

HOW TO GUIDE

***Hydraulic calculation of  
District Heating in energyPRO***



**energyPRO**

## **Preface**

energyPRO is a Windows-based modeling software package for combined techno-economic analysis and optimisation of complex energy projects with a combined supply of electricity and thermal energy from multiple different energy producing units.

The unique programming in energyPRO optimises the operations of the plant including energy storage (heat, fuel, cold and electrical storages) against technical and financial parameters to provide a detailed specification for the provision of the defined energy demands, including heating, cooling and electricity use.

energyPRO also provides the user with a detailed financial plan in a standard format accepted by international banks and funding institutions. The software enables the user to calculate and produce a report for the emissions by the proposed project.

energyPRO is very user-friendly and is the most advanced and flexible software package for making a combined technical and economic analysis of multi-dimensional energy projects.

For further information concerning the applications of energyPRO please visit [www.emd.dk](http://www.emd.dk).

## **Terms of application**

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## 1. Introduction

The hydraulic calculation in energyPRO allows you to include constraints introduced by the transmission pipes. This is important for district heating project with more sites. From the hydraulic calculations it is possible to include the transmission pipes in the economic optimal investment, knowing the impact of the: pipe diameters, the level of insulation and the pipe roughness. Finally, the work of the district heating pumps can be included in the economy.

This How To Guide contains three main parts:

**Section 2** – How to set up the hydraulic calculation in energyPRO. A step-by-step guide.

**Section 3** – How to inspect and use the results by the new reports (Transmission, graphic).

**Section 4 and 5** – Method and Validation of the hydraulic calculations in energyPRO

## 2. How to setup the hydraulic calculation in energyPRO

The energyPRO project case called: "Hydraulic calculation of a district heating grid with solar collector and storage, CHP and HP in separate sites" can be accessed from the English Project examples in the start window of energyPRO, please see Figure 1. The project is used in this guide to illustrate the hydraulic calculation in energyPRO, by the four steps described in the following.

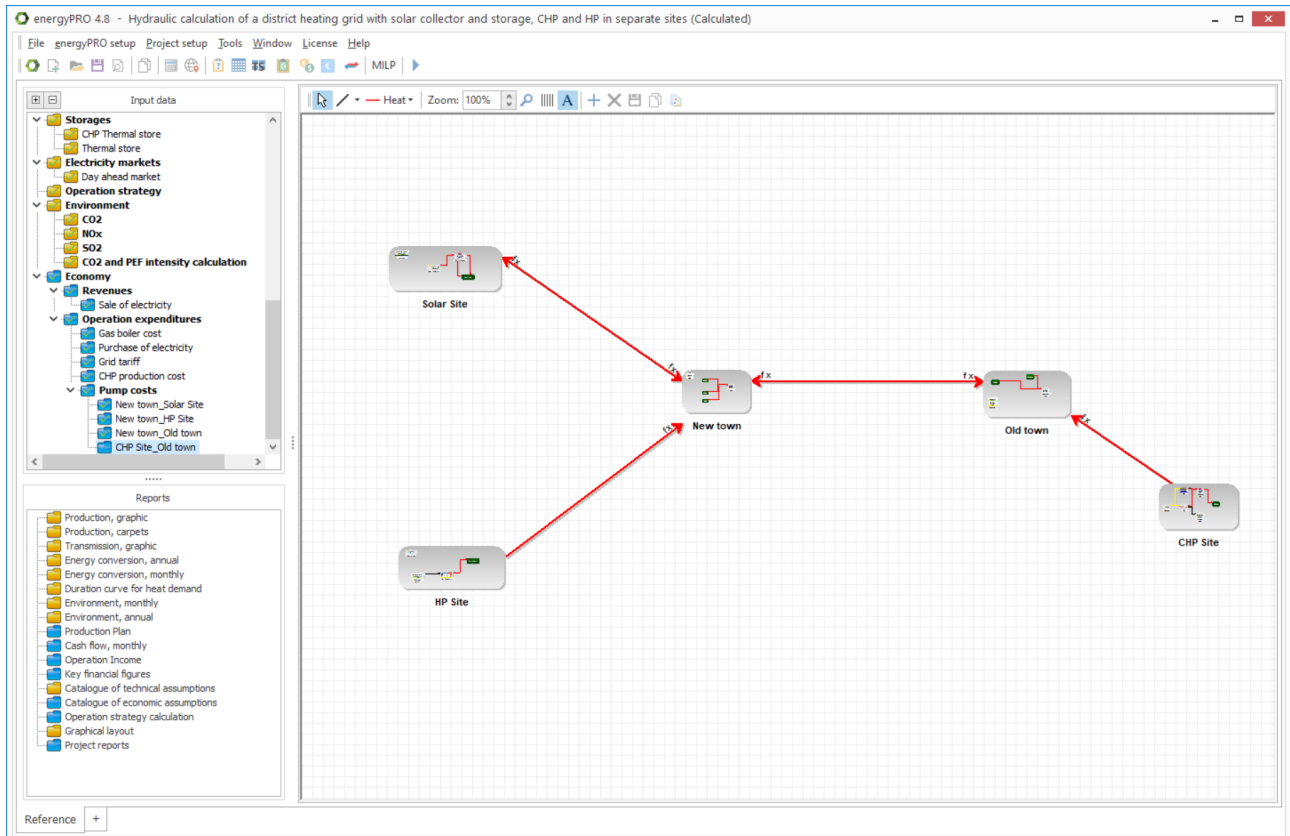


Figure 1. The energyPRO project case, "Hydraulic calculation of a district heating grid with solar collector and storage, CHP and HP in separate sites", used in this HowToGuide, having more sites and transmissions.

