 | 79 | 96.4 | 15 |
| 12 | 99 | 95.5 | 8 | 91 | 95.9 | 15 | 79 | 96.4 | 16 |

Table 22: Insulation layer in different depth with different asphalt thermal conductivity in Orebro

| Orebro | Asphalt<br>0.7 W/m ºC | | | CA<br>1.3 W/m ºC | | | CAC<br>2 W/m ºC | | |
|---|---|---|---|---|---|---|---|---|---|
| Insulation depth | F.H. | E | E.C. | F.H. | E | E.C. | F.H. | E | E.C. |
| cm | h/year | % | kWh/m$^2$/year | h/year | % | kWh/m$^2$/year | h/year | % | kWh/m$^2$/year |
| No insulation | 80 | 97.5 | 23 | 77 | 97.6 | 26 | 66 | 97.9 | 29 |
| **6** | 77 | 97.6 | 19 | 73 | 97.7 | 21 | 67 | 97.9 | 21 |
| 9 | 83 | 97.4 | 20 | 76 | 97.6 | 22 | 63 | 98 | 23 |
| 12 | 86 | 97.3 | 21 | 75 | 97.7 | 23 | 67 | 97.9 | 28 |

### 4.2.5. Some other simulations

Beside above simulation, some other simulation is done in order to compare with the other simulations.

- Orebro; put the heat source 12 cm under the surface, no insulation.

Table 23: Static simulation, Heat source 12 cm under the surface, no insulation, power 93 W/m$^2$, Orebro

| | Without heating source | Asphalt<br>0.7 W/m ºC | CA<br>1.3 W/m ºC | CAC<br>2 W/m ºC |
|---|---|---|---|---|
| **Frozen hours (h/year)** | 3200 | 1628 | 1744 | 1791 |
| **Efficiency (%)** | - | 26% | 20.7% | 18.6% |
| **Energy consumption (kWh/m$^2$/year)** | - | 223 | 232 | 237 |

Table 24: Static simulation, Heat source 12 cm under the surface, no insulation, power 347 W/m$^2$, Orebro

| | Without heating source | Asphalt<br>0.7 W/m ºC | CA<br>1.3 W/m ºC | CAC<br>2 W/m ºC |
|---|---|---|---|---|
| **Frozen hours (h/year)** | 3200 | 461 | 420 | 444 |
| **Efficiency (%)** | - | 79% | 80.9% | 79.8% |
| **Energy consumption (kWh/m$^2$/year)** | - | 237 | 389 | 406 |

**Table 25: Dynamic simulation, Heat source 12 cm under the surface, no insulation, power 93 W/m$^2$, Orebro**

| | Without heating source | Asphalt 0.7 W/m ºC | CA 1.3 W/m ºC | CAC 2 W/m ºC |
|---|---|---|---|---|
| **Frozen hours (h/year)** | 3200 | 62 | 56 | 54 |
| **Efficiency (%)** | - | 97.2% | 97.4% | 97.5% |
| **Energy consumption (kWh/m$^2$/year)** | - | 38 | 39 | 39 |

**Table 26: Dynamic simulation, Heat source 12 cm under the surface, no insulation, power 347 W/m$^2$, Orebro**

| | Without heating source | Asphalt 0.7 W/m ºC | CA 1.3 W/m ºC | CAC 2 W/m ºC |
|---|---|---|---|---|
| **Frozen hours (h/year)** | 3200 | 46 | 34 | 31 |
| **Efficiency (%)** | - | 97.9% | 98.4% | 98.6% |
| **Energy consumption (kWh/m$^2$/year)** | - | 56 | 53 | 51 |

- Gothenburg; heat source at 12 cm under the surface with insulation

**Table 27: Static simulation, Heat source 12 cm under the surface, Power 93 W/m$^{2-}$ Gothenburg**

| | Without heating source | Asphalt 0.7 W/m ºC | CA 1.3 W/m ºC | CAC 2 W/m ºC |
|---|---|---|---|---|
| **Frozen hours (h/year)** | 2200 | 1029 | 1052 | 1045 |
| **Efficiency (%)** | - | 53.2% | 52.2% | 52.5% |
| **Energy consumption (kWh/m$^2$/year)** | - | 132 | 140 | 143 |

**Table 28: Static simulation, Heat source 12 cm under the surface, Power 347 W/m$^2$ -Gothenburg**

| | Without heating source | Asphalt 0.7 W/m ºC | CA 1.3 W/m ºC | CAC 2 W/m ºC |
|---|---|---|---|---|
| **Frozen hours (h/year)** | 2200 | 227 | 265 | 237 |
| **Efficiency (%)** | - | 87.4% | 87.9% | 89.2% |
| **Energy consumption (kWh/m$^2$/year)** | - | 199 | 227 | 238 |

**Table 29: Dynamic simulation, Heat source 12 cm under the surface, Power 93 W/m2 -Gothenburg**

| | Without heating source | Asphalt 0.7 W/m ºC | CA 1.3 W/m ºC | CAC 2 W/m ºC |
|---|---|---|---|---|
| **Frozen hours (h/year)** | 2200 | 98 | 86 | 83 |
| **Efficiency (%)** | - | 95.5% | 96.1% | 96.2% |
| **Energy consumption (kWh/m$^2$/year)** | - | 24 | 25 | 24 |

**Table 30: Dynamic simulation, Heat source 12 cm under the surface, Power 347 W/m$^2$ - Gothenburg**

| | Without heating source | Asphalt 0.7 W/m ºC | CA 1.3 W/m ºC | CAC 2 W/m ºC |
|---|---|---|---|---|
| **Frozen hours (h/year)** | 2200 | 71 | 66 | 69 |
| **Efficiency (%)** | - | 96.8% | 97% | 96.8% |
| **Energy consumption (kWh/m$^2$/year)** | - | 41 | 36 | 33 |

- Gothenburg, heat source at 8 cm under the surface, no insulation

Table 31: Static simulation, Heat source 8 cm under the surface, no insulation, Power 93 W/m$^2$- Gothenburg

| | Without heating source | Asphalt 0.7 W/m ºC | CA 1.3 W/m ºC | CAC 2 W/m ºC |
|---|---|---|---|---|
| **Frozen hours (h/year)** | 2200 | 916 | 959 | 966 |
| **Efficiency (%)** | - | 58.3% | 56.4% | 56.1% |
| **Energy consumption (kWh/m$^2$/year)** | - | 131 | 137 | 142 |

Table 32: Static simulation, Heat source 8 cm under the surface, no insulation, power 347 W/m$^2$- Gothenburg

| | Without heating source | Asphalt 0.7 W/m ºC | CA 1.3 W/m ºC | CAC 2 W/m ºC |
|---|---|---|---|---|
| **Frozen hours (h/year)** | 2200 | 132 | 90 | 83 |
| **Efficiency (%)** | - | 94% | 95.9% | 96.2% |
| **Energy consumption (kWh/m$^2$/year)** | - | 187 | 214 | 227 |

Table 33: Dynamic simulation, Heat source 8 cm under the surface, no insulation, power 93 W/m$^2$, Gothenburg

| | Without heating source | Asphalt 0.7 W/m ºC | CA 1.3 W/m ºC | CAC 2 W/m ºC |
|---|---|---|---|---|
| **Frozen hours (h/year)** | 2200 | 80 | 75 | 74 |
| **Efficiency (%)** | - | 96.4% | 96.6% | 96.6% |
| **Energy consumption (kWh/m$^2$/year)** | - | 21 | 21 | 22 |

**Table 34: Dynamic simulation, Heat source 8 cm under the surface, no insulation, Power 347 W/m$^2$, Gothenburg**

|  | Without heating source | Asphalt 0.7 W/m ºC | CA 1.3 W/m ºC | CAC 2 W/m ºC |
|---|---|---|---|---|
| **Frozen hours (h/year)** | 2200 | 70 | 68 | 75 |
| **Efficiency (%)** | - | 96.8% | 96.9% | 96.6% |
| **Energy consumption (kWh/m$^2$/year)** | - | 27 | 26 | 26 |

## 5. Discussion

In this project, the deicing system for HalvorsLänk road in Gothenburg and Hällabacken road in Orebro are modeled. In these simulations effects of different parameters such as heat power, depth of pipe, thermal conductivity of asphalt and using the insulation layer are studied. Attempts were made to simulate them in both static and dynamic control. Then the values of energy consumption in different situation are extracted from the software.

