Energy Efficient Design of District Heating Substations

Rasmus Lillqvist

Rasmus Lillqvist

Degree Thesis

Distributed energy systems

2017

DEGREE THESIS	
Arcada	
Degree Programme:	Distributed energy systems
Identification number:	6162
Author:	Rasmus Lillqvist
Title:	Energy efficient design of district heating substations
Supervisor (Arcada):	Johnny Biström
Commissioned by:	Alfa Laval Nordic Oy

Abstract:

A certification system and point-based labelling system for district heating substations called Eco-efficient substation is about to be released in Europe. In this thesis, the potential benefits of the standardization were evaluated in terms of market fairness and transparency. A fictional building was specified and annual energy saving potential was calculated for each category that entitle to points in the labelling system. In the calculations, Finnish minimum requirements specified in regulations, were used as a reference to determine how much energy, or in some cases, costs, can be saved annually by designing energy efficient substations with the best level Eco-efficient substation labelling standard. A saving potential of 3.3 % annual energy consumption was determined for the example building. An 8.6 % annual cost saving in district heating was also determined, this including both direct, and indirect costs. The standardization system was concluded to have a potential positive environmental impact, as well as a strong possibility to improve market fairness. Cost and energy savings were noted to be positive for both the substation customer and the district heat provider. As part of this thesis I have produced a web-browser based software. The software compiles a tender specification where the dimensioning values and user-chosen substation functions are presented with the corresponding Eco-efficient substation label. The software is designed to help consultants understand the Eco-efficient substation concept, to calculate the correct label for a substation, and to compile the information into a technical specification to use in the tenders. Basic instructions on how to use this tool, and how it works play a part in this document.

Keywords:	District heating, Eco-efficient substation
Number of pages:	53
Language:	English
Date of acceptance:	

EXAMENSARBETE	
Arcada	
Utbildningsprogram:	Distribuerade energisystem
Identifikationsnummer:	6162
Författare:	Rasmus Lillqvist
Arbetets namn:	Energy efficient design of district heating substations
Handledare (Arcada):	Johnny Biström
Uppdragsgivare:	Alfa Laval Nordic Oy

Sammandrag:
En poängbaserad certifiering och märkning av fjärrvärmecentraler har utvecklats i Europa. Standarden heter Eco-efficient substation och den kommer inom kort att tas i bruk i Europa. I detta examensarbete har eventuella fördelar med standardiseringen studerats med tanke på rättvisa samt genomskinlighet inom marknaden. En exempelbyggnad fastställdes och uträkningar utfördes för energikonsumptions besparingar, samt i vissa fall kostnadsbesparingar. I uträkningarna jämfördes en fjärrvärme undercentral med maximala Eco-efficient substation poäng med en undercentral som endast uppfyller minimikraven i Finland. En årlig potentiell energibesparning på 3,3 % kunde fastställas för undercentralen med fulla Eco-efficient substation poäng. En besparning på 8,6 % i indirekta, samt direkta, fjärrvärmekostnader kombinerade kunde även anses mycket sannolik. Standardisering kunde också anses ha en positiv miljöinverkan samt en stor sannolikhet att kunna påverka marknadsrättvisan positivt. Ekonomiska och energiekonomiska fördelar kunde fastställas ha en positiv inverkan för både fjärrvärme kunder samt fjärrvärme leverantörer. Som en del av detta examensarbete har jag producerat ett webläsarbaserat program, som räknar ut Eco-efficient poängen, samt märkningen på basis av valda värden och funktioner för undercentralen. Programmet fogar ihop informationen till ett dokument som planeraren kan använda i offertförfrågningen som del av tekniska specificationen för undercentralen. Basinstruktioner samt funktionsprinciper för detta program finns beskrivna i detta examensarbete.

Nyckelord:	Fjärrvärme, Eco-efficient substation, Undercentral
Sidantal:	53
Språk:	Engelska
Datum för godkännande:	

OPINNÄYTE	
Arcada	
Koulutusohjelma:	Hajautetut energiajärjestelmät
Tunnistenumero:	6162
Tekijä:	Rasmus Lillqvist
Työn nimi:	Energy efficient design of district heating substations
Työn ohjaaja (Arcada):	Johnny Biström
Toimeksiantaja:	Alfa Laval Nordic Oy

Tiivistelmä:

Euroopassa otetaan kohta käyttöön lämmönjakokeskusten sertifiointi- sekä energiamerkintäjärjestelmä nimeltään Eco-efficient substation. Merkinnän taso määräytyy pisteillä, joita kertyy parantamalla lämmönjakokeskuksen energiatehokkuutta käyttämällä tiettyjä mitoitusparametrejä sekä lisäämällä tiettyjä toimintoja. Tässä opinnäytetyössä on selvitetty voiko tämä standardisointi- ja merkintäjärjestelmä vaikuttaa positiivisesti markkinoiden läpinäkyvyyteen ja oikeudenmukaisuuteen. Lisäksi on suoritettu laskenta jossa määritetään esimerkkitalon energian-, sekä joissain tapauksissa kulunsäästöpotentiaali vertaamalla kahta tapausta. Yhdessä tapauksessa talossa on lämmönjakokeskus joka ainoastaan täyttää suomen minimivaatimukset, ja toisessa tapauksessa lämmönjakokeskus on oikeutettu maksimi Eco-efficient substation pisteisiin. Energiansäästöpotentiaalin todettiin olevan 3,3 % tapauksessa jossa oli maksimi Eco-efficient substation pisteet. Lisäksi todettiin että 8,6 % säästöpotentiaali on todennäköinen kaukolämpöön liittyvissä, epäsuorissa ja suorissa kuluissa yhteensä. Energiamerkintäjärjestelmän todettiin pitävän sisällään etuja joista hyötyy sekä kaukolämmön toimittaja, että asiakas. Myös positiivinen vaikutus markkinoiden oikeudenmukaisuuteen sekä ympäristövaikutuksiin pystyttiin toteamaan. Osana opinnäytetyötä olen tehnyt selainpohjaisen ohjelman. Ohjelman tarkoitus on laskea oikea Eco-efficient substation merkintä annettujen mitoitusparametrien sekä valittujen toimintojen perusteella. Tämän jälkeen ohjelma kokoaa mitoitustiedot tekniselle erittelylle kytkentäkaavion kanssa, ja tätä dokumenttia suunnittelija voi käyttää osana työselitystä tarjouspyyntövaiheessa.