## 2.1 Step 1: Adding the hydraulic calculation

Go to Project setup and choose Project identification and Advanced settings. Scroll down and choose "Including pressure and velocity hydraulic constraints in transmission pipes". Please see Figure 2.

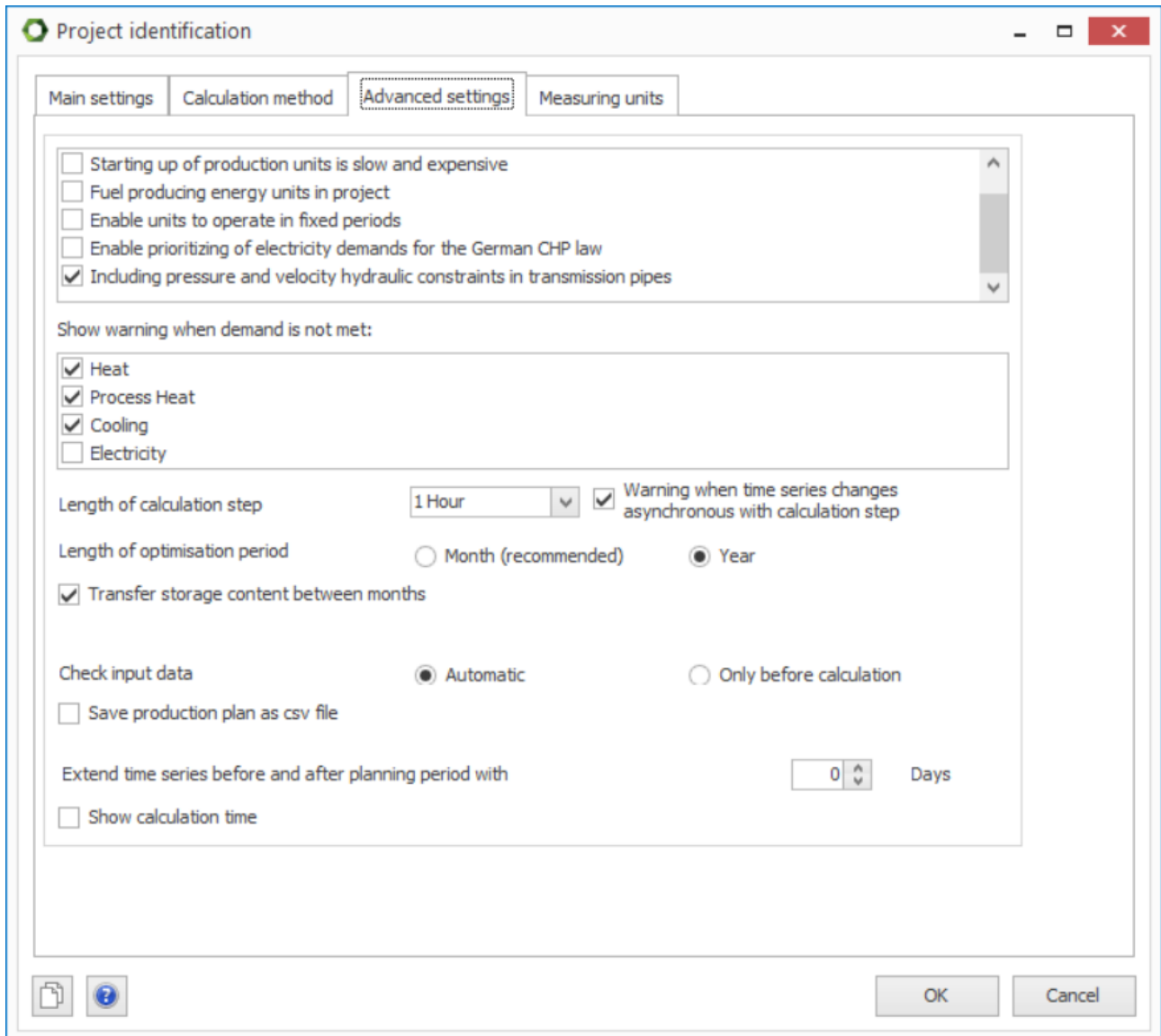


Figure 2. Add the hydraulic calculation in Project identification and Advanced settings.

