Calculation Application for Thermodynamic Properties of Piping Systems

District Heating and Cooling Analysis

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Abstract

District heating is an efficient method of thermal energy distribution. It is a popular and a safe way to outsource heating management, and it is widely used in Finland.

This thesis is based on the project given by Uponor Infra Oy, a Finnish company in piping infrastructure manufacturing. Objectives of the project were to develop a newer pipe dimensioning application that calculates thermodynamic properties of the piping systems. The methods used were the compilation of the formulas and calculating rules (1st part of the project, covered by Mr. Tamas Salamon) and development of an application with research of district heating and cooling (2nd part of the project, current thesis). The results indicate that the application is able to perform assigned calculations, however, for the implementation in real life systems it requires in-deep tests and comparison with the current industrial solutions. The results are also indicating that a few functions of the application require an improvement in the future.

Language: English Key words: District heating, Pipe dimensioning, Thermodynamics, Application development

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1 Introduction

Piping industry has been constantly moving forward, with the creation of new insulation compositions. One of the main engines of development is the comprehension of thermal and physical properties of the materials and systems.

Nowadays, many companies offer piping installations for district energy systems. Most of them have a long history in the piping industry and offer tailored solutions according to the requirements of the client. The standardized structure of the district heating pipe consists of the steel carrier pipe, polyurethane insulation and polyethylene casing.

Chemical industry is in charge of insulation and plastic development since piping installations go far beyond the distribution of heating and cooling. The modern compositions of plastic pipes are used for different energy and waste transportation tasks (LNG, gas, sewage etc.).

Since the promotion of district heating in Europe, the popularity of this energy distribution form has been showing a steady rise. The research by Euroheat & Power, shows that the district heating might lead to the energy price dump by 2050 (1). One of the main reasons leading to this result should be the effective use of energy and prevention of heat losses (cold losses considering the district cooling).

This work is based on the project for Uponor Infra, which has been made in collaboration with a fellow student, Mr. Tamas Salamon. The goal of the project was to create a new version of the Uponor Infra’s pipe dimensioning application for district heating, which has the functions of calculating thermodynamic properties of underground and aboveground pre-insulated piping systems. The previous version of the application was technically and overall outdated. The updated version of an application were supposed to be done with a possibility for further improvements.

The project was divided in two parts. The first one was a research of the piping installation standards and compilation of the formulas and calculating rules (covered by Mr. Tamas Salamon in thesis “Calculation formulas and description for dimensioning pre-insulated piping”). Creation and development of an application was the second part, and it is covered in the current thesis.

1.1 Aim and scope

Basic information about the heat transfer and pipe insulation is given for the comprehension of the goal project. Different insulation materials have different physical and thermal properties, hence affecting the heat (cold) loss in different ways. Therefore, the information for understanding the effects is covered to the required extent.

District heating, district cooling, and their role worldwide and within Finland are discussed, in order to comprehend the features and field of use of an application. Standardized district heating pipe structure and composition are described in detail.

The project is based on the application given by Uponor Infra, and on the formulas with calculating rules that were compiled by a project partner, Mr. Tamas Salamon. The aim of this project were to create an updated version of an application, which is calculating thermodynamic properties of pre-insulated piping systems. Objectives were to compile the formulas (1^{th} part of the project) and to develop an application (2^{nd} project part).

1.2 Methodology

The project and application development part had started in 2016, with the first program version being done in Microsoft Excel. Nevertheless, the Microsoft Excel version has been replaced by a GUI application made by using the Java programming language. The development process, as well as the tools and programming language that were used to make an application are explained in detail.

The district heating and cooling research were performed in order to gain more knowledge about the network and to comprehend the calculations of an application.

2 Company

Uponor Infra Oy is the company that had supervised the project at the first stages. Uponor Infra Oy specializes in piping solutions and are leaders in Northern Europe, with a strong business presence in North America and Asia.

Uponor Infra Oy is a joint venture of KWH Pipe (part of the KWH Group) and Uponor Corporation. The decision to merge has been forced by the effects of an economic recession, which had hit the piping industry.

Nowadays, the business of Uponor Infra Oy is mainly in the transportation of water, gas, air and electricity.

3 Heat transfer in piping systems

3.1 Heat transfer

Thermodynamics is the physics discipline that concerns the field of heat, temperature and their relation to work and energy. In thermodynamics, there are four laws that define the main physical quantities (entropy, energy, temperature) with characterization of thermodynamic systems at thermal equilibrium state.

1) The First law of thermodynamics states that the overall energy in an isolated system remains constant. The following Equation (1) shows that the change of internal energy equals to the subtraction of work done by the system from heat that has been added to it.

$$\Delta U = Q - W \quad (1)$$

where

ΔU – change of the internal energy

Q - heat which is added to the system

W - system work

2) The Second law of thermodynamics states that isolated system's entropy could only increase over time period. It may be constant only at the steady state (ideal case) or under the reversed processes.

3) The Third law of thermodynamics states that the perfect crystal's entropy equals to zero if the temperature of crystal is at absolute zero. This law concerned with the explanation of a system's behaviour that are on absolute zero temperature.

4) The Zeroth law of thermodynamics states that if two certain thermodynamic systems are in equilibrium with a third, then they are in thermal equilibrium with each other.

There are three types of heat transfer - radiation, conduction and convection. Radiation energy is transferred in the photon form. When the photons face the surface, they have three options – to be transmitted, reflected or absorbed (Figure 1).

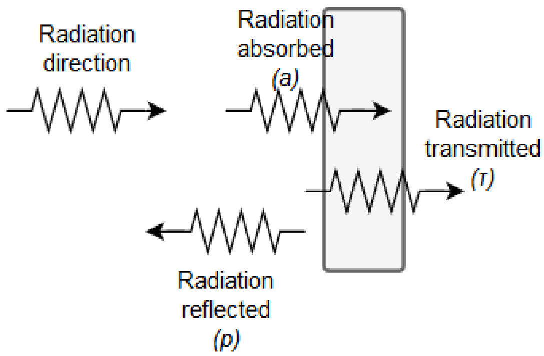


Figure 1 Radiation properties of a surface

Following chapter describes the conduction and convection processes.

3.2 Heat transfer of pipes and tubes

District heating is the thermal energy distribution system that uses the hot water as the transmitter. The main issue therefore is the heat losses that occur during the process. The most important factors that influence the heat transfer are the following (2):

1) Structure of the pipe, single pipe or twin pipe

2) Material and properties of the insulation layers

3) Ambient temperature and environment

Considering district heating pipes, the standards pre-define the following structures (either single or twin):

1) Carrier (service) pipe(-s) made of steel

2) Polyurethane (PUR) foam insulation

3) High density polyethylene (HDPE)

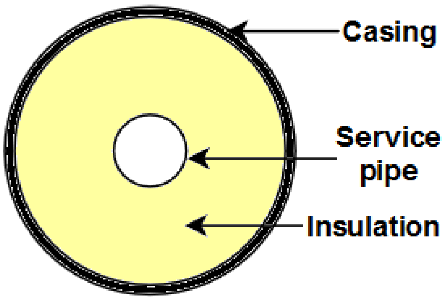


Figure 2 Single pipe

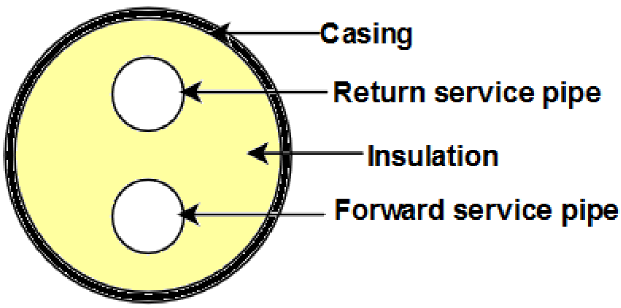


Figure 3 Double (twin) pipe

Composition and quality of the pipe is assured through the testing and measurements that stated in the standards EN 253:2009 (3) and EN 15698 – 1:2009 (4). The diameters of the service pipe as well as the minimum wall thickness have certain values that stated in there.