Avainsanat:	Kaukolämpö, Eco-efficient substation, Lämmönjakokeskus
Sivumäärä:	53
Kieli:	Englanti
Hyväksymispäivämäärä:	

CONTENTS

1 INTRODUCTION

1.1 Background

In December 2015 Dansk Standard published a CEN (European Committee for Standardization) workshop agreement (CWA 16975), with the title *“Eco-efficient Substations for District Heating”*. In the publication is specified what an eco-efficient substation (EES) is and how it can be certified and labelled. The workshop agreement focuses on optimizing the energy efficiency in district heating substations throughout Europe and aims to harmonize the manners and technical specifications within substation design. This is done by introducing a labelling system that an EES-certified manufacturer has the right to use, to affirm quality and energy efficiency of the product. It is based on a system of points that can be earned by improving certain aspects of the substations performance. (European Committee for Standardization 2015)

Teijo Aaltonen has represented Alfa Laval Nordic in the EES project and I have been assisting him in calculations and text production and editing for the documentation. Now the EES labelling and certification system is being finalized and ready to be introduced to the European market. In this study, I hope to answer questions that may be raised about EES upon its release.

1.2 Objectives of study

The main purpose of this study is to determine the potential of energy saving in energy efficient design of district heating customer substations. As part of the project I will try to establish if there is justification and need for an energy labelling, standardization and certification such as EES. Focus will be the need specifically in the Finnish market, and therefore the requirements specified by EES will be compared to the Finnish regulations and guidelines specified in *“Rakennusten kaukolämmitys Määräykset ja ohjeet Julkaisu K1/2013”* (Energiateollisuus ry 2013). This publication will be referred to as simply K1 in this study.

To determine the energy saving potential that lays in EES design I will establish a fictional example building. I will then carry out two different sets of calculations for each category and subcategory, that entitle to EES points. Case 1 will in all calculations represent a substation design that only fulfills the minimum requirements specified in K1. Case 2 will represent a substation design entitled to maximum amount of EES points. I will then compare the results in terms of energy usage, over a one year period. In some categories, there is no difference in energy usage, but instead a potential cost saving. In these calculations, I will use annual costs in € for the comparison. I will study all conditions and features of substations that entitle to EES points separately, and present arguments that support the values used in the calculations.

In this study, I hope to conclude if there is a need for the EES certification system regarding market fairness and transparency. Could EES certification be a benefit for the end-users, substation manufacturers and, or district heating facilities? Could EES certification improve competitiveness of district heating compared to other forms of heating?

As part of the project I have developed a web-browser based calculation tool. It uses user input data to calculates the EES-label and gives an insight on what annual savings can be achieved by picking features and functions that entitle to EES points. This software is more thoroughly discussed in section 5.

2 ECO-EFFICIENT SUBSTATION

2.1 General

In CWA 16957 the contexture of an EES is described, this includes a specification of features and performance figures that need to be fulfilled for the substation to be considered an EES. After the minimum requirements are explained, every feature that can earn the substation EES points is described in detail, both in terms of how points are earned and in what way this may affect the energy efficiency of the substation. The document also includes needed information about certification and testing procedures. It is explained in detail how an application procedure for a certificate is to be carried out. (European Committee for Standardization 2015)

2.2 Scope of EES

For a substation to be considered an EES, it cannot have heat exchanger capacity over 500 kW per heat exchanger. Single house substations are not part of EES certification, but no minimum capacity of individual heat exchangers is specified. An EES must always fulfill regulation and law of the locale where it is to be installed as well as the requirements specified in CWA 16975. It is to be marked with the correct label prior to leaving the factory and the manufacturer is to have an EES certificate approved by the certification Board. An EES must always include a document where the justification for corresponding label is specified. (European Committee for Standardization 2015)

2.3 EES label

Four different labels are identified based on points from functions and substation performance. They include Platinum (the best label), Gold, Silver, and Bronze (basic level). In table 2 the categories for points are listed. The summarized points for the EES corresponds with which label the EES is entitled to as illustrated in table 1. Both tables are used for substations with domestic hot water heat exchanger and one or more space heating heat exchangers.

Table 1, Eco efficient substation label based on points.

Points	Eco Efficient Substation label
70-100	EES - Platinum
45-69	EES - Gold
16-44	EES - Silver
0-15	EES - Bronze

Table 2, Summary of rating points.

Category for rating points	Minimum points to reach Silver level	Minimum points to reach Gold level	Minimum points to reach Platinum level	Max Points
2. Heat losses	0	0	0	10
3. Pressure losses in secondary side heating	0	0	3	5
4. Cooling of return temperature (heating)	0	10	10	20
4. Cooling of return temperature (DHW)	0	7	7	15
5.1 Control and limitation of max capacity / primary flow	0	0	0	15
5.2 Indoor temperature data	0	0	0	5
5.3 Remote monitoring and control	0	7	15	25
5.4 Eco function	0	5	5	5
Total points				100

A different table is to be used if the substation only includes heating heat exchangers. (European Committee for Standardization 2015)

3 EXAMPLE BUILDING AND CALCULATING ENERGY SAVING POTENTIAL

In this section energy efficiency of a substation designed per Finnish national minimum energy efficiency performance requirements specified in K1 is compared to a substation design per maximum EES points (100 points). The substation energy usage over a one year period is calculated for each case and compared to determine the energy saving potential of energy efficient design of district heating substations.

3.1 Example building information

The example building will be based on an example of a multi-story residential building from district heating price statistics, published by Energiateollisuus ry. The building explained in the publication is fictional, and aims to represent typical specifications for this type of building when the publisher presents statistics about district heating prices and expenses. The following values will be used from the publication:

- Number of apartments: 80
- Total district heating energy usage per year: 600 MWh
- Total hourly capacity demand for district heating: 230 kW
- Hourly domestic hot water district heating capacity demand: 69 kW
- Heating district heating capacity demand: 160 kW
- Total hourly district heating flow demand: 2.8 m^3/h
- Hourly domestic hot water flow demand: 0.68 m^3/h
- Heating district heating flow demand: 2.02 m^3/h

According to Energiateollisuus ry, the hourly demands listed above are calculated by following recommendations in the publication *”Teho ja vesivirta kaukolämmön maksuperusteina Suositus K15/2014”*. (Energiateollisuus ry 2011) This means that from the hourly demands above the actual capacity and flow demands can be determined for the domestic hot water heat exchanger. In the publication, it is recommended to use a factor of 20 % of total domestic hot water heat exchanger capacity and flow to determine the hourly capacity and flow for a building with 6-100 apartments (Energiateollisuus ry 2014 p.13). By reversing the calculation, the actual capacity and flow demands for domestic hot water heat exchanger for the building can be retrieved. The calculations are done as follows:

For capacity:

$$\Phi_{\mathrm{DHW}} = \frac{\Phi_{\mathrm{DHWh}}}{20\ \%}$$

where:

Φ_{DHWh} is domestic hot water heat exchanger hourly capacity demand kW

Φ_{DHW} is domestic hot water heat exchanger capacity demand in kW

This gives:

$$\Phi_{\mathrm{DHW}} = \frac{69\ \mathrm{kW}}{20\ \%} = 345\ \mathrm{kW}$$

For flow:

$$\dot{V}_{\mathrm{DHW}} = \frac{\dot{V}_{\mathrm{DHWh}}}{20\ \%}$$

where:

$\dot{V}_{DHWh}$ is domestic hot water heat exchanger hourly flow demand in m^3/h

$\dot{V}_{DHW}$ is domestic hot water heat exchanger flow demand m^3/h

This gives:

$$\dot{V}_{\mathrm{DHW}} = \frac{0.68\ \mathrm{m^3/h}}{20\ \%} = 3.4\ \mathrm{m^3/h}$$

The example building domestic hot water heat exchanger capacity and flow will thus be 345 kW and 3.4 m^3/h. The heating heat exchanger capacity above is not evened out over an hour, which means that the capacity, 160 kW mentioned in the example is the actual heat exchanger capacity. Same goes for the heating heat exchanger district heating flow demand being 2.02 m^3/h. The flow demands can now be summarized to 5.42 m^3/h or 1.51 dm^3/s, which is the maximum simultaneous district heating flow demand.

