Geothermal energy for utilization within tunnels

Case study: Helsinki city railway loop

Niklas Wiik

Degree Thesis
Distributed Energy Systems
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Tanken med detta examensarbete var att studera möjligheten med att använda tunnel lining teknologin i Centrumslingan i Helsingfors för att utvinna energi från berggrunden. Examensarbetet ger information om tunnel lining teknologin samt teknologins för- och nackdelar i det uppkommande projektet med Centrumslingan i Helsingfors. I arbetet behandlas likaså aspekten ifall geotermisk energi som utvinns med tunnel lining teknologin kan vara finansiellt gynnsammare än om man utvinner energin traditionellt med hjälp av borrhål. Då det i detta fall endast är Helsingfors Centrumslingan som behandlas i arbetet så kan tunnel lining teknologin tillämpas i de kommande tunnel projekten i Finland.

Som modell för examensarbetet användes tidigare studier inom tunnel lining teknologin från Österrike samt Kina. Med hjälp av dessa studier tillämpades formler som kan användas då man räknar ut mängden energi som utvinns genom teknologin i fråga. Resultatet uppnåddes genom att kombinera de matematiska formlerna med den kunskap samt expertis Granlund Oy erbjöd. Examensarbetet avgränsades med att inga fälttester kunde göras med tunnel lining teknologin.

Det positiva resultatet examensarbetet gav visar att tunnel lining teknologin har goda finansiella möjligheter att tillämpas i samband med Centrumslingan i Helsingfors. Ifall tunnel lining teknologin ska kunna användas måste dock byggandet av tunnlarna i Finland anpassas för ändamålet. Innan det görs ett byggbeslut om att ta i bruk tunnel lining teknologin för Centrumslingan måste även tilläggsundersökningar samt fälttester utföras.

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The idea with this thesis was to study the possibility of installing tunnel lining technology in the Helsinki city rail loop as a way to extract energy from the bedrock. The thesis provides knowledge about the tunnel lining technology and the benefits and drawbacks with the technology in the upcoming Helsinki city rail loop project. Another aspect in the thesis was if the geothermal energy acquired from the tunnel lining technology can be economically motivated by comparing it to traditional usage of geothermal energy. Even though the Helsinki city rail loop is the only project treated in the study, one should know that every upcoming tunnel project in Finland is affected by the possible usage of tunnel lining technology.

Earlier studies about tunnel lining technology from Austria and China were used to make mathematical formulas for calculating the available energy that could be extracted by the technology. The result was obtained by using the mathematical formulas combined with the data and expertise from Granlund Oy. The thesis was limited by the fact that no field tests could be performed with the technology.

The results from this thesis shows that the tunnel lining technology can be financially motivated in the Helsinki city rail loop as the preliminary studies in this thesis gave a positive result. The tunnel constructions methods in Finland must be adjusted if the tunnel lining technology should be used. Additional studies about optimization combined with field tests are required before any building decisions can be made in this case.

Keywords:	Granlund, tunnel lining, geothermal energy, Helsinki city rail loop, tunnel
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Tämän lopputyön ajatus oli tarkastella mahdollisuutta käyttää, Pisararadalla Helsingissä, tunneli lining teknologiaa, jolla energiaa voidaan talteen ottaa kallioperästä. Tämä lopputyö antaa tietoa tunneli lining:stä sekä sen teknologian eduista ja haittapuolista, tulevassa Pisararata projektissa Helsingissä. Lopputyön toinen tarkoitus oli myös kartoittaa josko geoterminen energian talteenotto tunneli lining:illä on taloudellisesti parempi vaihtoehto verrattuna perinteiseen talteenottoon porareillä. Vaikkakin tässä lopputyössä on ainoastaan otettu huomioon Helsingin Pisararata niin teknologia tunneli lining:illä voidaan soveltaa kaikkiin tuleviin tunneli projekteihin Suomessa.

Lopputyössä on käytetty aiempia tutkimuksia Itävallasta ja Kiinasta, tunneli linningistä, ja näiden avulla on saatu matemaattisia kaavoja joilla energian talteenoton määrän tunneli lining teknologialla voidaan laskea. Näiden matemaattisten kaavojen ja informaation kanssa sekä Granlund Oy:n asiantuntemuksen yhteydessä lopputyön lopputulos oli mahdollinen. Lopputyö on osin puutteellinen koska kenttätestejä tunneli liningistä ei ole, kun näitä testejä ei ole vielä tehty Suomessa.

Lopputyön tulos osoittautui kuitenkin positiiviseksi, sillä lopputyössä ilmensi että tunneli linging teknologialla on hyviä taloudellisia mahdollisuuksia tulla asennetuksi Helsingin Pisararadalle. Vaikkakin tapa jolla tunneleita rakennetaan Suomessa joudutaan modifioimaan, jotta tunneli lining teknologia voidaan asentaa suomalaisiin tunneleihin. Lisäksi tarvitaan lisätutkimuksia optimoimisesta sekä tehdä kenttätestejä, ennen kuin tehdään päätös rakentamisesta Pisararata tunneli lining teknologialla.

Avainsanat:	Granlund, tunneli, tunnel lining teknologia, geoterminen energia, Pisararata
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CONTENTS

Figures

Tables

Terms

Symbols	Explanation	Unit
T	Temperature	K, ^{0}C
ΔT	Temperature difference	K, ^{0}C
A	Area	m^2
P	Pressure	Pa
r	Radius	m
d	Diameter	m
L	Length	m
ρ	Density	kg/m^3
C_p	Specific heat capacity	kJ/kg.K
λ	Thermal conductivity	W/m.K
μ	Liquid viscosity	kg/(s·m)
R	Thermal resistance	m.K/W
$\dot{V}$	Volumetric flowrate	m^3/s
t	Time	h, s
E	Energy	Wh
q	Heat exchange	W
Q	Heat exchange per meter	W/m
$cost$	Cost of something	€

FOREWORD

The background to this thesis originates from Granlund Oy need in studying the usage of geothermal energy in the Helsinki city rail road. From there was the idea of studying tunnel lining in the Helsinki city rail road born. The thesis is written in 2015 in Arcada University of applied sciences at the engineering degree program distributed energy systems. This work has given me a comprehensive understanding about conventional geothermal heating systems and tunnel lining technology.

I would first like to thank the Granlund Oy which gave me the opportunity to do this thesis. Here I want to thank Paavo Tikkanen for the support and interest I have received in connection with the thesis. I also want to especially mention and thank Kari Äikäs from Saanio & Riekkola Oy for the accurate details about tunnel construction in Finland.

A warm thanks also go to my supervisor, Karis Badal Durbo who have given invaluable help for the project's professional content and appearance.

Helsinki, 12th of April 2015

Niklas Wiik

1 INTRODUCTION

The Helsinki city rail loop is a new rail loop that is planned beneath Helsinki to improve the commuters' life (Finnish Transport Agency, 2014). The construction of the Helsinki city rail loop will start in 2017 with the designing of it already started this year. I was requested at my work, Granlund Oy, to do a research if the utilization of geothermal energy could be an economical choice to district heating and conventional geothermal boreholes in the tunnel. The available geothermal energy in the ground will first be studied if it's enough energy for the heating and cooling of the Helsinki city rail loop.

This thesis will focus on the subject of tunnel lining method. The tunnel lining technology is based on traditional geothermal systems with the absorber loops in boreholes installed in the earth. The only difference with tunnel lining technology to get geothermal energy is that the absorber pipes are installed in the tunnel lining. The thesis will also focus on energy gained from tunnel lining and if it's more economical than conventional ground source heat pumps (GSHP) with 50–200 meters deep bore holes. This research subject is approved by Paavo Tikkanen from Granlund Oy (Tikkanen.P, 2014). There have already been made a few experimental studies on the usage of thermally activated tunnel constructions to harvest ground source energy (the text will use the term tunnel lining) but no study have been made yet in Finland about tunnel lining.

When the result from the study is ready it will be financially evaluated if possible. The financial evaluation of the tunnel lining system has to be for both 30 and 100 years lifetime. A 30 years interval is chosen because all systems will be replaced every 30 years in the tunnel and the tunnel is projected to have at least 100 years of total lifetime.

1.1 Background

Recent studies show that by 2050 nearly 70% of the world's population will be living in cities (United Nation, 2014). With this increased population growth and energy demand in mind are we inevitable forced to build structures underground to meet the populations' needs in regards to traffic infrastructure. It is possible to turn these underground structures into energy sources by actively use the available geothermal energy. With these new energy sources are the need for fossil fuels reduced and it further reduces the CO_2 emissions.

Geothermal energy represents a significant heat source and there is a ready supply of geothermal resources on earth (Axelsson, 2010). So tunnel lining and other ways to use geothermal energy as an energy source is inevitably becoming a more important factor in tunnel constructions.

Tunnel lining can be used for many purposes so there is a good economic in it. The large interface between the tunnel structure and the surrounding ground enables to harvest ground source energy by placing absorber pipes in the tunnel linings. This energy can be used to heat up the tunnel or be supplied to user above the ground. It is also possible to do the cooling of above ground buildings with tunnel lining because most tunnels are not prone to overheat. Or if the tunnel has considerable amount of heat building up by tunnel operation. Then it can be commercially viable to cool the tunnel by tunnel lining rather than use forced ventilation.

1.1.1 Research aim

The research aim is to get an environmental and economic option to the usage of conventional district heating in the Helsinki city loop tunnel. Another research aim is to provide knowledge about tunnel lining as a technology thus promote further studies about the subject. The research aim is to improve the knowledge about tunnel lining and the financial aspects of using geothermal energy acquired from tunnels. Another aim is to compare tunnel lining technology with geothermal heat pumps with vertical collector loops (borehole heat exchangers) drilled into the bedrock and make suggestions if tunnel lining is economical viable.

1.2 Problem

The tunnel lining technology is relative new and there have been only a few test tunnels constructed using tunnel lining technology. This means that before tunnel lining technology could be installed into the Helsinki city rail loop, some field testing with tunnel lining should be performed in Finland to test the Finnish bedrock's suitability for tunnel lining. With all the testing it would probably mean that the construction start of the rail loop would be delayed with about one year. Delays could have a negative impact on the decision makers and therefore on the possibility of installing tunnel lining into the Helsinki city rail loop. This could ultimately stop the studies about tunnel lining in Finland. Meaning that no tunnels get absorber pipes into the tunnel lining to extract energy.

1.3 Research scopes

1. Can the geothermal energy be utilized for the heating and cooling of the Helsinki city rail loop? 2. Can the usage of geothermal energy acquired from the tunnel be economically motivated? 3.Can the geothermal energy be utilized in any other way than through conventional ground source heat pumps with bore holes, for example by thermally activating the concrete structure by placing absorber pipes in the tunnel lining. All these points are equally important for the tunnel lining technology in Finland.

1.4 The Helsinki city loop

The Helsinki City Loop is a project (currently at the planning phase) run by the Finnish Transport Agency and the City of Helsinki. The loop-shaped track with a length of 7.8 kilometers, with 6 kilometers of tunnel, will serve the local traffic in the capital region. The track is designed to go from Pasila through a tunnel underneath Töölö, Helsinki city centre and Hakaniemi, returning to Pasila. The Loop will help make the entire railway system of Finland run more smoothly by freeing up railway space between Pasila and Helsinki thus leaving it for other trains. (Finnish Transport Agency, 2015)

Figure 1 Map of the city rail loop with the 3 stations (Töölö, Helsinki center and Hakaniemi) marked in white. (Finnish Transport Agency 2015)

There will be two separate tunnels going side by side beneath Helsinki thus it is possible for trains to travel both ways along the loop at the same time. With a service/rescue tunnel going next to the railway tunnels. No final building decision has been made yet about the Helsinki city rail loop. The planning phase has been underway since 2012 and will continue into year 2015 when the Finnish Parliament makes a final decision if the Helsinki city rail loop will be built.

1.4.1 The need of the Helsinki city rail loop

“The public transport system must be able to accommodate a continuously growing number of passengers. At present there are nearly 1.4 million inhabitants in the Helsinki region. This number is expected to increase by 40,000 this decade and by more than 400,000 during the next few decades.”(Finnish Transport Agency, 2015)

It is estimated that in 2035 there will be 138,000 people using the city rail loop every day with Hakaniemi being the busiest station with about 79,000 users every day. The city rail loop will promote the public transport in the area and improve the urban environment in Helsinki.

1.4.2 What is geothermal heating?

Geothermal heating is short described as a method to utilize the heat contained in the groundwater in the bedrock. The sun is, as so often in the context of energy, involved because it’s the sun’s energy that is stored in the bedrock. Geothermal heating is thus an indirect form of solar energy.
At 50 to 200 meters depth, the temperature is between two and eight degrees Celsius, as this temperature is roughly constant around the year, geothermal heat is a relatively stable form of energy. (Johnston, Narsilio and Colls, 2011)
The tunnel lining technology to gather geothermal energy is based on traditional geothermal systems with the absorber loops installed in boreholes into the earth. The only difference with tunnel lining technology to get geothermal energy is that the absorber pipes are installed in the tunnel lining.

1.5 Purpose

The purpose of this thesis work is to provide knowledge about the tunnel lining technology to the decision makers working with the Helsinki city rail loop. This work was ordered from Granlund Oy as a geothermal energy research.

At present day there hasn’t been done any research about tunnel lining in Finland and only some researches about tunnel lining worldwide in other tunnels. This thesis job is to provide knowledge about the tunnel lining technology and geothermal energy sources in general to people. And furthermore will this thesis provide some numbers about what the yearly heating and cooling effects could be with the usage of tunnel lining. The calculations will not be exact enough to make any final decision about tunnel lining technology. The calculations will only provide some guidelines if tunnel lining is possible in Finland and the Helsinki city rail loop. Further studies and field studies should be made before making a final decision about tunnel lining technology.

1.6 Method

The research will make use of earlier studies about the usage of tunnel lining done in the world, mostly from Germany and China. The theory and facts about tunnel lining and tunnels installed with tunnel lining will be analyzed from their material.

Granlund Oy have granted this research access to their database and knowledge about geothermal energy (Tikkanen P., 2014). Furthermore is the author allowed to visit the designing meetings of the Helsinki city rail loop. The Helsinki city rail loop will work as this thesis‘ example case and calculations will be based on it. The thesis uses interviews with HVAC engineers and geothermal engineers to provide professional opinions.

