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5th Generation district heating and cooling in the Efteling

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Eindhoven University of Technology
Department of Mechanical Engineering

5th Generation district heating and cooling in the Efteling

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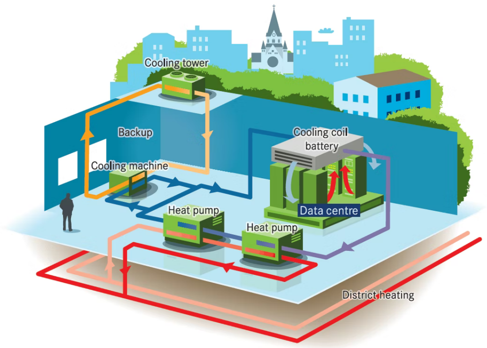

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First version

Eindhoven, June 2022

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List of symbols

Symbol	**Definition**	**Unit**	**Abbreviation**
A	Surface area	Meter squared	m^2
d	Diameter	Meter	m
ϵ	Emissivity	-	-
f	Friction factor	-	-
h	Heat transfer coefficient	Watt per square meter Kelvin	$W(m^2K)^{-1}$
k	Thermal conductivity	Watt per meter Kelvin	$W(mK^{-1})$
L	Length	Meter	m
μ	Dynamic viscosity	Pascal second	Pas
p	Pipe relative roughness	-	-
Q	Heat flow	Watt	W
r	Radius	Meter	m
Re	Reynolds number	-	-
ρ	Density	Kilogram per cubic meter	Kg/m^3
σ	Stefan Bolz constant	watt per square meter quartic Kelvin	$W(m^2K^4)$
T	Temperature	Degree Celsius	°C
t	Throughput	Kilogram per second	Kg/s
V	Velocity	Meter per second	m/s
x	Thickness	Meter	m

1. Introduction

Climate change is a hot topic around the world. General consensus is that the CO2 emittance should be reduced and a shift towards renewable energy sources is necessary. Heating and cooling buildings, is a big part of the energy consumption in Europe. The residential sector on itself is accountable for 40% of the energy usage[1]. Therefore, a big step towards renewable energy could be accomplished by reducing the traditional way of heating, by means of gas , and replacing it with a more novel way of temperature regulation. This is becoming more viable as the new way of providing the heating/cooling is becoming more and more efficient. The newest generation of heating networks are 4G and 5G district heating. The biggest benefit of this generation as appose to their predecessors is the lower operating temperature. The second generation heat network operated with water temperature of 100°C, the third at 80°C and the 4th and 5th operate at 50°C[2]. As a result of these lower temperatures the new generations are less prone to losing energy to its surrounding, and is thence more efficient.

The Efteling is a well known theme park within the Netherlands. The Efteling wants to innovate its way of heating and cooling their buildings to a more sustainable manner by use of district heating and cooling, instead of the conventional local gas heating.

A model that uses the 5th generation district heating and cooling is developed for the Efteling theme park. This model is made in the MODELICA software and is based on a previous model of the 5GDHC developed for the paper factory Smurfit Kappa [3]. The model as it stands is a decent representation of the reality. However a lot of general assumptions were made which can still be optimized. Therefore it is investigated which parameters have a big influence on the end results. With this knowledge, these parameters will be investigated and varied accordingly. In order to obtain a closer representation of the real situation and a more efficient system.

In this paper, an insight will be provided on how the model works, how it behaves and how it can be improved to get the best results possible.

2. Theory

2.1 What is a district heating and cooling system?

In a simple sense, a district heating and cooling network provides numerous consumers, in most cases households, of their cooling and heating demand. This can be done in different manners, the most common ones will be discussed.

The main idea of district heating and cooling is that demand is controlled by one central heat/cool supplier. From this centralized point the heat/cooling demand is distributed to consumers, by means of hot/cold water through insulated pipes. The temperature of the water in these pipes is around 50°-60°[4] for heating and 12°-14°[5] for cooling. The centralized heat/cooling source can be powered in different ways. For most of the large scale systems currently in operation a source is used which already creates large amounts of waste heat/cooling. For example in Aosta (Italy) waste heat from a steel-workshop is used to power the heat network. In Paris a cooling network is operated which uses the river Seine to cool the network[6]. Other options which are used to power the network are biomassa, waste heat from energy generation and large scale heat pumps in combination with solar power or wind power.

2.2 History of district heating and cooling

The district heating and cooling networks have been around for decades. First as a very simple network, but later in a more elaborate and complex form. The first generation network was fueled by coal and waste. It heated up the water to steam and the steam was distributed by concrete pipes. These systems where mainly used from 1880-1930, but are still in use in some places in the world. They were abandoned because of their high inefficiency and also because of the high danger of explosion[7].

In 1930 the 2nd generation was introduced. In the 2nd generation, the steam in the system was replaced by pressurized liquid water. This made the system less prone to explosions and more efficient due to a lower operating temperature. In comparison to the first generation district heating, now the waste heat from the power plant was used. Instead of the separate production of power and heat, which was the case for the first generation of district heating and cooling. As a result the system became much more efficient.

The third generation, which is most common nowadays [8], is more efficient due to a lower operating temperature. Additionally it is more cost-efficient as they make use of pre-fabrication and pre-assembley. The power for the source was altered, and more renewable energy was introduced in the form of solar energy and biomass.

The fourth generation is the described district heating and cooling system in section 2.1. This system is already in use, mostly in Denmark[9], has been expanding and is supposed to take over the market from the third generation district heating and cooling.

The fifth generation is the future generation. The main benefit similar to other improved generations, is the lower operating temperature for the heating cycle, near to ground level ambient temperatures ($\sim 10°C$). This reduces the heat losses in the pipes. This is possible because at the consumer end a heat pump is used. A heat pump makes low temperature heat a viable source for heating your building. As this lowers the requirements to the supply temperature level, this system makes it possible to use lower heat value waste, such as data centre heat waste.

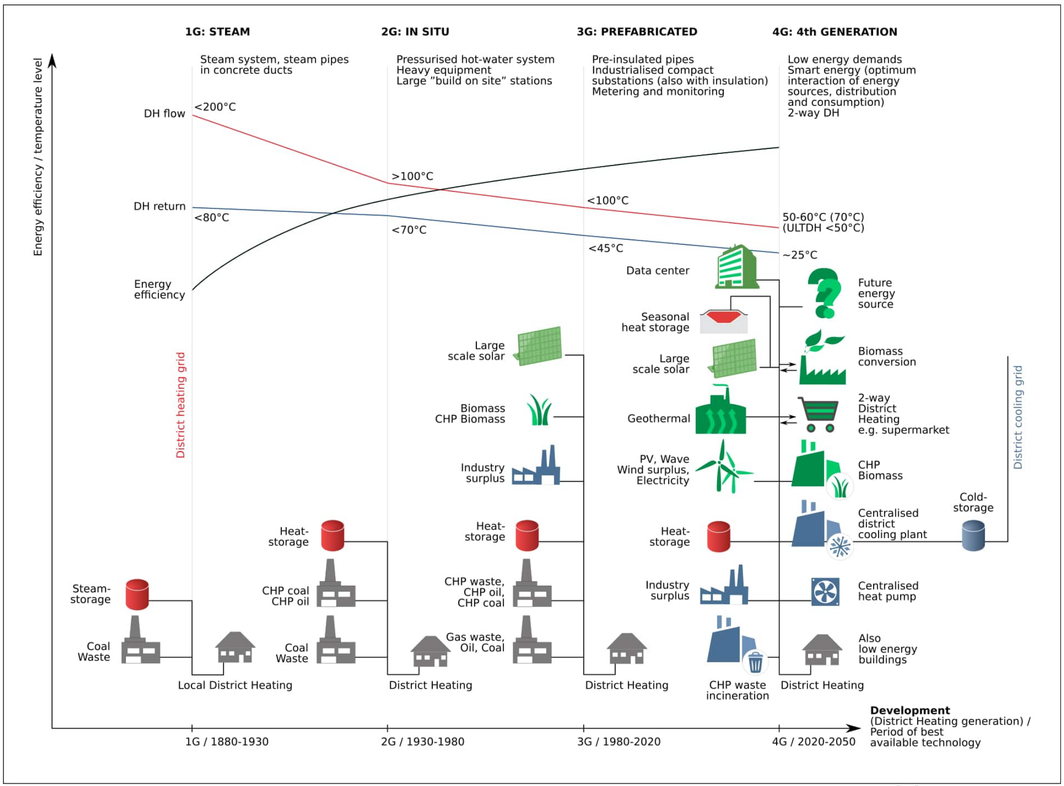


Figure 2.2.1: All the different generations of heating networks [4]

2.2.1 Heat pump

As described in section 2.2 the heat pump is a very important component of the fifth generation district heating and cooling system. As the heat pump allows the supply temperature of the hot/cold water to be closer to the soil temperature. To understand why this is the case, it needs to be understood how a heat pump works.