First, the systems are simulated by the power which can gain from the sun. The calculated power value from meteorological data is the same in both cities. The Orebro is on the higher latitude than Gothenburg and thus it is colder. But the power in Orebro is a bit more than Gothenburg (8 286 300 J/m$^2$/day in Orebro and 8 249 040 J/m$^2$/day in Gothenburg).

In this project the power of 8 000 000 J/m$^2$/day or 93 W/m$^2$ is considered for both cities.

In order to study the effect of different parameters, the efficiency of the system, both in the dynamic and the static control is considered. The system efficiency is calculated as a fraction of frozen hours reduction (when the heating system is on) to the total frozen hours (when the heating system is off). The total number of frozen hours is considered constant for the dynamic and static systems; 2200 in Gothenburg and 3200 in Orebro.

In the static control, the number of frozen hours calculated based on temperature and in the dynamic control based on temperature and humidity. Since the definition of the frozen hours in the dynamic and the static systems are not the same, the number of efficiency cannot represent the real value of the system efficiency. However it shows the effect of different parameters on the system.

By static simulation and the power of 93 W/m$^2$, the annual number of frozen hours decreases about 66% in Gothenburg and 63% in Orebro when the pipes are in the depth of 4cm. If the power is increased to 347 W/m$^2$ the number of frozen hours would decrease about 98.5% in Gothenburg and 97.5% in Orebro.

The energy consumption in this regulation will be 130 kWh/m$^2$/year in the Gothenburg and 224 kWh/m$^2$/year in Orebro. By increasing the power to 347 W/m$^2$, the energy consumption increase to 160 kWh/m$^2$/year in Gothenburg and 284 kWh/m$^2$/year in Orebro.

In dynamic simulation increasing the power, will increase the efficiency. But there is only a small difference between the efficiency of the systems when the power is increased. It is increased from 95.7% to 96.3% in Gothenburg and from 97.5% to 97.8% in Orebro. (Figure 22)

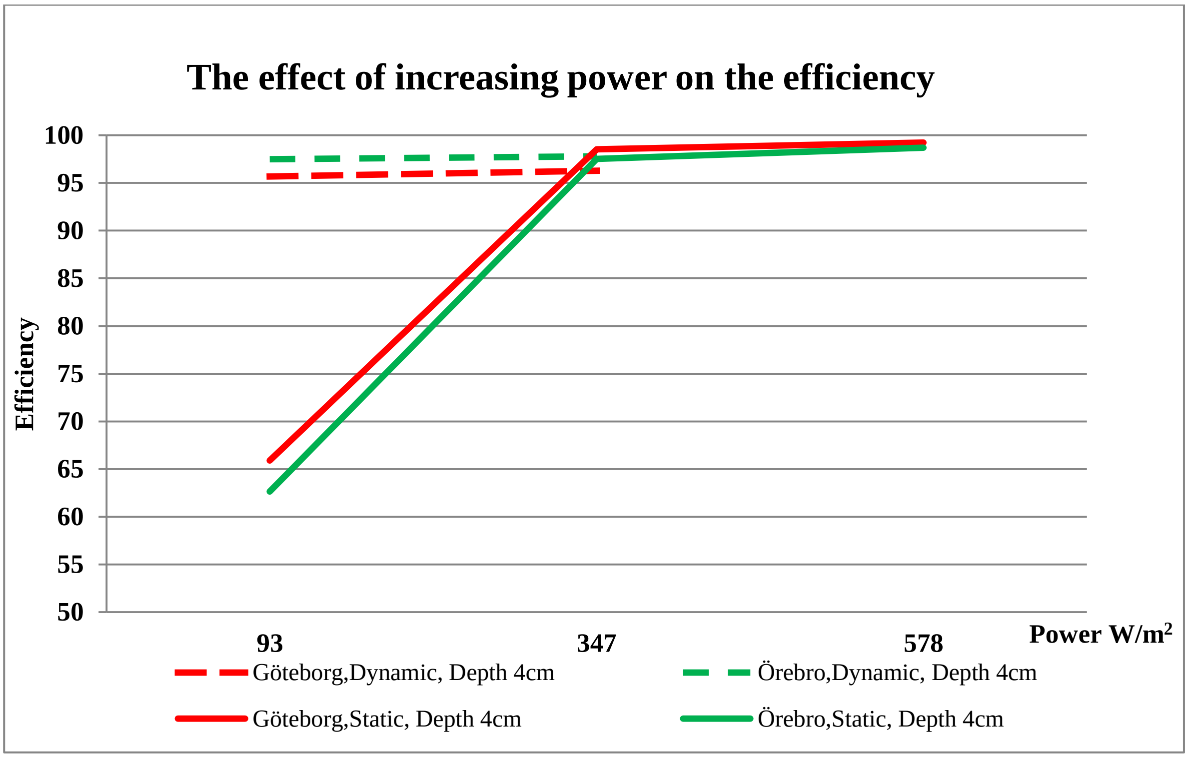

**Figure 22: The effect increasing power on efficincy when the system set by dynamic and static comtrol**

When the power is set by 93 W/m$^2$, the dynamic control gives higher efficiency than the static control.

Another interesting point is, when the system is set by static, the efficiency would be better in Gothenburg and when it is set by dynamic there is a higher efficiency in Orebro.

As it was mentioned, there is the same power in the both cities. Thus by dynamic system, less energy would be used. Since the Orebro has more frozen hours, the efficiency would be higher when the system is set by dynamic control.

The value of energy consumption is much more when the system is set by static. As an example the values of energy consumption in the table 2 (Static control) can be compared with table 4(Dynamic control). By the power of 93 W/m$^2$, the energy consumption is almost 10 times more in the static simulation.

When the power is set by 93 W/m$^2$, the energy consumption in Gothenburg and Orebro are respectively 14 and 23 kWh/m$^2$/year (Dynamic control). These values will increase to 18 and 26 kWh/m$^2$/year by improving the power to 347 W/m$^2$.

Figure 23 illustrate that the energy consumption is much higher when the system is set as static control. Although by this adjustment, system has less efficiency (Figure 22).

The effect of increasing power on energy consumption is clearer when the system is set by static control.