Insulation layer (PUR) and casing (HDPE) pipe dimensions are also defined in the mentioned standards.

When the hot fluid is transferred via piping installations, the heat losses mainly occur due to conduction and convection. Thermal insulation layers are used in order to decrease the losses within specific (covered) range. Conduction occurs because of the molecules collision in solid objects. Thermal conductivity is a property that evaluates the abilities of a material for the heat transfer via conduction. During the transfer, the temperature flow is always directed from the hottest to coldest, until the completion of complete equilibrium state.

The process of conductive heat transfer is fastest in metal, whilst in the non-metal compositions (e.g. concrete, polyurethane) it is slow. The reason for that are the electrons and the increase of their kinetic energy that is triggered by heating. Lower value of thermal conductivity stands for the better insulation capabilities. The ageing of material however may affect it, at least it has been the case with old insulation materials. One of the examples is a CO2-blown foam, which had changed after only two years of exploitation (5). The Fourier’s Law is used to express the conductive heat transfer.

Convective heat transfer on the other hand, is using the fluid motion as a force. It includes two different processes, which are advection (mass fluid flow heat transfer) and conduction (diffusion of the heat).

When the natural convection is discussed, it means that the triggers of the motion are the density differences inside the fluid. Therefore, the convection heat transfer is rather difficult to comprehend, since it varies upon the fluid flow (laminar or turbulent). The laminar flow resembles a “smooth” fluid motion in a parallel layers. This type of flow is usually happening at average or low velocities. Contrary, the turbulent flow is more unpredictable in terms of pressure and velocity. However, this is the most common type of flow in the pipes. To predict the behaviour and pattern of a certain flow, the dimensionless Reynolds number value is widely used.

So-called transitional flow is the average of the laminar and turbulent. The turbulent and laminar motion schemes are shown in Figure 4 and 5 respectively.

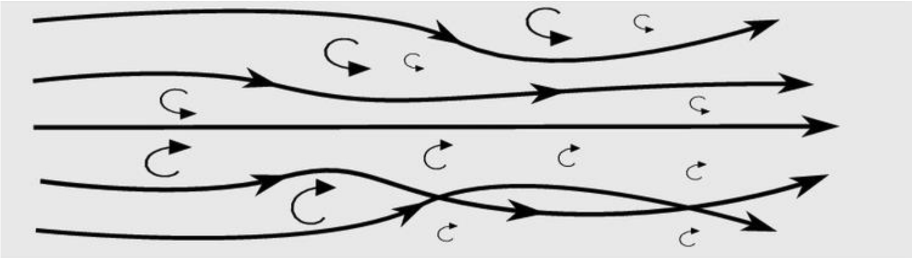


Figure 4 Turbulent flow

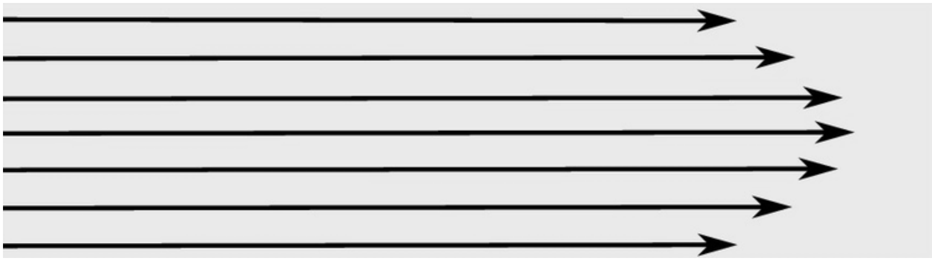


Figure 5 Laminar flow

Forced convection heat transfer, in contrary to a natural, is caused by external forces that agitate the fluid. The fluid is circulating more rapidly, resulting in the faster rate of heat transfer.

The full set of conditions that affects the convective heat transfer rate are the density, which is changing with a temperature, and specific properties of the fluid (viscosity, thermal expansion coefficient, thermal conductivity, specific heat capacity). Thermal expansion coefficient defines the rate of density change vs temperature. The movement of convection currents could be limited within the fluids of high viscosity, thus it has a very high importance. On the other hand, value of thermal conductivity is incredibly low in fluids, making this factor almost negligible. The amount of heat that fluid is able to hold is defined by specific heat capacity value.

The surrounding environment of the piping installation affect the heat transfer in different ways. Wind velocity is affecting the aboveground installations, while the conduction of soil is prerogative of the underground piping systems. The wind velocity and stable low ambient temperature might be a bigger challenge in the Nordic countries, considering the climate and geographical location. It is safe to say that environment conditions also affecting the cases of cold medium flow. Preventing the formation of dew is one of the main missions, while considering the cold media transfer. The reason is that the condensation might cause serious failures in the pipe structure.

3.3 Heat transfer calculations for pipe systems

The calculation formulas in this chapter are based on the standards EN 12241:2008 (single pipe) (6) and EN 15698-1:2009 (twin pipe) (4).

3.3.1 Single pipe heat loss calculations

The linear density of the heat flow rate for the multi-layered hollow cylinder is given by the following Equation (2). It is the rate of heat energy transfer per unit of length (W/m).

$$q_{\mathrm{l}} = \frac{\theta_{\mathrm{si}} - \theta_{\mathrm{se}}}{R'_{\mathrm{l}}} \quad (2)$$

where

θ_{si} – temperature of internal surface (K)

θ_{se} – temperature of external surface (K)

R'_{l} - linear thermal resistance (mK/W), and it is given by the following Equation (3)

$$R'_{\mathrm{l}} = \frac{1}{2\pi}\sum_{j=1}^{n}\left(\frac{1}{\lambda_j}\ln\frac{D_{\mathrm{e}j}}{D_{\mathrm{i}j}}\right) \quad (3)$$

where

λ_j – material's thermal conductivity (W/mK)

$D_{\mathrm{e}j}$ – external diameter of layer *j* (m)

$D_{\mathrm{i}j}$ – internal diameter of layer *j* (m)

Equation (3) shows how the thermal conductivity value of the material is affecting the heat flow rate. Chapter 7 describes the thermal conductivity property of various materials in detail. The number of insulation layers (*n*) is affecting the heat flow rate through the linear thermal resistance value.