1.7 Limitations

There are several ways of using geothermal energy from tunnels but this thesis focuses on the tunnel lining technology and conventional geothermal heat pumps with vertical collector loops drilled into the bedrock. There will only be used theoretical numbers with tunnel lining because there are no possibilities of field testing tunnel lining in Finland. With no earlier experience of tunnel lining technology usage in the Finnish bedrock there will always be a small uncertainty if the theoretical models work.

Another limitation with this research is the design of Finnish railway tunnels these days that does not allow tunnel lining. The Finnish bedrock which primary consist of granite is so stable that most tunnels including the Helsinki city rail road will only use 100mm shotcrete on the drilled tunnel walls. 100mm is too thin to fit the collector pipes that tunnel lining technology uses without risks for damaging the shotcrete. The shotcrete could be damaged of the thermal expansion of the absorber pipes. At least 200-300mm of shotcrete would be needed to be able to install the collector pipes. This means that a bigger tunnel is to be drilled which cost more. Furthermore if the collector pipes still would be installed is the risk big that the absorbed heat in the collector pipes would come from the tunnel's air and not the adjacent bedrock. (Äikäs K., 2014)

The final decision how the tunnel will be constructed are not made yet. This research will focus on earlier European experiences of tunnel lining with normal tunnel structure of several layers of materials in the tunnel walls. The Helsinki city rail loop tunnel structure will in this research use a more European tunnel structure to make tunnel lining calculations available and to give the decision makers a hint about how much energy is available. If the decision is made that the Helsinki city rail loop will use a tunnel model with only shotcrete there have to be made additional researches with field testes. (Äikäs K., 2014)

1.8 Theoretical framework

Peter von Rittinger developed and built the first heat pump in years 1855-1857 (Zogg, 2008). The Swiss turbine engineer Heinrich Zoelly was the first to propose an electrically driven geothermal heat pump for the production of low temperatures and received a patent for it in 1912 (Zogg, 2008). In 1940, dug Robert C. Webber down 152 m copper to 2 meters deep for his heat pump and built the first geothermal heat pump (Zogg, 2008). But it is only in the last decades that there has been a dramatic increase in the use of ground source heat pumps (GSHPs) to heat and cool buildings. (Johnston, Narsilio and Colls, 2011)

The first experiments with thermal activation of tunnels started for about 10 to 15 years ago in Austria. (Baujard, 2010). There have been some models and testing of thermally activating tunnels across the word. Zhang, G. and other from Tongji University in Shanghai have made a model of analytical solution for the heat conduction of tunnel lining ground heat exchangers to prevent the tunnels of freezing in the winter. (Zhang, G.,2014)

Use of geothermal energy absorbers (tunnel lining) have been researched by Adam and Markiewicz with well-made formulas for calculating the available energy gain (Adam and Markiewicz, 2010). A test plant is in operation on Metro Line 6 at Stuttgart's Fasanenhof underground station. The University of Stuttgart is using this test plant to test different load profiles for heating and cooling. The tunnel lining technology enable geothermal air-conditioning in Metro Line 6. (Bine.info, 2013)

All geothermal energy systems have to be dimensioned right at the first try Increasing the collector area is not financially possible after the installation has been made. Furthermore do designer of the system have to think about sustainable geothermal utilization like Axelsson wrote about in his article: Sustainable geothermal utilization – Case histories; definitions; research issues and modelling. Without thinking about sustainable utilization could the tunnel's surrounding bedrock temperature drop after a few years and efficiency drop drastically. (Axelsson, 2010).

This thesis work will use similar methods in the calculations of available energy that Adam and Markiewicz used. By using earlier studies will this research try to make a model for sustainable geothermal utilization during the 30 and 100 years of project life.

2 GEOTHERMAL ENERGY TECHNOLOGY

2.1 Heat pumps

The basic principle of a heat pump is that it captures the heat that already exists naturally in your surroundings. The heat can be from boreholes in the ground next to or under your house (ground source), it can be in the uppermost soil layer on your lot, and there are heat pumps that use heat stored in a nearby lake bottom (lake heat), or simply the heat present in the air. The heat pump is thus a form of solar energy because it takes advantage of the sun heat stored around us. (EGEC 2008)

Contrary to many people's perception does not heat pumps use traditional geothermal energy, i.e. heat from the Earth's interior. If the heat from the Earth's interior was intended to be utilized in Finland should the required drill holes depth be a minimum depth of 1000-2000 meters deep. This deep drilling method is in the current situation extremely costly and in practice not possible to use regular extraction of large amounts of energy. With a few exceptions in countries were the Earth’s crust is thin enough, like Iceland.

2.1.1 Heat factor or Coefficient of Performance (COP)

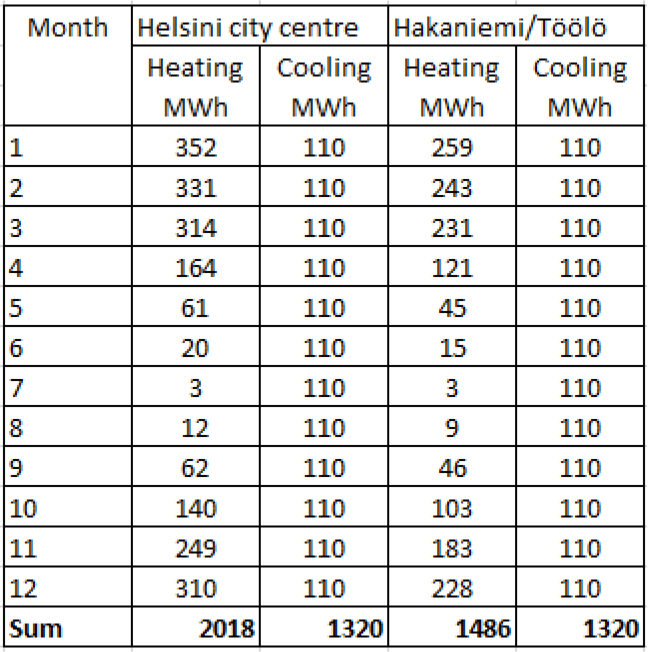
The heat pump's job is to collect the heat and then make sure that your house gets more kilowatt hours (kWh) of heat energy than it consumes in electricity. The heat factor is simply the ratio of how many kWh it requires and how many it generates. Another word for heat factor is Coefficient of Performance (COP). E.g. the marking COP 4 means that 4 kW heat energy can be produced with 1 kW electricity.

The old coefficient COP is about to be phased out and be replaced with SCOP (Seasonal Coefficient of Performance) that indicates the efficiency of the entire heating season, that is, the annual efficiency. This change is a part in the European Union's climate and energy targets 20-20-20. Making it easier for the customers to compare heat pumps with the same standard. (European Commission 2014)

2.1.2 Needed geothermal energy

Granlund Oy have made preliminary reports and calculations on the needed energy for each of stations the Helsinki city rail loop. With the planning of the rail loop being in the start phase the only energy need that is considered is the ventilation's heating and cooling energy for each station. The ventilation at each station will be the biggest energy user in the tunnel. The tunnel in itself will at the depth it's situated maintain a fairly constant temperature all around the year and only need a little additional heating. The needed energy for the rail loop will be tweaked and recalculated by Granlund Oy when a building decision is made. Without any other sources on needed energy for the tunnel will this research base its energy need on Loisa's and Pietarila's report from 13.10.2014. The following table is from Loisa's and Pietarila's report showing the energy need for each station. Hakaniemi and Töölö have about the same area so they share the same values in this table.

Table 1 Energy needed for each station monthly in MWh (Loisa, and Pietarila , 2014)



Month	Helsini city centre		Hakaniemi/Töölö	
	Heating MWh	Cooling MWh	Heating MWh	Cooling MWh
1	352	110	259	110
2	331	110	243	110
3	314	110	231	110
4	164	110	121	110
5	61	110	45	110
6	20	110	15	110
7	3	110	3	110
8	12	110	9	110
9	62	110	46	110
10	140	110	103	110
11	249	110	183	110
12	310	110	228	110
Sum	**2018**	**1320**	**1486**	**1320**

2.2 Ground Source Heat Pump Technology

A ground source heat pump (GSHP) is a device that is able to transfer heat from one fluid at a lower temperature to another at a higher temperature. Heat pumps have got their name from the fact that they allow heat to be carried from a lower to a higher temperature level, inverting natural heat flow which, as is well known in nature tends to be from a higher to a lower temperature. The central components of a heat pump are; the compressor, expansion valve and two heat exchangers, one of which is the evaporator and the other is the condenser. In the evaporator, heat is transferred from the collector to the heat pump refrigerant. In the condenser, is heat transferred from the heat pump refrigerant to the heat distribution system. The heat collected in the collector evaporates the refrigerant circulating in the heat pump. (Johnston, Narsilio and Colls, 2011)

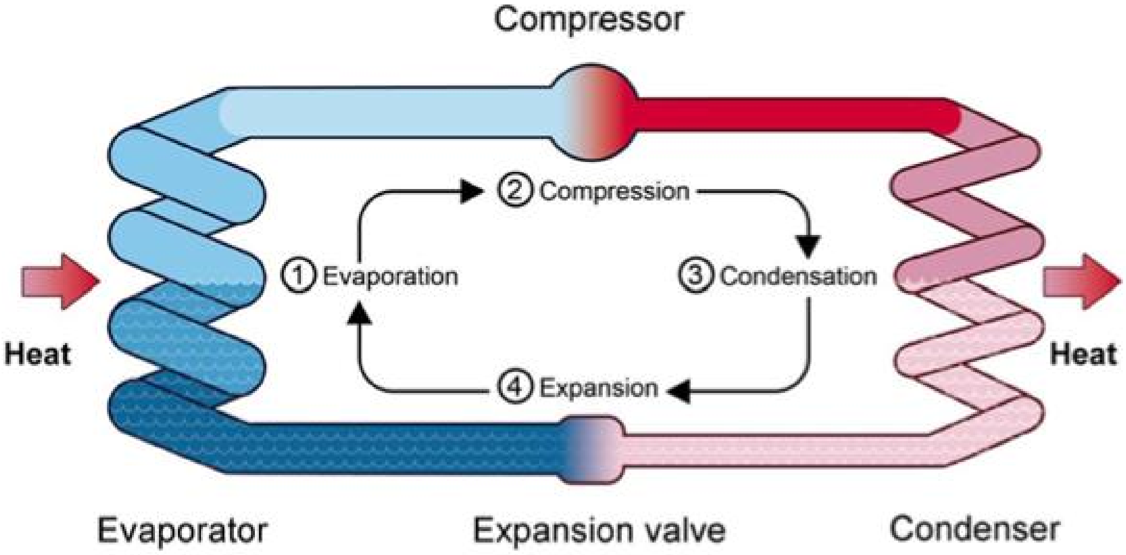


Figure 2 Schematic representation of a heat pump cycle (Johnston, Narsilio and Colls, 2011)

In Fig. 2, liquid refrigerant absorbs heat from a heat source and evaporates completely at point 1. The refrigerant must initially be cooler than the heat source and have a boiling point (at relatively low pressure) below the heat source temperature. The warm refrigerant, in a gaseous state and at low pressure, coming from the evaporator, is taken to a high pressure; during compression (point 2) it is heated, absorbing a certain amount of heat. At this higher pressure, the refrigerant gas will now condense at a much higher temperature than at which it boiled. The refrigerant flowing from the compressor passes from a gaseous to liquid state at the condenser (point 3), giving off heat to the outside. The hot, high pressure liquid refrigerant then passes through an expansion valve (point

4) which returns the pressure and temperature of the liquid to its original conditions prior to point passing through the expansion valve, the liquid refrigerant cools and is partially transformed into vapour(Motiva, 2014)

2.3 Structure of Ground source heat exchanger system

The basic parts in a ground source heat exchanger system are: the primary circuit situated in the ground, the heat exchanger and the secondary circuit situated inside the building.

The primary circuit is a ground loop filled with a non-freezing fluid. The ground loop can be installed horizontally on depth of 1-2 meters (need to be below the frost line) with about 300-600meters of piping for a normal house using a lot of space for the installation. Another more expensive alternative for the ground loop is to be installed vertically in boreholes like figure 3 is showing with the benefit of allowing cooling of the building in the summer and less space is needed on the yard. The primary circuit could also be installed into a lake or sea if the house was situated near either with the benefits of reduced installation costs. (Liu, Shukla and Zhang, 2014)

The primary circuit in ground source heat pump system works the same regardless of how it is installed. The primary circuits circulating fluid absorbs heat from the ground. The heat is then extracted by the heat pump situated inside the house. The cooled circulating fluid is re-injected into the ground where it absorbs heat again and completes the cycle.