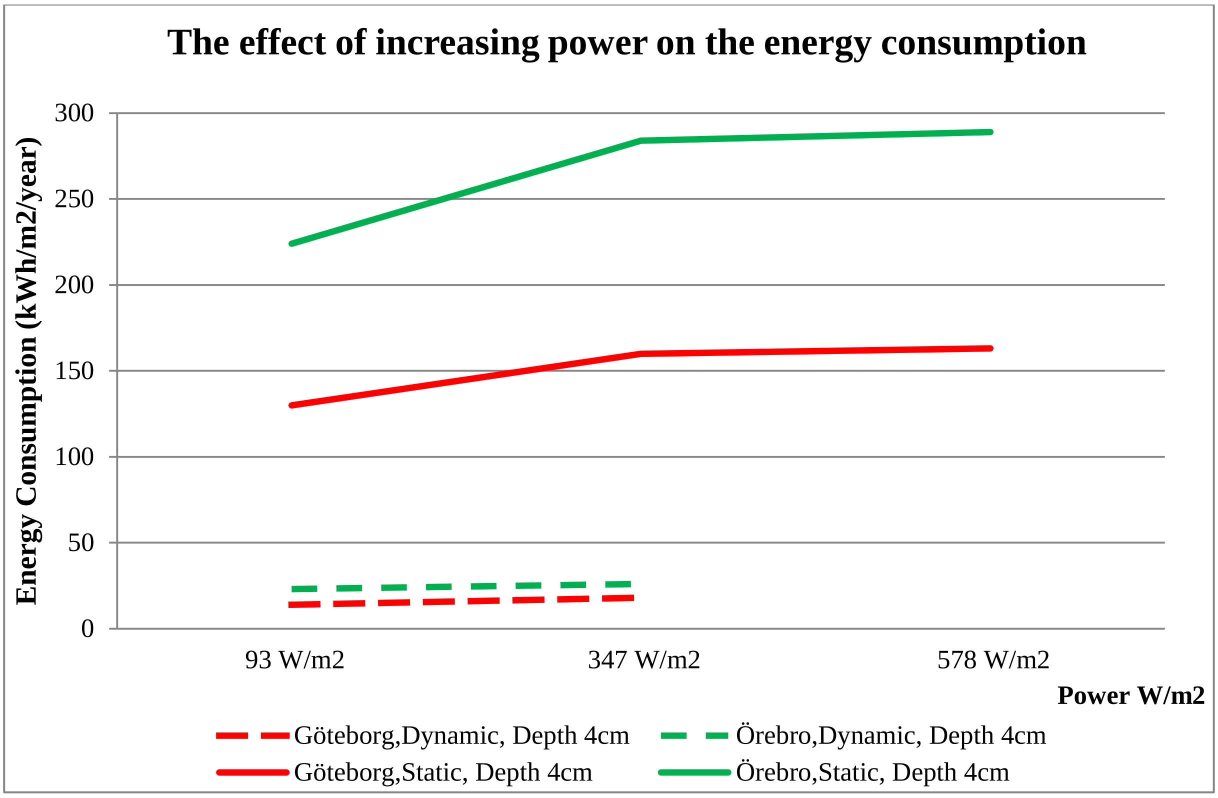

**Figure 23: The effect increasing power on energy consumption when the system set by dynamic and static control**

Another parameter is the depth of the pipes. The results show that the efficiency decreases by increasing the depth of the pipes. When the pipes are nearer to the surface, the heat should transfer a shorter path and gives better results. The effect of depth is clearer in the static system than the dynamics. For this project the depth of 4 cm can be suggested. Figure 24 illustrate the effect of pipe depth on the system efficiency.

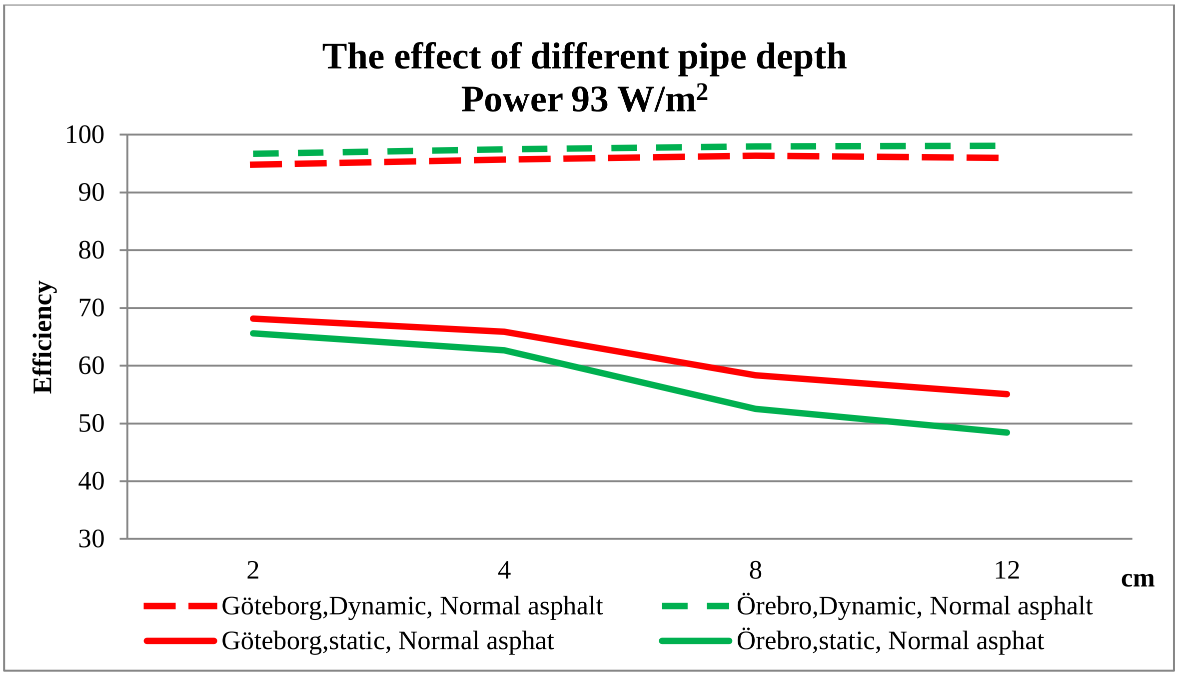

**Figure 24: The effect of different depth of the pipe on the efficiency of the system**

The energy consumption is increased by the depth. The reason can be the more energy waste when the distance is longer. As it illustrated on the figure 25, the effect of depth on the energy consumption is more visible when the system is by dynamic control.