Knowing the capacity and flow demands for the heating heat exchanger the primary side return temperature can be determined as follows:

$$T_{\mathrm{DHreturn}} = T_{\mathrm{DHflow}} - \frac{P}{\dot{Q}c}$$

where:

$T_{DHreturn}$ is district heating return temperature in °C

T_{DHflow} is district heating flow temperature in °C

P is heat exchanger capacity in kW

$\dot{Q}$ is district heating water flow in dm^3/s

c district heating water specific heat in J/kg·K

This gives:

$$T_{\mathrm{DHreturn}} = 115\ °\mathrm{C} - \frac{160\ \mathrm{kW}}{\left(0.56\ \frac{\mathrm{dm^3}}{\mathrm{s}}\right)\left(4.186\ \frac{\mathrm{J}}{\mathrm{kgK}}\right)} = 46\ °\mathrm{C}$$

The heating heat exchanger return temperature is 46 °C in the example case. The example building has a radiator network for heating. The network flow temperature is 60 °C and return temperature 40 °C. This means that the district heating return temperature must be adjusted to 43 °C in the example case since the temperature difference between secondary side return and district heating return cannot exceed 3 °C according to K1 (Energiateollisuus ry 2013 p.57). Therefore, the final temperature program for the district heating side is considered 115-43 °C for all calculations.

3.2 District heating network connected to example building

In order to not single out the calculations to only apply to a specific district heating supplier, average values in Finland will be used regarding the district heating network. All values will be corresponding with high temperature networks as the low temperature networks only take up a small part of the Finnish district heating network (Energiateollisuus ry 2006 p.143). According to statistics published in "*Kaukolämpötilasto 2015"* the district heating net production in 2015 in Finland was 33270 GWh, of this 3420 GWh was lost in distribution losses and measurement differences. An assumption will be made that the measurement differences included in this figure is mostly evened out between positive and negative and thus marginal. Therefore, the distribution heat losses in all calculations will be based on the 3420 GWh. Concluded from this is that 10 % of the produced district heating energy was lost in distribution heat losses.

146370 buildings were connected to a district heating network in Finland in 2015. The combined network length was 14600 km, which makes the average length of network per connected customer to be 100 m. (Energiateollisuus ry 2016 p.3-4)

The supply temperature of the district heating water in the network is dependent on outside air temperature as seen in figure 1.

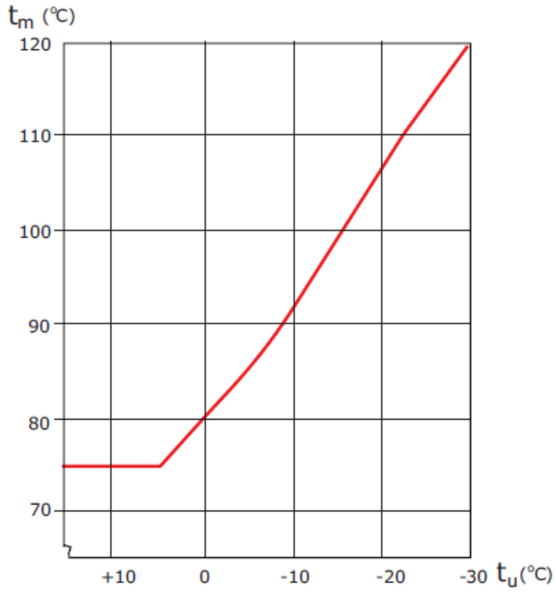

Figure 1. District heating supply temperature as function of outside air temperature. (Energiateollisuus ry 2006 p.336)

The average temperatures in Finnish district heating networks are 85 °C for the flow pipe and 55 °C for the return pipe. (Energiateollisuus ry 2006 p.216)

3.3 Calculations for each category that entitles to points

In the upcoming calculations for each category, Case 1 will depict a substation design according to minimum regulations in Finland, whereas case 2 will depict an EES design worthy of full 100-point Platinum standard.

3.3.1 Heat losses

In CWA 16975 is specified that an EES must be insulated, and 10 points can be earned by insulating the primary side piping with an insulation material that has a U-value lower than, or equal to 0.5 W/(m^2K) (European Committee for Standardization 2015 p.22-23).

In K1 it is also stated that the substation shall be insulated. In neither document, any specification for minimum requirements on insulation material or thickness is mentioned. In K1 the only part requiring insulation that has a specific quality standard set is the domestic hot water circulation pipe. It must be insulated with a material and thickness with the thermal resistivity of at least 1 m^2K/W. (Energiateollisuus ry 2013 p.58) In *"D1 Kiinteistöjen vesi- ja viemärilaitteistot MÄÄRÄYKSET JA OHJEET 2007"* it is stated that this can be achieved with 50 mm thick insulation with a k-value of 0.05 W/mK (Ympäristöministeriö 2007a p.9). This is a false statement, since the increase in heat loss is nonlinear in accordance with the pipe diameter if the insulation thickness is not increased. The calculation in the publication is based on heat transfer through an insulation layer as part of a flat surfaced wall per square meter. The same calculation cannot be applied to piping insulation layers. It is therefore somewhat misleading to use units involving surface areas when describing piping insulation. A better praxis would be to use a coefficient in W/Km, where m would be the pipe length in meters. Same problem arises when specifying the overall heat transfer coefficient in U-value, W/m^2K. In CWA 16975 a formula for calculating the U-value, taking into consideration pipe dimension and insulation thickness is however presented (European Committee for Standardization 2015 p.24). In following calculations, it is assumed that the same insulation thermal conductivity mentioned in K1, 0.05 W/mK (k-value of insulation material) is used for the primary side piping insulation.