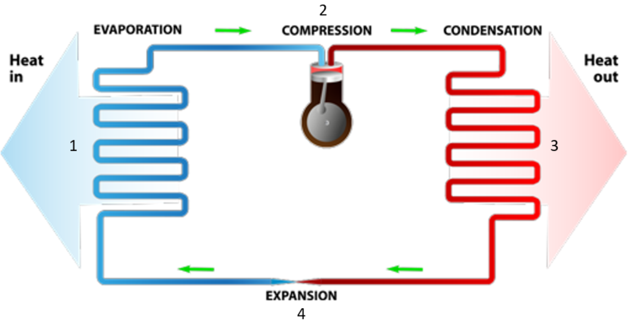


Figure 2.2.2: The functioning of a heat pump[10]

In Figure 2.2.2 a simplified picture of a heat pump is provided. Within the pipes of a heat pump there is a refrigerant, which most of the times is R410 A. This refrigerant has a very low evaporation temperature, which is dependent on the pressure within the system. This low evaporation temperature allows the refrigerant to evaporate with low supply temperature. At the left side[1] of the system the supply heat gets captured and the refrigerant evaporates. The evaporated refrigerant is compressed to increase the temperature. By increasing the temperature the refrigerant is hot enough to supply heat at the right side[3]. As a result of this process, it is possible to use a lower supply heat. Because of the supply of the heat, the refrigerant is cooled down in the condenser where after it goes to an expansion valve, releasing the pressure and thus cooling down the refrigerant. After this the process starts over again. Of course this process can also be inverted by supplying cold water at [3], resulting in cooling at [1].

2.3 Theory behind the heat flow

In the system, several variables can be altered to influence the heat flow. Describing the heat flow within the system is important, as this creates an overview of where energy is lost/gained. Parameters that can have a big influence on this heat flow are the diameter/flow surface, the thickness and the insulation material of the piping system which supplies the hot/cold water.

2.3.1 General heat flow

General heat flow is prescribed by three main influences: Conduction, convection and radiation.

Conduction describes the flow of heat through a material when there is a temperature difference at both ends of the material. The general equation for conduction is displayed in Equation 2.3.1.

$$\dot{Q}_{cond} = -kA\frac{dT}{dx} \tag{2.3.1}$$

In this model mostly circular tubes are considered and for that case the conduction equation rewrites to Equation 2.3.2

$$\dot{Q}_{cond} = \frac{2\pi Lk}{ln(\frac{r_o}{r_i})}(T_i - T_o) \tag{2.3.2}$$

Radiation is described as energy that is moved from one place to another place using particles or waves. In radiation it is important to take into account that the lower temperature object also radiates towards the higher temperature object. Radiation can be described using Equation 2.3.3.

$$\dot{Q} = \epsilon\sigma A(T_2^4 - T_1^4) \tag{2.3.3}$$

Convection is a heat flow that occurs due to temperature differences in a liquid or a gas. As the gas/liquid heats up, it gets lighter and moves upward. The heat flow due to convection is described using Equation 2.3.4. The model described mainly operates underground. In the soil, convection is also present, as soil contains moisture. However, h in Equation 2.3.4 is a lot smaller. For average moisture contents the parameter h in soil is $2.3[W(mK)^{-1}]$ [11], appose to $0.5 - 1000[W(mK)^{-1}]$ for free air/gasses and $50 - 3000[W(mK)^{-1}]$ for water and liquids[12].

$$\dot{Q} = hA(T_2 - T_1) \tag{2.3.4}$$

2.3.2 Tube diameter

Flow of energy

The tube diameter can be altered to increase or decrease the flow surface of the pipes. Potential benefits to increasing the flow surface of the pipe would be the reduction of the outer surface area relative to the throughput. By increasing the flow surface the variable A in Equation 2.3.1 increases, and the throughput increases with a factor D^2.

Increasing the flow surface of the pipe will have an effect on the internal convection of the liquid. Internal convection is caused by temperature differences within the flow surface of the pipe. The temperature differences will cause the cold liquid to flow down and the hot liquid will flow up, as the hot liquid is lighter than the cold liquid. For the hot pipes, this means that all the liquid at the outside will flow to the bottom, for the cold pipes it is the other way around. When the flow surface is increased, there is relatively less contact surface with the outside world and thus the internal convection also reduces.

In the model that will be considered, the water that is not in the pipe is present in the storage tanks. Despite the advantage of a relatively smaller heat loss in the tubes, it is more desirable to have the water stored in the tanks apposed to running it through the pipes.

Flow of the liquid

The flow within the pipe will also change, as the Reynolds number (Equation 2.3.5) is dependent on the flow velocity of the liquid and the diameter of the pipe. The flow within the pipes needs to be fully developed. In other words, the Reynolds number needs to be larger than 2900. When the pipe diameter is varying the Reynolds number is proportional to $1/D$ as can be seen inEquation 2.3.6.

$$Re = \frac{\rho V D}{\mu} \tag{2.3.5}$$

$$Re \propto VD = \frac{1}{D} \tag{2.3.6}$$

From this follows that the Reynolds number increases as the tube diameter decreases, therefor by decreasing the tube diameter the flow will not become laminar. The pressure loss is big factor when altering the diameter of the tubes. ΔP is proportional to $1/D^3$, therefore if the diameter is decreased the pressure loss in the tubes increases with a factor x^3. The pressure loss equation, follows:

$$\Delta P = f\frac{L\rho V^2}{2D} \tag{2.3.7}$$

To solve Equation 2.3.7, f the friction factor should be determined. The friction factor f can be obtained from the moody diagram in Figure 2.3.1

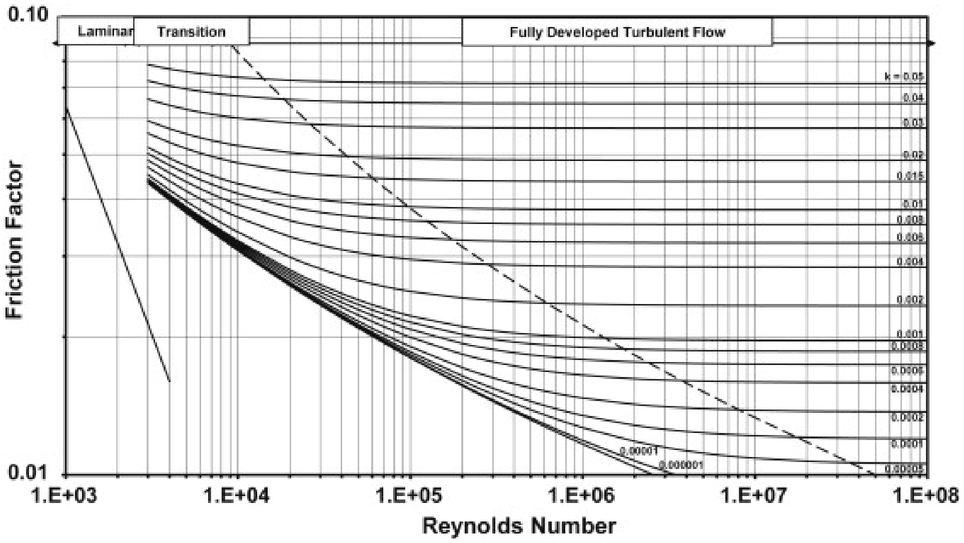


Figure 2.3.1: The moody diagram

However to iterate and get the optimal diameter it is easier to use an equation instead of a diagram. The equation to find the friction factor f is Equation 2.3.8

$$\frac{1}{\sqrt{f}} = 2log(\frac{3.7}{p}) - 2log(1 + \frac{9.335}{pRe\sqrt{f}}) \tag{2.3.8}$$