The heat gained from the primary circuit is then distributed along the secondary circuit inside the house to heating elements or floor heating where the heat is used. (Liu, Shukla and Zhang, 2014)

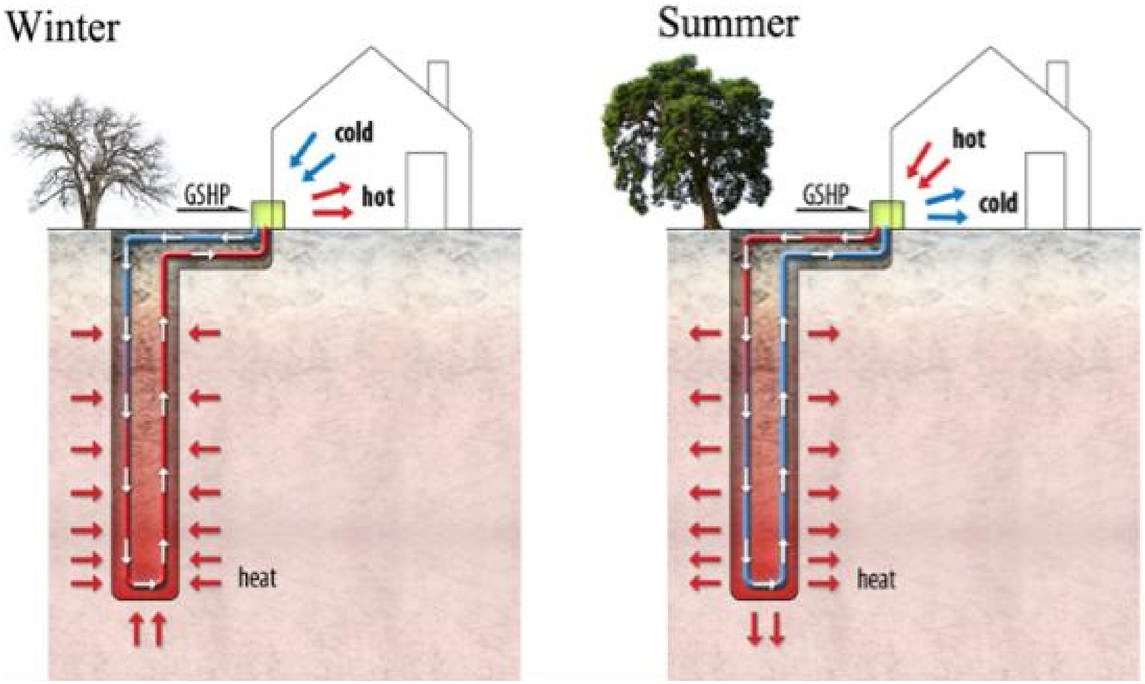


Figure 3 Design of a vertical heating and cooling system using a heat exchanger. (Johnston, Narsilio and Colls, 2011)

2.3.1 Ground source heat exchanger system calculations in the Helsinki city rail loop

There have already been done preliminary calculations at Granlund Oy about the possibility of conventional ground source heat pumps (GSHP) with about 200-250 meters deep bore holes. The calculations were done for every station separately with 25 bore holes situated at each station. The boreholes would be drilled in the service tunnel close by the stations with 15 meters between each other. (Loisa, and Pietarila ,2014)

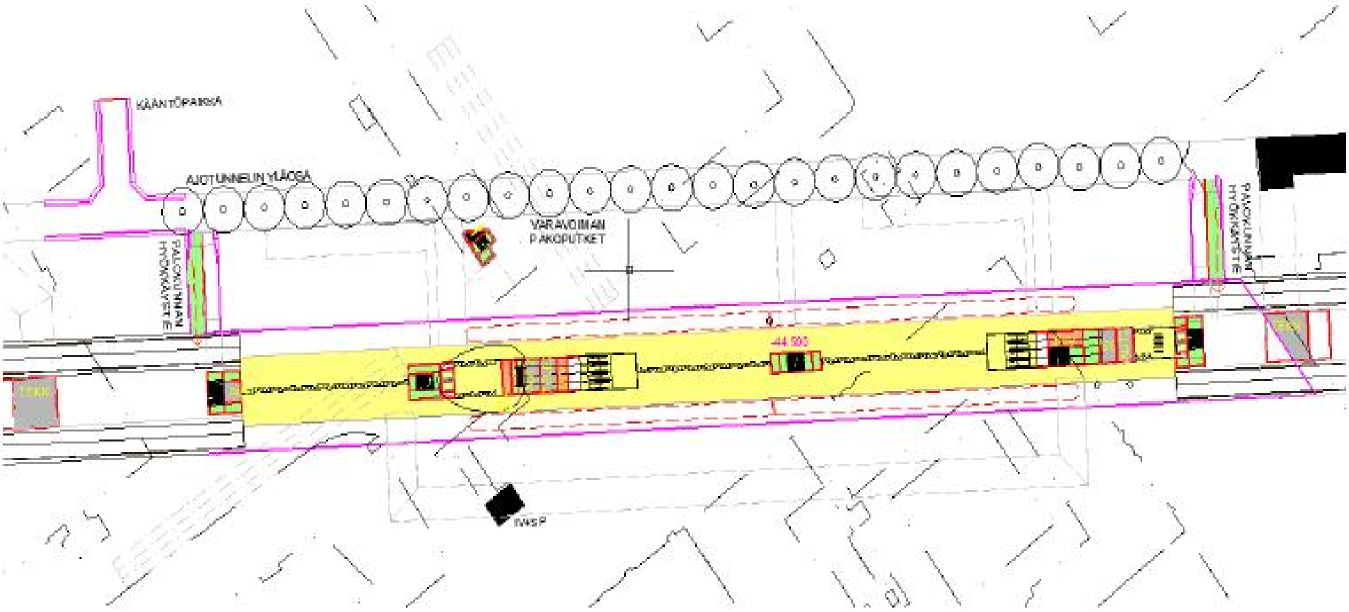


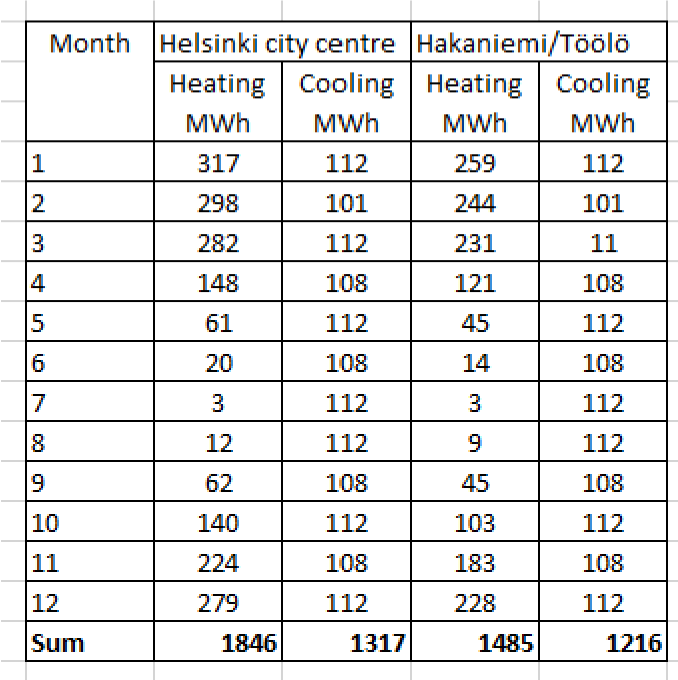
Figure 4 Showing the location of the bore holes (the white circles) at the Helsinki city centre station. (Loisa, and Pietarila , 2014)

The calculations used in the following input data:

- The thermal conductivity of the bedrock was calculated to be 3.2 W / (mK) and a thermal capacity of 2500 kJ/(Km^3)
- Bore hole diameter 160 mm
- The bedrock temperature of 8 ° C degrees
- The ground loop circuit have heat carrier liquid with 25% ethanol and 75% water. This liquid's density is 948,5 kg/m^3, Specific heat C_p is 3735 J/Kg K and the thermal conductivity is 0,493 W/(mK).

These input data were inserted into the simulation and calculations program GLHEPRO that calculated the usable energy. The following table show the results from GLHEPRO as gained heating and cooling energy in MWh during 1 year at year 50 after the installation of the bore hole. Year 50 is chosen because the bedrock's temperature decreases fast for some years until reaching a specific temperature and after that is the decrease in temperature much slower. Year 50 is optimal to be sure that the bedrock's temperatures have had time to stabilize.

Table 2 Ground energy calculations results (Loisa, and Pietarila , 2014)



Month	Helsinki city centre		Hakaniemi/Töölö	
	Heating MWh	Cooling MWh	Heating MWh	Cooling MWh
1	317	112	259	112
2	298	101	244	101
3	282	112	231	11
4	148	108	121	108
5	61	112	45	112
6	20	108	14	108
7	3	112	3	112
8	12	112	9	112
9	62	108	45	108
10	140	112	103	112
11	224	108	183	108
12	279	112	228	112
Sum	**1846**	**1317**	**1485**	**1216**

This research about tunnel lining technology in the Helsinki city rail loop will make use of the above result as a measure to compare the available energy gained by tunnel lining.

2.4 Tunnel lining Technology

The tunnel lining technology to gather geothermal energy is based on traditional geothermal systems with the absorber loop horizontally installed in the ground. The only difference with tunnel lining technology to get geothermal energy is that the absorber pipes are installed in the tunnel lining. Tunnel lining technology is based on two things. The first aspect is that the tunnel has to be deep enough beneath the ground to ensure that the bedrock is at a constant temperature around the year. This constant temperature is a source for cooling in the summer and heating in the winter. The second aspect is that the concrete used in the tunnel is an excellent heat exchanger because concrete has great thermal conductivity and thermal storage capacity.(Zhang, G.,2014)

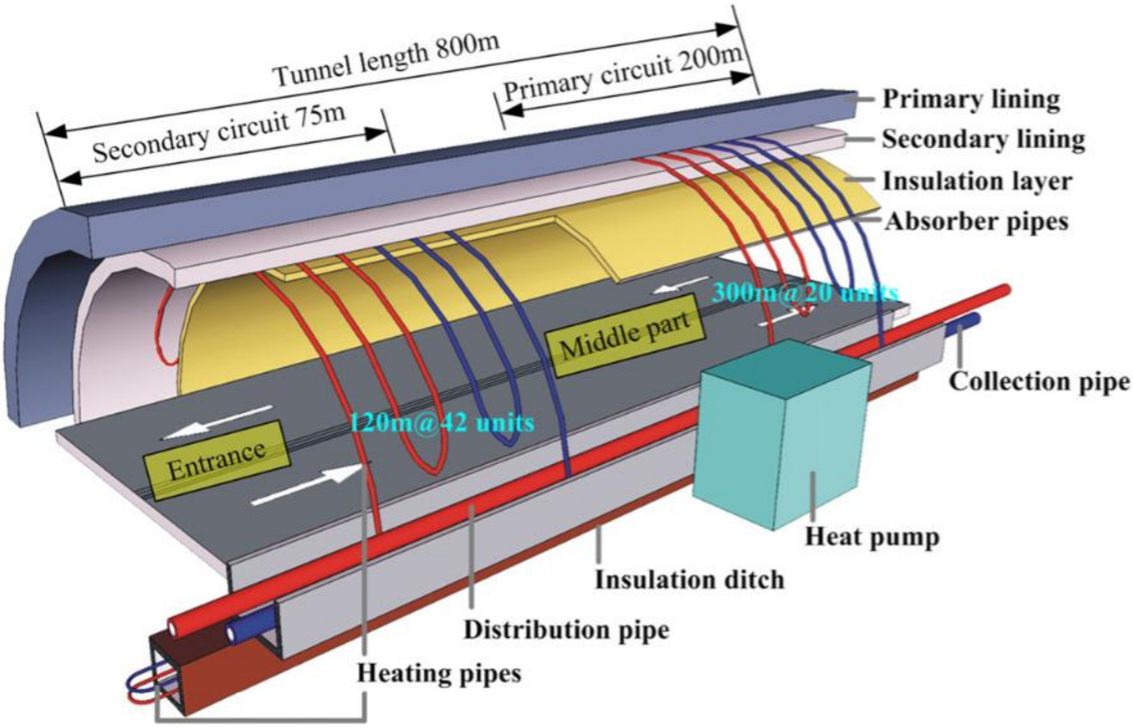


Figure 5 Schematic view of the tunnel heating system using geothermal energy. (Zhang, G.,2013)

Figure 4 is a schematic view of tunnel lining in Lichang tunnel in Inner Mongolia, China. The figure shows all the main parts of tunnel lining. Like all geothermal energy systems does tunnel lining consist of a primary circuit, a secondary circuit and a heat pump. The primary circuit is the absorber pipes situated between the primary and secondary lining in the tunnel. These absorber pipes are connected to the heat pump forming a closed loop. The loop contains a non-freezing fluid to prevent it from freezing in the winter. The fluid extracts geothermal energy in the loop and is heated from it. The heated fluid is then transported through a heat pump that further heat up the fluid. The warm fluid is then distributed through a distribution pipe to the secondary circuit consisting of heating pipes situated between the secondary lining and insulation layer. (Zhang, G., 2013)

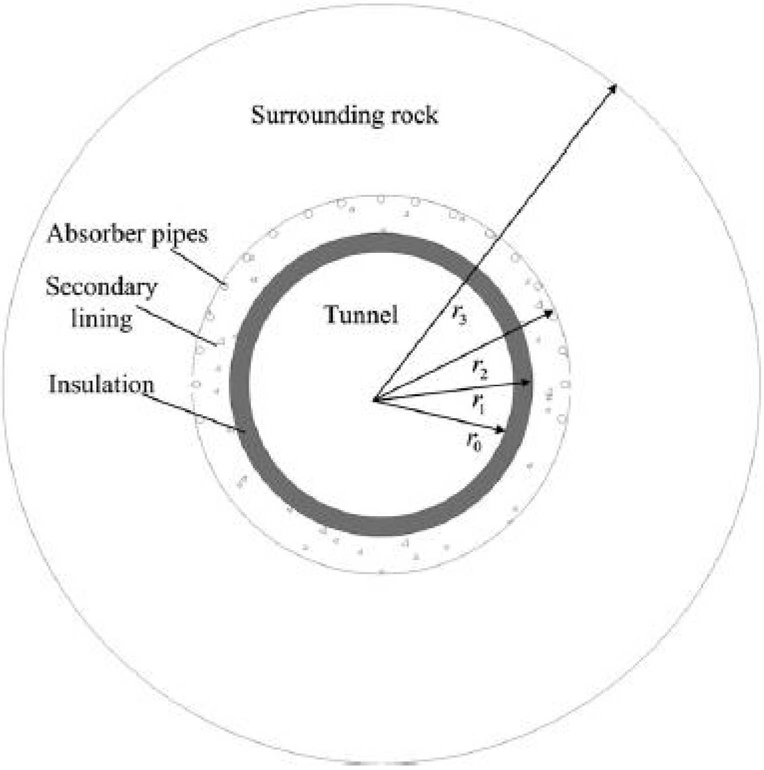


Figure 6 2-D schematic of tunnel lining. (Zhang, G.,2013)

A tunnel is a complicated structure and to make it easy to analyze tunnels we need to make some assumptions. The schematic two-dimensional view of tunnel that is presented above in figure 6 helps us analyze tunnel lining. As seen here is the absorber pipe very small, barely 25 mm in diameter, compared with the tunnel structure. Making the absorber pipe viable to make use of the geothermal energy. For easy calculations are the primary lining and surrounding rock regarded as a homogenous layer with thermal abilities not affected by the temperature. (Zhang, G.,2014)

2.5 Available geothermal energy

By analysing bedrock map of the city of Helsinki (Helsinki city map service, 2015) the knowledge about what bedrock surrounds the Helsinki city rail loop is acquired. By knowing what kind of bedrock there are beneath Helsinki it is possible to calculate the available geothermal energy in the bedrock. The results of the analysis suggests that the Helsinki centre station's and Hakaniemi station's bedrock are mostly of granite and mica. The results suggests that Töölö station's bedrock is a combination of granite, amphibolite and metavolcanic rocks. By using the bedrock research that Posiva Oy have provided to Granlund Oy the following thermal conductivities are given to each material. Mica has about 3 W/(mK), granite has 3,3 W/(mK), amphibolite 2,7 W/(mK) and metavolcanic rocks have 2,7 W/(mK). To simplify the calculations an average thermal conductivity value was used. The average value was calculated from mica and granite, 3,2 W/(mK). The heat capacity of the bedrock beneath Helsinki is 2500 kJ/(Km^3). (Loisa, and Pietarila, 2014)

2.6 Regulations and laws

There are many regulations that dictate where and how an installation of conventional ground source heat pumps (GSHP) in Finland can be made. Tunnel lining is such a new subject so it's not mentioned in the regulations but Kari Äikäs said in his interview the 4th February that the decision makers in Finland will use the same regulations with tunnel lining as with GSHPs. Some of the most relevant laws with geothermal energy are: land use and building act (132/1999), the water act (587/2011) and the environmental protection act (527/2014)

2.6.1 The land use and building act 132/1999

‘’The objective of this act is to ensure that the use of land and water areas and building activities on them create preconditions for a favorable living environment and promote ecologically, economically, socially and culturally sustainable development’’ (Finlex 132/1999, first chapter)

The land use and building act (132/1999) tells that new building's heating system construction is treated as part of the construction permit. According to § 125 in the land use and building act: The construction permit is required for construction of a building and in addition to a number of renovations and alterations of the building. The construction permit is also required in a buildings technical systems repair and modification work, which can contribute significantly to the building’s energy efficiency.