## 2.2 Step 2: Enter temperature data for each site

At each site you need to add input for the hydraulic calculation. Right click a site and choose Open, as shown in Figure 3.

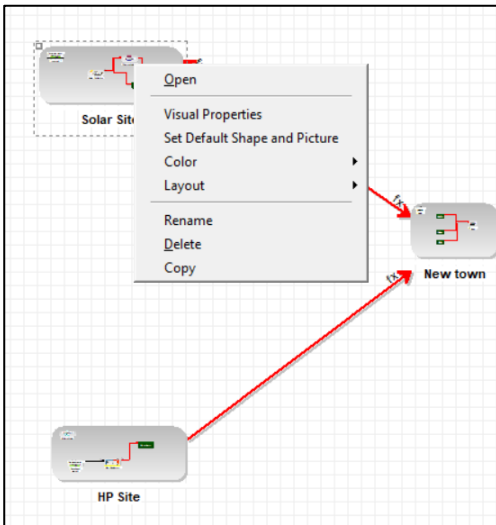


Figure 3. Enter new input data for each site by right clicking a site and choosing Open

Next enter the minimum required supply and return temperatures for the site, see example in Figure 4.

The supply temperature is the minimum temperature needed at the site. The value can for example be determined based on the minimum temperature needed to supply heat demands, the minimum temperature at which a unit at the site produces heat or the minimum temperature at which a unit at the site consumes heat.

The return temperature is the mixed temperature returning from heat demands in the site or from transmission lines to the site.

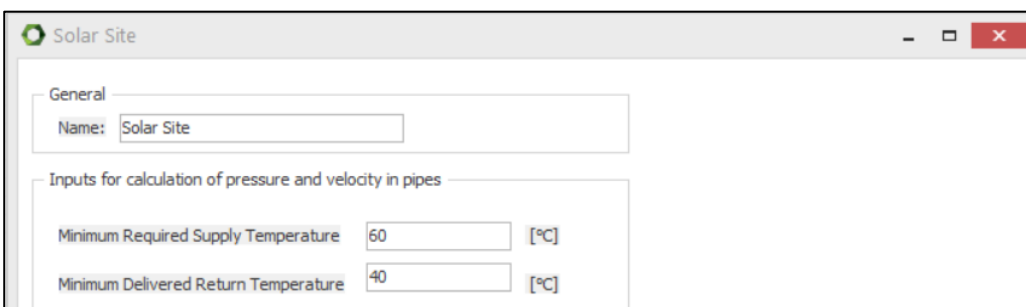


Figure 4. Minimum Required Supply Temperature and Minimum Delivered Return Temperature are entered for each site



After adding a hydraulic calculation to an energyPRO model a new “temperature” icon becomes visible, as shown in Figure 5.



Figure 5. A new “temperature” icon is visible when added the hydraulic.

By clicking the icon, the site data are seen in a table as illustrated in Figure 6.

Site	Min. Required Supply Temperature °C	Min. Delivered Return Temperature °C	Temperature Zone	Graph	Supply Temperature in the Zone °C	Return Temperature in the Zone °C
Old town	60	40	1	<input type="checkbox"/>	60	40
CHP Site	90	50	2	<input type="checkbox"/>	90	50
New town	60	35	1	<input type="checkbox"/>	60	40
Solar Site	60	40	1	<input type="checkbox"/>	60	40
HP Site	70	35	3	<input type="checkbox"/>	70	35

Figure 6. You can enter site data in the Sites Overview table. When choosing Update, the temperatures to be used in the temperature zones are shown.

Please notice, that the hydraulic calculations in energyPRO are based on splitting the district heating grid in temperature zones – this is described in section 4.3 .

## 2.3 Step 3: Entering new data in transmission window


For each of the defined transmissions, seven inputs related to the transmission line must be specified as shown in Figure 7. Double click "Old town\_New town" under Transmissions in the Input data. The inputs are:

- Length
- Internal diameter
- Pipe roughness
- Specific heat loss
- Max. velocity
- Max. pressure gradient
- Ground temperature (as a formula field)

The screenshot shows a software window titled "Old town\_New town" with the following fields and options:

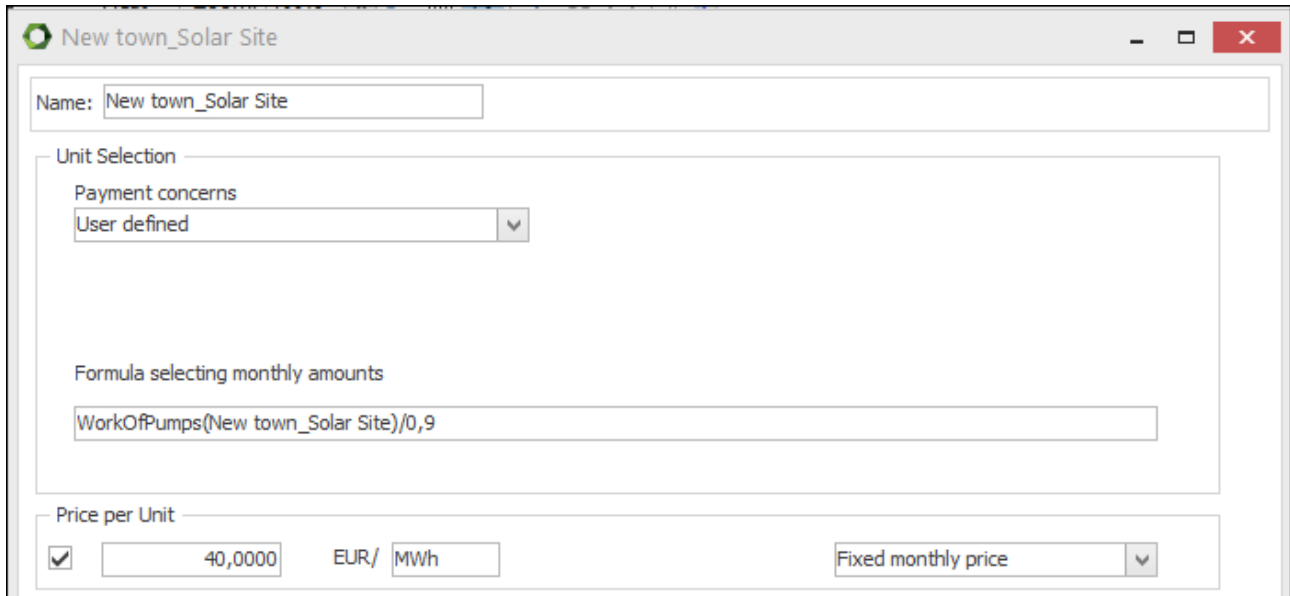
- Name: Old town\_New town
- Type of Transmission: Heat
- Energy Type: Heat
- Non availability periods:
- Site A: Old town
- Site B: New town
- Site A can transmit to B:
- Site B can transmit to A:
- Transmission pipes parameters and constraints:
  - Length: 4000,00 m
  - Internal diameter: 300,00 mm
  - Pipe roughness: 0,10000 mm
  - Specific heat loss: 0,30 W/(m\*K)
  - Max. velocity: 2,00 m/s
  - Max. pressure gradient: 100,00 Pa/m
  - Ground temperature: 8,00 °C
  - Transmission Capacity: 11,44 [MWh] as of 01-05-2022 00:00
- Operation restricted to period:
- Comments: (empty text area)
- Bottom left icons: Home, Help, and a graph icon.
- Buttons: OK, Cancel

Figure 7. When having added the hydraulic calculation, the seven pipe inputs are entered.

The icon at the bottom left,  shows the capacity and loss – calculated based on the method presented in section 4.

## 2.4 New function available in payments – WorkOfPumps

A new function is made available in the payments and it is called: WorkOfPumps(Transmission). The new function reflects the work of pumps for the specified transmission based on the pressure calculation in each time step. The calculation of work of pumps is shown in section 4.8 .



The screenshot shows a software window titled "New town\_Solar Site" with the following configuration options:

- Name:** New town\_Solar Site
- Unit Selection:**
  - Payment concerns:** User defined
  - Formula selecting monthly amounts:** WorkOfPumps(New town\_Solar Site)/0,9
- Price per Unit:**
  - EUR/
  -

Figure 8. A new function is made available in the payments – WorkOfPumps.

### 3. New hydraulic reports

The new hydraulic reports are found in the folder "Transmission, graphic" under "Reports". In "Transmission, graphic", you can choose "Transmission" to see one of the transmission lines.

Figure 9 shows an example with the plots of Pressure Gradient, Flow velocity and transmitted heat as a function of time. Beside the shown plots, you can select Total Pressure Drop, Volume Flow Rate and Work of Pumps.

The calculation of Pressure Gradient and Flow velocity is shown in section 4.