Because Equation 2.3.8[13] is an implicit equation, it is more difficult to solve. To solve this equation for f, the Newton-Raphson method should be applied. This is a complicated and lengthy method. Fortunately an equation that accurately approximates the friction factor exists, which will suffice for this problem. This approximation is presented in Equation 2.3.9

$$\frac{1}{\sqrt{f}} = -2log\left(\frac{p}{3.7065} - \frac{5.0452}{Re} \cdot log\left(\frac{p^{1.1098}}{2.8257} + \left(\frac{7.149}{Re}\right)^{0.8981}\right)\right) \tag{2.3.9}$$

Using Equation 2.3.9[13] the friction factor can be approximated and from that result the pressure loss can be determined together with the Reynolds number. These are presented in Figure 2.3.2 and Figure 2.3.3.

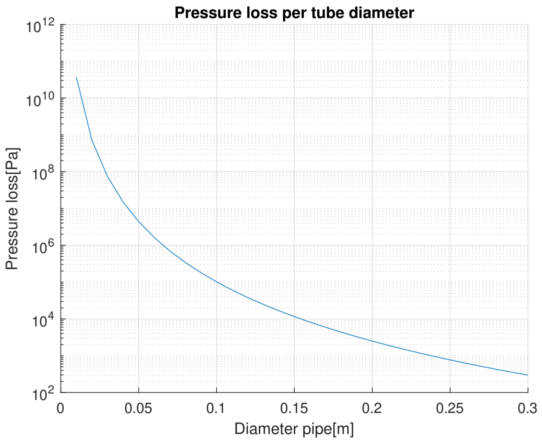


Figure 2.3.2: Pressure drop against pipe diameter

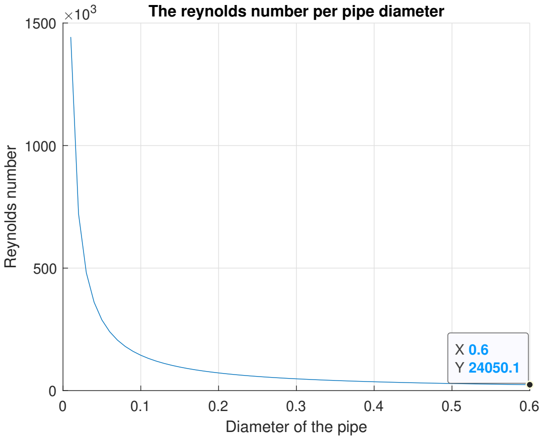


Figure 2.3.3: Reynolds number against pipe diameter

As mentioned before the flow should be fully developed as described in [14]. As visualized in Figure 2.3.3 the Reynolds number is decreasing with increasing diameter. Which makes sense, according to Equation 2.3.5. When considering that the Reynolds number should be larger than 2900, the graph shows that this is the case for all diameters displayed. From Figure 2.3.2 it can be seen that the difference in pressure drop becomes very big as the diameter decreases. It is however hard to determine what an acceptable pressure drop over the length of the pipe is.

The velocity of the water within the tubes is dependent on both the throughput of the system and the diameter of the pipes. The throughput of the system is set to be 34[kg/s] constantly. This means that with solely varying the diameter the velocity will vary accordingly.

$$t = 34 = \frac{\pi D^2 V \rho}{4} \rightarrow V = \frac{136}{\pi D^2 \rho} \tag{2.3.10}$$

However in the model of [15], the maximum flow velocity of the water is set at 2 m/s. A diameter of 0.14 meter gives a flow velocity of 2.20 m/s and 0.15 meter gives a flow velocity of 1.92 m/s. Therefore 0.15 meter is the smallest acceptable diameter.

2.3.3 Thickness of the pipe/insulation

The thickness of the pipe is very straightforward and relates to Equation 2.3.1 since the tubes in the model are circular, the equation rewrites to Equation 2.3.2.

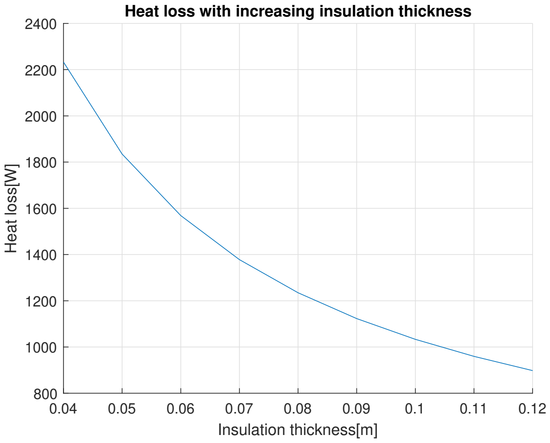


Figure 2.3.4: Heat loss to the surroundings with varying thickness

When the heat loss is plotted over a varying thickness of isolation, Figure 2.3.4 is obtained. In this case the extreme temperature differences are taken where $T_{out} = 15°C$ and $T_{in} = 8°C$

3. Experimental set-up

The configuration that is used for this project is a set up of the Anderrijk region in the Efteling theme park, build by the Kuijpers Ecopartners [15]. This set up is made by Kuijpers Ecopartners in order to provide the Anderrijk region of a gasless heating and cooling system. A model has been developed in the Dymola software using the Modelica programming language. The model was developed by T.J.J.Niemark for his thesis research at the TU Eindhoven, and an elaborate explanation can be found in his thesis. [14].

3.1 Model

The model has been build around the Anderrijk region, which is one of the five regions in theme park the Efteling. The region lay-out is visualized in Figure 3.1.1