For the underground single multi-layered pipe, the Equation (2) can be used with a slight change as shown in Equation (4).

$$q_{\mathrm{l,E}} = \frac{\theta_{\mathrm{i}} - \theta_{\mathrm{sE}}}{R_{\mathrm{l}}' + R_{\mathrm{E}}} \quad (4)$$

where

θ_{i} – medium temperature (K)

θ_{sE} – temperature of external surface

R_{l}' - insulation's linear thermal resistance (mK/W)

R_{E} – ground's linear thermal resistance (mK/W)

The above mentioned Equation (3) gives the value of linear thermal resistance of an insulation layer(s). The linear thermal resistance of the ground found by the Equation (5).

$$R_{\mathrm{E}} = \frac{1}{2\pi\lambda_{\mathrm{E}}} \cosh^{-1} \frac{2H_{\mathrm{E}}}{D_n} \quad (5)$$

where

λ_{E} – thermal conductivity of the soil (W/mK)

H_{E} – distance between ground surface and pipe center (m), given by Equation (6)

D_n is the square cross section of soil's outer most layer (with consideration of equivalent diameter) which is calculated by Equation (7)

$$H_{\mathrm{E}} = H + \frac{D_{\mathrm{e}}}{2} \text{ (6)}$$

where

H – distance between ground surface and the pipe (m)

D_{e} – external most diameter of the pipe (m)

$$D_n = 1.073 \times a \text{ (7)}$$

where

a – side length of the cross section (m)

The formulas show that the properties of the material play main role while considering the heat flow rate. The multiple layered installations contribute to the better thermal resistance value, meaning that the combined solutions provide better results.

Considering the aboveground installations, the calculations of heat flow rate proceed in the same manner as the underground ones (Equation (4)), however, the ground's linear thermal resistance has been changed for the same property of pipe's external surface (Equation (8))

$$q_{\mathrm{l,E}} = \frac{\theta_{\mathrm{i}} - \theta_{\mathrm{sE}}}{R_{\mathrm{l}}' + R_{\mathrm{le}}} \text{ (8)}$$

where

R_{le} – linear thermal resistance of pipe's external surface, and it is obtained from the Equation (9)

$$R_{le} = \frac{1}{h_{se}*\pi*D_e} \quad (9)$$

where

D_e – external diameter (m)

h_{se} – heat transfer coefficient of outer surface. To obtain the value, different equations are applied depending on the certain case. If $D_e \leq 0.25$ then Equation (10) used. Equation (11) is applied for every other case.

$$h_{se} = \frac{8.1*10^{-3}}{D_e} + 3.14 * \sqrt{\frac{v}{D_e}} \quad (10)$$

$$h_{se} = 3.96 * \sqrt{\frac{v}{D_e}} \quad (11)$$

where

D_e – external diameter (m)

v – velocity of the wind (m/s)

3.3.2 Double (twin) pipe heat loss calculations

The application has a function of calculating the heat loss for standardized district heating twin pipe. Considering the structure of the pipe, the following Equation (12) is used to obtain the heat loss per meter (W/m).

$$q_t = 4\pi\lambda_{PUR}h_s\left(\frac{T_1+T_2}{2} - T_0\right) \quad (12)$$

where

λ_{PUR} – PUR insulation thermal conductivity (W/mK)

T_0 – casing surface temperature (C)

T_1 – medium temperature in pipe 1 (C)

T_2 – medium temperature in pipe 2 (C)

h_s – surface coefficient of heat transfer (W/m^{2}K), given by the following Equation (13)

$$h_s = \frac{1}{\ln\left(\frac{(r_1)^2}{2Dr_2}\right) - \ln\left(\frac{(r_1)^4}{(r_1)^4 - D^4}\right) - \frac{\left(\frac{r_2}{2D} + \frac{2r_2D^3}{(r_1)^4 - D^4}\right)^2}{1 + \left(\frac{r_2}{2D}\right)^2 - \left(\frac{2r_2(r_1)^2D}{(r_1)^4 - D^4}\right)^2}} \quad (13)$$

where

D – half distance between center of double pipes (m)

r_1 – casing pipe radius (m)

r_2 – inner pipe radius (m)

Assuming the fact that the standardized twin pipe have pre-defined dimensions, the unidentified values of temperature are the only variables that are in question.

4 District heating

A district heating (DH) network transmits energy to the customers in a form of hot water. The network is a closed system, including supply and return pipes.

Water that circulates in the supply pipe transmits energy with the help of a heat exchanger, then returns back to the production plant for reheating purposes. The temperature in the supply pipe is in range of 65 – 115 °C, and in return pipe 40 - 60 °C (7). The system circulation is agitated and supported by the pumps located at the heat sources. A DH scheme is shown in the Figure 6.

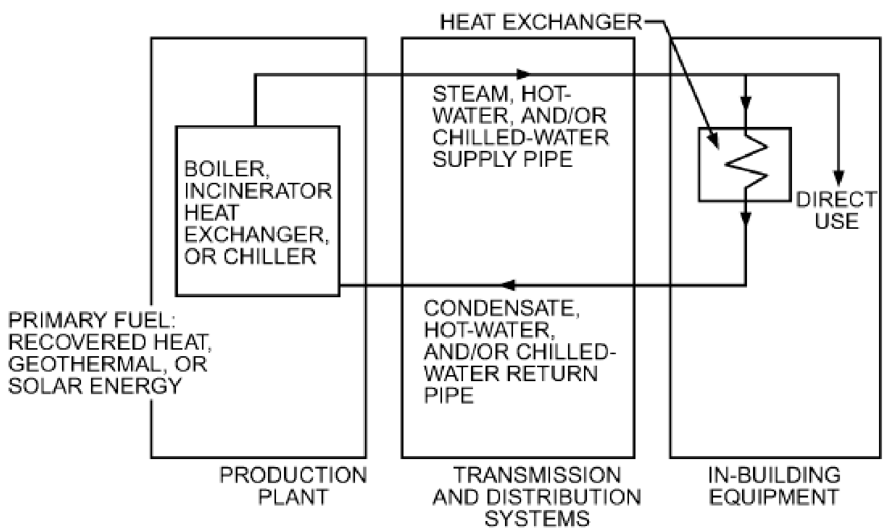


Figure 6 Components of district heating system (8)

The closed and indirect system of a DH network connection is safest and most comfortable. This system operates in Finland and every building has its own substation, which allows the temperature regulation according to days whilst also considering the outside temperature. The effects of a sudden leakage in the pipeline or radiator are not spread to other system and the customers are independent by having control over the temperature settings with the help of e.g. a simple thermostat (Picture 1). The system is functional throughout the whole year, and the heating is triggered by the low outside temperature.

Picture 1 Thermostat

An open and direct system on the other hand is dangerous and not energy-efficient. The same water runs inside the domestic hot water system and radiator. Thus, this makes it hard for the customers to regulate the temperature. The water temperature in that case is set by the district heating system parameters. Nevertheless, cheapness of this system might be considered as a plus, since it does not require pumps or heat exchangers.

The water in the DH system is always treated with chemicals to anticipate the risks of a pipe corrosion, as well as to remove the impurities. The DH pipes positioned under the city streets, parks, pavements and laid on depth of 0.5 – 1 m. The thermal insulation layer that is included in a standardized DH pipe version, helps to prevent temperature leakage through the transfer. (7).