To calculate the heat losses the DN-size of the primary side piping is to be determined. CWA 16975 does not specify any limits for pressure drops in primary side piping. It only states that no unnecessary pressure drops should be caused by piping in general, and that the pipe dimensioning shall be done per calculated flows. The total flow demand was determined to be 1.51 dm^3/s in section 3.1. Looking up this value from maximum flows for DN-sizes listed in K1, the dimension DN40 is sufficient for the primary side piping (Energiateollisuus ry 2013 p.20). The outer pipe diameter for a DN40 district heating pipe is 48 mm (Energiateollisuus ry 2006 p.217). The needed insulation thickness needs to be calculated for each case. A formula that lacks an explicit solution for the needed insulation thickness based on R-value has been published by insulation manufacturer Armacell (Armacell 2010). To clarify the following calculations, an explanation as to how this formula is derived is needed. It is based on the following principles and formulas. First the formula for conductive resistivity of a cylindrical layer (Cengel 2002 p.147):

$$R_{cyl} = \frac{\ln\left(\frac{r_1}{r_2}\right)}{2\pi L k}$$

where:

R_{cyl} is insulation layer conductive resistivity in K/W

ln is natural logarithm

k is insulation material thermal conductivity in W/mK

r_1 is pipe radius in m

r_2 is pipe radius and insulation material thickness summarized in m

L is examined pipe length in m

As the R_{cyl} unit is in K/W, it is necessary to add an area in m^2 to make it match the needed R-value unit of m^2K/W. The new area will be called $A_{external}$ as is depicts the outer surface area of the insulation material. Now a conclusion can be made with formula:

$$R = R_{cyl} A_{external} = \frac{\ln\left(\frac{r_1}{r_2}\right)}{2\pi L k} \cdot 2\pi r_2 L$$

From this equation, everything else cancels each other out, and all that is left is the formula published by Armacell (Armacell 2010):

$$R = \frac{r_2 \ln\left(\frac{r_2}{r_1}\right)}{k}$$

To unify the units for the calculation the thermal resistivity of 1 m^2K/W is converted to U-value in accordance with EES-specification for the requirement. The conversion is done as follows (Cengel 2002 p.175):

$$R^{-1} = U$$

Which gives:

$$U = 1\ \mathrm{m^2K/W^{-1}} = 1\ \mathrm{W/(m^2K)}$$

Now the Armacell formula can be rewritten as:

$$U = 1/\left(\frac{r_2 \ln\left(\frac{r_2}{r_1}\right)}{k}\right)$$

where:

R is insulation thermal resistivity in m^2K/W

ln is natural logarithm

U is insulation thermal conductivity in W/m^2K

k is insulation material thermal conductivity in W/mK

r_1 is pipe radius in m

r_2 is pipe radius and insulation material thickness summarized in m

This formula lacks an explicit solution for r_2, and the required insulation thickness to reach a certain U-value can thus only be solved implicitly. In table 3 the corresponding U-values for different thicknesses of insulation layers with a k-value of 0.05 W/mK for a DN40 pipe are presented.

Table 3. Needed insulation thicknesses to reach specific U-values.

U-value W/m^2K	Insulation thickness in mm	
1.142	30	
1.096	31	
1.054	32	
1.014	33	
0.977	34	Case 1.
0.942	35	
0.909	36	

U-value W/m^2K	Insulation thickness in mm	
0.544	54	
0.531	55	
0.519	56	
0.507	57	
0.496	58	Case 2.
0.486	59	
0.475	60	

The used in calculating the heat losses for primary side piping in each case are; 34 mm for case 1 and 58 mm for case 2.

The length of the district heating flow and return pipes of the substation needs to be known for the calculating the heat losses. Using figure 2 an estimation is made that the district heating flow pipe length is 0.6 m (red marking), and the return pipe length is 0.8 m (green and orange marking).

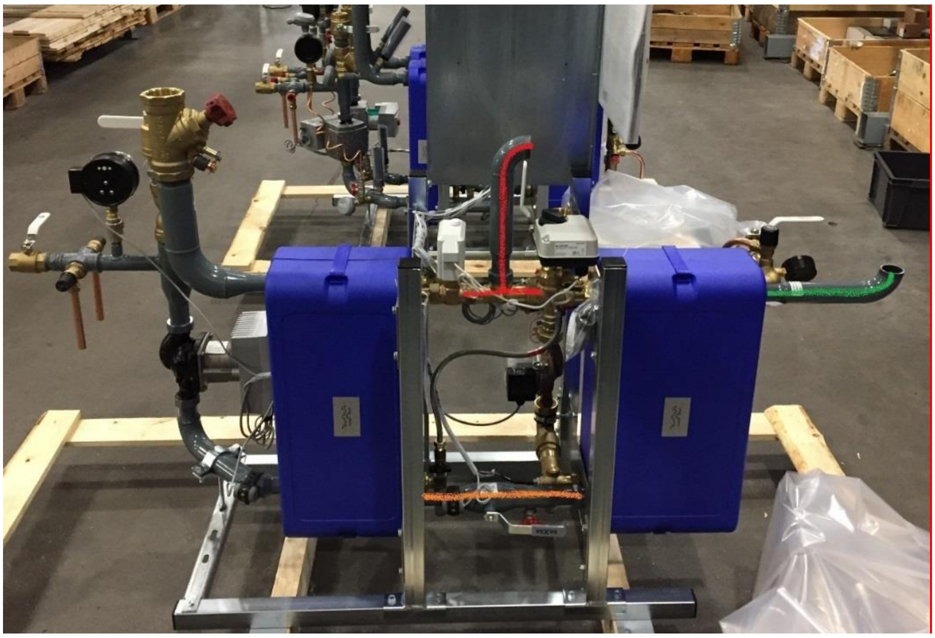

Figure 2. Alfa Laval Maxi substation, marked with colors; red is district heating flow piping, green is district heating return pipe, orange is district heating return from heating heat exchanger into domestic hot water pre-heater. (Photo; J-Steel 2017)

The desired room temperature around the substation is assumed to be 21 °C. Convection resistance between the fluid and pipe, and convection resistance between air and the insulation outer surface will be considered marginal and are neglected.
Using the yearly average temperatures of district heating network specified in section 3.1 the yearly heat loss for each case can be determined using the following formula (Cengel 2002 p.136, p.147 (formulas combined and rearranged)):

$$Q=\left[\frac{T_{1\infty}-T_{3\infty}}{\left(\frac{ln\left(\frac{r+L_{\text{ins}}}{r}\right)}{2\pi L_1 k}\right)}+\frac{T_{2\infty}-T_{3\infty}}{\left(\frac{ln\left(\frac{r+L_{\text{ins}}}{r}\right)}{2\pi L_2 k}\right)}\right]h\,(0.001)$$

where:

Q is yearly heat loss from primary side piping in kWh

$T_{1\infty}$ is yearly average temperature of district heating flow °C

$T_{2\infty}$ is yearly average temperature of district heating return in °C

$T_{3\infty}$ is desired temperature around substation in °C

L_1 is length of district heating flow pipe in m

L_2 is length of district heating return pipe in m

r is primary side piping radius in m

L_{ins} is piping insulation thickness in m

k is insulation material h

h is hours in one year

0,001 is factor for converting Wh to kWh

Case 1. Calculated yearly heat loss with insulation U-value 1 W/m^2K

$$Q=\left[\frac{85\text{ °C}-21\text{ °C}}{\left(\frac{\ln\left(\frac{(0.024\text{ m}+0.034\text{ m})}{0.024\text{ m}}\right)}{2\pi(0.6\text{ m})\frac{0.05\text{ W}}{\text{mK}}}\right)}+\frac{55\text{ °C}-21\text{ °C}}{\left(\frac{\ln\left(\frac{(0.024\text{ m}+0.034\text{ m})}{0.024\text{ m}}\right)}{2\pi(0.8\text{ m})\frac{0.05\text{ W}}{\text{mK}}}\right)}\right](8760\text{ h})(0.001)$$

$$=4714\text{ kWh}$$

Case 2. Calculated yearly heat loss with insulation U-value 0.5 W/m^2K

$$Q = \left[\frac{85\ \text{°C} - 21\ \text{°C}}{\left(\frac{\ln\left(\frac{(0.024\ \text{m} + 0.058\text{m})}{0.024\ \text{m}}\right)}{2\pi(0.6\ \text{m})\frac{0.05\ \text{W}}{\text{mK}}} \right)} + \frac{55\ \text{°C} - 21\ \text{°C}}{\left(\frac{\ln\left(\frac{0.024\ \text{m} + 0.058\ \text{m}}{0.024\ \text{m}}\right)}{2\pi(0.8\ \text{m})\frac{0.05\ \text{W}}{\text{mK}}} \right)} \right] (8760\ \text{h})(0.001)$$

$$= 3385\ \text{kWh}$$

This means that by choosing an insulation with a U-value of 0.5 W/(m^{2}K) instead of the assumed insulation with U-value 1 W/(m^{2}K), a yearly saving of 1329 kWh is achieved by reducing the heat losses in primary side piping. As this heat loss happens after the energy meter the saving is directed to the customer. The reduction in heat loss is 28 %.

3.3.2 Pressure losses in secondary side heating

When choosing a circulation pump for heating networks the pump needs to be able to deliver the required flow to a specific lifting height. The required lifting height is determined by the hydraulic resistance in the heating network as well as by pressure drops caused by components in the heating substation connected to the network. The heat exchanger is one of these components and by choosing a heat exchanger with a lower secondary side pressure drop, a saving in electricity can be achieved.
5 EES points can be earned if the heat exchanger secondary side pressure drop is below or equal to 12 kPa. 3 points are earned for a maximum of 17 kPa. (European Committee for Standardization 2015 p.24) K1 specifies the heating circuit secondary side heat exchanger maximum pressure drop to 20 kPa (Energiateollisuus ry 2013 p.9).

For calculating the electricity saving in using a heat exchanger causing 12 kPa secondary side pressure drop compared to one that causes 20 kPa, a circulation pump for the network is to be specified. For this the secondary side flow is needed. It can be calculated using formula:

$$\dot{Q} = \frac{P}{c(T_2 - T_1)}$$

where:

$\dot{Q}$ is heating network flow in dm^3/s

P is heat exchanger capacity in kW

c heating network water specific heat in J/kg·K

T_1 is heating network return temperature in °C

T_2 is heating network flow temperature in °C

$$\dot{Q} = \frac{160 \text{ kW}}{4.186 \text{ J/kg} \cdot \text{K}(60\text{ °C} - 40\text{ °C})} = 1.91 \text{ dm}^3/s$$

The heating network flow being 1.91 dm^3/s, and assuming the secondary side circuit pressure drop to 35 kPa, and adding the maximum allowed heat exchanger pressure drop of 20 kPa, the combined pressure drop is 55 kPa in case 1. The chosen pump for the network circulation is Grundfos Magna 3 25-120. The Magna 3 pump is auto adaptive and the 25-120 model is of a realistic size for the example building. The electrical efficiency of the pump is 0.98-0.99 and maximum power output is 193 W. Using a Grundfos product selection tool, which can be found online the pump is determined to run at 0.177 kW in case 1. Lowering the heat exchanger secondary side pressure drop for case 2 to 12 kPa, which entitles to maximum points, and using the same tool, the pump is determined to run at 0.154 kW. (Grundfos product center 2017) Calculations for the annual pumping electricity usages in both cases can now be done with formula.

$$E = \frac{hP}{\varphi}$$

where:

P is pump output power in kW

φ is circulation pump electrical efficiency factor

h is hours

E is pump electrical energy usage in kWh/year

Case 1.

$$E = \frac{((0.177\ \text{kW} \cdot 8760\ \text{h}))}{0.99} = 1551\ \text{kWh}$$

Case 2.

$$E = \frac{(0.154\ \text{kW} \cdot 8760\ \text{h})}{0.99} = 1363\ \text{kWh}$$

This shows that 188 kWh can be saved annually by choosing a heat exchanger with maximum EES points compared to one that fulfills minimum regulations in Finland. It is notable that this is a saving in electricity, not in district heat. The utilizer of this saving is the district heating customer and the saving is 12 % in pump electricity usage. Furthermore, it is notable that a lower secondary side pressure drop makes the radiator network more stable.

In general, the electricity usage of domestic hot water circulation pumps is small and therefore the saving caused by this can be considered marginal. Even if no points are awarded for reducing domestic hot water heat exchanger pressure drop it is recommended in the EES specification (European Committee for Standardization 2015 p.24).

3.3.3 Cooling of the return temperature

A high cooling of the district heating water in all customer substations is essential in helping reduce heat losses in the network and improve overall efficiency of the grid (Frederiksen & Werner 2013 p.363-364). EES points can be earned by choosing heat exchangers that can reduce the return temperature efficiently. Points can be earned for both domestic hot water heat exchanger and for heating heat exchangers. In this section both domestic hot water heat exchanger and heating heat exchanger will be handled separately.

Domestic hot water heat exchanger

In Finland, the temperature program for domestic hot water heat exchangers is set to values seen in table 4.

Table 4. Domestic hot water heat exchanger dimensioning parameters. (Energiateollisuus ry 2013 p.8)

District heating flow	District heating re-turn	Cold water	Hot water
70°C	20°C (MAX)	10°C	58°C

In table 5 the middle level rating for 7 EES points is illustrated and in table 6 the best level worthy of 15 points.