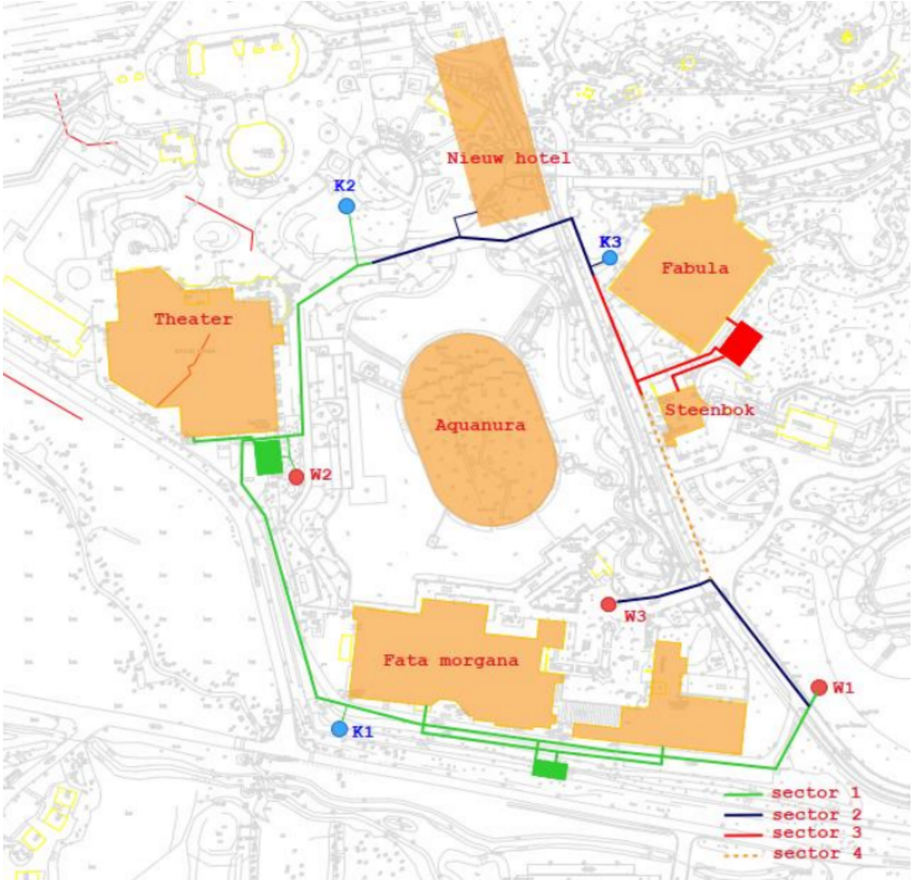


Figure 3.1.1: The set up in the Anderrijk region of theme park the Efteling[15]

This set-up has been modeled in the Dymola software. Every Building has its own cooling and heating demand that has to be matched. This set-up has been recreated in different formats: an unregulated model without a buffer, an unregulated model with Aquanura as buffer and a regulated model with Aquanura as buffer. For this research the most basic model is considered, which is the unregulated model without buffer. This model is picked, because the parameters of interest, are not affected by the buffer or regulation of the model and therefor it is more straightforward to investigate the unregulated model without buffer. The model is shown in Figure 3.1.2

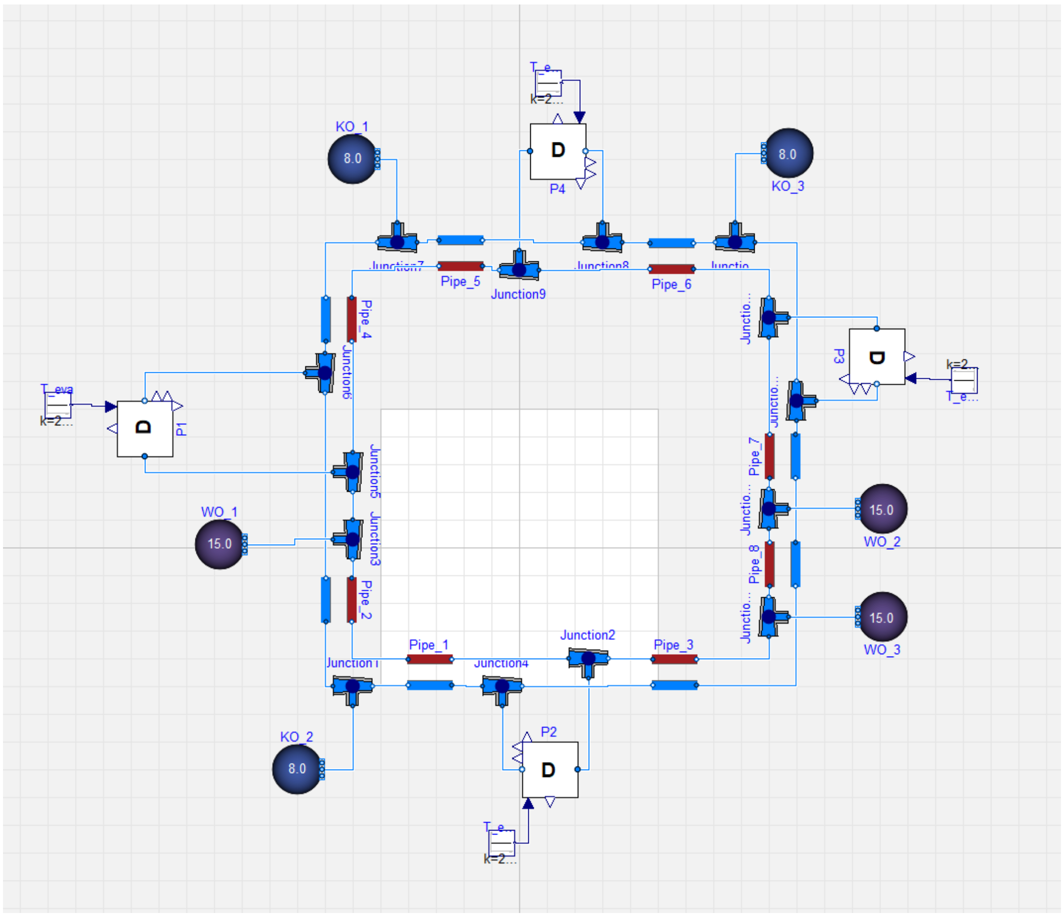


Figure 3.1.2: The unregulated Dymola model of the Anderrijk region

There are four prosumers in the model. A prosumer is a combination of consumer and producer, indicating that all the buildings both take heat/cold and produce heat/cold. These prosumers are denoted with P1, P2, P3 and P4, which respectively are the Theather, Fata Morgana, Fubala and the new Hotel . All these components are connected via the 8 pipes running in the model. Within the prosumer components, the cooling and heating demand of the prosumer are implemented in such a way that the demands of the buildings are known.

In Figure 3.1.2 there are 3 KO's and 3 WO's. The KO stands for cold storage (in dutch "Koude Opslag") and the WO stands for heat storage (in dutch "Warmte Opslag"). Here the excessive heat and cold of the buildings is stored. During the winters the demand of buildings solely consists of heat demand. By supplying heat to the buildings, the water cools down and there is an excessive amount of cold energy. This energy can be put back into the ground, however it is better to store the energy. That is what the KO and WO storage's are used for. From Table 3.2.1 the demand of each of the buildings can be obtained. It is clear that the total demand of the cooling is a lot smaller than the total demand of the heating. This means that the energy can not be completely balanced by use of the KO's and WO's. It does help in reducing the energy needed to heat/cool the buildings.

3.2 Energy demand of the buildings

The demand of each of the buildings is provided by Kuipers Ecopartners [15] and can be found in Table 3.2.1.

		Power[kW]			Demand[MWh]		Tipping point[°C]	
		Heat	Cold	Tap water	Heat	Cold	Heating	Cooling
1	Theater	1500	500	40	849	66	14	17
	Aquanura		0	0	365	0	4	18
2	Fata Morgana	580	0	0	627	0	12	15
	Fata Morgana Palace		0	7,6	116	0	12	15
	Bazaar		50	6	57	33	12	15
3	Fabula	400	155	16,8	634	35	14	17
4	New Hotel	500	650	80	487	550	15	18

Table 3.2.1: Heating and cooling demand of every building [15]

The demand shown in Table 3.2.1 is based on a full year, so 365 days. There is however no exact data of the demand per day/hour/minute/second. Therefore the demand had to be modeled over the span of a year in order to meet the complete demand displayed in Table 3.2.1. Table 3.2.1 consists of three columns: Power, Demand and Tipping point. The power indicates the cooling/heating power that is present at the facility. The heating and the cooling present the room regulation demands. The tap water is referring to water that is coming from the faucet, to supply your shower/bath/sink water. The column demand displays the total demand of energy in terms of heating or cooling of the buildings per year. The tipping points indicate when the heating/cooling will kick in for the particular buildings. To get an accurate estimation of the demand over time of the buildings the NEN5060 was used.