4.1 District heating in Finland

According to the Finnish Energy organization (7), the heat losses of the DH system are rather small, with 5-8% for the larger areas and networks (such as Helsinki, Tampere etc.) and 10-15% for the smaller networks. By the end of the 2015, the length of the DH network was approx. 14.600 km. The district heating in Finland, has been in operation since the 1950-s. Nowadays, the total number of customers is about 2.7 millions.

The Finland's DH pipe network is constantly increasing in the length, approximately in 250-500 km. Other than that, 50-70 km. of old parts of the network are changed or refurbished. The lifetime of the pipes is long, up to 100 years. However, at poor conditions there is more chances for the damages (7).

Combined Heat and Power (CHP) plants allow efficient and environmentally friendly energy and heat production. Today, Finland is one of the leaders in this combined solution, and it is understandable by the fact that the total share of CHP in the DH production is 73% (9).

It is worth mentioning, that currently Finland's DH network is striving to a carbon-neutral production, and according to 2015 data it is almost 36%. The use of biofuels on the plants is constantly growing, whilst the share of fossil fuels is decreasing (10). The plants where combustion is not the only way of energy production, are becoming more popular. Heat pumps are able to turn waste water heat and surplus heat from industries into the DH system (11).

The latest trends in district heating are solar and geothermal heating. However, considering Finland's climate and geographical location, it may be not that effective.

The Impacts on the environment from the DH systems are including the events of pipe leakage, environmental emissions in the case of combustion units, and overall disturbances (noise, smell, dust etc.) in case of installments and repair. In the events of leakage, the hot water is definitely damaging roots of the plants as well as the fundaments of the road. The concentration of the chemicals that is used for water treatment does not cause any harm, by being kept at minimal level possible. Nevertheless, any dangerous events and causes are predicted with the help of the continuous maintenance of the network.

4.2 District heating worldwide

The mentioned trend of solar district heating has been widespread all over Europe (with a most notable presence in Denmark) and China. By the end of year 2015, solar thermal power of an amount of 577 MW had been supplied to the municipal DH systems in Denmark (12). That indicates usability and efficiency of the deliberately new method.

Considering worldwide statistics, a publication by Euroheat & Power (2013 data) shows that the Scandinavian countries are fond of the DH.

Table 1 Worldwide district heating statistics

Top 5	1	2	3	4	5
% of citizens using district heating	(92%) Iceland	(65%) Latvia	(63%) Denmark	(62%) Estonia	(57%) Lithuania
Largest growth of DH capacity (GW) (2013)	(463) China	(56.5) Poland	(49.7) Germany	(30) South Korea	(23) Czezh Rep. and Finland
Largest increase in district heating pipe system length (2009-2013)	(58%) Italy	(53%) Norway	(52%) Switzerland	(43%) China	(21%) Austria and Sweden
Largest sales (million terajoule) (2013)	(3.2) China	(0.26) Germany	(0.25) Poland	(0.18) Sweden	(0.18) South Korea
Renewable energy share (without CHP)	(76%) Iceland	(61%) Norway	(46%) Denmark	(39%) France	(31%) Switzerland

This research show that Iceland is a leading country in terms of renewable energy use share. The popularity of this heating method in Iceland is supposedly caused by the fact that municipality have the monopoly rights for system operation. However, considering the energy sales, the Chinese market showed by far the best results amongst other countries. The study by Euroheat & Power shows that the market in the Asian region most likely will grow and expand. (9)

5 District cooling

District cooling (DC) is the same system as district heating, with exception that the medium is cold water instead of hot. It works according to the same principle. Cooling and heating energy are usually produced in the same plants and transferred following the same loop. The cold water circulates in the piping installations and is fed to the customers, after that returning back to the plant for chilling. The temperature of the water that is fed to the customers is around 6 °C, with the return temperature usually being 10 °C or more.

The DC extensively used in the areas with a high average temperature. Parallel to heating, the DC system is far more convenient than the conventional solutions. Considering the worldwide usage, there are many facilities, buildings, etc. that are in the need of cooling services. Industries, hospitals, shopping malls, schools, etc. are at the need of the service whole year.

DC production differs depending on the season. In the summertime, the typical compressor technologies are extensively used. The condensate heat from the process is then used in the district heating network. Winter, at the other hand, is more efficient in the sense of productivity, since the water and outside air are cost-free. Processed water then transferred back to the source, without causing any harm. The snow is also used in the areas that do not have access to sea or lakes.

Other solution that is widely used in the industry is called absorption cooling. The energy that is generated in the process of heating used along with leftover industry heat or incinerated waste heat. In the process, the water is steadily vaporized at 3 °C for the cooling system. (13) This result is achieved by the fact that if the system has low pressure then the liquid has lower point of boiling temperature. In the basis, the absorption cooling relies on the mentioned principle. The compressor is using two fluids that are absorbent and refrigerant. Ammonia (NH3) or lithium bromide (LiBr) are usually used as an absorbent, causing the liquid (refrigerant) change the boiling point to the lower one, thus transferring the heat.

Compared to the engine or electric-driven chillers, the absorption chiller installations are usually 20-50 % more expensive (14). The main advantage of the absorption system is that it runs on heat, therefore allowing to use excess heat from industries. It helps in the summertime at peak cooling energy demands. Other advantages are including the low use of Global Warming Potential (GWP) refrigerants, low noise and low power requirements. At the other hand, the use of lithium bromide and ammonia is dangerous, since these are the toxic chemicals. Considering disadvantages, these could be the quite high heat rejection rate (excess heat from the system) which is 1.7 – 2.5 kWhh/kWhr, and large size of the system (14).

5.1 District cooling in Finland

According to Finnish Energy, DC services are offered in eight towns that are Helsinki (1998), Lahti, Turku (both from 2000), Vierumaki (2002), Lemppala (2008) with last ones being Pori, Tampere and Espoo (all from 2012) (15). Although Vierumaki mostly serves as a resort and could hardly be considered as a town.

DC revenues however are not compared to DH's, especially considering Finland, but the extensive use of the servers, computers and other applications that are in the need of cooling services 24/7, is leaving a mark on the overall consumption rate.

The number of customers show the steady growth since the beginning of operations (and storage of the statistical data) which could be seen from the sale statistics in Figure 7.

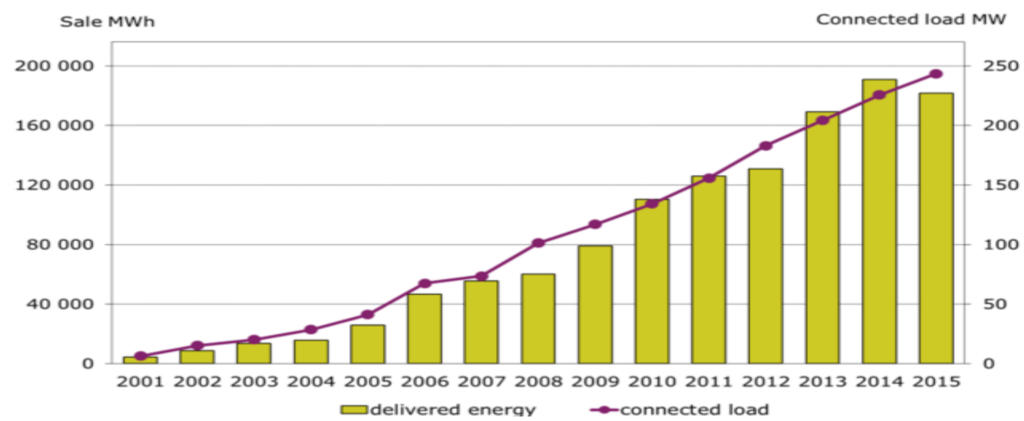


Figure 7 District cooling sale statistics (16)

In terms of the effectiveness of DC system, Finland is showing decent results, since the 80% of the DC production is based on the free sources or energy that would be wasted anyway. The biggest DC system in Helsinki is showing rapid growth, and by the 2014 statistics, it was considered to be the 3rd largest supplier of cooling services in Europe (17).