Table 5. Middle level for domestic hot water (European Committee for Standardization 2015 p.26)

DHW	ΔT_2				
$\vartheta 2$	ΔT_2=< 35	ΔT_2=36-40	ΔT_2=41-45	ΔT_2=46-50	ΔT_2=51-60
>=40	*2,0*	*2,5*			
35-39	*2,5*	*3,0*	*3,5*		
30-34	*3,5*	*4,0*	*4,0*	*5,0*	
25-29	*4,5*	*5,0*	*5,5*	*6,5*	*9,0*
20-24	*6,0*	*6,5*	*7,0*	*8,5*	*9,5*
15-19	*8,0*	*8,5*	*9,0*	*9,5*	*10,5*
10-14	*8,5*	*9,5*	*10,5*	*11,5*	*12,0*
<=9	*10,0*	*11,5*	*13,0*	*14,0*	*15,0*

Table 6. Best level for domestic hot water, yellow marking shows the minimum Finnish requirement, which entitles to 15 EES points. (European Committee for Standardization 2015 p.26)

DHW	ΔT_2				
$\vartheta 2$	ΔT_2=< 35	ΔT_2=36-40	ΔT_2=41-45	ΔT_2=46-50	ΔT_2=51-60
>=40	*1,0*	*1,5*			
35-39	*1,5*	*2,0*	*2,5*		
30-34	*2,5*	*3,0*	*3,0*	*4,0*	
25-29	*3,5*	*4,0*	*4,5*	*5,5*	*8,0*
20-24	*5,0*	*5,5*	*6,0*	*7,5*	*8,5*
15-19	*7,0*	*7,5*	*8,0*	*8,5*	*9,0*
10-14	*7,5*	*8,5*	*9,5*	*10,0*	*10,0*
<=9	*9,0*	*10,5*	*11,5*	*12,0*	*12,0*

If these values are implemented into the procedure described in CWA 16975 to determine the ϑ_1 value in the tables, we automatically receive a value entitling to best level (marked yellow in table 6).

The calculations as described in CWA 16975:

$$\vartheta_2 = T_{11} - T_{22}$$
$$\Delta T_2 = T_{22} - T_{21}$$

where:

T_{11} is district heating flow temperature in °C

T_{22} is domestic hot water flow temperature in °C

T_{21} is cold water temperature in °C

This gives:

$$\vartheta_2 = 70\ ℃ - 58\ ℃ = 12\ ℃$$

$$\Delta T_2 = 58\ ℃ - 10\ ℃ = 48\ ℃$$

Now the corresponding values are looked up in the table above, and the maximum ϑ_1 value is found (marked with yellow in table 6). The ϑ_1 value is used to calculate the maximum allowed district heating return temperature to obtain the points. Calculation is done with formula:

$$T_{\text{DHreturn}} = T_{21} + \vartheta_1$$

where:

$T_{DHreturn}$ is the maximum allowed district heating return temperature in °C

T_{21} is cold water temperature in °C

ϑ_1 is the value obtain from the table.

This gives:

$$T_{\text{DHreturn}} = 10\ ℃ + 10\ ℃ = 20\ ℃$$

Which is the maximum allowed district heating return temperature in domestic hot water heat exchangers in Finland as seen earlier in table 4. (European Committee for Standardization 2015 p.15-16)

The Finnish standard for domestic hot water heat exchanger performance is set higher than the one recommended by Euroheat & power, which has worked as a frame for the EES workshop development (Euroheat & Power 2008 p.14). The EES points for the domestic hot water will therefore not result in any energy saving in Finland. In other European countries savings are likely to be achieved if the dimensioning temperature regulations are less strict.

Space heating heat exchanger

The heating heat exchanger temperature program determined for the example building earlier in section 3.1 is illustrated in table 7.

Table 7. Example building temperature program, heating heat exchanger

District heating flow	District heating return	Secondary return	Secondary flow
115°C	MAX 43°C (Sec.ret.+ 3°C)	60°C	40°C

In table 8 the ϑ1-values for EES-middle level is illustrated, in table 8 the values that entitle to best level.

Table 8. Middle level for heating (European Committee for Standardization 2015 p.25)

Space Heating	**ΔT_2**		
ϑ2	**ΔT_2 = < 20**	**ΔT_2 = 21-30**	**ΔT_2 = 31-45**
>=40	*2,0*	*2,0*	*2,0*
35-39	*2,0*	*2,0*	*2,5*
30-34	*2,0*	*2,0*	*3,0*
25-29	*2,5*	*2,5*	*4,0*
20-24	*3,0*	*3,0*	*5,0*
15-19	*4,0*	*4,5*	*5,5*
10-14	*4,5*	*5,5*	*7,0*
<=9	*5,5*	*8,0*	*10,5*

Table 9. Best level for heating (European Committee for Standardization 2015 p.25)

Space Heating	**ΔT_2**		
ϑ2	**ΔT_2 =< 20**	**ΔT_2 = 21-30**	**ΔT_2 = 31-45**
>=40	*1,0*	*1,0*	*1,0*
35-39	*1,0*	*1,0*	*1,5*
30-34	*1,0*	*1,0*	*2,0*
25-29	*1,5*	*1,5*	*3,0*
20-24	*2,0*	*2,0*	*4,0*
15-19	*3,0*	*3,5*	*4,5*
10-14	*3,5*	*4,5*	*5,5*
<=9	*4,5*	*6,5*	*8,0*

If the values in table 8 can be met 10 EES points are earned, 20 EES points are earned if the heat exchanger can perform according to table 8. Applying the same calculations as for domestic hot water heat exchanger for the space heating heat exchanger no points in case 1 are to be earned. The minimum EES standard, 3.0 °C, is still fulfilled, the table for that can be found in CWA 16975. If the district heating return temperature is cooled down to 41 °C by the heat exchanger, the best level and 20 points can be achieved. This ϑ1-value is marked as green in table 9, and represents case 2. (European Committee for Standardization 2015 p.14, p.25)

In section 3.2 the district heating yearly average return temperature in the network was determined to 55 °C and the average length of district heating network pipes per customer was determined to 100 m. The average heat transmission coefficient of a district heating network in Sweden is 0.8-1.0 W/(m^2K), and the average pipe diameter is 140 mm (Frederiksen & Werner 2013 p.83). The Swedish district heating network is highly similar to the Finnish. The Swedish network has a distribution heat loss between 9-10 %. (Masatin 2016 p.279, p.283) This correlates with the Finnish value, 10 %, mentioned earlier in section 3.1. In calculations, the value 1.0 W/m^2K will therefore be used for heat transfer coefficient and 140 mm for average pipe diameter. Average temperature in Finland nationwide is 3 °C. (Ympäristöministeriö 2007a p.56) District heating pipes are installed 0.5-1.0 m below the ground and the average temperature at that depth, with some offset, can be considered the same on annual basis (Frederiksen & Werner 2013 p. 80). The average annual distribution heat loss per customer can be calculated with formula (Masatin 2016 p.280)

$$Q = K\pi D_a L(T_r - T_s)h \cdot 0.001$$

where:

Q is yearly distribution heat loss in district heating return pipe in kWh

K is network effective average heat transmission coefficient in W/m^{2}K

T_r is district heating return from example building in °C

T_s is yearly average soil temperature in °C

L is average distance in district heating network between customer connections in m

D_a is average district heating pipe inner diameter in m

8760 is hours in one year

0,001 is factor to convert Wh to kWh

Case 1.

$$Q = 1.0\ \frac{\mathrm{W}}{\mathrm{m^2K}}\ \pi\ (0.14\ \mathrm{m})(100\ \mathrm{m})(55\ °\mathrm{C} - 3\ °\mathrm{C})\ 8760\ \mathrm{h} \cdot 0.001 = 20035\ \mathrm{kWh}$$

Case 2.

$$Q = 1.0\ \frac{\mathrm{W}}{\mathrm{m^2K}}\ \pi\ (0.14\ \mathrm{m})(100\ \mathrm{m})(53°\mathrm{C} - 3°\mathrm{C})\ 8760\ \mathrm{h} \cdot 0.001 = 19264\ \mathrm{kWh}$$

This shows a saving potential of 771 kWh per year in distribution heat losses if the heat exchanger return temperature is reduced by 2 °C. Taking into consideration only the pipe length for this customer the saving would be 1.5 % of the overall heat loss for both flow- and return pipes. The beneficiary in this case would be the district heating supplier.