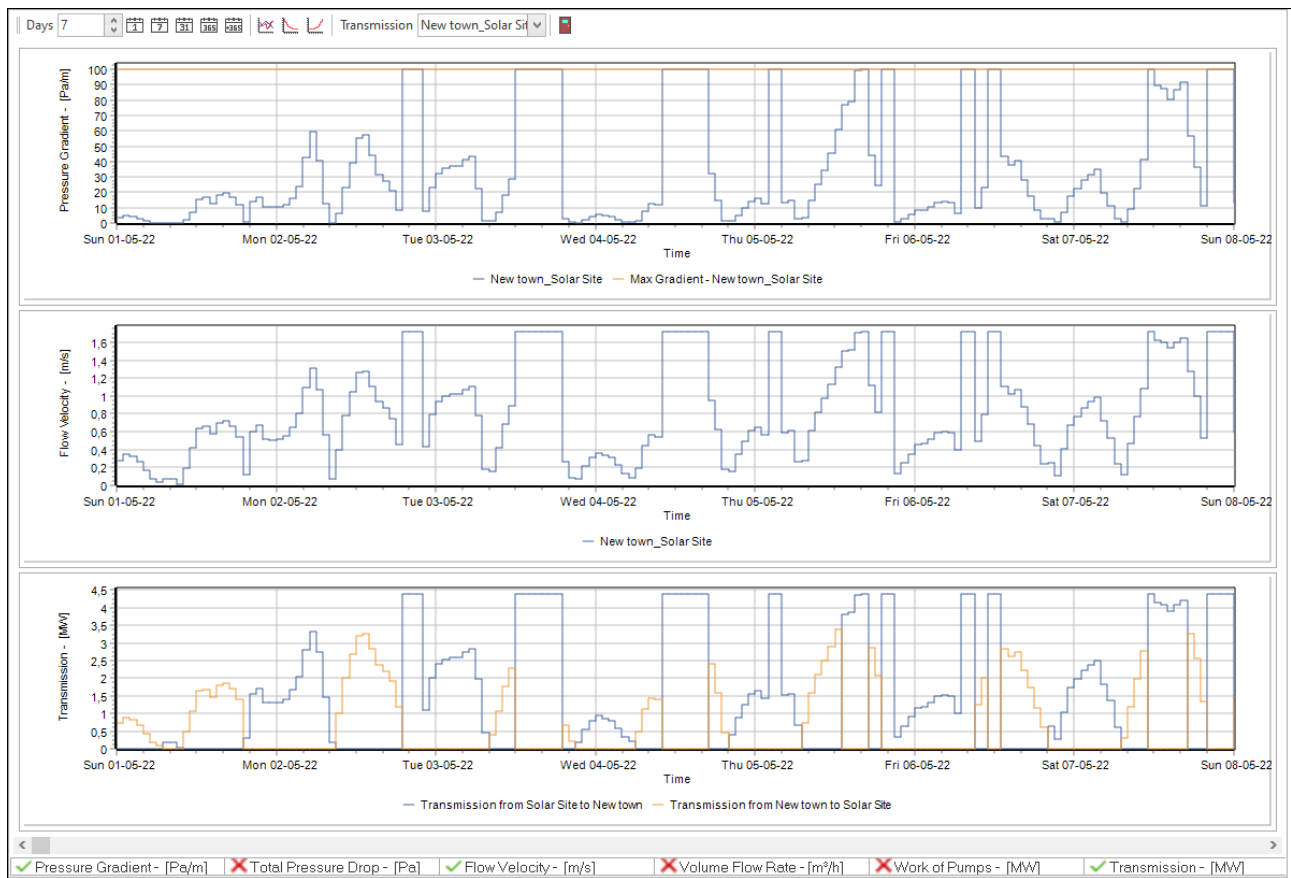


Figure 9. For a transmission you can in "Transmission, graphic" see e.g., Pressure Gradient and Flow velocity.

## 4. The hydraulic calculation method used in energyPRO

### 4.1 Restrictions in the hydraulic calculation

The transmission temperatures are decided as external conditions, *i.e.*, no temperature optimization is included.

### 4.2 Input for the hydraulic calculation

#### 4.2.1 General constants

- Specific heat capacity of water,  $C_p$
- Density of water,  $\rho$
- Time step in optimization period,  $\Delta t$

#### 4.2.2 Input for each site

Two inputs are present in the calculation method:

- Supply temperature,  $T_{sup}$
- Return temperature,  $T_{ret}$

$T_{sup}$  is understood as the minimum temperature needed in the site. It can be determined by the minimum temperature needed to supply heat demands, minimum temperature at which a unit at the site produces heat or minimum temperature at which a unit at the site consumes heat.

$T_{ret}$  is understood as the mixed temperature returning from heat demands in the site or from transmission lines to the site.

#### 4.2.3 Input for each transmission

Five inputs are present in the calculation method:

- Length of transmission,  $L$
- Internal diameter of forward and return pipes,  $d$
- Specific heat loss,  $U$
- Pipe roughness,  $\epsilon$
- Ground temperature,  $T_g$

## 4.3 Temperature zoning in a hydraulic calculation in energyPRO

The sites and transmissions are divided into temperature zones. Each site and each transmission belong to only one of the temperature zones.

If the energy can flow from one site to another site through certain transmissions and can flow back through certain transmissions, all the sites connected by the transmissions, and the transmissions in which the flow may happen, are in the same temperature zone. Such a system can be formulated as a graph with strongly connected components [3].

One-way transmissions are always in the same zone as the site from which the transmission is possible. If there is a site to which no energy flow back is possible, it is together with the outgoing transmission, in their own temperature zone.

In each temperature zone the sites and transmissions are operated at the same supply temperature,  $T_{sup}$ , and return temperature,  $T_{ret}$ . This is done by choosing the highest supply and highest return temperature from all the sites in the temperature zone. These operation temperatures in each temperature zone can change from time step to time step.