According to § 126 in act 132/1999 an operation permit is needed if you want to change the heating system in an existing building. The same applies when borehole heat exchangers are wanted as an additional source of heat. § 166 (132/1999) instructs the building owners to ensure the building’s condition and including the energy supply system shall be kept in such condition that they meet the energy performance requirements.(Finlex 132/1999, 2015)

2.6.2 The water act 587/2011

“This law aims to:1) to promote, organize and coordinate the resources and the aquatic environment in use so that it is economically and environmentally sustainable; 2) to prevent and reduce negative impacts on the groundwater; and 3) to improve water resources and water environment.” (Finlex 587/2011, §1)

If the project is in area where groundwater is located then the project need authorization of the regional administration according to the water act 587/2011. The consequences of the project can alter the groundwater quality, quantity or substantially reduce important water supply or otherwise cause damage or harm to water extraction. Therefore there have to be thorough investigations on what effects the projects has on the groundwater according to the water act § 3:2. (Finlex 587/2011, 2015)

2.6.3 The environmental protection act 527/2014

“This law is intended to: 1) to prevent environmental pollution and danger, to prevent and reduce emissions, and prevent damage to the environment; 2) to ensure a healthy and comfortable, and ecologically sustainable and diverse environment, support sustainable development; 3) to promote the sustainable use of resources and to reduce the amount of waste and its harmfulness, and to prevent the harmful effects of waste; 4) to improve the polluting activities in such a way that they pollute less; together with 5) enables citizens to influence environmental decision-making” (Finlex 527/2014, §1)

The environmental act has big impacts on energy efficient buildings and promotes the use of renewable energy. But the use of all the energy sources has to be well controlled and no harm to environmental is allowed. Geothermal energy usage is affected by § 17 that states that groundwater pollution is prohibited. Subjects or energy cannot be lead to a place or handled in such a way that:

1. An important water supply or otherwise suitable groundwater may become hazardous to health or its quality otherwise decreased.
2. Another property’s groundwater may become hazardous to health or unfit for the purpose for which it could be used. (Finlex 527/2014, 2015)

2.6.4 Summary of laws affecting geothermal energy

The above stated laws are the most relevant laws affecting geothermal energy: land use and building act (132/1999), the water act (587/2011) and the environmental protection act (527/2014). With the addition of the chemicals act 599/2013. The chemicals act also affects geothermal energy usage and tunnel lining by stating in § 15 that ground loop circuit fluid have to be handled with the necessary care and respect to prevent environmental impact. The common denominators are energy efficiency and environmental care, all the laws and regulations that affects geothermal energy promotes the use of renewable energy. But the laws and acts states that there have to be knowledge with each project so the environment doesn’t suffer from any project. The installation has to be right and the service of the geothermal energy equipment has to be good. (Finlex, 2015)

The city of Helsinki also has some restrictions with the usage of geothermal energy. There are reservations for upcoming projects beneath the ground of Helsinki city that prevents construction of geothermal borehole heat exchangers in most parts of Helsinki. But the tunnel lining in the Helsinki city loop isn't affected by this restriction by being about 30 meters beneath the ground already. Helsinki city has also identified certain issues that need to be taken into account in when drilling the thermal wells. The two drill holes need a spacing of at least 15 meters and the distance from the parcel's boundary need to be at least 7.5 meters. If the borehole is installed closer than 7.5 meters to the neighboring parcel is the consent of the neighbor needed. (Äikäs. K, 2015).

3 FINANCIAL ASPECTS

3.1 General investment theory

An investment includes an initial investment cost which in turn will generate a series of positive cash flows during the life of the investment. The positive cash flows, together with the salvage value will in turn make the investment profitable for the investor. The long-term efforts that investment involves forms the basis for a company to be able to operate and develop their business. (Ljung and Högberg, 1999)

3.2 Net present value, NPV

The net present value is the difference between the present value of cash inflows and the present value of cash outflows at the moment of the initial investment. This make it possible to compare the projects all income and costs at the same time. The conversion of the cash inflows and cash outflows is done with the help of the discount rate that is depreciation of all future inflows and outflows. With the net present value, NPV, calculations is the present value on the investment's all payment consequences added up to give a present value. If this present value is more than zero is the investment profitable to make, the higher value the better. (Ljung and Högberg, 1999)

The decision rules of the NPV method are in short the following:

- If the calculated present value exceeds zero is the investment profitable to make. The present value indicate the value that future positive and negative cash flows are worth today.
- At a situation ranking different investments is the investment with the highest present value selected. Therefore is desirable with as high as possible present value.

If the present value in a project was to be negative means it that it is better to invest in the alternative that has a yield like the discount rate that was used in the calculations. This means that the precision of the calculation is highly dependent on what discount rate is used.

The definition of NPV calculations is the following:

$$\mathrm{NPV}(i,N)=\sum_{t=0}^{N}\frac{R_t}{(1+i)^t}$$

- t : The time of the cash flow
- i : The discount rate
- R_t : The net cash flow, at time t .

3.3 Life cycle cost, LCC

The life cycle cost for a building project is the total cost of project throughout the project's lifetime, from the planning until when the building need to be demolished. The Life cycle cost calculations promote bigger investments in a project if the money and energy are saved during the lifetime of the building. (Kibert, 2008)

The key components when to calculate a project's LCC are:

- Energy costs during the life of the building.
- Investment costs for the building.
- Maintenance costs for the building during its life.
- Lifetime of the building
- Reinvestment to keep the building at same standard during its lifetime.
- Discount rate and inflation

To calculate the life cycle cost for a project could the following formula be used:

LCC_{tot} = investment cost + LCC_{energy} + $LCC_{maintenance}$
LCC_{energy} = annual energy cost • present value factor
$LCC_{maintenance}$ = annual maintenance cost • present value factor

A table of present value factor (Cp/Cn) is included in the appendices. (Levin, Lilliehorn and Sandesten, 2008)

4 RESULTS

4.1 Background data for calculations

The Helsinki city loop tunnel part is nearly 6 kilometers. Of these 6 kilometers of tunnel do 700 meters at each opening need to be extra insulated to not freeze in the winter and thus are not suitable for tunnel lining making only 4,6 kilometres of usable length. The absorber pipes used in tunnel lining won't be installed at the stations because it would be hard to fix them if they got any problems during their lifetime. Each station is about 300 metres long making with 3 stations 900 metres more unusable for tunnel lining. The total length usable for absorber pipes in a tunnels is then 3700 metres. With 2 tunnels going next to each other with a usable length of 3700 metres each making 7400 metres of usable tunnel for tunnel lining. (Finnish Transport Agency, 2015) The problem with installing tunnel lining as above suggested is that the train traffic have to be stopped when any maintenance is to be done to the absorber pipes. A better place for tunnel lining in the Helsinki city rail loop is the service/rescue tunnel that run next to the train tunnels. The length of the service tunnel is about 6 kilometres of usable length. The benefit of using the service tunnel for the tunnel lining is that there can be done maintenance 24/7 without any consequences on the train traffic.

To be able to calculate the total square metre available for tunnel lining for each metre in the service tunnel was the upcoming figure 7 used. The dimensions in figure 7 are the most up to date dimension figures when this thesis was made. The wall in the tunnel is 4 metre high up to the point that the arch starts and the total height of the tunnel is about 5,4 metre. To be able to calculate the total area was Pythagorean Theorem used.

$$a^2 + b^2 = c^2$$

Where a in this formula is the difference between total height in the tunnel of 5,4 meter and the height of the arch of 1,4 meter.

$$a = 5{,}4m - 4{,}0m = 1{,}4m$$

b in this formula is the width of half of the tunnel, 4,05 meter.

When inserting these numbers into the Pythagorean Theorem and solve it with focus on c was the following data acquired:

$$c = \sqrt{a^2 + b^2}$$

$$c = \sqrt{(1{,}4m)^2 + (4{,}05m)^2}$$

$$c = 4{,}29m$$

The total length of half of the arch, c, and the height up to the arch, 4,0m, is:

$$Half\ of\ the\ \ length = 4{,}29m + 4m = 8{,}29m$$

$$The\ tunnel's\ total\ inner\ surface\ area\ is\ \ = 8{,}29 \bullet 2 = 16{,}6m$$

This means that the total area available for tunnel lining in 1 meter of the tunnel is 16,6m^2.

The service tunnel's inner surface is about 16,6m^2 when taking a tunnel cross-section and disregarding the tunnel floor. The minimum pipe distance from each other should be 100 cm to avoid problems with taking away too much energy from the bedrock. The primary layer is 0,3 meter. Making it possible to install 16 absorber pipes in the tunnel's cross-section. The absorber pipes would be installed in normal tunnel lining tunnels like figure 7 shows along the tunnel. There could be a risk for the bedrock to freeze if additional absorber pipes are installed with the same flowrate that is used in this research. (Baujard and Kohl, 2010)

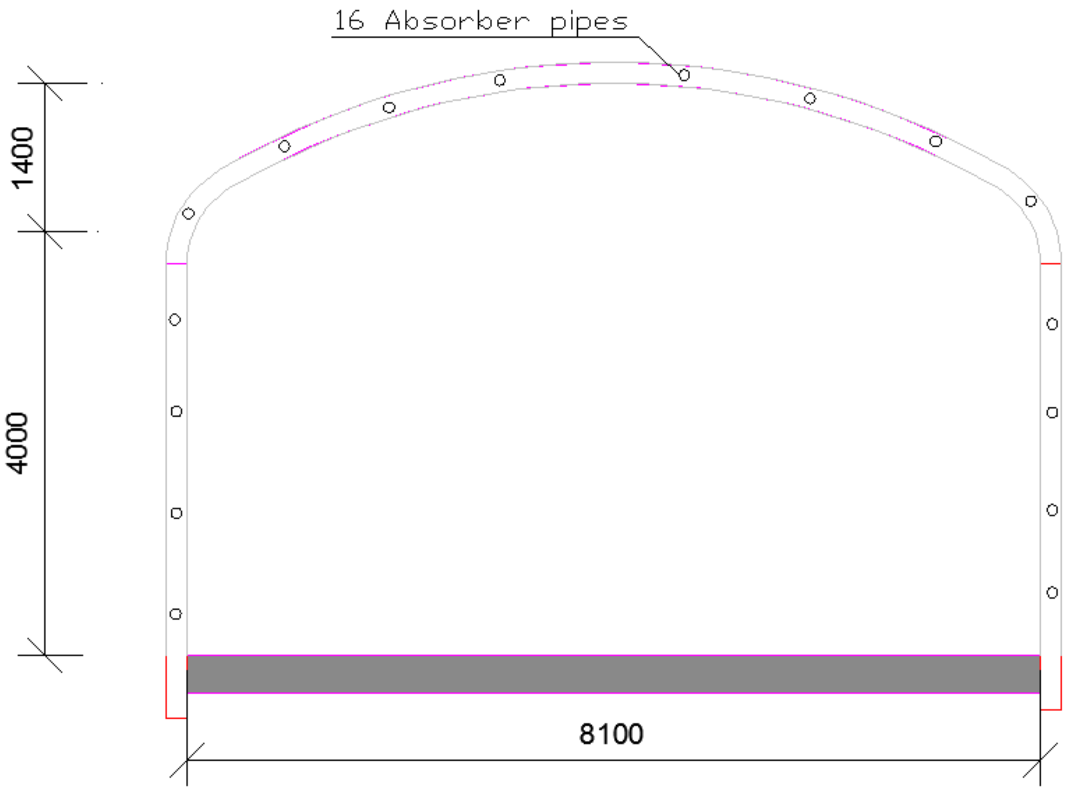


Figure 7 Cross-section of the service tunnel shows how the tunnel lining pipes could be installed in the service tunnel at Helsinki city rail loop. Original picture from Granlund Oy then modified by Niklas Wiik.

To prevent too long absorber pipe loops and make the maintenance easier of the tunnels are the maximal length of every absorber pipe loop 400 meters. With 16 absorber loops on each tunnel meters will one loop be:

$$\frac{400m}{16m} = 25m$$

Meaning that one absorber loop is 25 meters long in the tunnel. With the usable tunnel length of 6000 meters in total there will be:

$$\frac{6000m}{25m} = 240\ absorber\ loops\ in\ total$$

The absorber pipe loops will be connected to a distribution pipes situated in an insulated ditch that is beside the railway in the tunnel. With these distribution pipes can every absorber pipe loop be individually be turned on and off. The individual absorber loops can also be adjusted for heating or cooling need.