3.3 NEN 5060 profile

The NEN 5060 is a profile which takes the average outside temperature of the past ten years. This profile was fitted to the complete year demand in such a manner that the year demand of the profile was equal to the year demand stated by Kuijpers Ecopartners. This should provide a realistic energy demand profile. The temperature over time of the NEN profile can be seen in Figure 3.3.1.

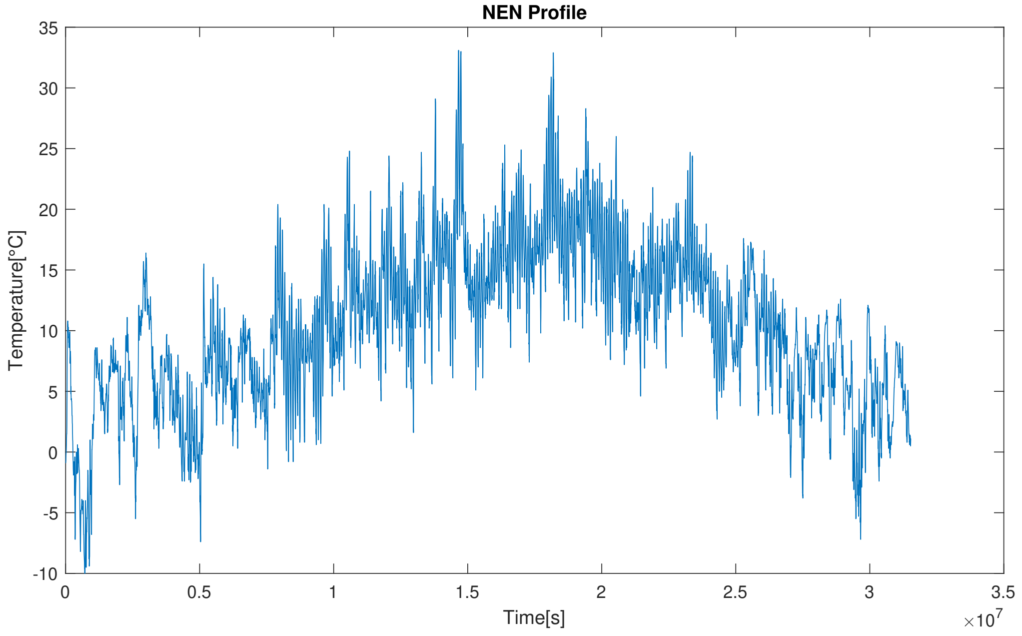


Figure 3.3.1: NEN 5060 temperature profile

In Figure 3.3.1 the NEN5060 profile can be found, this is used to construct the demand profile for the buildings. The profile appears to be varying a lot with small changes over time. This is the case as a really big time frame is shown on a very small picture. The time covers a complete year(365 days) and within a day the temperature can easily vary 15 $^\circ C$.

In Figure 3.3.2 the NEN profile of a specific day can be seen. This shows a zoomed in view of Figure 3.3.1. In Figure 3.3.3 the demand of building 1 is shown. As expected the curve of the demand is an inverted version of the NEN-profile.

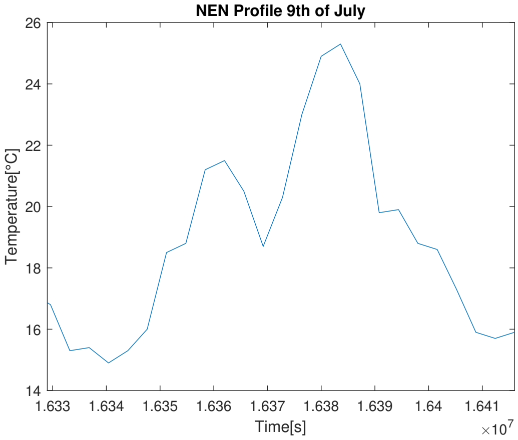


Figure 3.3.2: NEN profile on 9th of July

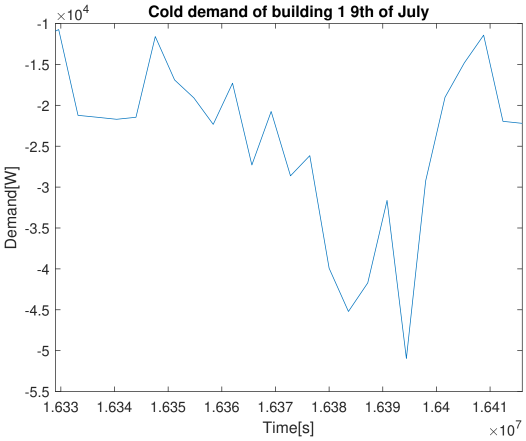


Figure 3.3.3: Cold demand building 1 9th of July

4. Results and discussion

The main goal of the project was to validate and optimize the results obtained from the model, build for the Anderrijk region. The parameters which are taken into account and that are investigated consist of:the diameter of the pipes, the thickness of the pipes, the amount of insulation and number of segments the pipe is split up into to get an accurate approximation. The heat pumps used in the model, are heat pumps that were standard in the model. Therefore not much could be investigated considering the heat pump. The reason that all of this is investigated, is because the model itself is set-up to properly function at first. However no analyses has been performed yet,in order to optimise and fully validate the model.

4.1 Diameter comparison

From theory it was concluded, that the diameter of the tubes should be as small as possible to keep the time of the hot water within the tubes limited. The speed of the water is limited to 2[m/s], which means that the diameter of the tubes can be 0.15[m] at its smallest. Keeping the diameters small, the outer surface area of the tubes remains as small as possible as well, losing less heat to the surroundings. It could be argued that using a big diameter 'protects' the water at the inside of the tube from heat loss and since the surface area increases with the diameter squared and the outer area only increases linearly you would lose less heat per capita. However this model is built to keep the flow rate at 34[kg/s], which means that the speed will be reduced when the cross section is larger. In that case, it is more desirable to have the hot water within the heat storage rather than in the tubes itself.

To confirm this theory, several runs were peformed on all the 8 pipes with different diameters/cross-sections. This provides an insight into the heat losses that occur at different diameter sizes.

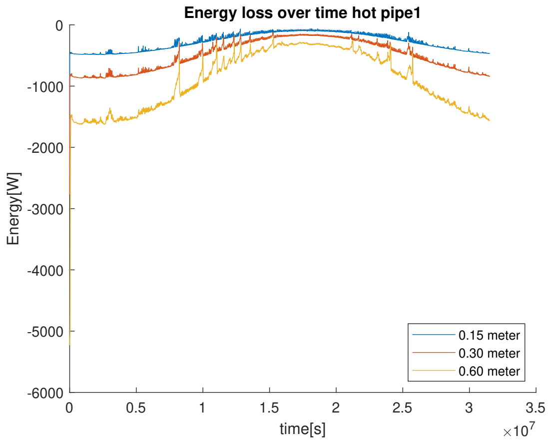


Figure 4.1.1: Heat loss in pipe 2

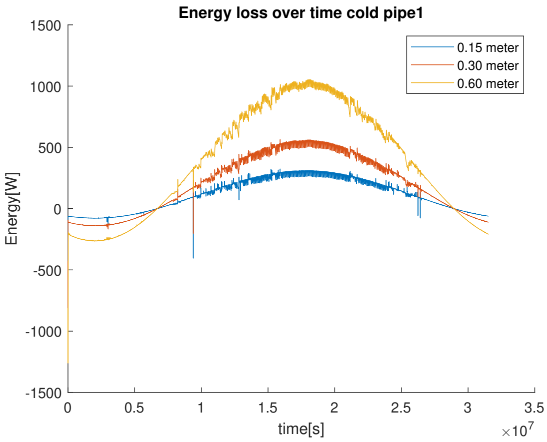


Figure 4.1.2: Cold loss in pipe 3

When looking at Figure 4.1.1 and Figure 4.1.2, it can be clearly seen that it follows the path of the NEN profile, at the beginning and the end of the year large activity can be observed at hot pipes(i.e heat loss) and during the middle of the year(the summer), large activity can be seen at the cold pipes(i.e heat gain).