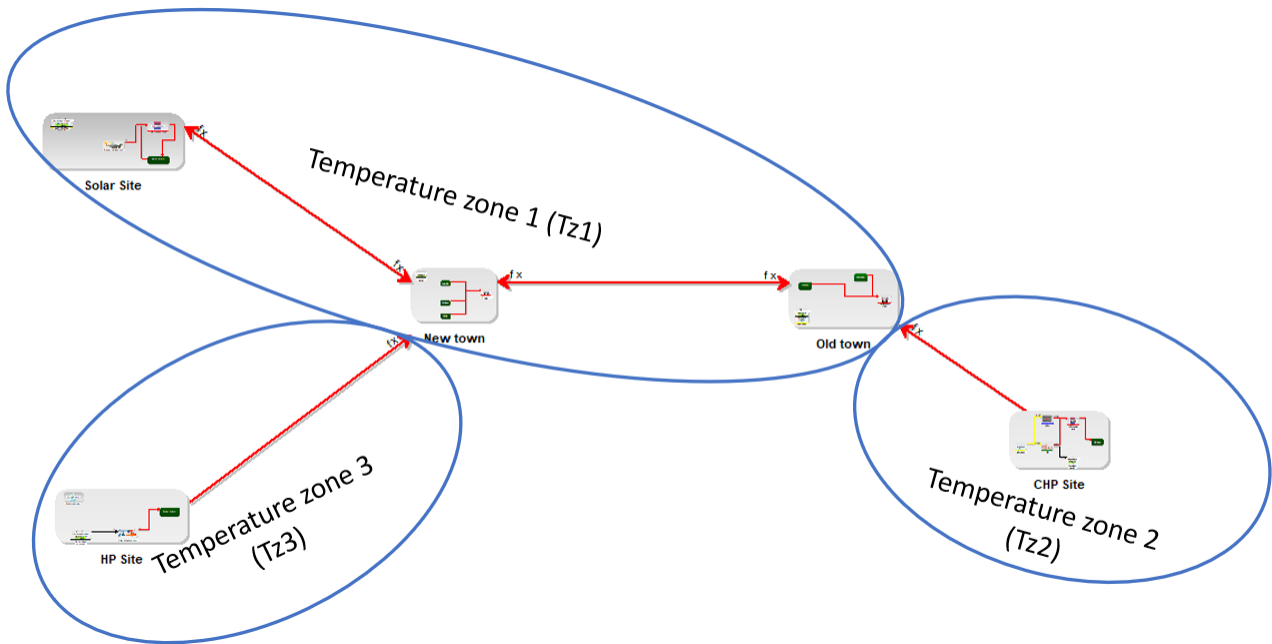


Figure 10. An example of a project, where there are three temperature zones.

Example presented Figure 10 has three temperature zones.  $Tz2$  and  $Tz3$  are created because there is no energy flow back to HP site or CHP Site and the outgoing transmissions form a temperature zone with the source sites.  $Tz1$  connects three sites, where the energy can flow out of and back again to every of the sites.

The supply and return temperatures in the presented example, entered in the sites, are shown in Table 1. For simplicity these are assumed to be constants but entering them as timeseries is also possible.

Site	Tsup [°C]	Tret [°C]
HP Site	70	35
New town	65	35
Solar Site	60	40
Old town	70	40
CHP Site	90	50

Table 1: Examples of supply and return temperatures in the sites.

As previously described, Tsup and Tret in a temperature zone are chosen as maximum values entered in the sites belonging to the considered temperature zone. In the considered example we have one temperature zone with more than one site – Tz1. Tsup and Tret for all sites in Tz1 are summarized in Table 2 and in the last column the maximum values are highlighted.

Temperature zone B				
	New town	Solar Site	Old town	Operation temperatures in temperature zone
Tsup [°C]	65	60	70	70
Tret [°C]	35	40	40	40

Table 2. Example of calculated temperatures in a “last” temperature zone

The operation temperatures in the temperature zone in Table 2 is possible to be realised sufficiently precise in a real system.

If e.g., the energy flows from Old town to New town, you can shunt the 65°C arriving at New town with colder water to get the 65°C, and you can shunt the 35°C returning from a demand in New town with warmer water, to bring it to the 40 °C of the return temperature in the temperature zone.

In Tz2 and Tz3 there is only one site. This means that the supply and return temperatures in Tz2 are the same as the one specified for CHP Site. The same goes for Tz3, where the supply and return temperatures are equal to the ones specified in the HP Site.

The user must keep track on the feasibility of the flows. Flow from a temperature zone with lower supply temperature to a temperature zone with higher required supply temperature will not represent a realistic case.

#### 4.4 Velocity in the pipe calculation

The calculation of velocity in the pipe is used for determining the maximum transmission capacity based on maximum allowable velocity in the pipes, as well as for determining hourly flow parameters.

The maximum allowable velocity in the pipes will act as an energy flow boundary condition and the transmission energy flow in a pipe will be constrained to be within this value.