Another notable fact considering Finland, is that the “Katri Vala” heat pump is the largest one in the world to produce heating and cooling energy at the same time, and it is also using purified sewage water as a source. This heat pump is placed under the Katri Vala Park in Helsinki, inside a cave. It has been in operation since 2006. The overall system’s energy outputs are 60 MW for DC and 90 MW for DH (18).

In 2015, the overall production of DC was 182 GWh. The following Figure 8 shows the detailed statistics of production, with specification of the used method.

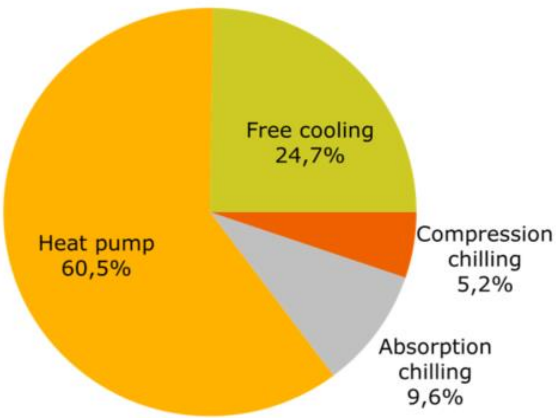


Figure 8 District cooling production statistics (16)

According to Finnish Energy, in Helsinki area, the overall combined demand of DC and DH services is greater than for electricity. (17)

Environmental friendliness of the system along with high energy efficiency, definitely contributed to the popularity of district cooling (and heating) on the contemporary thermal energy market.

5.2 District cooling worldwide

The Euroheat & Power publication (data from 2013) shows that the district cooling is not popular in Eastern Europe, in contrast to countries in Central part of it. Table 2 shows the district cooling statistics for various European countries. (9)

Table 2 District cooling statistics

	France	Poland	Germany	Italy
Capacity (MW)	669	43	153	182
Sales (TJ)	3168	251	588	366
Trench length of pipeline system (km)	158	20	51	67

Considering the Middle East region, different cooling technologies are in use along with district cooling. The information from Dubai regulatory and supervisory bureau, shows the market share and efficiency of each cooling method used in the region.

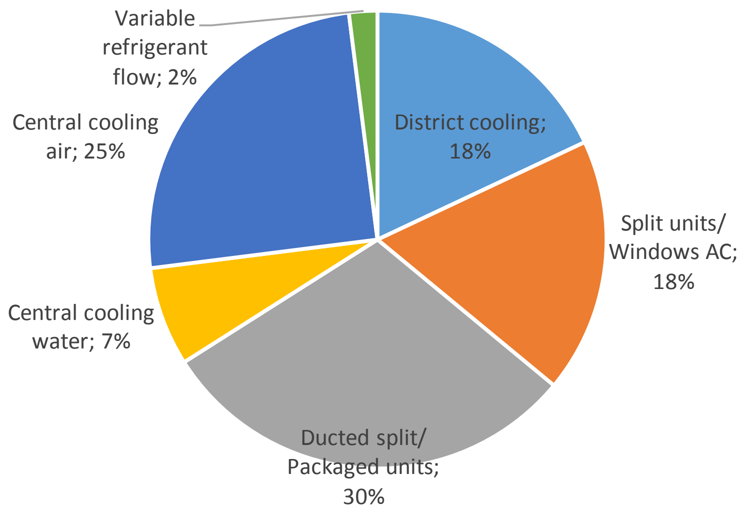


Figure 9 Cooling solutions in Dubai

The energy efficiency of these cooling methods however is not the best. Split cooling systems consume much electricity, however having other advantages, mainly in control and usability terms. Figure 10 show the average efficiency values in KW/Ton.

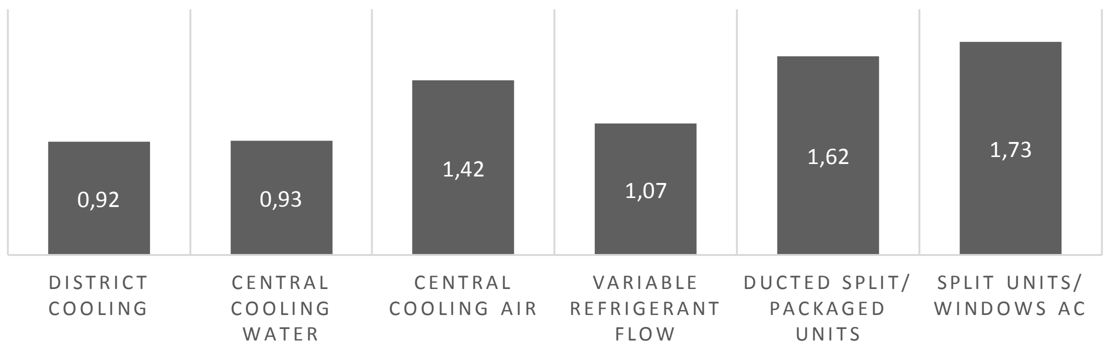


Figure 10 Average efficiencies of different cooling solutions. (19)

This information lead to a thought that there is a huge potential for energy savings in Dubai with promotion of district cooling. This statistics example of Dubai may be projected on Middle East region in general. (19)

6 Pre-insulated pipe

It is hard to underestimate the importance of thermal insulation in the piping installations. Nowadays, the piping systems are placed practically anywhere, would it be underground, underwater, aboveground etc. Thus, the proper insulation capabilities of the particular material are of high importance.

Considering the heat flow itself, the value of the material's thermal conductivity and emissivity properties are important. With thermal insulation, the heat losses are kept at minimum level, as has been mentioned before in district heating chapter. Considering the cold media, the required function of insulation layer is to prevent dew formation.

In application's database, numerous insulation materials properties (as well as casing) are included. The following Table 3 shows the properties of each material that is included in application.

Table 3

Material	Thermal conductivity (λ)	Emissivity (ε)
High-density polyethylene (HDPE)	0.42	0.94
Low-density polyethylene (LDPE)	0.32	0.94
XLPE	0.38	0.94
Steel	45	0.15
Stainless steel	16	0.15
Fiberglass	0.2	0.94
Polypropylene (PP)	0.22	0.94
Polyvinyl chloride (PVC)	0.18	0.94
Polybutylene (PB)	0.22	0.94
Aluminium	218	0.05
Copper	390	0.26
Polyurethane (PUR)	0.025	0.94

The standardized version of the district heating pipe, which consists of the steel carrier pipe, polyurethane insulation and high-density polyethylene casing, deserves a closer look. In the following subchapters, the mentioned materials' properties are described in detail.