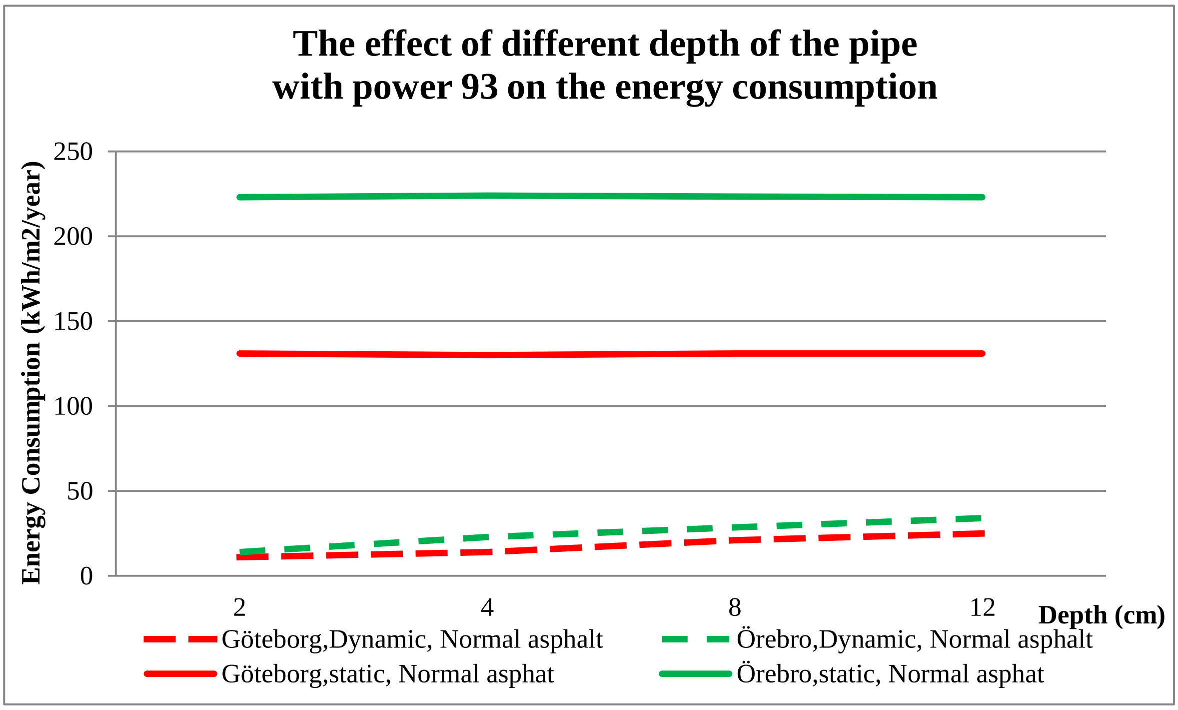

**Figure 25: The effect of different depth of the pipe on the energy consumption**

Thermal conductivity of a material shows the ability of the material to transfer heat. When the thermal conductivity of a material is higher, the heat can transfer better. The results of the simulations also prove it.

Some of the simulations are done by different kind of asphalts with different thermal conductivities. Normal asphalt, Asphalt Concrete (AC) and Conductive Asphalt Concrete (CAC) are investigated. Their thermal conductivities are respectively: 0.7 W/m ºC, 1.3 W/m ºC and 2 W/m ºC.

Since the heat can transfer easier through the asphalt by higher thermal conductivity, the system efficiency may increase by changing the asphalt from normal to CA and from CA to CAC.

It seems that when the power is high, increasing the thermal conductivity from 1.3 to 2 (using CAC) does not affect the system. In Gothenburg simulation, number of frozen hours is decrease from 32 to 21 hours when the thermal conductivity is increased from 0.7 to 1.3 W/m ºC. But any change cannot be seen on the number of frozen hours when it is increased from 1.3 to 2 W/m ºC.

In Orebro simulations there is also a reduction from 84 to 40 hours when the thermal conductivity changes from 0.7 to 1.3 W/m ºC. But by increasing the thermal conductivity from 1.3 to 2 W/m ºC, the result does not change significantly.

In this project, CA or CAC with higher thermal conductivity than normal asphalt is suggested.

Figure 26 illustrate the effect of thermal conductivity on the system when the system is set by Dynamic control.

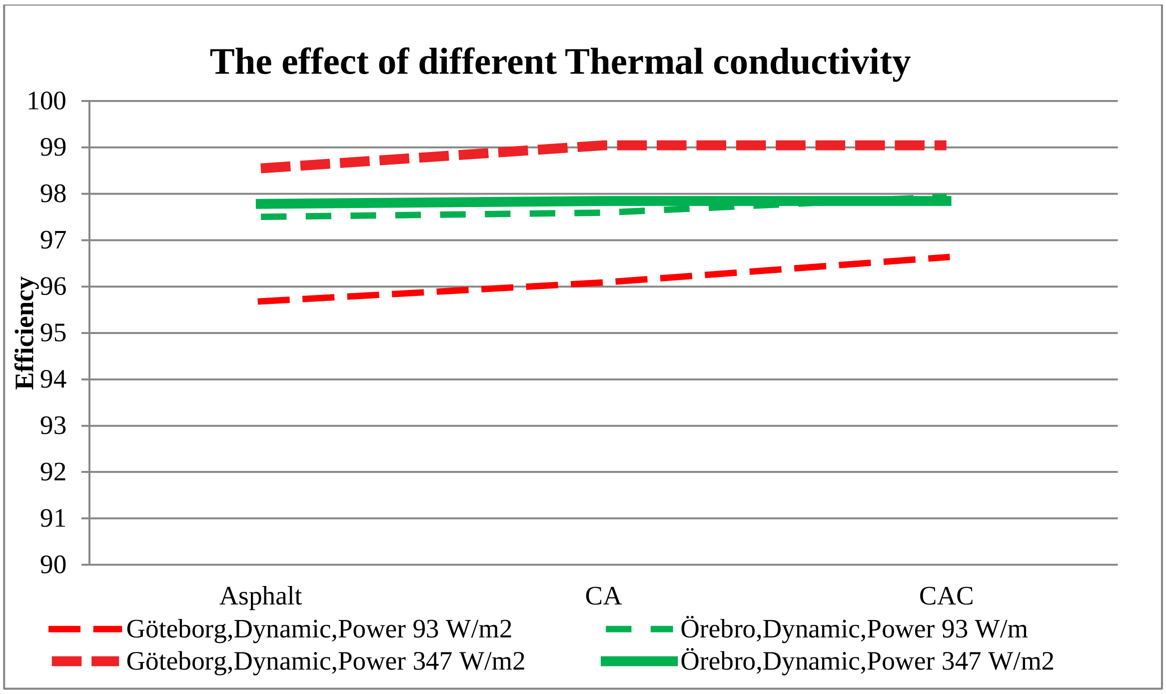

**Figure 26: The effect of different thermal conductivity on Efficiency- Dynamic control**

In the case of energy consumption, the act of system is almost strange when the thermal conductivity is changed. Figure 27 illustrate the effect of thermal conductivity on the system efficiency.

Since by higher thermal conductivity, the heat can be transfer easier, it can be expected the energy consumption is lower in higher thermal conductivity. But figure 27 shows that, the energy consumption increase by improving the thermal conductivity in the dynamic system. In the both cities, same results out comes by CoupModel. There is a same trend in different power as well.

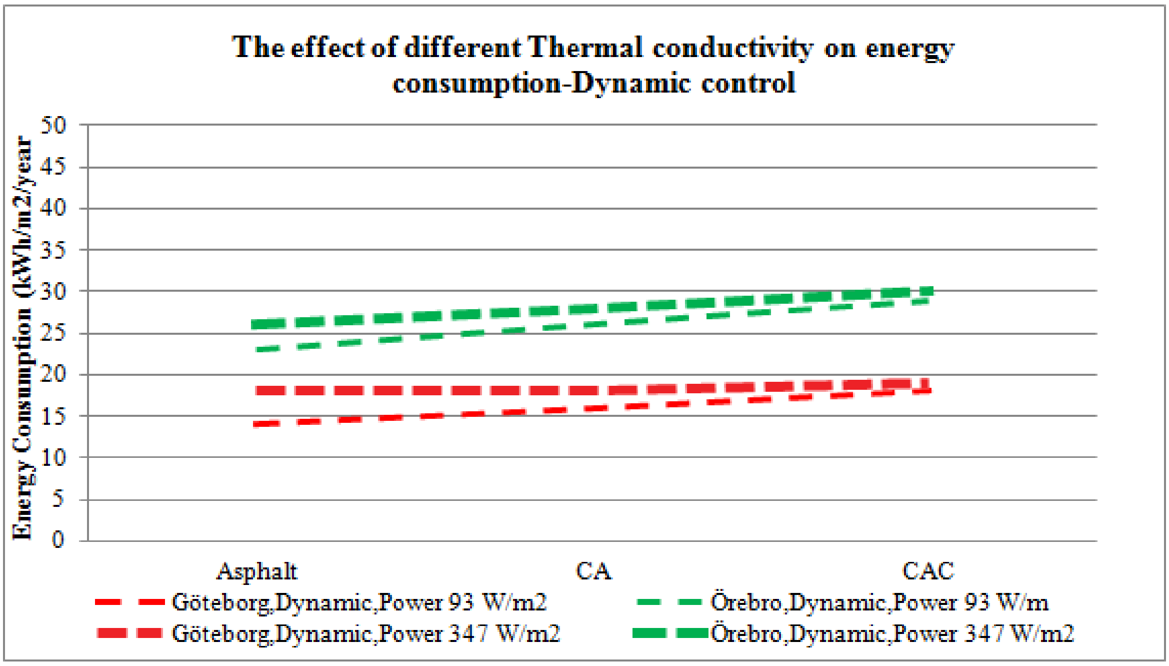

**Figure 27: The effect of different thermal conductivity on energy consumption- Dynamic control**

Figure 28 also shows the same trend on the energy consumption by changing the type of asphalt in the static system. There is only an exception in a simulation of Orebro when the power is 93 W/m$^2$. Here the energy consumption decreases by increasing the thermal conductivity. Actually, this is something which could be expected.