Lowering the return temperature also decreases the flow demand for the connected building since more of the energy is transferred from the district heating water into the building heating circuit. This reduction in flow demand results in less need for pumping electricity for the district heating supplier. The following calculation will only consider the flow needed for the heating circuit, it will for simplicity be regarded as a separate substation, with separate piping, also pressure drops will be considered only for the heating primary side piping and equipment.

Of the energy consumed in residential buildings in Finland in year 2015, 82 % was used for space heating and domestic hot water combined. This 82 % can be considered the 600 MWh/year district heating energy of the example building. 16 % of the overall energy was used for heating domestic hot water. This means that approximately 80 % of the 600 MWh/year, or 480 MWh/year in the example building would be used for space heating. (Tilastokeskus 2015)

Knowing this, the average heating district heating flow of the building can be determined for both cases with formula (Energiateollisuus ry 2014 p.5):

$$\dot{Q} = \frac{\left(\frac{E}{h}\right)}{c(T_2 - T_1)} 3.6$$

where:

$\dot{Q}$ is average required district heating flow to cover capacity in m^3/h

E is annual district heating energy usage in kWh

h is hours in a year

c district heating network water specific heat in J/kg·K

T_2 is average district heating flow temperature in ºC

T_1 is average district heating return temperature in ºC

3.6 is conversion factor from dm^3/s to m^3/h

Case 1.

$$\dot{Q} = \frac{\left(\frac{480000\ \mathrm{kWh}}{8760\ \mathrm{h}}\right)}{4.186 \frac{\mathrm{J}}{\mathrm{kgK}} (85\ ^\circ\mathrm{C} - 55\ ^\circ\mathrm{C})} 3.6 = 1.57\ \mathrm{m^3/h}$$

Case 2.

$$\dot{Q} = \frac{\left(\frac{480000\ \text{kWh}}{8760\ \text{h}}\right)}{4.186\frac{\text{J}}{\text{kgK}}(85\ ^\circ\text{C} - 53\ ^\circ\text{C})} 3.6 = 1.47\ \text{m}^3/\text{h}$$

The customer connection piping is dimensioned to have a 2 bar/km pressure drop and the main network pipe is generally dimensioned to have 1 bar/km. (Energiateollisuus ry 2006 p.156) The average of these two is 1.5 bar/km, that value will be used in the following calculation. This gives a pressure drop of 0.30 bar, or 30 kPa, for the entire per customer piping of 200 m, including 100 m flow pipe and 100 m return pipe. The customer primary side pressure drops also need to be taken into consideration. The maximum allowed pressure drop for the heating heat exchanger primary side is 20 kPa (Energiateollisuus ry 2013 p.9). This value will be used in calculations. The substation primary side piping and component pressure drop will be assumed 5 kPa, and the control valve pressure drop 30 kPa. The entire customer circuit pressure drop, including the district heating flow and return pipes, summarized is 85 kPa.

The pressure drop for case 2, where the flow is decreased, can be determined with formula:

$$\Delta P_2 = \left(\frac{\dot{Q}_1}{\dot{Q}_2}\right)^2 \cdot \Delta P_1$$

where:

ΔP_2 is pressure drop in district heating per customer piping and substation primary side pressure drop combined in case 2 in kPa

ΔP_1 is pressure drop in district heating per customer piping and substation primary side pressure drop combined in case 1 in kPa

$\dot{Q}_1$ is district heating return flow in case 1 in m^3/h

$\dot{Q}_2$ is district heating return flow in case 2 in m^3/h

Case 2.

$$\Delta P_2 = \left(\frac{1.57\frac{\text{m}^3}{\text{h}}}{1.47\frac{\text{m}^3}{\text{h}}}\right)^2 \cdot 85\ \ \text{kPa} = 75\ \text{kPa}$$

Considering the district heating network pump to have an electrical efficiency factor of 80 % the saving in pump electricity can now be determined using the following formula:

$$E = \frac{\Delta P \dot{Q} \varphi h}{1000}$$

where:

ΔP is pressure drop in district heating per customer piping and substation primary side pressure drop combined in kPa.

$\dot{Q}$ is annual average flow in dm^3/ s $\left(\frac{m^3/h}{3.6}\right)$

φ is circulation pump electrical efficiency factor

h is hours

1000 is factor to convert Wh to kWh

E is electrical energy needed to compensate for piping pressure drop in kWh

Case 1.

$$E = \frac{(85\ \text{kPa})(0.43\ \frac{\text{dm}^3}{\text{s}})\ 0.8 \cdot (8760\ \text{h})}{1000} = \ 256\ \text{kWh}$$

Case 2.

$$E = \frac{(75\ \text{kPa})(0{,}41\ \text{dm}^3)\ 0.8 \cdot (8760\ \text{h})}{1000} = 215\ \text{kWh}$$

This shows that an additional 41 kWh electricity saving in pump energy is achieved for the supplier. This alone does not seem significant, but considering that this saving is 16 % of the pump electricity used to provide district heat to the customer, it becomes highly significant. Especially if applied on a larger scale such as an entire network.

A 1 ºC higher return temperature also causes a decrease in electricity production of combined heat and power plants by 0.2 %. (Energiateollisuus 2006 p.298) In 2015 73.4 % of district heat was produced in combined heat and power plants. For each unit of district heat produced, the plants produced 0.35 units of electricity. (Energiateollisuus 2016 p. 3) With these values the annual electricity production from combined heat and power production can be calculated with the formula:

$$E_{\text{electricity}} = E_{\text{heating}}(73.4\ \%)(0.35)$$

where:

$E_{heating}$ is example building annual district heating energy usage for heating

$E_{electricity}$ is annual electricity produced as combined heat and power production abreast district heat production for the example building

Case 1.

$$E_{\text{electricity}} = (480000\ \frac{\text{kWh}}{\text{a}})(73.4\ \%)(0.35) = 123312\ \text{kWh}$$

For case 2, the $E_{electricity}$ can be used to calculate an increase of 0.4 % electricity production coming from the lowered return temperature.