The used heat carrier in the absorber pipes will be 25% ethanol and 75% water liquid. The liquid have a specific heat C_p of 3735 J/Kg K, a liquid viscosity of 0,0012 kg/(s·m),same as Pa·s, a density ρ of 948,5 kg/m^3 and a thermal conductivity of 0,493 W/m.K. These values were calculated using the properties of ethanol and water at 20 degrees Celsius. The absorber pipes will be made of polyethylene with an outer diameter of 25 mm and a wall thickness of 2.4mm). Polyethylene has an thermal conductivity of 0,38 W/m.K.(John E. Patterson and Ronald J. Miers, 2010)

The liquid has a flowrate of 1 m^3/h, in m^3/s:

$$\frac{1\frac{m^3}{h}}{3600} = 0{,}000278\frac{m^3}{s}$$

This is 0,000278m^3/s and the pipe has an inner diameter of 22,6 mm (radius of 11,3 mm) making the flowrate:

$$\frac{(0{,}000278\frac{m^3}{s})}{(\pi \bullet (0{,}0113m)^2)} = 0{,}693\frac{m}{s}$$

The thermal resistance, R-value, (m.K/W) of the absorber pipe is the heat thermal resistance between the circulating fluid in a certain absorber pipe and surrounding bedrock. R_{sr} consists of the convective resistance of the fluid, thermal resistance of the fluid/pipe and contact resistance of pipe and primary layer/soil:

$$R_{sr} = R_{pipe} + R_f + R_{soil}$$

The R_{pipe} part is calculated by the following formula:

$$R_{pipe} = \frac{ln\frac{r_e}{r_i}}{2\pi\lambda_k}$$

Where r_e is the outer radius if the pipe in meter, r_i is the inner radius of the pipe in meter and λ_k is the thermal conductivity of the pipe in W/m.K

$$R_{pipe} = \frac{ln\frac{0{,}0025m}{0{,}00226m}}{2\pi \bullet 0{,}38\ \frac{W}{m.K}}$$

$$R_{pipe} = 0{,}042\frac{m.K}{W}$$

The R_{soil} part is calculated by the formula below. r_e is here 4,05m(width of the tunnel)+0,3m(thickness of the primary layer of the tunnel), r_i is 4,05m (width of the tunnel) and λ_{soil} is the average thermal conductivity of the soil of 3,2 W/m.K

$$R_{soil} = \frac{ln\frac{r_e}{r_i}}{2\pi\lambda_{soil}}$$

$$R_{soil} = \frac{ln\frac{4{,}35m}{4{,}05m}}{2\pi \bullet 3{,}2\ \frac{W}{m.K}}$$

$$R_{soil} = 0{,}00355\frac{m.K}{W}$$

The R_f part is calculated by the following formulas:

$$R_f = \frac{1}{\pi d_{pi} h_{ci}} + \frac{1}{2\pi\lambda_p}\ln\left(\frac{d_{po}}{d_{pi}}\right)$$

$$h_{ci} = \frac{0{,}023Re^{0{,}8}Pr^{0{,}4}\lambda_f}{d_{pi}}$$

$$Re = \frac{vd_{pi}}{\mu}$$

$$Pr = \frac{\mu\rho_f c_f}{\lambda_f}$$

Where the inner diameter of pipe is d_{pi}, the outer diameter of pipe is d_{po}, the thermal conductivity of the absorber pipe's wall is λ_p, the thermal conductivity of the liquid is λ_f, the flow rate of the liquid is v, the viscosity coefficient of liquid is μ, the density of liquid is ρ_f and the specific heat of liquid is c_f.

The equation is solved by starting with solving Re and Pr then inserting them into the formula.

$$Pr = \frac{0{,}0012\frac{kg}{sm} \bullet 948{,}5\ \frac{kg}{m^3} \bullet 3735\ \frac{J}{Kg.K}}{0{,}493\ \frac{W}{m.K}}$$

$$Pr = 8623{,}1\frac{Kg}{m^3}$$

$$Re = \frac{vd_{pi}}{\mu}$$

$$Re = \frac{0{,}693\frac{m}{s} \bullet 0{,}00226m}{0{,}0012\frac{kg}{sm}}$$

$$Re = 1{,}305\frac{m^3}{kg}$$

$$h_{ci} = \frac{0{,}023Re^{0{,}8}Pr^{0{,}4}\lambda_f}{d_{pi}}$$

$$h_{ci} = \frac{0{,}023 \times (1{,}305\frac{m^3}{kg})^{0{,}8} \bullet (8623{,}1\frac{kg}{m^3})^{0{,}4} \bullet 0{,}493\ \frac{W}{m.K}}{0{,}00226m}$$

$$h_{ci} = 232{,}7\frac{W}{m^2K}$$

$$R_f = \frac{1}{\pi \bullet 0{,}00226m \bullet 232{,}7\frac{W}{m^2K}} + \frac{1}{2\pi \bullet 0{,}38\ \frac{W}{m.K}} \ln\left(\frac{0{,}0025m}{0{,}00226m}\right)$$

$$R_f = \frac{1}{1{,}65\frac{W}{m.K}} + \frac{1}{2{,}387\ \frac{W}{m.K}} \bullet 0{,}10$$

$$R_f = 0{,}64\frac{m.K}{W}$$

When all parts of R_{sr} is calculated it's a simple addition to add them all together:

$$R_{sr} = R_{pipe} + R_f + R_{soil}$$

$$R_{sr} = 0{,}042\frac{m.K}{W} + 0{,}64\frac{m.K}{W} + 0{,}00355\frac{m.K}{W}$$

$$R_{sr=}0{,}685\frac{m.K}{W}$$

The service tunnel's bedrocks average temperature and the tunnel's average air temperature had to be calculated by yearly mean temperatures and earlier studies. The results would be even more accurate if field testes on the tunnel's temperatures could have been made. The average temperature of the bedrock used in this thesis' calculations is 8°C. This average value is acquired from the preliminary calculations about the possibility of conventional ground source heat pumps in the Helsinki city rail loop done by Loisa, and Pietarila in 2014.

The average air temperature in the service tunnel was calculated by using the average coldest and warmest months for Helsinki, these were acquired from the Finnish meteorological institute. The average temperature in July in Helsinki is +17,8 °C. The coldest month February is in average -4,7°C. Thomas Schlosser et al have made in their research "Potenzial der Tunnelbaustrecke des Bahnprojektes Stuttgart 21 zur Wärme- und Kältenutzung" an interesting formula on pages 33-35 about the air temperature in tunnels. They state that the air temperature in tunnels is decided by the outside temperature and the length from the tunnel opening. Their formulas for the air temperature in the winter and summer are the following:

- Air temperature winter formula:

$$\vartheta_{Air,tunnel,winter} = \vartheta_{outdoor\ air,winter} + a(1 - e^{(-b*L)})$$

- Air temperature summer formula:

$$\vartheta_{Air,tunnel,summer} = (\vartheta_{outdoor\ air,summer} - \Delta\vartheta_{max}) + ae^{(-b*L)}$$

Where L is the distance from the service tunnel opening in meters. *a,b* are coefficients Thomas Schlosser et al derived from their test data. $\Delta\vartheta_{max}$ is the maximum temperature difference between outside air and the air in the tunnel. By combining these formulas above for the air temperature in the service tunnel with the average temperatures in Helsinki was the following figure 8 made.

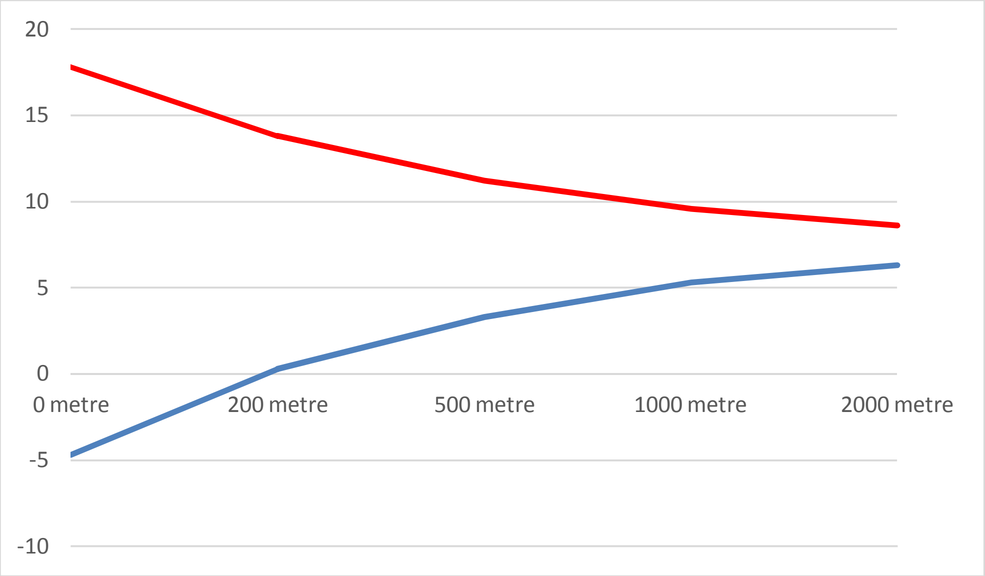


Figure 8 showing the air temperature inside the Helsinki city railway tunnel. The distance is from the service tunnel's opening. The blue line is the average temperature in the winter while the red line is the average temperature in the summer

As seen from figure 8 is the yearly variation of the tunnel temperature at 700meters from the service tunnel opening in the interval of +4°C in the winter to +11°C in the summer. The variation decreases when going into the tunnel and by 1500 meters is the average temperature at winter +6°C and at summer +8°C. To simplify the energy calculations for the Helsinki city railway loop service tunnel is an average value of the seasonal variations used. This value is +7°C for the tunnel air temperature, this value is the average value at all places of the service tunnel.

The total thermal resistance between the circulating fluid in a certain absorber pipe and surrounding air:

$$R_{air} = \mathrm{R}\alpha + R_f + R_{pipe}$$

The thermal resistance, R-value, (m.K/W) between the circulating fluid in a certain absorber pipe and surrounding air.

$$R_{pipe} = \frac{ln\frac{r_e}{r_i}}{2\pi\lambda_k}$$

Where r_e is the outer radius if the pipe in meter, r_i is the inner radius of the pipe in meter and λ_k is the thermal conductivity of the pipe in W/m.K

$$R_{pipe} = \frac{ln\frac{0{,}0025m}{0{,}00226m}}{2\pi \bullet 0{,}38\ \frac{W}{m.K}}$$

$$R_{pipe} = 0{,}042\frac{m.K}{W}$$

As an additional parameter on the air side of the heat transfer coefficient is α. This value was determined based on typical values used in building with free convection on walls. Here in this research is the inverse of α used, Rα the thermal resistance. Since the thermal resistance is dependent on the heat flow direction and the position of the surface here was a mean of Rα = 0.12 m.°C/ W assumed for the examined.

The R_f part is calculated by the following formulas:

$$R_f = \frac{1}{\pi d_{pi} h_{ci}} + \frac{1}{2\pi\lambda_p}\ln\left(\frac{d_{po}}{d_{pi}}\right)$$

$$h_{ci} = \frac{0{,}023Re^{0{,}8}Pr^{0{,}4}\lambda_f}{d_{pi}}$$

$$Re = \frac{vd_{pi}}{\mu}$$

$$Pr = \frac{\mu\rho_f c_f}{\lambda_f}$$

Where the inner diameter of pipe is d_{pi}, the outer diameter of pipe is d_{po}, the thermal conductivity of the absorber pipe's wall is λ_p, the thermal conductivity of the liquid is λ_f, the flow rate of the liquid is v, the viscosity coefficient of liquid is μ, the density of liquid is ρ_f and the specific heat of liquid is c_f.

The equation is solved by starting with solving Re and Pr then inserting them into the formula.

$$Pr = \frac{0{,}0012\frac{kg}{sm} \bullet 948{,}5\ \frac{kg}{m^3} \bullet 3735\ \frac{J}{Kg.K}}{0{,}493\ \frac{W}{m.K}}$$

$$Pr = 8623{,}1\frac{Kg}{m^3}$$

$$Re = \frac{vd_{pi}}{\mu}$$

$$Re = \frac{0{,}693\frac{m}{s} \bullet 0{,}00226m}{0{,}0012\frac{kg}{sm}}$$

$$Re = 1{,}305\frac{m^3}{kg}$$

$$h_{ci} = \frac{0{,}023Re^{0{,}8}Pr^{0{,}4}\lambda_f}{d_{pi}}$$

$$h_{ci} = \frac{0{,}023 \times (1{,}305\frac{m^3}{kg})^{0{,}8} \bullet (8623{,}1\frac{kg}{m^3})^{0{,}4} \bullet 0{,}493\ \frac{W}{m.K}}{0{,}00226m}$$

$$h_{ci} = 232{,}7\frac{W}{m^2K}$$

$$R_f = \frac{1}{\pi \bullet 0{,}00226m \bullet 232{,}7\frac{W}{m^2K}} + \frac{1}{2\pi \bullet 0{,}38\ \frac{\mathrm{W}}{m.K}}\ln\left(\frac{0{,}0025m}{0{,}00226m}\right)$$

$$R_f = \frac{1}{1{,}65\frac{W}{m.K}} + \frac{1}{2{,}387\ \frac{\mathrm{W}}{m.K}} \bullet 0{,}10$$

$$R_f = 0{,}64\frac{m.K}{W}$$

The total thermal resistance between the circulating fluid in a certain absorber pipe and surrounding air is then:

$$R_{air} = \mathrm{R}\alpha + R_f + R_{pipe}$$

$$R_{air} = 0.12\ \frac{\mathrm{m.°C}}{W} + 0{,}64\frac{m.K}{W} + 0{,}042\frac{m.°\mathrm{C}}{W}$$

$$R_{air} = 0{,}802\frac{m.°\mathrm{C}}{W}$$

4.2 Energy calculations for heat exchangers

The simple formula for heat exchange of the heat exchangers' absorber tubes are the following equation. (Eq.1):

$$q = \rho\dot{V}cp(T_{out} - T_{in}) \quad (1)$$

Where q is the heat exchange of the absorber tubes in W: ρ is the density of the liquid: $\dot{V}$ is the mass flow rate in m^3/s: c_p is the specific heat of the liquid in J/(kg°C): T_{out} is the temperature of outlet water in °C : T_{in} is the temperature of inlet water in °C. To get the heat exchange per meter, q, we use the following formula. (Eq.2.)

$$Q = \frac{q}{H} \quad (2)$$

Q is the heat exchange rate per meter in W/m: H is how deep the absorber pipes are buried in m.

To be able to use the formula above and expand on it are the explanation of the various impacting things needed. Because the heat exchange in W/m from tunnel lining is dependent on many things:

1. The first thing is mentioned earlier and that is the different pipe distances used in tunnel lining. Zhang et al did in the Linchang tunnel experimental with pipe distances on 50cm and 100cm. They concluded that the pipes' distance from each other will have a significant effect on the heat exchange rate of the heat exchange pipes. The bigger the pipe distance is, the faster the ground temperature recovery from extracting energy from it. (Zhang, G.,2014)
2. The inlet temperature of the absorber loop's heat carrier liquid. The heat exchange rate increase as a linear variation as the inlet temperature of the heat carrier liquid increases. With higher temperatures the larger the heat exchange is.