The maximum allowable velocity in the pipe usually depends on the pipe nominal diameter and the typical values are given in Table 3. These values are selected as industry standard as higher velocities have been known to cause noise problems and damage internal layer of pipes [1].

Nominal diameter	Maximum allowable velocity, $v_{max}$
DN 20-400	2 m/s
> DN400	3 m/s

Table 3. Pipe nominal diameter and corresponding max flow velocity

The transmission capacity is dependent on mass flow and supply and return temperatures:

$$Q = \dot{m} \cdot C_p \cdot (T_{sup} - T_{ret})$$

Where,  $Q$  is the heat transmission,  $\dot{m}$  is the corresponding mass flow rate,  $C_p$  is specific heat capacity of water and  $T_{sup}$  and  $T_{ret}$  is supply and return temperatures in the temperature zone.

The mass flow rate is dependent on the velocity in the pipe, density of water and the pipe diameter:

$$\dot{m} = v \cdot \rho \cdot \pi \cdot \left(\frac{d^2}{4}\right)$$

Where  $\dot{m}$  is the flow rate,  $v$  is the flow velocity and  $\rho$  is the density of water.

The above equations are used for calculating the maximum allowable transmission capacity – considering the maximum velocity constraint. They are also used for calculation of hourly values of volume flow rate and flow velocity.

## 4.5 Pressure gradient calculation

The calculation of pressure gradient is used for determining the maximum transmission capacity based on maximum allowable pressure gradient, as well as for determining the hourly flow parameters.

Pressure losses are mainly due to frictional resistance. Calculating the Reynolds number for the flow is the first step. The procedure for calculating the Reynolds number is described as.

$$\mu = \exp(-3.016 + (-0.0139) \cdot (T_{sup} + 273.15))$$

$$\dot{V} = \frac{\dot{m}}{\rho} = \frac{Q}{\rho \cdot C_p \cdot (T_{sup} - T_{ret})}$$

$$v = \frac{\dot{m}}{\rho \cdot \pi \cdot \left(\frac{d^2}{4}\right)}$$



$$Re = \frac{\rho \cdot v \cdot d}{\mu}$$

Where,  $\mu$  is the dynamic viscosity [6],  $\dot{V}$  is the volume flow rate,  $v$  is the corresponding flow velocity and  $Re$  is the Reynolds number. For district heating systems the flow is between transitional and fully developed turbulent flow with Reynolds number being higher than  $10^4$ . The Darcy friction factor for such flows can be estimated using Serghide's method [2], which is similar to the paper by Gudmundsson 2021 [2] :

$$\begin{aligned}\alpha &= -2 \log_{10} \left( \frac{\epsilon}{3.7} - \frac{12}{Re} \right) \\ \beta &= -2 \log_{10} \left( \frac{\epsilon}{3.7} - \frac{2.51}{Re} \cdot \alpha \right) \\ \theta &= -2 \log_{10} \left( \frac{\epsilon}{3.7} - \frac{2.51}{Re} \cdot \beta \right) \\ f &= \left( \alpha - \frac{(\beta - \alpha)^2}{\theta - 2\beta + \alpha} \right)^{-2}\end{aligned}$$

Where,  $f$  is the Darcy friction factor [-] and  $\epsilon$  is the pipe roughness [m]. Thus, the pressure loss of the system and the friction pressure gradient can be calculated as.

$$\Delta P = \frac{fL}{d_{pipe}} \cdot \frac{\rho v^2}{2}$$

$$\text{Pressure gradient: } PG = \frac{\Delta P}{L}$$

Where,  $\Delta P$  is the major pressure loss and the pressure gradient is obtained by dividing it by the pipe length.

The above equations are used for determining the hourly pressure gradient. They are also used for calculating the maximum allowable transmission capacity, where the boundary condition for the maximum allowable pressure gradient in the system is a user input. The default value for most systems is 100 Pa/m and rarely goes up to 150 Pa/m in transmission pipes [6]. The calculated friction pressure gradient is compared with the maximum allowable value and converted to maximum allowable transmission capacity using the equations in section 4.4 .

## 4.6 Heat Loss calculation

A typical transmission pipe cross section representing the insulation and casing is shown in Figure 11.

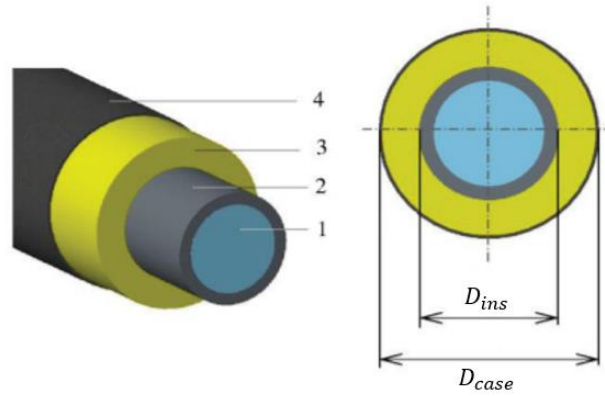


Figure 11. Representation of DH pipe where 1- is water, 2- is media pipe, 3- is insulation layer and 4- is outer casing.