6.1 Steel

Steel could be determined as the iron with the lowest carbon level, and it has a dominant share in metal production that is around 95%. Industrial production of steel started in the late 19-th, however the contemporary methods of production are based on the Bessemer process. Idea of the Bessemer process lies in the most efficient usage of O_2 (oxygen) in order to put down the level of carbon in the iron. Considering the thermal properties of steel, it is seen that it has high thermal conductivity value, thus easily heating up from the hot fluid transfer. Therefore, the polyurethane foam is widely used in district heating installations in order to prevent escape of the heat from the system. Steel is a durable material and it is tolerant to practically any conditions. These advantages, along with recycling abilities, put steel in the leading position in terms of carrier (service) pipe production. Re-processing the steel or iron is a deliberately easy process, since it requires only magnetic forces to be separated from the waste. The percentage of the crude steel that is produced by recycling means is around 40% (20). The problems might arise from the corrosion, however as it has been mentioned before, the water in the DH system is being consistently treated with chemicals in order to prevent it.

Production of iron has a significant impact on the environment and it is understood by the fact that 6.5 % of the overall CO_2 emissions are caused by manufacturing of iron and steel. In a theoretic way, all of the CO_2 emissions are contributing to overall climate changes. Thus, one may guess that it has a high importance. Another environmental problem is the processed water from steel cooling. However, the dangerous pollutants are filtrated before released back to the environment (20).

Considering other piping installations, various materials are widely used. Polyvinyl chloride along with fiberglass pipes are used in the conditions where the steel pipes are not able to deliver quality. Plastic materials are not corrosion prone, thus they are used in sewage, wastewater etc. installations.

6.2 Polyurethane

Pre-insulated polyurethane pipes has been widely used in the industry for quite some time, due to mechanical and thermal properties of the material. Polyurethane is obtained from the reaction of polyol and isocyanate. This reaction is usually processed under the supervision of an expert, since it requires the selection of catalysts and additives during the process. Density value of the polyurethane for the piping installations is usually in range of 40-80 kg/m^3. (21)

The use of a polyurethane foam along with casing (usually polyethylene) prevents the pipes to receive any harm in underground conditions. Rigid polyurethane foam besides the excellent thermal properties has many other qualities, such as resistance to water ingress and an overall contribution to the structure of the pipe. Nowadays, there are many companies that offer pre-insulated pipes, thus dumping the price of that particular item. Assembling the insulation foam with the carrier pipe on the field, has become outdated. Considering the temperature, polyurethane can not be continuously exposed to degrees that are above 85-90 °C.

The manufacturing of an insulated pipe is varying according to the chosen method. Production is done usually by two different ways, which are:

1) Discontinuous or continuous molding process

2) Application of the rotary spray

Molding process can be considered as the oldest one, and for the most of time it has been a popular way of pre-insulated pipe production. This process has many advantages, because it is well suited for the steel and plastic pipes with small diameters. It does not require big investments and it has been widely used in the district heating pipe industry. However, the structure of the molded foam cells is uneven due to the stretches, expansions during the process. This problem contributes to the uneven compressive strength along the pipe. The molded foam usually has a higher density than those that are processed with spray (in order to achieve the same compressive strength). Therefore, the insulation capabilities of material are suffering.

The second method is considered to be the most popular at production in North America. The foam is sprayed onto a rotating pipe, therefore delivering a consistent layer. Comparing to the molded foam insulation, the compressive strength value of the foam is not changing along the length of pipe. It is allowing the bigger joint length of pipe, 18-25 meters. (22)

6.3 Polyethylene

High-density polyethylene is the most used type of plastic nowadays. Firstly, the polyethylene has been synthesized by Hans von Pechmann in 1898. However, the practical industrial synthesis method has been found out in 1933, by E. Fawcett and R. Gibson. The composition of polyethylene is consisting of together stringed ethylene molecules.

Polyethylene have outstanding physical properties and versatility, which made it popular in the many different industries. Strength-to-density ratio (specific strength) of HDPE is 970 kg/m3, and it means that it is light and strong. As any other type of plastic, it has anti-corrosion and water resistance qualities. (23)

Considering the conditions where the piping systems are usually placed, the polyethylene casing is greatly contributing to the overall durability and heat saving.

7 Development of a Calculation Application

The development of calculation application had started in 2016, at the same time when the project partner was deriving and compiling formulas for calculations. The functionality and design have been finally formed after number of trials and errors.

The first version of the application has been done in Microsoft Excel, in the form of spreadsheets. Nevertheless, the final version of the calculation application was programmed using the Java language. The Java language has been chosen because of its functionality, popularity and deliberate simplicity.

7.1 Java

The Java programming language was created in 1990-s at Sun Microsystem, and since then gaining a wide popularity among the community of programmers and developers. It was deliberately easy to write Java code and it was free from many issues and obstacles that other programming languages had. Main web browsers had quickly implemented the ability to run Java applets within the pages, thus contributing to the popularity of the language.

Java is an object-oriented language and it has been built with a vision that programmers will “write once, run anywhere”. Applications that are based on Java are usually compiled to bytecode, which is then able to run on any Java Virtual Machine (JVM). Thus, the computer architecture itself does not matter (24).

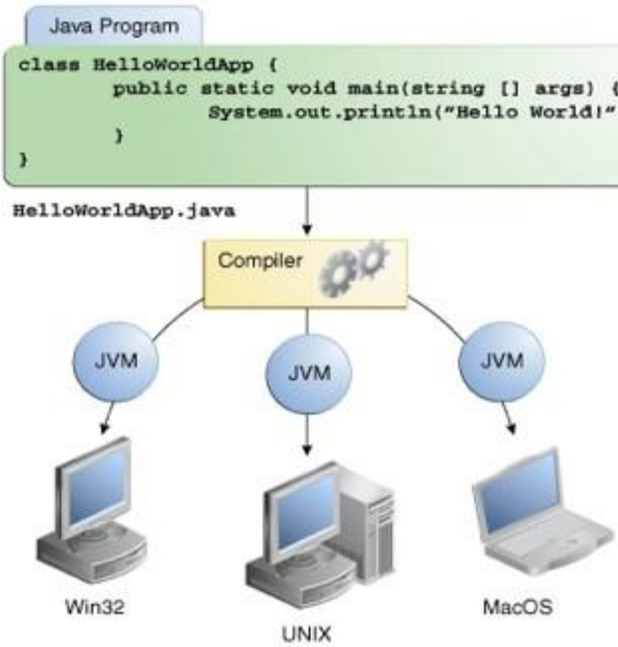


Figure 11 Java application able to run on different platforms (25)

Java is divided in three different editions, with each one being adapted to different needs. These are the following:

1) Java Standard Edition (Java SE) – the core platform for creating desktop and/or server environment application. The main functionality of Java language is provided in Java SE API (application programming interface).

2) Java Enterprise Edition (Java EE) – the platform for creating enterprise software (such as web and network services). It is built upon the Standard Edition platform.