By using Eq. 1 with the heat carrier liquid we get that the heat carrier liquid's temperature has a great significance on the heat transfer performance.

3. The heat exchange rate changes with different flow rates of the heat carrier. Zhang et al observed that the heat exchange rate raised exponentially as the flow rate increased. But with higher flow rates the circulation pump has to work with larger circulation resistance. This lead eventually to a bigger circulation pump that use more electricity. Therefore, should the flow rate not only be chosen by efficiency but also by economic factors. (Zhang, G.,2014)

As mentioned above is the heat transfer in the tunnel lining's absorber pipes highly dependent of the flow rate of the circulating liquid and the inlet/outlet temperatures of the liquid. The usable fluid in the system is known, the fluid would be 25% ethanol and 75% water to prevent freezing. The thermodynamics for this fluid was explained in chapter 4.1. To be able to use equation 1 field testes in the tunnel should be performed to acquire the optimum flow rate, inlet temperature and outlet temperature in the Helsinki city railway loop. These field-tests haven't been made yet therefore does this thesis disregard the possibility to get optimum flow rates and temperatures for the circulating fluid in the absorber pipes. The above equation 1 shows that the heat exchange rate increases for heat exchangers for every increase in the inlet temperature. Knowing the importance of the liquid temperature it's important to consider the absorber pipes fluids' temperature when designing a tunnel lining system.

4.3 Energy calculations for tunnel lining

To be able to understand the full heat exchange process of tunnel lining ground heat exchangers we need to go study figure 9 where it is shown the origin of the energy in tunnel lining.

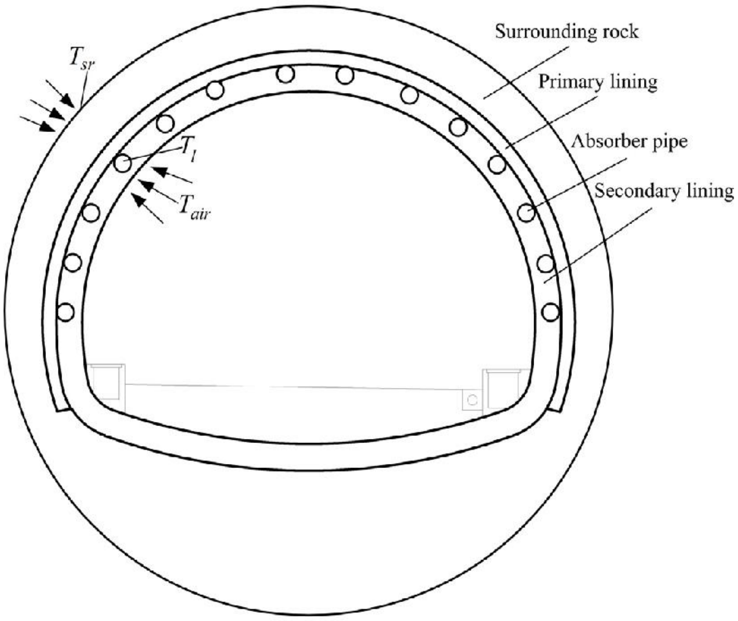


Figure 9 shows the principle from where ground heat exchangers get their energy.

By studying figure 9, it is seen that the heat exchange of the tunnel lining ground heat exchangers consist of 2 different parts. One part of the energy derives from the tunnel's air and the other part comes from the bedrock surrounding the tunnel.

$$Q_{a,l}(t) = \frac{T_{a,l}(t) - T_{sr}(t)}{R_{sr}} + \frac{T_{a,l}(t) - T_{air}(t)}{R_{air}} + \sum_{b=1}^{k} \frac{T_{a,l}(t) - T_{a,l}(t)}{R_{ab,p}}$$

The above equation describe the heat exchanges in the tunnel. $Qa,_l(t)$ is the total heat exchange rate of the absorber pipe a in watt. $T_{a,l}(t)$ is the absorber pipe's heat carrier fluid temperature in °C. $T_{sr}(t)$ is the temperature of the surrounding bedrock in °C. $T_{air}(t)$ is the air temperature in the tunnel in °C. R_{sr} is the heat thermal resistance between the absorber pipe's circulating heat carrier fluid and the surrounding bedrock in m^2°C/W. R_{air} is the heat thermal resistance between the absorber pipe's circulating heat carrier fluid and the air in the tunnel in m°C/W. $R_{ab,p}$ is the heat thermal resistance between 2 adjacent absorber pipes *a* and *b* in m°C/W.

Because of the short longitudinal length of each absorber pipe, 25 meters, is the temperature difference neglectable between absorber pipe *a* and *b*. The equation can therefore be simplified by leaving out the final part of the equation and then is the equation for energy gained from tunnel lining the following:

$$Q_{a,l}(t) = \frac{T_{a,l}(t) - T_{sr}(t)}{R_{sr}} + \frac{T_{a,l}(t) - T_{air}(t)}{R_{air}}$$

The data used in the equation to acquire data on possible energy gain from tunnel lining is the following. T_{air} is in this case +7°C, this proven to be the average air temperature in the tunnel. T_{sr} is +8°C, this is the bedrock's temperature beneath Helsinki acquired from Loisa and Pietarila research about GSHPs in the Helsinki city rail loop. R_{air} is a value that was determined based on typical values used in building with free convection on walls. Since the thermal resistance is dependent on the heat flow direction and the position of the surface here was a mean of R_{air} = 0.802 m°C/ W assumed for the examined. R_{sr} is in this case with polyethylene absorber pipes 0,685 m°C/W. $T_{a,l}$ is the most important factor in calculating the available energy in tunnel lining, as proven earlier with equation 1 is the heat exchange directly comparable with temperature of the absorber pipe's liquid. As important as $T_{a,l}$ is as hard is it to decide a good heat carrier liquid temperature without field-tests. Zhang et al (2014) did in the Linchang tunnel perform their research with various temperature on the heat carrier liquid. Their most common temperature was 20°C, this thesis' research will us the same 20°C for $T_{a,l}$ in the lack of field-tests and tunnel lining technology data from Finland.

$T_{a,l}$=20°C T_{sr}= 8°C T_{air}= 7°C

$$R_{sr=}0{,}685\frac{m.K}{W}$$

$$R_{air} = 0{,}802\frac{m.°C}{W}$$

$$Q_{a,l} = \frac{20°C - 8°C}{0{,}685\ \frac{m°C}{W}} + \frac{20°C - 7°C}{0{,}802\ \frac{m°C}{W}} =$$

$$Q_{a,l} = \frac{12°\mathrm{C}}{0{,}685\frac{m°\mathrm{C}}{\mathrm{W}}} + \frac{13°\mathrm{C}}{0{,}802\frac{m°\mathrm{C}}{\mathrm{W}}} =$$

$$Q_{a,l} = 17{,}5\frac{W}{m} + 16{,}25\frac{W}{m} =$$

$$Q_{a,l} \approx 33{,}75\frac{W}{m}$$

This means that a meter of tunnel generates about 33,75 watt using tunnel lining technology with 20°C in heat carrier temperature. As seen in the calculations does the bigger part of energy originate from the bedrock and a smaller part of the energy derives from the tunnel’s air.

If all of the total available length of 6000 meters are used for tunnel lining, then by using earlier calculations that 240 absorber loops fits into the tunnel each with a length of 400 m are the following calculations calculated:

$$Total\ available\ distance\ for\ tunneling = 240\ loops\ \bullet 400m$$

$$Tot. = 96000\mathrm{m}$$

The total usable energy with tunnel lining would then be during 1 hour:

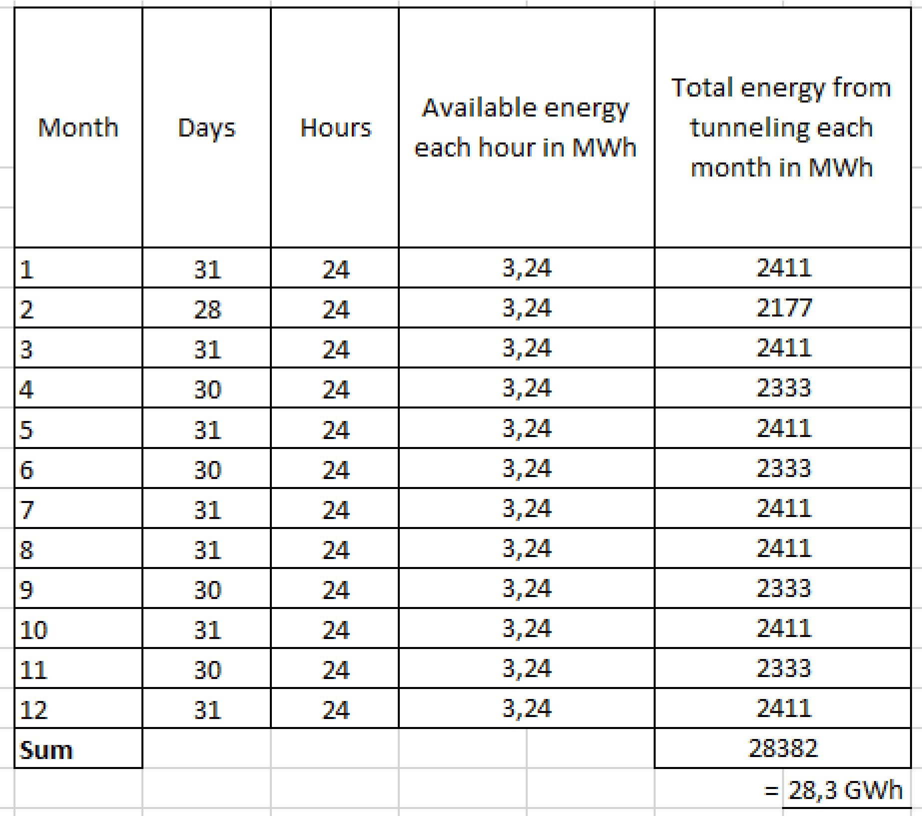
$$Q_{tot} = 33{,}75\frac{W}{m} \bullet 96000m \bullet 1h$$

$$Q_{tot} \approx 3240KW = 3{,}24MW$$

$$\text{Daily } Q_{tot} = 3240KW \bullet 24h$$

$$Daily\ Q_{tot} \approx 77{,}76\ MWh$$

Table 3 Available energy from tunnel lining in Helsinki city rail loop in MWh with 20°C in heat carrier temperature.



Month	Days	Hours	Available energy each hour in MWh	Total energy from tunneling each month in MWh
1	31	24	3,24	2411
2	28	24	3,24	2177
3	31	24	3,24	2411
4	30	24	3,24	2333
5	31	24	3,24	2411
6	30	24	3,24	2333
7	31	24	3,24	2411
8	31	24	3,24	2411
9	30	24	3,24	2333
10	31	24	3,24	2411
11	30	24	3,24	2333
12	31	24	3,24	2411
Sum				28382
				= 28,3 GWh

The table above shows the available energy each month that could be taken from the bedrock in MWh with 20°C in heat carrier temperature. The yearly available energy in GWh from tunnel lining in Helsinki city rail loop is 28,3 GWh. About 3,24 MW of effect each hour is a lot and these calculations are based on optimum solutions and temperatures with no regards on the cooling of the bedrock. In the reality need the flow rate to be smaller and therefore is the available energy for tunnel lining less.

But as mentioned earlier if the heat carrier liquid’s temperature would be 15°C instead of 20°C would the usable energy be decreased greatly. This is shown over the following calculations:

$T_{a,l}$=15°C T_{sr}= 8°C T_{air}= 7°C

$$R_{sr=}0{,}685\frac{m.K}{W}$$

$$R_{air} = 0{,}802\frac{m.\,°\mathrm{C}}{W}$$

$$Q_{a,l} = \frac{15°\mathrm{C} - 8°\mathrm{C}}{0{,}685\ \frac{m°\mathrm{C}}{\mathrm{W}}} + \frac{15°\mathrm{C} - 7°\mathrm{C}}{0{,}802\ \frac{m°\mathrm{C}}{\mathrm{W}}} =$$

$$Q_{a,l} = \frac{7°\mathrm{C}}{0{,}685\frac{m°\mathrm{C}}{\mathrm{W}}} + \frac{8°\mathrm{C}}{0{,}802\frac{m°\mathrm{C}}{\mathrm{W}}} =$$

$$Q_{a,l} = 10{,}2\frac{W}{m} + 9{,}98\frac{W}{m} =$$

$$Q_{a,l} \approx 20{,}18\frac{W}{m}$$

This means that a meter of tunnel generates about 20,18 watt using tunnel lining technology with 15°C in heat carrier temperature. As seen in the calculations does the bigger part of energy originate from the bedrock and a smaller part of the energy derives from the air.