The heat loss in a pipe is calculated with the following formula.

$$Loss = U \cdot L \cdot \left( (T_{sup} - T_g) + (T_{ret} - T_g) \right)$$

Where  $T_{sup}$  and  $T_{ret}$  is supply and return temperatures in the temperature zone.  $T_g$  is ground temperature.  $U$  is the specific heat loss, as shown in section 2.3 .

#### 4.7 Total pressure drop calculation

The total pressure drops in supply and return pipe can be calculated using a simplification: the pressure gradient in supply and return pipe are equal.

The calculation method presented in 4.5 are used to calculate the pressure gradient (PG) in supply pipe, thus making the assumption that the pressure gradient is equal in supply and return. Hence, the following formula can be used for calculation of total pressure drop in a transmission line:

$$TotPressDrop_{Trans} = PG \cdot L \cdot 2$$

#### 4.8 Work of pumps calculation

A rough estimation of the needed work from pumps can be made by assuming that the pumps need to cover the total pressure drop. This assumption will cause an underestimation of the work, since no information about the pipes are considered (bends, valves etc.). To estimate the work of pumps the following formula can be used:

$$WoP = TotPressDrop_{Trans} \cdot \dot{V}$$

Where both  $TotPressDrop_{Trans}$  and  $\dot{V}$  are different values for each time step.

## 5. Validation of the hydraulic calculation method used

### 5.1 Logstor validation

The hydraulic calculation method in energyPRO has been validated against Logstor Pressure Loss Calculator [7]. The Logstor Calculator is widely used and known in the industry and thus a good baseline for validation of the calculated pressure losses in energyPRO. The Logstor Calculator has also been used for validation in the paper by Gudmundsson (2021) [2].

The focus of the validation has been to compare calculations of flow velocity ( $v$ ) [m/s], pressure gradient ( $PG$ ) [Pa/m] and total pressure loss ( $\Delta P$ ) [kPa].

However, the user does not have access in the Logstor Pressure Loss Calculator to some of the parameters, these are: specific heat of water, density of water and pipe roughness. Whereas specific heat of water should not vary significantly, there could be a more significant variation in pipe roughness ( $\varepsilon$ ) and density of water ( $\rho$ ). The latter can in Logstor be a function of the change of water temperature in the pipe from inlet to outlet, which is not part of calculations in energyPRO. The pipe roughness is a constant value in energyPRO.

Moreover, the input about transmission of heat is given as a volume flow rate [m<sup>3</sup>/h] in the Logstor Calculator.

The volume flow rate is found based on the heat transmission ( $Q$ ) as follows:

$$\dot{V} = \frac{\dot{m}}{\rho} = \frac{Q}{\rho \cdot c_p \cdot (T_{sup} - T_{ret})}$$

Another difference is that the calculations performed in the Logstor Calculator are done for the forward and return pipe separately. In this way the parameters such as velocity ( $v$ ) [m/s] and pressure gradient ( $PG$ ) [Pa/m] have different values for forward and return flow. The pressure loss ( $\Delta P$ ) [kPa] is calculated as a sum of loss in the supply and return pipe. The approach in the energyPRO hydraulic calculations does not consider differences in the supply and return flow and the pressure loss is calculated only for the supply flow and multiplied by two. This gives a small difference in the total calculated pressure loss.

With these constraints on the validation, it still shows a good compliance between energyPRO and the Logstor Pressure Loss Calculator, when it comes to calculated flow velocity, pressure gradient and total pressure loss, with a deviation less than 1%.

Table 4 shows an example of the validation of the hydraulic calculation method in energyPRO against Logstor Pressure Loss Calculator, at a Logstor DN250 TwinPipe of 1000 meter. The average deviation is less than 0.5%.

Logstor DN250 TwinPipe 1000 meter						
Transmitted heat [MW-heat]	Velocity in pipe [m/s]		Pressure gradient [Pa/m]		Pressure loss [kPa]	
	ener- gyPRO	Logstor	ener- gyPRO	Logstor	ener- gyPRO	Logstor
1	0,15	0,15	0,86	1,00	1,7	1,7
2	0,30	0,30	3,15	3,00	6,3	6,4
3	0,45	0,45	6,83	7,00	13,7	13,8
4	0,60	0,60	11,89	12,00	23,8	24,0
5	0,75	0,76	18,32	18,50	36,6	36,9
6	0,91	0,91	26,14	26,50	52,3	52,5
7	1,06	1,06	35,32	35,50	70,6	70,8
8	1,21	1,21	45,88	46,00	91,8	91,8
9	1,36	1,36	57,82	58,00	115,6	115,5
10	1,51	1,51	71,13	71,00	142,3	141,9

Table 4. The hydraulic calculation method in energyPRO validated against Logstor Pressure Loss Calculator, at a Logstor DN250 TwinPipe 1000 meter.

## 6. References

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