Something noticeable in the design of the model is that during the cold periods there is also an energy loss in the cold pipes, on the contrary there is no energy gain in the hot pipes during the warm periods. This happens because the temperature of the pipes is $T_{set,cold} = 8°C$ and $T_{set,hot} = 15°C$ and the soil temperature is based at $10°C$ with a deviation of $5°C$, in the summer and the winter. This means that the soil temperature in the winter is lower than the cold pipe temperature but this is not the case for the pipes as the pipe temperature and soil temperature will both be 15 $°C$.

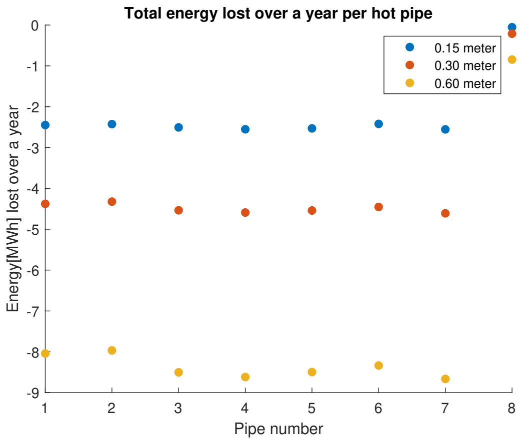


Figure 4.1.3: Total energy loss over a year

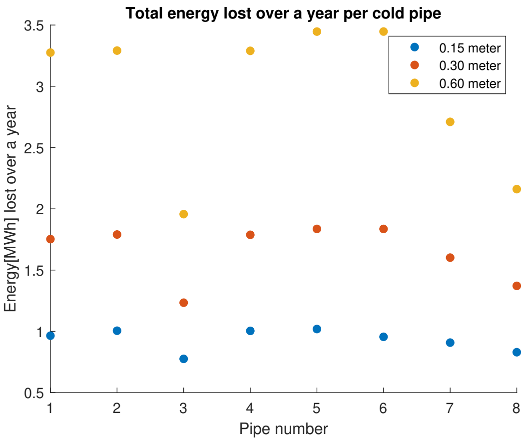


Figure 4.1.4: Total energy loss over a year

In Figure 4.1.3 and Figure 4.1.4 the total energy loss per tube over a year can be seen, displayed for different diameters. It can be seen that the increase in energy loss is linear with the increase in diameter. This confirms the theory earlier discussed in section 2.3. In Figure 4.1.3 the heat loss per pipe is relatively low. When considering the tube with a diameter of 0.15[m] the total loss over all pipes in a year is only approximately $17,5MWh(7 \cdot 2,5)$. While the total heat demand of all the buildings combined in a year is 3135 MWh. Which means only 0,56% of all the heat supply is lost within the tubing. This show how efficient the 5th generation system is. The losses to the surroundings are kept this low because of the low operating temperature within the pipes, which are almost equal to the ambient soil temperature.

4.2 Validation

It was unsure whether the model shows the $\dot{Q}_{flow}$ for the pipes to the soil only or also displays the heat lost at the consumer. This is of course an important aspect, in order to be able to analyze the influence of the parameters to the heat loss of the system. To investigate this, the cold demand of the Hotel(prosumer 1) was halved. How to create a half demand is shown in subsection A.0.1 This gives a clear picture whether flow of energy only describes the interaction between pipe and soil or also between pipe and prosumer. When having a look at the model in Figure 3.1.2, it can be seen that pipe 4 is the pipe that delivers the cold energy towards prosumer 1.

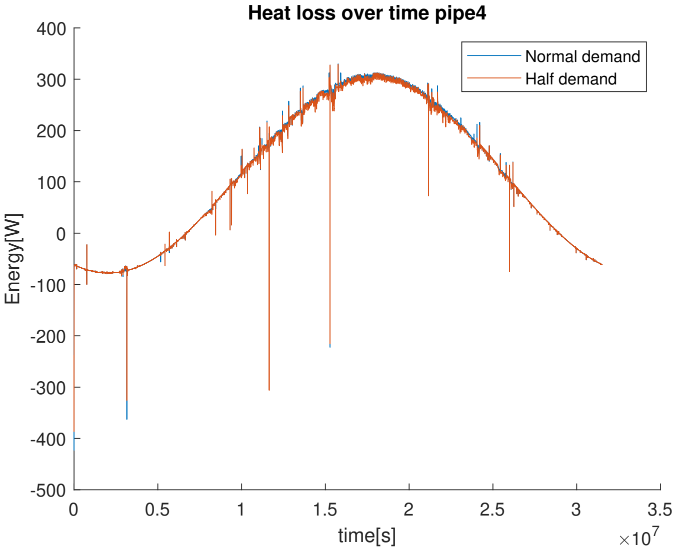


Figure 4.2.1: The energy loss in pipe 4, normal demand vs half demand

When looking at Figure 4.2.1 you can see that there are small differences, however these are almost negligible. This clearly indicates that the heat loss from the pipes does not include the heat loss towards the prosumer. Otherwise big changes should have occurred, as most of the energy flow goes to the consumer.

4.3 Insulation thickness

The insulation thickness of the pipes also has an influence on the heat flow towards the soil. This parameter is altered over different thicknesses to see what this does to the heat flow. Obviously it is expected that heat flow towards the soil will decrease with an increase in insulation thickness. The heat conductivity of the isolation material was set at 0.12 [W/mK]. It is unknown which material is being recreated here, but the thermal conductivity of PVC equals 0.19[W/mK] which indicates that the insulator used is not a lot more heat resistant than the PVC itself.

When varying the thickness of the isolation, the results shown in Figure 4.3.1 and Figure 4.3.2 are obtained.

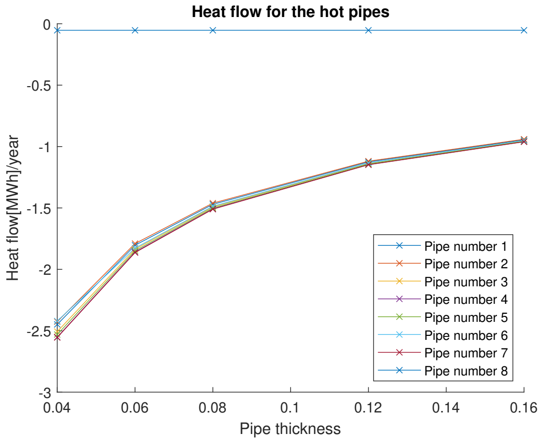


Figure 4.3.1: Hot pipes with varying thickness

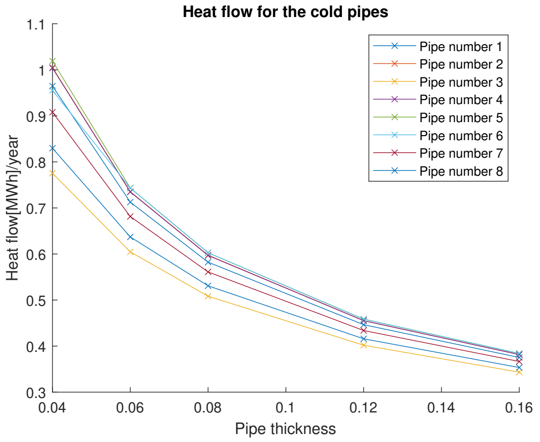


Figure 4.3.2: Cold pipes with varying thickness

In Figure 4.3.1 and Figure 4.3.2 it can be seen that the pipes almost exactly behave as predicted in Figure 2.3.4. By increasing the insulation thickness, the heat losses get reduced, but only by 1,5 MWh for the hot pipes and approximately 0,6 MWh for the cold pipes. Over the span of a complete year this is not much in comparison to the total demand of all the buildings. Which means it is not worth it, to further increase the isolation of the pipes.