If all of the total available length of 6000 meters are used for tunnel lining, then by using earlier calculations that 240 absorber loops fits into the tunnel each with a length of 400 m are the following calculations calculated:

$$Total\ available\ distance\ for\ tunneling = 240\ loops\ \bullet 400m$$

$$Tot. = 96000\mathrm{m}$$

The total usable energy with tunnel lining would then be during 1 hour:

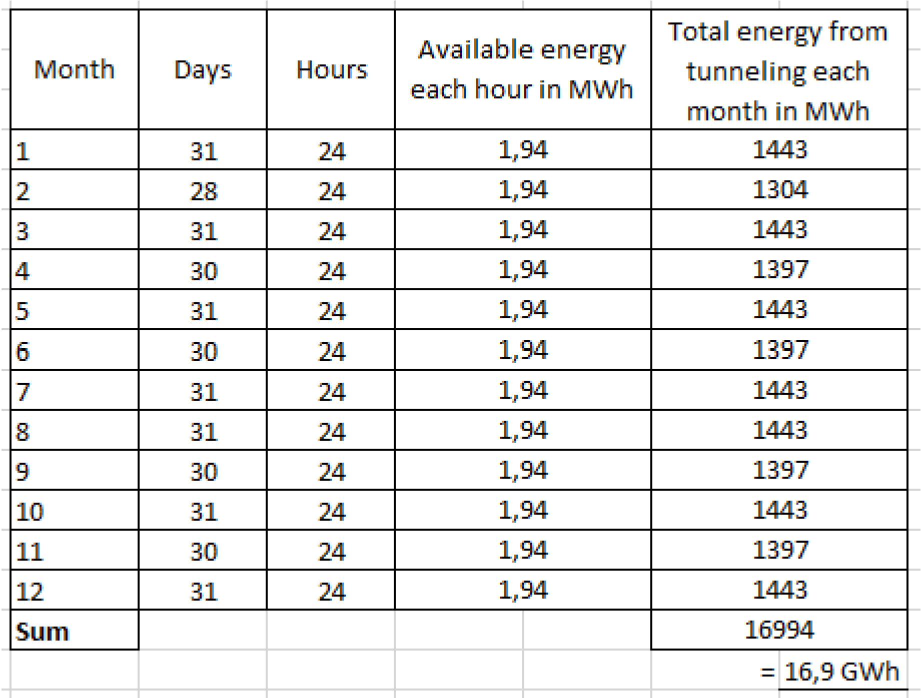
$$Q_{tot} = 20{,}18\frac{W}{m} \bullet 96000m$$

$$Q_{tot} \approx 1937KW = 1{,}94MW$$

$$\text{Daily } Q_{tot} = 1937KW \bullet 24h$$

Table 4 Available energy from tunnel lining in Helsinki city rail loop in MWh with 15°C in heat carrier temperature.

$$Daily\ Q_{tot} \approx 46{,}49\ MWh$$



Month	Days	Hours	Available energy each hour in MWh	Total energy from tunneling each month in MWh
1	31	24	1,94	1443
2	28	24	1,94	1304
3	31	24	1,94	1443
4	30	24	1,94	1397
5	31	24	1,94	1443
6	30	24	1,94	1397
7	31	24	1,94	1443
8	31	24	1,94	1443
9	30	24	1,94	1397
10	31	24	1,94	1443
11	30	24	1,94	1397
12	31	24	1,94	1443
Sum				16994
				= 16,9 GWh

The table above shows the available energy each month that could be taken from the bedrock in MWh with 15°C in heat carrier temperature. The yearly available energy in GWh from tunnel lining in Helsinki city rail loop is about 16,9 GWh. About 1,94 MW of effect each hour is a lot and these calculations are based on optimum solutions and temperatures with no regards on the cooling of the bedrock. In the reality need the flow rate to be smaller and therefore is the available energy for tunnel lining less.

But as mentioned earlier if the heat carrier liquid's temperature would be 10°C instead of 20°C would the usable energy be decreased even more. This is shown over the following calculations to provide more context to the heat carrier's temperatures significance:

$T_{a,l}$=10°C T_{sr}= 8°C T_{air}= 7°C

$$R_{sr=}0{,}685\frac{m.K}{W}$$

$$R_{air}=0{,}802\frac{m.°\mathrm{C}}{W}$$

$$Q_{a,l}=\frac{10°\mathrm{C}-8°\mathrm{C}}{0{,}685\ \frac{m°\mathrm{C}}{\mathrm{W}}}+\frac{10°\mathrm{C}-7°\mathrm{C}}{0{,}802\ \frac{m°\mathrm{C}}{\mathrm{W}}}=$$

$$Q_{a,l}=\frac{2°\mathrm{C}}{0{,}685\frac{m°\mathrm{C}}{\mathrm{W}}}+\frac{3°\mathrm{C}}{0{,}802\frac{m°\mathrm{C}}{\mathrm{W}}}=$$

$$Q_{a,l}=2{,}92\frac{W}{m}+3{,}74\frac{W}{m}=$$

$$Q_{a,l}\approx 6{,}66\frac{W}{m}$$

This means that a meter of tunnel gives about 6,66 watt using tunnel lining technology with 10°C in heat carrier temperature. As seen in the calculations have the order from where the biggest part of energy changed in these low temperatures. Now does the bigger part of energy originate from the air and a smaller part of the energy derives from the bedrock. This can be explained by the thermal resistances and different temperatures at the bedrock and in the air.

If all of the total available length of 6000 meters are used for tunnel lining, then by using earlier calculations that 240 absorber loops fits into the tunnel each with a length of 400 m are the following calculations calculated:

$$Total\ available\ distance\ for\ tunneling=240\ loops\ \bullet 400m$$

$$Tot.=96000\mathrm{m}$$

The total usable energy with tunnel lining would then be during 1 hour:

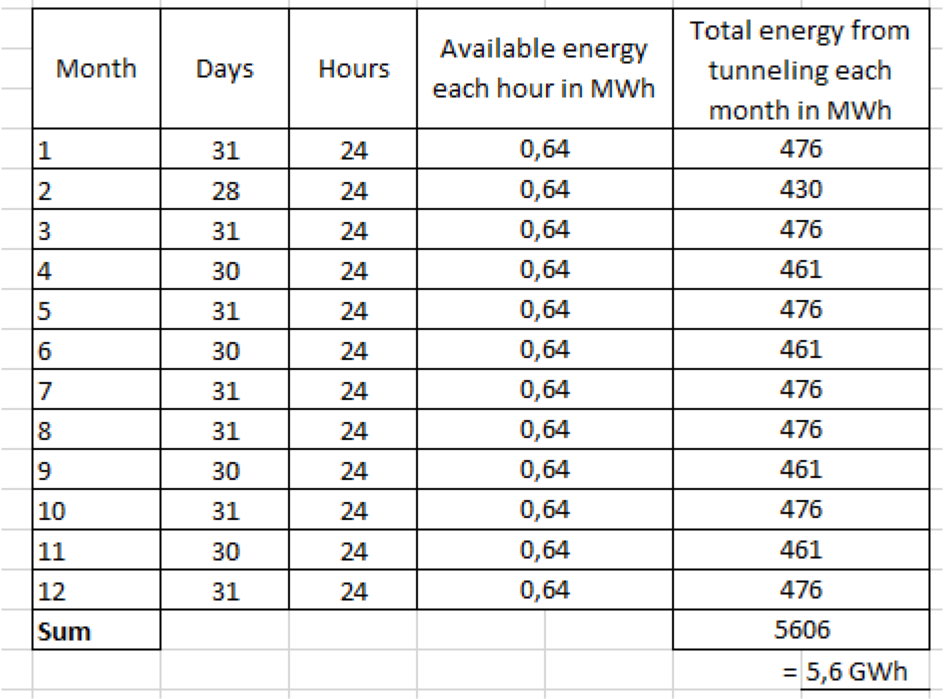
$$Q_{tot} = 6{,}66\frac{W}{m} \bullet 96000m$$

$$Q_{tot} \approx 639{,}36KW = 0{,}64MW$$

$$\text{Daily } Q_{tot} = 639{,}4KW \bullet 24h$$

$$Daily\ Q_{tot} \approx 15{,}3\ MWh$$

Table 5 Available energy from tunnel lining in Helsinki city rail loop in MWh with 10°C in heat carrier temperature.



Month	Days	Hours	Available energy each hour in MWh	Total energy from tunneling each month in MWh
1	31	24	0,64	476
2	28	24	0,64	430
3	31	24	0,64	476
4	30	24	0,64	461
5	31	24	0,64	476
6	30	24	0,64	461
7	31	24	0,64	476
8	31	24	0,64	476
9	30	24	0,64	461
10	31	24	0,64	476
11	30	24	0,64	461
12	31	24	0,64	476
Sum				5606
				= 5,6 GWh

The table above shows the available energy each month that could be taken from the bedrock in MWh with 10°C in heat carrier temperature. The yearly available energy in GWh from tunnel lining in Helsinki city rail loop is about 5,6 GWh. About 0,64MW of effect each hour is a lot at these temperatures and these calculations are based on optimum solutions and temperatures with no regards on the cooling of the bedrock. In the reality need the flow rate to be smaller and therefore is the available energy for tunnel lining less.

4.4 Profitability calculations

Due to the lack of projects with tunnel lining in Finland and outside Finland are no direct cost figures available for tunnel lining technology. L. Loisa and E. Pietarila have made preliminary cost analyses about conventional geothermal usage with borehole heat exchangers and district heating in the Helsinki city railway loop in their report "Pisararadan Asemat Geoenergiaselvitys". Loisa and Pietarila do state that their cost figures need to be updated before making any bigger decision and therefore do this thesis state the same that the exact costs and energy need are needed before making a final decision. The cost estimate for conventional geothermal usage is approximately 1500€/kW. This cost include the drilling, circulation pumps, pipes and installation. Tunnel lining is a cheaper method than geothermal borehole heat exchangers because no expensive drilling is needed. Instead are the absorber pipes attached to the primary layer with fasteners that are cheap to made and the installation of the absorber pipes is easy and fast during the construction of the tunnel. The drilling of borehole heat exchangers are on the ground about 30-35€/m and probably more expensive inside a tunnel with the problem of getting the drilling machine there. The Swedish energy department (Energimyndigheten, 2014) have stated that 30-50W/m can be extracted from a borehole heat exchanger the number is dependent on the bedrock and other factors. The simple formula below with 35€/m costs for drilling and 45W/m gained energy shows the costs of drilling/kW:

$$Approx. drilling\ costs = \frac{1000W}{45\frac{W}{m}} \bullet 35\frac{€}{m}$$

$$Approx. drilling\ costs = 778€/kW$$

$$Approx. \frac{Total\ cost}{kW} = 1500€/kW$$

$$Installation\ and\ pump\ costs = \frac{1500€}{kW} - \frac{778€}{kW} = 722€/kW$$

As seen from the formula above is the drilling cost a little over half of the total price of geothermal borehole heat exchangers with ground source heat exchangers. This cost doesn't exist in tunnel lining technology instead there is a bigger installation cost of the absorber pipes when they have to be fastened to the tunnel's primary layer. There are no calculations published about how much the installation work of tunnel lining could cost so this research assumes a value of 200€/m in the tunnel. The 200€/m represents the absorber pipe's cost and couple of work hours for 2 installers to do the installation. A polyethylene absorber pipe cost about 500-1000€ for 400m (1 absorber loop) and 240 loops are situated in the tunnel. Further there have to be installed the distribution pipe in an insulated ditch, this work is done much faster than the fastening of the absorber pipe but the pipes are more expensive so a cost of 100€/m could be expected at least. This cost include the relatively big distribution pipes and the installation of these. Furthermore are circulations pumps needed, the exact number is dependent how the system will be used. The heating and cooling need separate circulations pumps so the systems can work simultaneously. Further studies are needed to establish the pressure in the distribution pipes and adjust the number of pumps needed for the distribution pipes accordingly. Every of the 240 absorber loops need a heat exchanger to make the system stable and adjustable. 2 loops can be connected to the same heat exchanger to reduce the number of heat exchangers. There would then be a need of 120 heat exchangers that can handle 2 absorber loops of 400m. For these profitability calculations was the geothermal heat exchanger Nibe F1135 15 Kw (Nibe, 2015) chosen because it can easily handle 2 absorber loops and the needed calculated flowrate for the absorber loops. The price installed for each one of these would at least be 8000€. As mentioned earlier in this thesis can't installed in only 100mm shotcrete that will be installed in the Helsinki city rail loop, another 100 mm have to be at least added upon this and Kari Äikäs said that it will cost about 35€/m^2 at the moment for the shotcrete. This is a cost that will be at least doubled for the parts where tunnel lining technology will be installed this concrete cost is another cost that need to be considered when a more exact calculation about tunnel lining is made. But it won't be included in the following cost calculations because of the simplicity of the calculations.(Äikäs,K., 2015)

200€/m+ 100€/m makes 300€/m in the tunnel for cost in tunnel lining with 6000 meter tunnel then adding 120 Nibe heat exchangers making the total costs with 20°C heat carrier liquid:

$$Rough\ estimation\ of\ the\ tunnel\ lining\ technology\ costs$$
$$= 300\frac{€}{m} \bullet 6000m + 120 \bullet 8000€ = 2\ 760\ 000€$$

$$Q_{tot\ with\ \text{20°C heat carrier liquid}} = 33{,}75\frac{W}{m} \bullet 96000m$$

$$Q_{tot\ with\ \text{20°C heat carrier liquid}} \approx 3240KW$$

$$Cost\ per\ KW = \frac{2\ 760\ 000€}{3240\ KW} \approx 852\frac{€}{KW}$$

The costs/ KW with 15°C heat carrier liquid is:

$$Q_{tot\ with\ \text{15°C heat carrier liquid}} = 20{,}18\frac{W}{m} \bullet 96000m$$

$$Q_{tot\ with\ \text{15°C heat carrier liquid}} \approx 1937KWh$$

$$Cost\ per\ KW = \frac{2\ 760\ 000€}{1937\ KW} \approx 1425\frac{€}{KW}$$

The costs/ KW with 10°C heat carrier liquid is:

$$Q_{tot\ with\ \text{10°C heat carrier liquid}} = 6{,}66\frac{W}{m} \bullet 96000m$$

$$Q_{tot\ with\ \text{10°C heat carrier liquid}} \approx 639KWh$$

$$Cost\ per\ KW = \frac{2\ 760\ 000€}{639\ KW} \approx 4319\frac{€}{KW}$$

As seen from the calculations above is the cost per KW highly dependent on the gained energy from tunnel lining. The tunnel lining is like earlier in this thesis proven to be dependent on the heat carrier liquid's temperature. These calculations are based on rough estimations and more exact calculations have to be made before any decision is made about tunnel lining. But as said earlier will the shotcrete cost be added to this cost/KW.