Nevertheless, the overall results show that the efficiency and the energy consumption increase by improving the thermal conductivity.

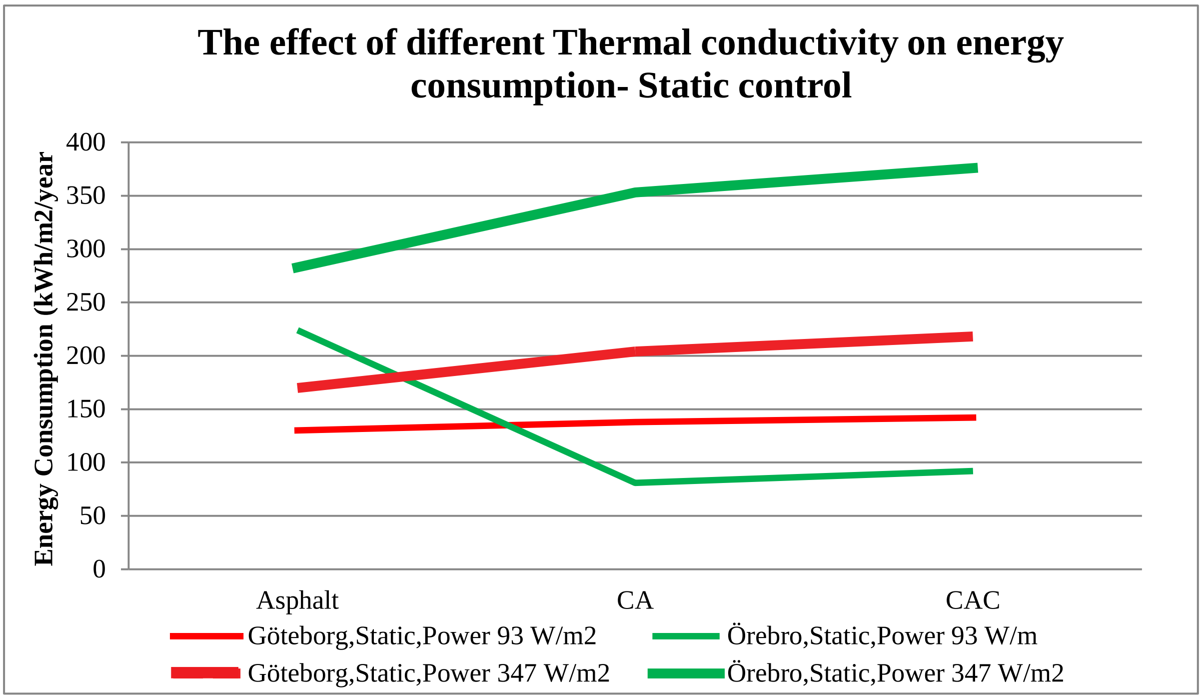

**Figure 26: The effect of different thermal conductivity on energy consumption- Static control**

The only ideal heat transmission is between surface and pipes. Thus using insulation layer may improve the results by stopping the heat transmission to the lower layer. In these simulations the results do not show a significant difference when insulation layer is used. But it seems that the system works better when the insulation layer is near to the pipes.

According this study, the depth of 9 cm is more suitable to implant the insulation layer. Figure 30 illustrate how the insulation layer effect on the efficiency by considering different kind of asphalt. Since the results cannot show a significant change, more investigations will be needed to examine the effect of insulation layer.

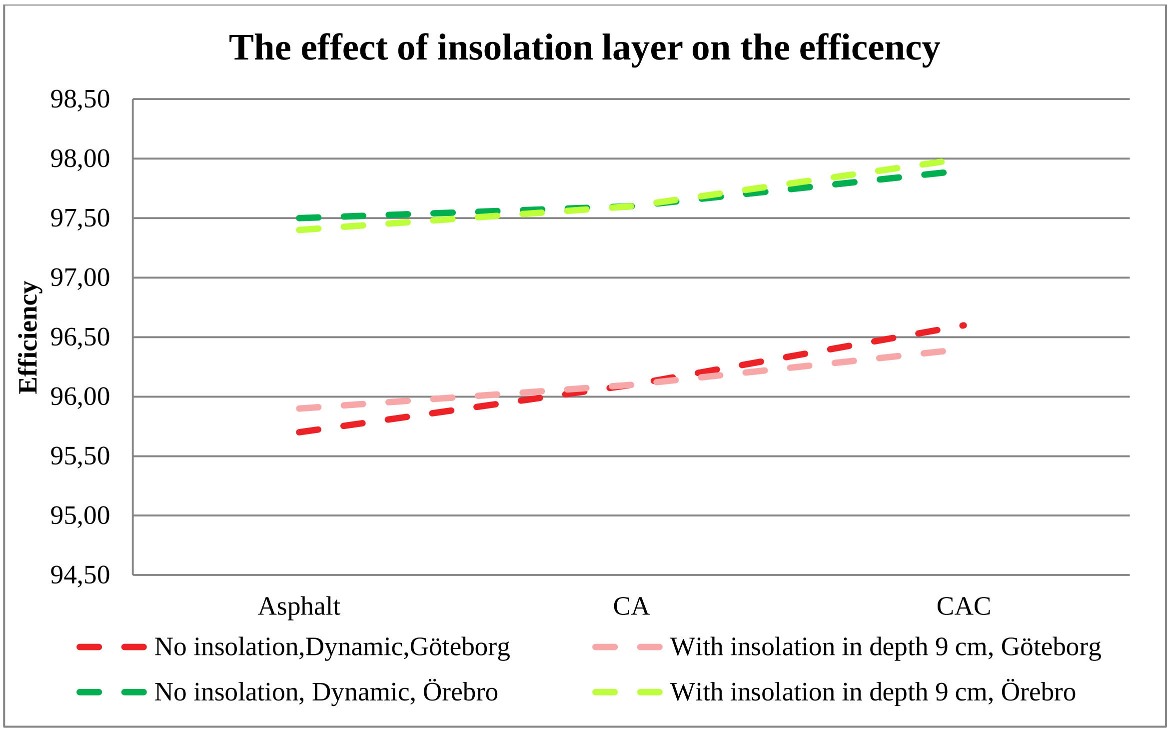

**Figure 29: The effect of insulation layer on the system efficiency**

Although using insulation layer cannot make a huge impact on the efficiency it can effect on the energy consumption. Figure 30 shows the effect of insulation layer at decline the energy consumption.