4.4 Segment refinement

The model currently runs with 50 segments per pipe. This means that every pipe is divided into 50 segments and over each segment the flow and the losses of the pipe are modeled. It is possible to change this segment size. The advantage of reducing the amount of segments is that the computing time decreases as the computer has to perform less calculations. The disadvantage is that by reducing the amount of calculations, the accuracy goes down. At some point, this increase in accuracy is not worth anymore and additional computations are a waste of time. To find the point where this is the case, the model is solved with a varying number of segments.

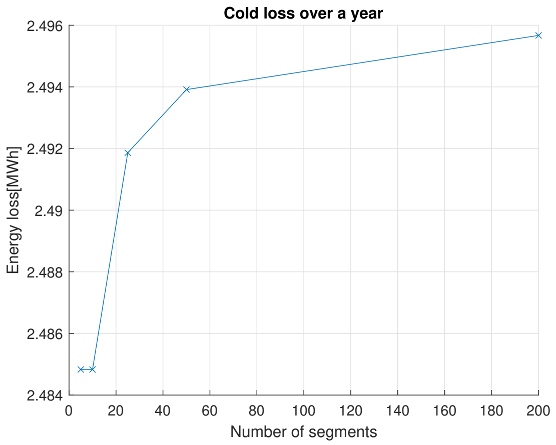


Figure 4.4.1: Heat loss in the pipe for different amount segments per pipe

In Table 4.4.1 the computational times can be seen. This shows that increasing the number of segments gives a big increase in running time. When looking at Figure 4.4.1 the difference in heat losses over a year is very small. When modeling for a complete year, it is thus possible to decrease the amount of segments in order to get a faster running time, without losing a lot accuracy.

Number of segments	Time
5	8min 21sec
10	9min 28sec
25	15min 58sec
50	35min 30sec
200	159min 36sec

Table 4.4.1: Running time per number of segments

Considering the big picture no maintainable differences between the amount of segments used can be observed. When zooming on smaller timescales, this changes and some differences occur, as can be found in Figure 4.4.3. When modeling a specific time interval it is thus better to model with a large amount of segments. As the plot of the 50 segments is further away from the 200 segments than for example the 10 and 25 segments, there is no convergence towards the 200 segments plot. This makes it hard to determine an exact amount of segments that would be needed to get an accurate plot for a small time interval.

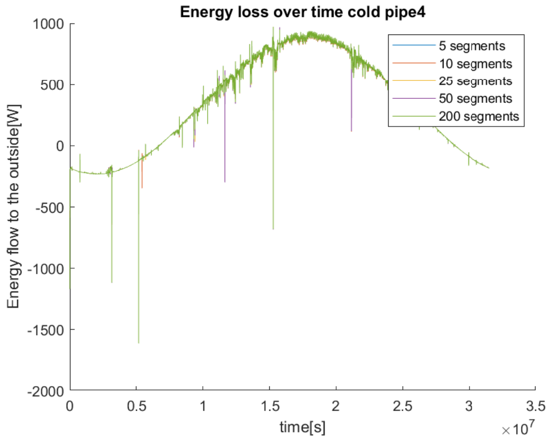


Figure 4.4.2: Energy loss pipe 4 with different amount of segments

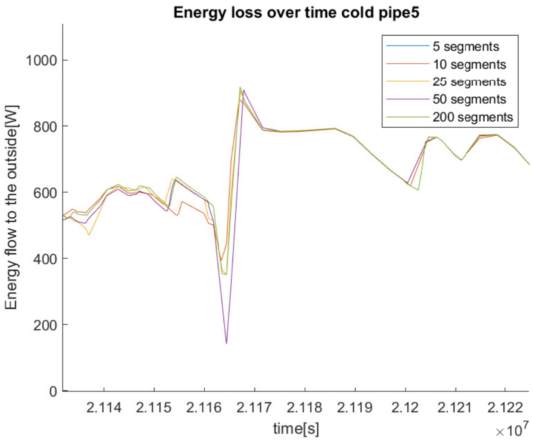


Figure 4.4.3: Small time interval of pipe 4

4.5 Unexpected results

Something that is very evident in the plots of the heat loss of the pipes, is the heat loss of the hot pipe 8. Especially in Figure 4.3.1 this stands out very clearly. To get an insight at this pipe, the heat loss is plotted in Figure 4.5.1.

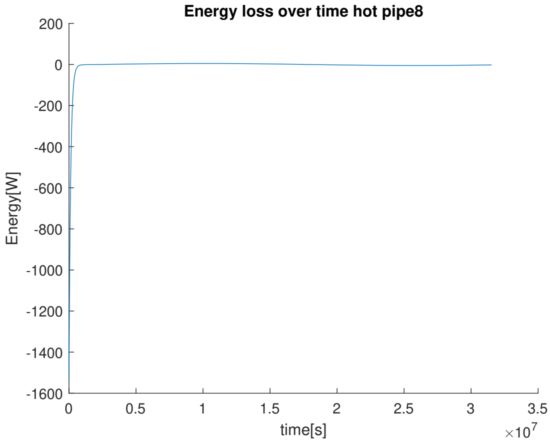


Figure 4.5.1: Energy loss of hot pipe 8

It can be seen that nothing happens in pipe 8. This is probably cause by the fact that hot pipe 8 is situated between two heat storages as can be seen in Figure 3.1.2. There is no demand from heat storage 2 towards heat storage 3 and the other way around. Therefore nothing happens at the hot pipe. This explains why there are also no losses in this pipe.

5. Conclusion

From this paper a few things can be concluded, however there are also still things that need to improved to get a better model and to improve the convenience of working with the Dymola software.

From the theory that was discussed, it turned out that the model represents values that you would expect to get as an outcome. For example in varying the thickness of the insulation the exact same pattern occurred in the theory as in the results of the model. The same thing holds for the variation in diameter, the expectation was that more energy would be lost by an increase in pipe diameter and that is exactly what happened.

When analyzing the results of the parameters it was concluded that the best possible diameter is 0.15 [m]. The down sizing of the tubes was limited by maximum speed of the water in the tubes, which is 2 [m/s]. For the insulation thickness, it is beneficial to increase the insulation as one would expect, however as the losses of the 5th generation model are already so small, it is not worth it to do so. From the segment refinement it was concluded that, when results are analyzed over the span of a complete year the number of segments can be brought down significantly without a reduction in accuracy. When analyzing a specific time interval it is better to keep this number of segments high to obtain a more accurate result.

Things that could be further improved in the model, is the accuracy in soil temperature. At the moment the soil temperature follows the NEN-model to reach the fluctuation of the soil temperature, however over time, the heat losses in the pipes will cause the soil around the pipes to warm up. When this is modeled accordingly the system gets even more accurate.

Apart from the model itself, the way of working with Dymola can be improved. The software makes it very hard to display results. A complete exportation of the results in Dymola, to Matlab is not possible, as Dymola formats its results in a different way. Because of this every single data file has to be exported separately which takes a lot of time. For future use of Dymola it would be convenient to have a Matlab model which formats the results correctly and allows the results to be exported as a whole.

Concerning the model as a whole, the calculations of the software give the results that would be expected and the parameters of the model are optimized, if this was deemed to be useful. The 5th generation district heating and cooling network is proven to be very efficient and works with small losses, as can be seen in the results obtained from the model. The results give a good insight to where these losses occur and why they are so low. They thus give a good insight to why this system is better and more efficient than the previous generations of heating and cooling networks.