The tunnel will be fully renewed every 30th year with no difference what energy system is installed. This means that the need of calculating the NPV for tunnel lining is irrelevant. The life cycle cost (LCC) could be calculated for the project with the following formula:

LCC_{tot} = investment cost + LCC_{energy} + $LCC_{maintenance}$

LCC_{energy} = annual energy cost • present value factor

$LCC_{maintenance}$ = annual maintenance cost • present value factor

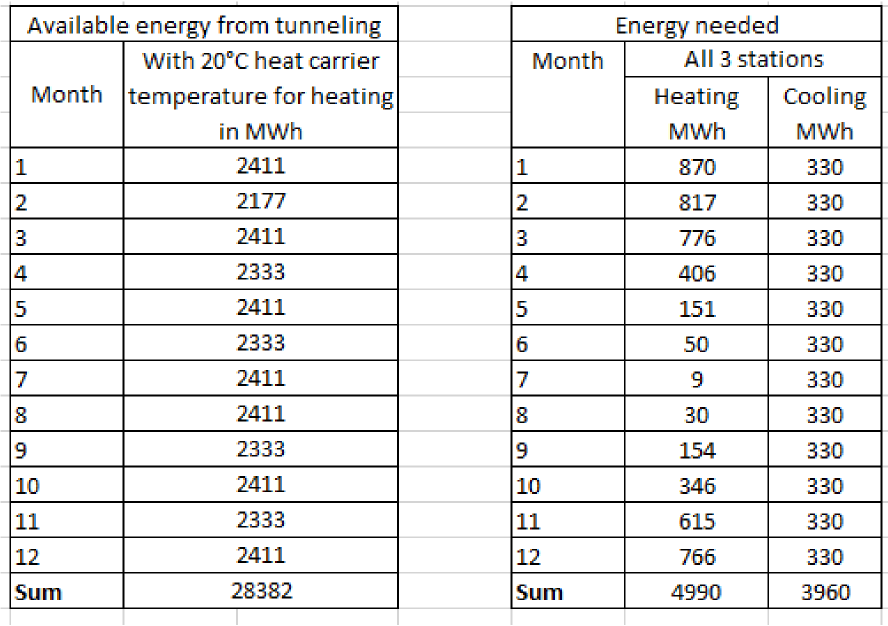
The problem with calculating the LCC with no reliable investment cost or maintenance cost is that it gives a false picture of tunnel lining. The LCC represents the life cycle cost of the project and there is no practical need of a LCC that needs to be recalculated before it can be used. Instead does this thesis focus on the cost/KW seemingly as this is the most accurate measure point at this time before any project with tunnel lining has started.

5 DISCUSSION AND ANALYSE

As seen in the profitability chapter is tunnel lining in this thesis more profitable than conventional geothermal usage with borehole heat exchangers as long as the heat carrier liquid's temperature is at least 15°C. 15°C of heat carrier temperature is not impossible in the Helsinki city railroad loop so the author of this thesis thinks that further researches should be made about installing tunnel lining. With these rough cost and energy estimations are tunnel lining about 40%, with 20°C of heat carrier temperature, cheaper than conventional geothermal usage. Although that these results in this thesis only are indicative but they could work in discussions about tunnel lining among the decision makers if the Helsinki city rail loop will be built if tunnel lining could be the way to go.

In the energy calculations in this thesis is no energy for cooling calculated due to uncertainty in the total cooling need for the Helsinki city railway loop. Although with 240 absorber loops in the tunnels would the simple solution be to have about half of the loops to produce cooling and the other half heating. The following table shows the energy needed for the 3 stations (Hakaniemi, Töölö and Helsinki city centre) and the gained energy from tunnel lining technology with optimal conditions with 20°C of heat carrier temperature.

Table 6 Comparison between the available energy from tunnel lining and the energy needed



Available energy from tunneling	
Month	With 20°C heat carrier temperature for heating in MWh
1	2411
2	2177
3	2411
4	2333
5	2411
6	2333
7	2411
8	2411
9	2333
10	2411
11	2333
12	2411
Sum	28382

Energy needed		
Month	All 3 stations	
	Heating MWh	Cooling MWh
1	870	330
2	817	330
3	776	330
4	406	330
5	151	330
6	50	330
7	9	330
8	30	330
9	154	330
10	346	330
11	615	330
12	766	330
Sum	4990	3960

As can be seen from table 6 is not the tunnel's heating included in the needed energy table because there have not yet been done a research how much energy is needed to heat the tunnel. But the needed energy for the tunnel will be less than for 1 station because the temperature in the tunnel can be much lower. When comparing the numbers in table 6 can it be found that the heating and cooling needed for the Helsinki city railway loop with stations could be produced within the tunnel and therefore would no energy be needed to buy from the outside. This argument could be a benefit for tunnel lining technology in the Helsinki city railway loop with all the talks' nowadays about renewable energy and self-sufficiency. Although the energy gained from tunnel lining will be less than what this thesis shows because the thesis has used optimal solutions and rough estimations that need to be carefully recalculated before any decision is to be made about tunnel lining.

5.1 Answering the research questions

In the start of this thesis was 3 research scopes presented. By interpreting the research's results are the following results gained. The first 2 research scopes can be answered at the same time as they were: Can the geothermal energy be utilized for the heating and cooling of the Helsinki city rail loop? And can the usage of geothermal energy acquired from the tunnel be economically motivated? Loisa and Pietarila described in their report "Pisaradan Asemat Geoenergiaselvitys" about the possibility of installing conventional geothermal borehole heat exchangers drilled into the floor of the tunnel. They pointed out in their report that it is possible and highly recommendable to install geothermal borehole heat exchangers into the Helsinki city rail loop. With a positive economic comparing to district heating in less than 20 years. The same positive result about the usage of geothermal energy usage did this thesis about tunnel lining technology conclude. The usage of tunnel lining can't be financially validated yet as the cost figures yet only are rough estimations but the indications are that it could be even more cost effective than traditional geothermal usage. The last research scope was: Can the geothermal energy be utilized in any other way than through conventional ground source heat pumps with bore holes, for example by thermally activating the concrete structure by placing absorber pipes in the tunnel lining? This research scope has already been answered here and the answer is yes geothermal energy can be utilized by using tunnel lining. The thing to take from this research is that geothermal energy can and should be utilized in one form or another for the heating and cooling of the Helsinki city rail loop.

5.2 Approach of the thesis

This thesis about geothermal energy for utilization within tunnels, case study: Helsinki city railway loop was about enlightening the decision makers and the people about the possibility of utilizing the tunnel lining technology. The fact that there have been so few projects utilizing tunnel lining worldwide and no project in Finland yet did the author find that people needed to know about the possibilities of tunnel lining. This thesis has strictly been theoretical as no field testes have been made as the tunnel doesn't exist yet. This approach of the subject was inspired by the company Granlund Oy as they ordered a research about alternative usage of geothermal energy usage within the Helsinki city railway loop. The study could have included the cooling calculations from tunnel lining but since no exact cooling demand exist yet and the efficiency of tunnel lining still isn't confirmed did this thesis only focus on the heating part. The author has striven to make this thesis to be a model for further tunnel lining researches in Finland. Although this thesis has its faults like not include the cooling part of tunnel lining and flaws like no reliable costs nor are energy calculations the most accurate but by providing some rough calculations and estimations about tunnel lining in the Helsinki city rail loop are the interest for further studies hopefully awaken.

There would have been other subjects also to write about in this thesis like utilizing the energy from the groundwater entering the tunnel but as this would have been an equal big subject like tunnel lining didn't the author include it in this research. Only focusing on tunnel lining technology gives the reader a good picture of how the technology works and how it could be utilized in the Helsinki city rail loop. The subject about how to utilize the energy from the groundwater entering the tunnel through the tunnel walls could be an own thesis subject that would be very interesting if somebody studied it more and made a research about it.

6 CONCLUSION AND RECOMMENDATION

The theoretical calculations about tunnel lining technology at the Helsinki city rail loop expanded the understanding of heat exchangers buried between the primary lining and secondary lining. First, compared with a conventional borehole heat exchanger, some similarities and heat transfer characteristics of tunnel lining ground heat exchangers were revealed. Second, by analysing other people's work and calculating, was the inlet temperature and flow rate of the heat carrier liquid proven to be very important factors influencing the heat exchange of tunnel lining. In this thesis the different inlet temperatures are calculated to prove the importance of the temperature. From the results of this study, can the following conclusions be drawn:

1. Tunnel lining in the Helsinki city rail loop can be financially motivated if the necessary studies and optimization are made. Tunnel lining can more effective than conventional borehole heat exchanger with the right optimal settings.
2. The heat exchange rate presents a linear variation with the inlet temperature of the heat carrier fluid. On average increases the heat exchange rate 2.7 W/m for every 1°C in the inlet temperature over 10°C.
3. The flowrate affects the heat exchange rate exponentially with higher flow rates. But the water pressure increase also linearly with the flow rate resulting into that a bigger water pump is needed. Therefore is additional studies needed to determine the optimal flowrate in efficiency and economy.
4. The heat exchange rate in tunnel lining consists of two parts. Like seen in the calculations does the bigger part of energy originate from the surrounding rock and smaller part originates from the air in the tunnel.
5. Tunnel lining technology in the Helsinki city rail loop can with optimal solutions be utilized for heating and cooling of the train tunnel and train stations. Eliminating the need of buying external energy and therefore making tunnel lining even more economical viable.
6. Potential weak points in the tunnel lining system could be the collection pipe as it connects all the absorber pipes together. If something happens to the collection pipe then large parts of the system have to be turned off while the collection pipe is fixed. Another weak point with tunnel lining is potential concrete cracking that than happen if the temperature difference is too big.

The author recommend that further studies about tunnel lining in the Helsinki city rail loop should be made as these preliminary studies gave such a positive result. Further does the author wish that someone could do a thesis about utilizing the energy from the groundwater entering the tunnel through the tunnel walls as this could be another major energy source within the tunnel.With further studies about tunnel lining and the utilization of the energy from the groundwater could the Helsinki city rail loop be the first long tunnel that utilize geothermal energy to the maximum.

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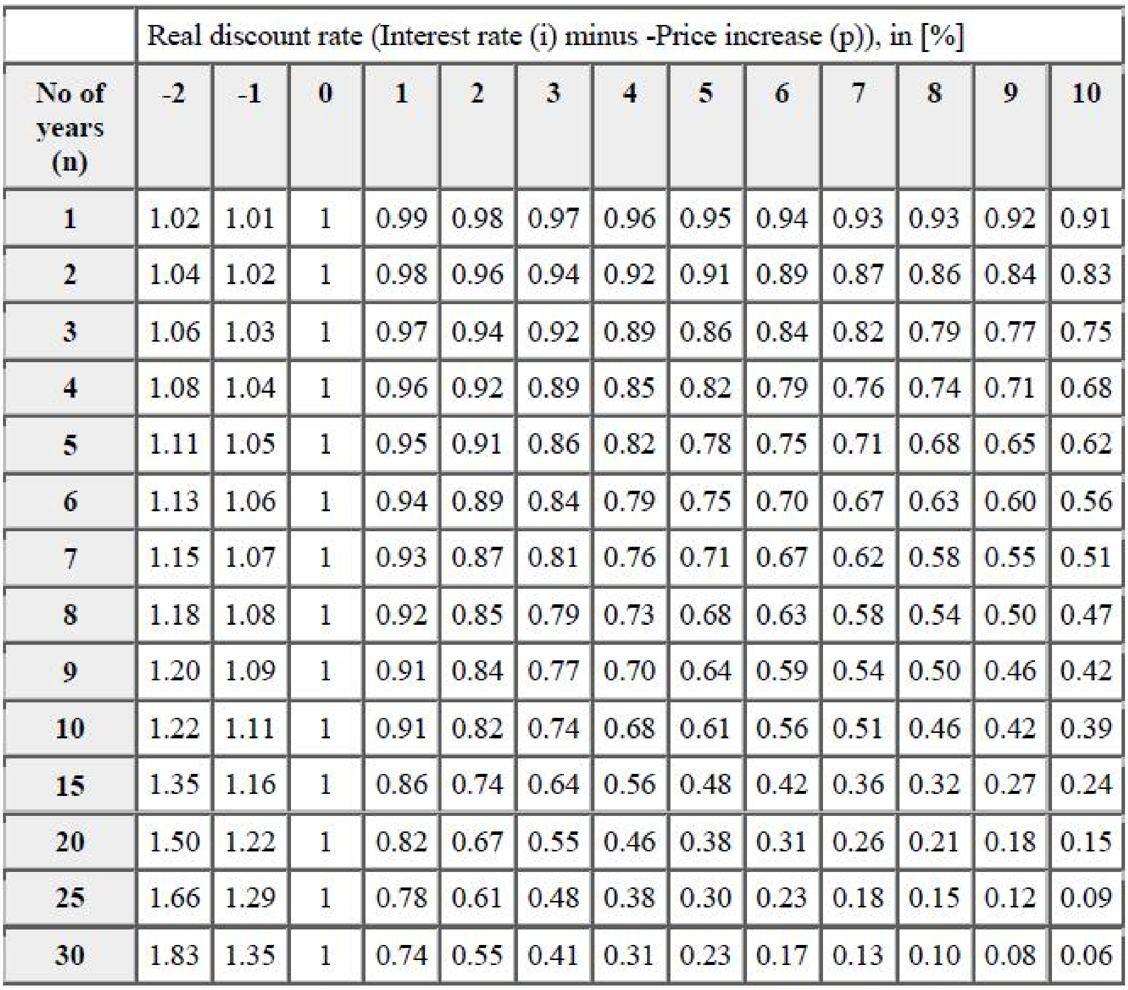
APPENDICES

Table of present value factor, Cp/Cn , for a single cost element after n years.



	Real discount rate (Interest rate (i) minus -Price increase (p)), in [%]												
No of years (n)	**-2**	**-1**	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
1	1.02	1.01	1	0.99	0.98	0.97	0.96	0.95	0.94	0.93	0.93	0.92	0.91
2	1.04	1.02	1	0.98	0.96	0.94	0.92	0.91	0.89	0.87	0.86	0.84	0.83
3	1.06	1.03	1	0.97	0.94	0.92	0.89	0.86	0.84	0.82	0.79	0.77	0.75
4	1.08	1.04	1	0.96	0.92	0.89	0.85	0.82	0.79	0.76	0.74	0.71	0.68
5	1.11	1.05	1	0.95	0.91	0.86	0.82	0.78	0.75	0.71	0.68	0.65	0.62
6	1.13	1.06	1	0.94	0.89	0.84	0.79	0.75	0.70	0.67	0.63	0.60	0.56
7	1.15	1.07	1	0.93	0.87	0.81	0.76	0.71	0.67	0.62	0.58	0.55	0.51
8	1.18	1.08	1	0.92	0.85	0.79	0.73	0.68	0.63	0.58	0.54	0.50	0.47
9	1.20	1.09	1	0.91	0.84	0.77	0.70	0.64	0.59	0.54	0.50	0.46	0.42
10	1.22	1.11	1	0.91	0.82	0.74	0.68	0.61	0.56	0.51	0.46	0.42	0.39
15	1.35	1.16	1	0.86	0.74	0.64	0.56	0.48	0.42	0.36	0.32	0.27	0.24
20	1.50	1.22	1	0.82	0.67	0.55	0.46	0.38	0.31	0.26	0.21	0.18	0.15
25	1.66	1.29	1	0.78	0.61	0.48	0.38	0.30	0.23	0.18	0.15	0.12	0.09
30	1.83	1.35	1	0.74	0.55	0.41	0.31	0.23	0.17	0.13	0.10	0.08	0.06