3) Java Micro Edition (Java ME) – the platform for creating the software for mobile or embedded devices (such as sensors, micro-controllers, mobile phones etc.). The API is considered to be a subset of Java SE, with addition of special class libraries that are used for development of small application.

7.2 Java Development Kit

In order to create a Java application, the Java Development Kit (JDK) is necessary. JDK includes JVM, JRE (Java Runtime Environment) and Java development tools. The following Table 4 shows the list of tools (as well as the explanation) that are used in Java application development. (26)

Table 4

jdb	Debugger, used to find errors in Java applications
javap	Disassembler for the class files
javah	Used to produce the C heard and source files for implementing native method
javadoc	This command is used to create HTML documentation from corresponding Java source files
javac	Java complier. It reads the information in Java programming language and complies it into bytecode
java	Java interpreter that is launching the Java application
appletviewer	Used to view the applets outside of the web browser

7.3 JavaFX

JavaFX is a Java library that allows the programmers to develop the graphical user interface (GUI) applications that work steadily on different platforms. JavaFX is meant to replace the older Swing library in the near future.

JavaFX have many features that are important for software developing. For example, it allows the programmers to separate the view of the application (user interface (UI)) from the application's logic. User interface is written in the FXML scripting language. However, with the introduction of JavaFX Scene Builder, the tool which allows to design the GUI interactively, there is no need to manually write the interface code. SceneBuilder is generating the FXML code that then can be imported to the developer's IDE (integrated development environment). In that case, the developer can see the graphical interface before implementing it into the application. (27)

7.4 Model-view-controller

Model-view-controller (MVC) is software development pattern. It is helping the developers to separate the software logic from the user interface.

Model represent the application data and rules, by which the data is accessed or updated.

View represent the user interface, through which user interacts with the application. It is visualizing the model data.

Controller is interpreting the user's interaction with the application, to the format that model will read and execute. It is also updating the view, at the cases when the model data is changed. (28)

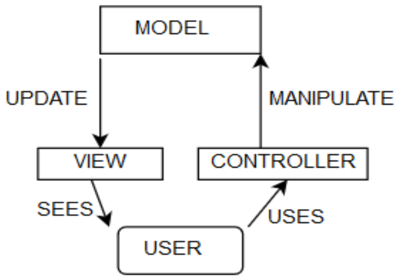


Figure 12 MVC algorithm

8 The Pipe Thermodynamic Calculations Application

The application has been named “PTCalc”, which stands for Pipe Thermodynamic Calculations. The MVC pattern has been used for the application development. Programming has been done in IntelliJ IDEA IDE.

The source code of an application is divided in three file categories, which are:

1) Controller

2) Model

3) Views

Each calculation function has assigned controller and view file. View files contain the visual data in the FXML format (the calculation page). Controller files contain the functions and logic of an application. Most of the logic from model files were moved to the controller, in order to avoid the complication of the application structure.

The application development project included two main tasks which are the development of application logic (deciding the functions of controller), and the view (user interface). In contrast to the first version, which was in spreadsheet form, the GUI gave more freedom in terms of appearance development.

The SceneBuilder have been used for the graphical interface development. The design of an application has been done with the emphasis on simplicity and usability.

Controller derives the user data by addressing the FXML (input menus and boxes) and performs calculation. The calculation formulas were written according to the Java programming language rules.

The application menu is divided in seven calculating options, which are:

1) Standardized single underground pipe heat loss (Single buried pipe)

2) Standardized twin underground pipe heat loss (Double buried pipe)

3) Heat and cold loss for aboveground and underground single pipe systems (Heat and cold loss)

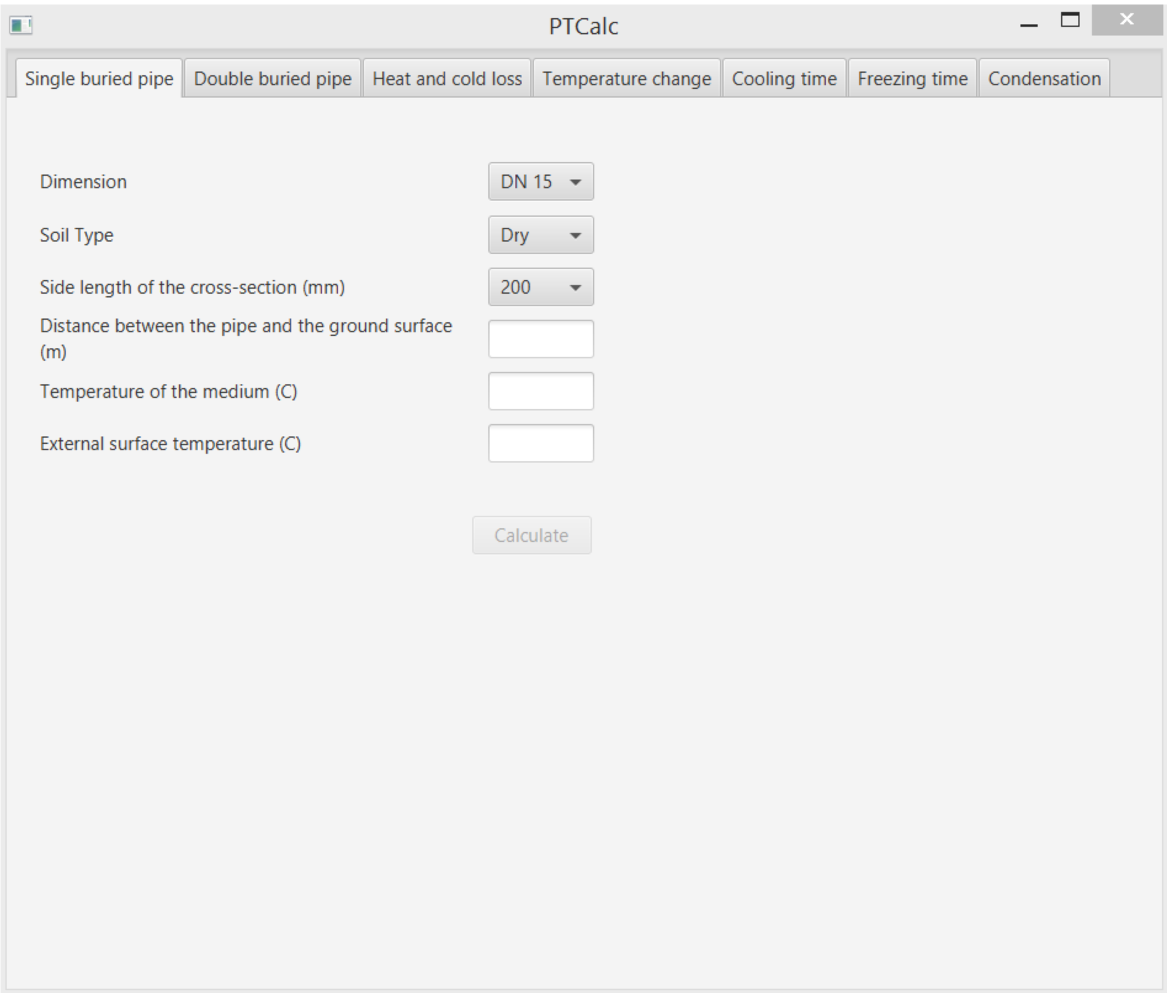
4) Temperature change for aboveground and underground single pipe systems (Temperature change)