Bibliography

[1] Simone Buffa, Marco Cozzini, Matteo D'Antoni, Marco Baratieri, and Roberto Fedrizzi. 5th generation district heating and cooling systems: A review of existing cases in europe, 4 2019. 2

[2] Marwan Abugabbara and Jonas Lindhe. A novel method for designing fifth-generation district heating and cooling systems. volume 246. EDP Sciences, 3 2021. 2

[3] L Moerenhout. Model-based design and performance analysis of a 5 th generation district heating and cooling network, 2020. 2

[4] Interreg. Different generations of dhc — 5gdhc, 2021. 3, 4

[5] Maria Jangsten, Peter Filipsson, Torbjörn Lindholm, and Jan Olof Dalenbäck. High temperature district cooling: Challenges and possibilities based on an existing district cooling system and its connected buildings. *Energy*, 199, 5 2020. 3

[6] ENGIE. District heating and cooling systems, 2 2013. 3

[7] Iván De la Cruz and Carlos E. Ugalde-Loo. District heating and cooling systems. *Microgrids and Local Energy Systems*, 12 2021. 3

[8] Chiera Delmastro. District heating – analysis - iea, 2021. 3

[9] Peter Sorknæs, Poul Alberg Østergaard, Jakob Zinck Thellufsen, Henrik Lund, Steffen Nielsen, Søren Djørup, and Karl Sperling. The benefits of 4th generation district heating in a 100energy system. *Energy*, 213, 12 2020. 3

[10] How a heat pump works— heat pump video —goodman. 4

[11] Pavel Neuberger, Radomír Adamovský, and Michaela Šedová. Temperatures and heat flows in a soil enclosing a slinky horizontal heat exchanger. *Energies*, 7:972–987, 2014. 5

[12] Engineering toolbox. Convective heat transfer, 2003. 5

[13] Gabor Takacs. A review of production engineering fundamentals, 2015. 6

[14] T.J.J.Niemark. Dynamic modeling: Simulating a thermal energy storage network, 2022. 7, 9

[15] Energievoorziening anderrijk definitief ontwerp. 7, 9, 10, 11

A. My First Appendix

A.0.1 How to obtain half demand of the system?

The demand is an input within the prosumer building block. As can be seen in Figure A.0.1. By double clicking this building block, the demand can be altered at the redsquare in Figure A.0.2

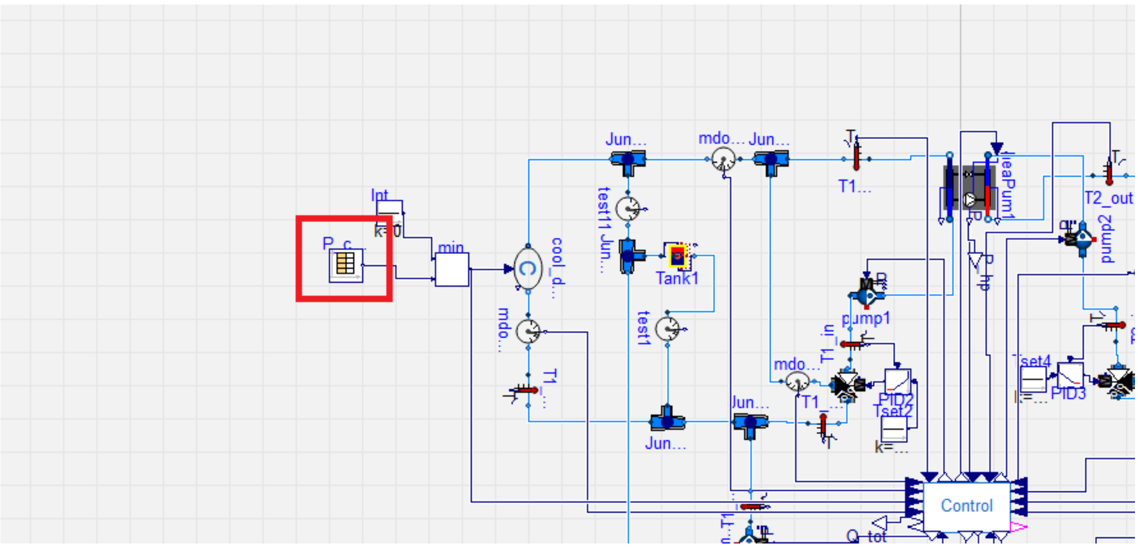
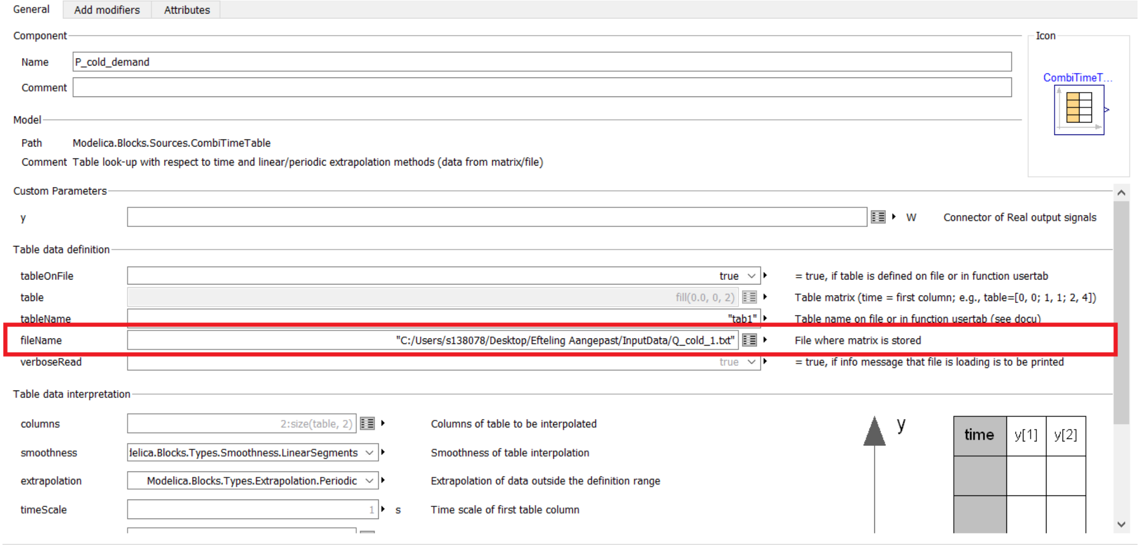


Figure A.0.1: Building block to change the demand within the system



General | Add modifiers | Attributes

Component
Name: P_cold_demand
Comment:

Model
Path: Modelica.Blocks.Sources.CombiTimeTable
Comment: Table look-up with respect to time and linear/periodic extrapolation methods (data from matrix/file)

Icon: CombiTimeT...

Custom Parameters

y		W	Connector of Real output signals

Table data definition

tableOnFile	true		= true, if table is defined on file or in function usertab
table	fill(0.0, 0, 2)		Table matrix (time = first column; e.g., table=[0, 0; 1, 1; 2, 4])
tableName	"tab1"		Table name on file or in function usertab (see docu)
fileName	"C:/Users/s138078/Desktop/Efteling Aangepast/InputData/Q_cold_1.txt"		File where matrix is stored
verboseRead	true		= true, if info message that file is loading is to be printed

Table data interpretation

columns	2:size(table, 2)		Columns of table to be interpolated
smoothness	lelica.Blocks.Types.Smoothness.LinearSegments		Smoothness of table interpolation
extrapolation	Modelica.Blocks.Types.Extrapolation.Periodic		Extrapolation of data outside the definition range
timeScale	1	s	Time scale of first table column

Figure A.0.2: The object to change the demand of the system

The .txt file itself can be halfed by importing it into excel. This can be done via the menu Data → Get Data → from file → from text. Import the desired file and press load. Now the second column(the demand column) can be halved by using the =(Column_value)*0.5. Excel will fill in the remaining values. The time column and demand column can be added together, by using the =CONCATENATE() function. Lastly the column can be copied and put back into a .txt file.