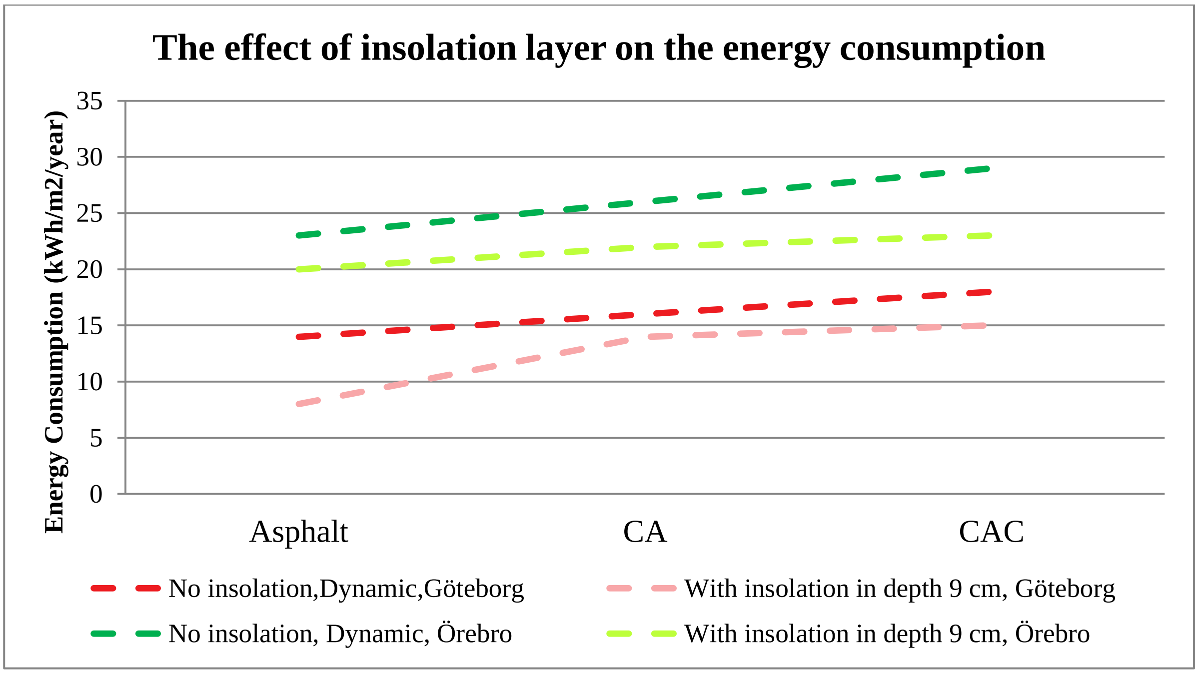

**Figure 30: The effect of insulation layer on the energy consumption**

## 6. Conclusion

After all the simulations, the best road condition to give the best answer can be suggested. The simulations shows that there are not a huge different between the roads in Gothenburg and Orebro. Almost all the changes in both of them give the same answer. In addition, the results show that the both of them work better when the systems are set by dynamic control.

The highest efficiency of the project (99%) can be reached when the power is 347 W/m$^2$ or even more and the system is static. But in this system the energy consumption (more than 200 kWh/m$^2$/year) is almost 10 times more than the dynamic system. By considering environmental effect and the energy cost this option is not suitable.

It is suggested to use the solar energy as the only source of the energy with the power of 93W/m$^2$. This is the total energy which can be absorbed by the road. The system should be set by dynamic control that this power can be sufficient.

It should be mentioned that in this project, the entire related subjects to the storage are ignored. Since some energy is lost during the storing process, using a heat pump may compensate this energy lost. By using the heat pump, the power of 93 W/m$^2$ might be enough. It is need more investigation to be sure if this energy is sufficient in the real project.

It seems that the best depth to implant the pipes is the depth of 4 cm under the road surface. For the first layer of the road, asphalt with higher thermal conductivity (CA or CAC) is suggested.

There is not a significant change on the efficiency by using the insulation layer. But on the other hand it effect on the energy consumption. By using the isolation layer the energy consumption significantly decrease. Thus in order to save more energy, using the insulation layer can be suggested.

By using the above setting, the efficiency of the system would be 97-98%.

In these simulations, the effect of power, depth, material and insulation layer are considered. But there are some other important properties which can be considered in the future studies. For example CoupModel is not able to model the spiral pipes. The heating pipes are considered as a plate heat source.

During the heat transmission, a part of heat will waste. For further investigation, these wasted heats can be studied.

Here the roads are simulated by three different layer, Asphalt, crushed rock and bed rock. In a real situation, a road has more different layers. Since different materials have different thermal conductivity, it is suggested to consider these layers.

## 7. References

1. Trafikverket. (2013). Available from: < http://www. Trafikverket.se/Privat/Projekt/Vastra-Gotaland/Hisingsleden-VadermotetKlareberg/> [25 September 2013]

2. Andersson, A. K. (2010). Winter Road Conditions and Traffic Accidents in Sweden and UK-Present and Future Climate Scenarios. Department of Earth Sciences; Institutionen för geovetenskaper.

3. The World Bank. (2011). Available from: < http://data.worldbank.org/country/sweden> [10 April 2013]

4. Elvik, R. (2000). How much do road accidents cost the national economy?.Accident Analysis & Prevention, 32(6), 849-851.

5. Eugster, Walter J.(2007). Road and Bridge Heating Using Geothermal Energy Overview and Examples. In Proceedings European Geothermal Congress, Unterhaching, Germany.

6. Nordin, L. (2011). Energy Use Within Road Maintenance Operations with Potentials for Increased Efficiency (Doctoral dissertation, Department of Earth Sciences, University of Gothenburg)

7. Morita, K., & Tago, M. (2005). Snow Melting on Sidewalks with Ground-Coupled Heat Pumps in a Heavy Snowfall City. In Proceedings World Geothermal Congress. Turkey: Antalya (pp. 24-29).

8. Groundwater pollution primer. (1998). Available from: <http://www.webapps.cee.vt.edu/ewr/environmental/teach/gwprimer/roadsalt/roadsalt.html#refs>. [27 September 2013].

9. EPA. (2013). Available from: <http://www.epa.gov/heatisld/about/index.htm>. [01 October 2013].

10. Svesnk Fjärvärm. (2013). Available from: <http://www.svenskfjarrvarme.se/In-English/District-Heating-in-Sweden/District-Heating/What-is-District-Heating/> . [01 October 2013].

11. NASA earth data. (2012). Available from: <http://disc.gsfc.nasa.gov/hydrology/data-holdings/parameters/sensible_heat_flux.shtml>. [17 April 2013].

12. Jansson P-E. (2012). CoupModel:Model Use, Calibration and Validation. Sent to American Society of Agricultural and Biological Engineers.

13. Conrad, Y. & Fohre, N. (2009). Application of the Bayesian calibration methodology for the parameter estimation in CoupModel. Copernicus Publications on behalf of the European Geosciences Union 21: 13–24

14. Trafikverket. (2013). Available from: <http://www. Trafikverket.se/Privat/Projekt/Vastra-Gotaland/Vag-155-Torslandavagen/Hisingsleden-Halvors-lank/>. [23 April 2013].

15. Lund, J. (2000) Pavement Snow Melting. Available from: <http://geoheat.oit.edu/bulletin/bull21-2/art4.pdf>. [22 April 2013].

16. Technovelgy.(2008). Use Roads As Solar Energy Collectors. Available from: < http://www.technovelgy.com/ct/Science-Fiction-News.asp?NewsNum=1383 >. [3 October 2013].

17. ASCE. (2011). Properties of Asphalt Conductive Concrete Containing Carbon Fibers and Graphite Powder. Available from: < http://ascelibrary.org/doi/abs/10.1061/41177(415)76>. [3 October 2013].

18. Mallick, R. B., Chen, B. L., & Bhowmick, S. (2009, September). Reduction of urban heat island effect through harvest of heat energy from asphalt pavements. In The proceedings of the 2nd international conference on countermeasures to urban heat Islands effect, September. Berkeley, CA.