5) Cooling time for aboveground and underground single pipe systems (Cooling time)

6) Freezing time for aboveground and underground single pipe systems (Freezing time)

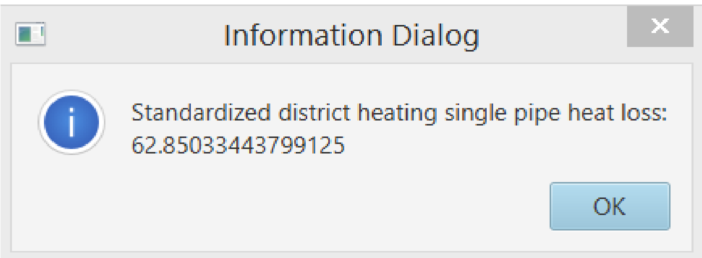
7) Condensation calculations for aboveground and underground single pipe systems (Condensation)

The application starts from the 1-st calculating option, and the user can navigate through the menu on the top (Picture 2).



Picture 2 “PTCalc” start-up calculating option and menu

In the input boxes, the units of properties are specified. After the data is set, the user is able to click “Calculate” button, which is performing the calculations and pops out the answer in “Information dialog” box (Picture 3).



Picture 3 Answer box

8.1 Standardized district heating heat loss

Standardized single and twin pipes, as already has been mentioned, consist of the steel (stainless steel) carrier pipe, polyurethane (PUR) foam insulation and polyethylene (PE) casing.

For the single underground pipe, the user has the option to choose the dimensions of the pipe, soil type and side-length of the cross-section from the drop-down menu.

The dimensions of the pipe set the diameter parameters that are needed for calculation. Different soil types have certain thermal conductivities, and the user is able to choose from “Dry”, “Frozen” and “Saturated with water” types.

The distance between the pipe and the ground surface, as well as the external and medium temperatures are set manually.

For the double (twin) standardized underground pipe, the dimensions are ranging from DN 15 to DN 250. Besides the dimensions, the user has the option to set the surface casing temperature and the medium temperatures of the pipes. The answer is given in watts per meter (W/m).

8.2 Heat and cold loss

In this section, the user is able to calculate the single pipe heat/cold loss, with the free choice of pipe materials (up to five layers). User needs to specify the external and internal diameters. Inputs for the underground and aboveground system’s parameters are in the drop-down boxes. For the underground pipe, the calculations are same as for the standardized heat loss.

Aboveground system is requiring the wind velocity data for calculations, in contrast to the underground installations which require soil data.

The cold loss calculations refer to the situations when the temperature of the medium is lower than the surrounding one. Therefore, it differs from the heat loss calculations, only by the swapped values of the medium and external pipe temperatures.

8.3 Temperature change

The temperature change calculations are only for the single underground systems. User can observe the change of a temperature on a selected distance. The answer is given in Celsius (C).

Underground and aboveground systems calculation principles are almost identical, except the outer surface coefficient of heat transfer value (which is calculated according to whether it is underground or aboveground system).

8.4 Cooling time

This section allows to calculate the cooling time for the single underground systems. The answer is given in hours (h).

It is assumed that the media does not absorb heat, therefore the calculated cooling time could be considered as the fastest one. The underground and aboveground systems are separated by the drop-down box function.

8.5 Freezing time

Freezing time of the pipe is referring to the certain case of cooling process. The importance of this knowledge can't be underestimated, since the frozen medium can lead to serious structural damages in the pipe. Therefore, even though it is not possible to prevent it, the time before the liquid freeze is possible to calculate.

The application calculates the freezing time for single pipe systems (underground and aboveground). The answer is given in hours (h).

8.6 Condensation

Dew formation prevention is highly important for the piping systems with the cold medium. Condensation may cause the failure in the pipe structure.

The application is able to determine the minimum insulation thickness for the single pipe systems that is required to prevent the dew formation. The answer is given in meters (m).

9 Calculation examples

The heat loss calculation for the standardized underground pipe installation assuming the following conditions:

Dimension – DN15

Soil type - dry

Side-length of the cross-section - 200 mm.

Distance between the pipe and ground surface – 1 m

Temperature of the medium – 80 °C

External surface temperature – 20 °C

Considering this case, the heat loss value is 70.458 W/m. However, if the pipe dimensions are changed for the bigger value of DN80, the heat losses are increasing up to 109.445 W/m, since bigger pipe surface allows the heat to escape the system faster. The difference in soil types does not affect the heat transfer to the same extent as the pipe dimensions, or the temperature conditions.

Heat loss for the standardized twin pipe assuming the following conditions:

Dimension – DN50

Surface temperature of the casing – 20 °C

Temperature of the medium in pipe 1 – 90 °C

Temperature of the medium in pipe 2 – 50 °C

The value of heat loss in that case is 58.613 W/m. Considering same temperature conditions but a bigger installation dimensions (DN100) will result in heat loss value of

61.477 W/m. This shows that the twin pipe dimensions do not affect the heat loss as much as it is the case with the single structured pipes.

10 Analysis and discussion

The performance of the calculation application is mainly based on the formulas and calculating rules, which are covered in the thesis by project partner, Mr. Tamas Salamon. The heat loss calculations for the standardized pipes seem to be valid (referring to the calculation examples and the standards). One of the major functions that needs to be developed is the insulation thickness determination. Choice of the layer quantity is lacking in this part, making it rather unproductive for the use.

Considering the programming part, the application is made by simple design and rules. In comparison to the older type of an application which were given by the project holder, "PTCalc" is made in modern programming language (DOS vs Java). The MVC algorithm had allowed the program logic to be separated from the design, therefore contributing to the simplicity of the logic. However, the Java programming language may have been switched to C#, considering that C# language is built for developing desktop GUI-s, whilst Java have been rather used for the development of the applets. Nevertheless, the structure of developed application has been simple enough for both languages to comply.

In future, the possibility for the full calculation report print should be implemented into application. The program design is minimalistic, therefore it may be done in the more colorful (and informative) manner.

The results indicate that the final application is able to run on any OS (cross-platform) and perform assigned calculations. As for the implementation in the real life systems, it requires more precise testing and development in the calculation logic.

11 Conclusion

Considering the initial and main goal of the project – the creation and development of the pipe dimensioning application, the mission may be assumed as completed. The district heating and cooling are the main providers of thermal energy in Scandinavian countries (not considering other regions), therefore the application may find it use in the local research. An implementation in the real life systems, as has been mentioned before, ought to be done after precise testing and evaluation. For the certain parts, the calculation formulas and methods are supposed to be re-evaluated.

The main features of the final application are the code and design simplicity. Therefore, the future updates and improvements are open for any contributor. The application logic is clear and easy to understand. Other distinctive feature is that the database of an application have the material's thermal conductivities, as well as the standardized pipes dimensions information included in it, therefore allowing the user to choose the needed parameters from the drop down menu.

The source files are open in the Github repository for the future contributors and research.

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Appendix 1 – Github repository link

https://github.com/shakermaker1/PTCalc