19. World Meteorological Organization; Weather, Climate,Water (2010). Guide to Meteorological Instruments and Methods of Observation: WMO-No. 8, Seventh, Available from:<http://http://www.wmo.int/pages/prog/gcos/documents/gruanmanuals/CIMO/CIMO_Guide-7th_Edition-2008.pdf>. [07 May 2013].

20. Chen, M., Wu, S., Wang, H., & Zhang, J. (2011). Study of ice and snow melting process on conductive asphalt solar collector. Solar Energy Materials and Solar Cells, 95(12), 3241-3250.

21. The Engineering ToolBox.(n.d). Available from: <http://www.engineeringtoolbox.com/thermal-conductivity-d_429.html> . [27 September 2013].

22. Jansson, P. E., & Kasmaei, L. P. (n.d.), ‘Energy Balance-Heat and Mass Transfer in Atmosphere and Soil’, Royal Institute of Technology, Stockholm. Available from: < ftp://www.lwr.kth.se/CoupModel/Tutorials/Ebal.pdf> [4 January 2014]

23. The weather prediction. (n.d). Available from: <http://www.theweatherprediction.com/habyhints/347/> [4 January 2014]

24. Eisma, D. (1995). Climate ChangeImpact on Coastal Habitation

25. CoupModel, 2013 Available from: < http://www2.lwr.kth.se/CoupModel/> [4 January 2014]

26. Sundberg, J & Lidén, P. In progress. Non-skid winter roads – Case studies, Solar heat and heat storage for environmentally sound deicing.

- # Appendix

## I. Summary of the simulations which used in the thesis

| city | system control | Insulation depth(cm) | depth of pipes (cm) | power W/m$^2$ | Number of frozen hours Asphalt (0.7W/m °C) | Efficiency Asphalt (0.7W/m °C) | Number of frozen hours CA (1.3 W/m °C) | Efficiency CA (1.3 W/m °C) | Number of frozen hours CAC (2 W/m °C) |
|---|---|---|---|---|---|---|---|---|---|
| Göteborg | No cable | - | - | No cable | 2200 | 0 | 2200 | 0 | 2200 |
| Göteborg | Static | - | 2 | 93 | 700 | 68,2 | - | - | - |
| Göteborg | Static | - | 2 | 347 | 9 | 99,6 | - | - | - |
| Göteborg | Static | - | 4 | 93 | 750 | 65,9 | 841 | 61,8 | 889 |
| Göteborg | Static | - | 4 | 347 | 32 | 98,5 | 21 | 99,0 | 21 |
| Göteborg | Static | - | 4 | 578 | 17 | 99,2 | - | - | - |
| Göteborg | Static | - | 8 | 93 | 916 | 58,4 | 959 | 56,4 | 966 |
| Göteborg | Static | - | 8 | 347 | 132 | 94,0 | 90 | 95,9 | 83 |
| Göteborg | Static | - | 12 | 93 | **988** | 55,1 | 1025 | 53,4 | 1013 |
| Göteborg | Static | - | 12 | 347 | 154 | 93,0 | - | - | - |
| Göteborg | Static | 15 | 12 | 93 | 1029 | 53,2 | 1052 | 52,2 | 1045 |
| Göteborg | Static | 15 | 12 | 347 | 277 | 87,4 | 265 | 88,0 | 237 |
| Göteborg | Dynamic | - | 2 | 93 | 114 | 94,8 | - | - | - |
| Göteborg | Dynamic | - | 2 | 347 | 120 | 94,5 | - | - | - |
| Göteborg | Dynamic | - | 4 | 93 | 95 | 95,7 | 86 | 96,1 | 74 |
| Göteborg | Dynamic | - | 4 | 347 | 82 | 96,3 | 79 | 96,4 | 78 |
| Göteborg | Dynamic | 6 | 4 | 93 | 100 | 95,5 | 89 | 96,0 | 82 |
| Göteborg | Dynamic | 9 | 4 | 93 | 90 | 95,9 | 85 | 96,1 | 79 |
| Göteborg | Dynamic | 12 | 4 | 93 | 99 | 95,5 | 91 | 95,9 | 79 |
| Göteborg | Dynamic | - | 8 | 93 | 80 | 96,4 | 75 | 96,6 | 74 |
| Göteborg | Dynamic | - | 8 | 347 | 70 | 96,8 | 68 | 96,9 | 75 |
| Göteborg | Dynamic | - | 12 | 93 | 88 | 96,0 | - | - | - |
| Göteborg | Dynamic | - | 12 | 347 | 75 | 96,6 | - | - | - |
| Göteborg | Dynamic | 15 | 12 | 93 | 98 | 95,5 | 86 | 96,1 | 83 |
| Göteborg | Dynamic | 15 | 12 | 347 | 71 | 96,8 | 66 | 97,0 | 69 |

| city | system control | Insulation depth(cm) | depth of pipes (cm) | power W/m$^2$ | Number of frozen hours Asphalt (0.7W/m °C) | Efficiency Asphalt (0.7W/m °C) | Number of frozen hours CA (1.3 W/m °C) | Efficiency CA (1.3 W/m °C) | Number of frozen hours CAC (2 W/m °C) |
|---|---|---|---|---|---|---|---|---|---|
| Örebro | No cable | - | - | No cable | 3200 | 0 | 3200 | 0 | 3200 |
| Örebro | Static | - | 2 | 93 | 1100 | 65,6 | - | - | - |
| Örebro | Static | - | 2 | 347 | 6 | 99,8 | - | - | - |
| Örebro | Static | - | 4 | 93 | 1195 | 62,7 | 1437 | 55,1 | 1541 |
| Örebro | Static | - | 4 | 347 | 79 | 97,5 | 43 | 98,7 | 96 |
| Örebro | Static | - | 4 | 578 | 41 | 98,7 | - | - | - |
| Örebro | Static | - | 8 | 93 | 1680 | 52,5 |  |  |  |
| Örebro | Static | - | 12 | 93 | 1650 | 48,4 | - | - | - |
| Örebro | Static | - | 12 | 347 | 454 | 85,8 | - | - | - |
| Örebro | Static | - | 12 | 93 | 1628 | 49,1 | 1744 | 45,5 | 1791 |
| Örebro | Static | - | 12 | 347 | 461 | 85,6 | 420 | 86,9 | 444 |
| Örebro | Dynamic | - | 2 | 93 | 106 | 96,7 | - | - | - |
| Örebro | Dynamic | - | 2 | 347 | 111 | 96,5 | - | - | - |
| Örebro | Dynamic | - | 4 | 93 | 80 | 97,5 | 77 | 97,6 | 66 |
| Örebro | Dynamic | - | 4 | 347 | 71 | 97,8 | 69 | 97,8 | 69 |
| Örebro | Dynamic | 6 | 4 | 93 | 77 | 97,6 | 73 | 97,7 | 67 |
| Örebro | Dynamic | 9 | 4 | 93 | 83 | 97,4 | 76 | 97,6 | 63 |
| Örebro | Dynamic | - | 8 | 93 | 64,5 | 98,0 |  |  |  |
| Örebro | Dynamic | 12 | 4 | 93 | 86 | 97,3 | 75 | 97,7 | 67 |
| Örebro | Dynamic | - | 12 | 93 | 62 | 98,1 | 56 | 98,3 | 54 |
| Örebro | Dynamic | - | 12 | 347 | 46 | 98,6 | 34 | 98,9 | 31 |
| Örebro | Dynamic | - | 12 | 347 | 46 | 98,6 | - | - | - |

## II. Setting of the CoupModel

The calculation of heat flows are based on soil properties

- The heat capacity (the latent heat at melting point is included)
- The thermal conductivity.

Software is based on some equation:

**Heat equation:** heat equation on CoupModel can have binary value which is defined by on and off. The off value means any heat flows are calculated and a constant soil temperature is assumed based on the selected preliminary conditions. The On value means that the heat flows between the soil layers are calculated. It is set with On in this simulation.

**Water equation:** has also binary value (On and Off). When it is set to On, it means that no water flows is calculated and the soil water content is assumed constant. In this simulation the value of this parameter set by On with complete profile.

Water and heat equation can be considered separately or together. If only one of them is solved the other consider as constant for simulation.

**Snowpack define**: it is the situation of snow fall in the area. If it is Off it means neither snow accumulation nor melting is considered. If it is On snow is simulated by a sub model which consider snow accumulation, heat condition, melting and the heat exchange between the atmosphere and snow. Since the aim of the project is to prevent the ice formation, and on the other hand there is heavy traffic there, it would not be snow on the road and this option is set to off.

The soil is assumed to be unsaturated and thus Ground water flow is defined by off.

**Soil surface temperature**, **bare soil**, **the surface temperature** or **the upper boundary** can be identified in different ways. If there is any data for soil surface temperature, the temperature of the air can be used for the snow free periods when the temperature of the air and the soil are the same. This approach is used if the soil evaporation is ignored.

**Explicit Energy Balance (EBAL):** EBAL is an assumption to simulation a soil surface temperature. This approach is made according to the law of conservation of energy at the surface when net radiation flux is in balance with latent and sensible heat to the air and soil heat flux (Jansson,n.d.).

$R_{ns} = H_s + q_h + L_v E_s$

$R_{ns}$ is the net radiation at the soil surface which is assumed to be equal to the sum of the sensible heat flux to the air, $H_s$, the heat flux to the soil, $q_h$ *and* the latent heat flux, $L_v E_s$ (Coupmanual).

These three fluxes are estimated by a repetitive process which is based on surface temperature. This repetitive action continues until they reach equilibrium.

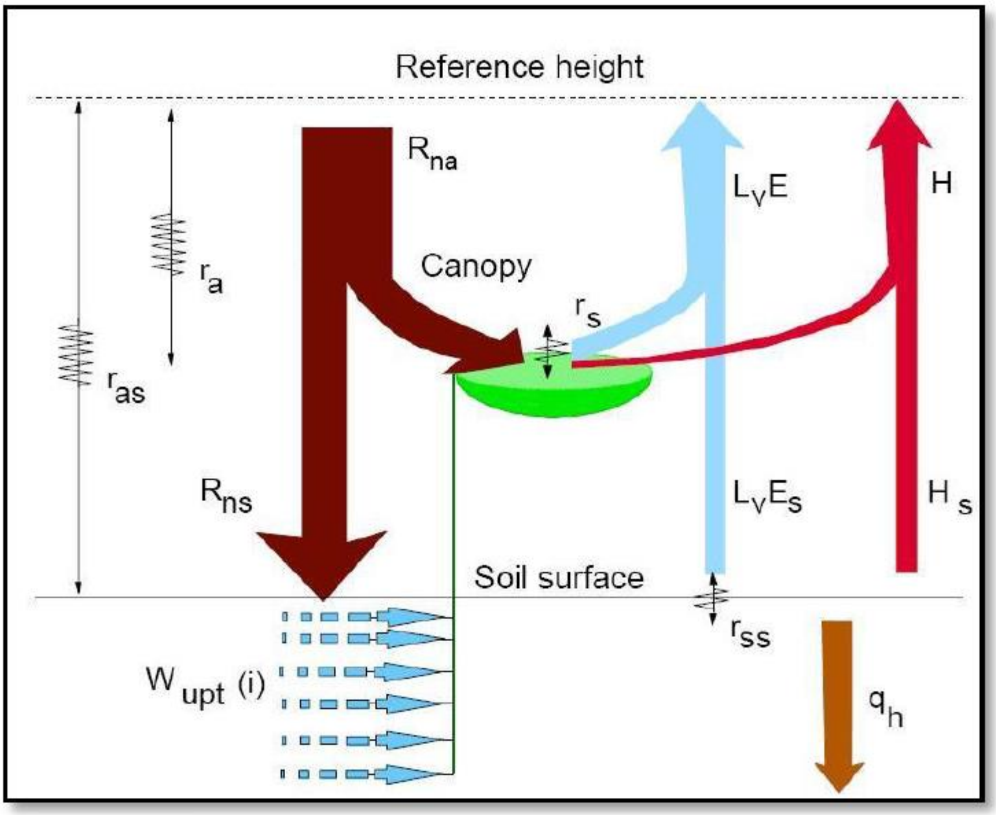

Figure 27: Heat energy balance atsoil surface (Jansson & Karberg- 2004) (Jansson,n.d.)

There are some accounted resistances during the heat flux; Soil surface resistance $r_{ss}$, aerodynamic resistance which is calculated as a function of canopy, temperature and wind $[r_{as} = r_{ab} + r_{aa}]$. ($r_{ab}$) is the canopy resistance and ($r_{aa}$) is aerodynamic resistance from soil to reference height above canopy.( Jansson,n.d.)

**Surface temperature:** Here there are 3 choices based on;

1) Air temperature which is an assumed temperature equal to air temperature when there is no snow on the surface.

2) f (PM-equation) based on the surface sensible heat flux and calculated as residual of the surface energy equilibrium by using the soil evaporation rate. The evaporation Method should be set to PM-Eq, (1Par), PM-Eq., (3Par) or K-function if this option will be used.

3) f (E-balance Solution) which is an iterative numerical solution. It is used to estimate the soil evaporation and vapor pressure at the surface. The Evaporation Method should be set to iterative energy balance to use this option (coupmanual).

Initial heat conditions have four conditions; uniform temperature which is used to calculate the initial storage. Temp(z) table which is used to allocate value of initial temperature at different soil layers to estimate initial heat storage. Temp(z)-Estimated where a temperature profile is taken from the analytical solution of the sine variation at the surface and a mean-value of damping depth for the soil profile. The last choice for the initial heat conditions is Heat(z) which is used to assign values of initial values for heat state variable. For this simulation the third alternative is chosen, Temp(z)-Estimated.

**Cloud input** on the CoupModel has three alternatives, it can be estimated which is estimated from global radiation input. The second is ‘Generated by parameters’. The last one is Read from PG-file which is calculated the value by using the PG-Bin file.

**Net radiation $R_n$** is calculated by Brunt’s formula which is the sum of the long wave radiation $R_{lnet}$ and the short wave net radiation $R_{snet}$ .

$$R_n = R_{lnet} + R_{snet}$$

Both the long and short waves radiation are estimated from other metrological variables (Jansson,n.d.).

**Pipe power** is one of the important parameters on the software. It shows the heat power of the pipe to warming up the road. In this project water pipes are used instead of pipe power to warm up the road. Since the power source of pipes comes from the sun, the power can be calculated by the measured sun radiation.

Meteorological data from the cities have been used for the calculations. Calculation of radiation is done by these settings:

It is assumed that the energy is saved when the temperature is more than 25.

- **Efficient radiation:** radiation corresponding to the hours when the temperature is more than 25.

The hours with a temperature more than 25 in each day are filtered. Then sum of the radiation in for each day is calculated.

- **Total efficient radiation:** the summation of the efficient radiation in one day.

Then we have one table consist of total efficient radian for each day.

- **The maximum value of total efficient radiation** for one day is 8 000 000 J/m$^2$/day.