Case 2.

$$E_{\text{electricity}} = (123312\ \text{kWh})(0.4\ \%) = 123805\ \text{kWh}$$

This means that the combined heat and power plant electricity production increases with 493 kWh annually abreast the district heat production for the example building.

All three calculations in this category only consider the average per customer pipe length and capacities and energy consumption of the example building. The calculations are applicable to any length and dimension of district heating pipes, and the more connected customers take this measure to reduce the return temperature the bigger the saving for the supplier.

An example of the effects of temperature reduction was presented by Timo Piippanen in 2015. The district heating utility in the example was a combined heat and power plant with a yearly production of 30000 MWh, 260 customers and 26 km district heating network length. The result from a 1 °C increase in average annual district heating return temperature would result in a 0.5-1.5 % increase in heat losses. This combined with the fact that temperature increase would cause a lower efficiency factor for the electricity production in the plant, and an increase in pump electricity usage, it would cost the utility 23000 € per year. (Piippanen 2015)

A saving for the customer can also potentially be achieved, if the district heat provider has a price system based on flow demand. A higher cooling of the return temperature means less demanded flow and may result in a lower flow demand tariff. In case 1 we already know the total flow demand is 2.8 m^3/h. For case 2 the lowered flow demand is determined with formula:

$$\dot{Q} = \left(\frac{P}{c(T_1 - T_{\mathrm{case2}})} 3.6\right) + \dot{Q}_{\mathrm{DHWh}}$$

where:

$\dot{Q}$ is primary flow demand to cover in m^3/h

$\dot{Q}_{DHWh}$ is domestic hot water hourly primary flow demand in m^3/h

P is heating capacity in kW

c district heating network water specific heat in J/kg·K

T_1 is district heating dimensioning flow temperature in ºC

T_{case2} is district heating return temperature in case 2 in ºC

3,6 is conversion factor from dm^3/s to m^3/h

Case 2

$$\dot{Q} = \left(\frac{160\ \mathrm{kW}}{4.186\,\frac{\mathrm{J}}{\mathrm{kgK}}(115\ ^\circ\mathrm{C} - 41\ ^\circ\mathrm{C})} 3.6\right) + \frac{0.68\ \mathrm{m}^3}{\mathrm{h}} = \frac{2.54\ \mathrm{m}^3}{\mathrm{h}}$$

Using prices from Helen Oy, a large district heating provider in Helsinki, which has prices slightly below national averages the annual capacity demand costs for the cases would be as follows (Helen Oy 2017):

Case 1: 8234 €

Case 2: 7767 €

For the customer, the 2 ºC lower return temperature would mean a saving of 467 € annually in district heating flow demands costs. The lowered flow demand also frees capacity in the network, which opens the opportunity for the supplier to provide the flow to other customers. Using the same prices without VAT the freed capacity (0.2 m^3/h) value as sold to another single customer is determined to 773 €. This means an annual potential 397 € increase in income for the district heating supplier.

3.3.4 Energy saving functions

Having an automatic electric control system is a requirement for both EES and all substations in Finland (Energiateollisuus ry 2013). EES points can be earned in four different categories by adding energy saving functions to the controller (European Committee for Standardization 2015 p.27). In this section these four categories are examined separately.

Control and limitation of max capacity / primary flow

A reduction in the capacity demand at peaks may be lowered by prioritizing domestic hot water capacity need over the heating capacity need. In doing so the max capacity need peaks for the building may be lowered. The annual district heat consumption will remain the same for the building, but the peaks in demand can be evened out over a longer period. Inertia in the building will ensure that the room temperature fluctuation will be minimal even if the heating control valve is closed when domestic hot water usage is high (Lindén 2009 p.23-24). A substation with a control system that limits or closes the heating control valve when the domestic hot water usage is at peak level is entitled to 5 EES points. This is already highly common in most controllers used in the Finnish market. An even better result can be achieved if the control system uses data from the energy meter to limit the max capacity or primary flow. With this feature 15 points can be earned (European Committee for Standardization 2015 p.27).

In figure 3, the peaks in district heating capacity demand is illustrated as a curve (solid line). The dotted line depicts the new capacity demand if domestic hot water prioritizing is implemented by lowering the heating circuit flow temperature by closing the control valve. It is clear in the illustration that the peak demand for district heating capacity is during the morning hours when domestic hot water usage is high. Hourly heat meter readings are not yet available for every connected customer, but as wireless data transferring improves it is safe to consider that it will be standard praxis in near future. Therefore, the following calculation assumes that hourly primary flow readings are available, and the flow demand tariffs are adjusted accordingly by the district heat provider.

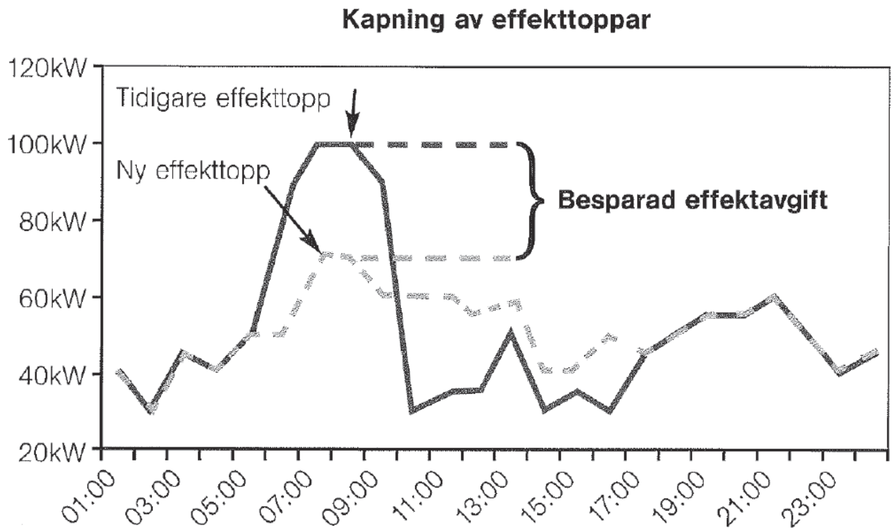

Figure 3. Lowered capacity need from limitation of max capacity / primary flow (Lindén 2009 p.24)

As no district heating energy is saved by control and limitation of max capacity or primary flow functions, a calculation of cost savings from lowering the district heating flow demand is carried out. The cost of district heating consists of energy consumption in MWh and capacity demand, or flow demand, in MWh or m^3/h respectively.
The annual district heating consumption for the example building was determined to be 600 MWh. The district heating hourly capacity demand was determined to 230 kW or 2.8 m^3/h. According to figure 3, this can be lowered by 30 % with control and limitation

of max capacity or primary flow functions. The flow for case 2 is thus considered 70 % or, 1.96 m^3/h, of the 2.8 m^3/h. Using the same prices as in section 3.3.3 form Helen Oy, the annual capacity demand costs for the cases would be as follows (Helen Oy 2017):

Case 1. 8234 €/year
Case 2. 6346 €/year

This indicates a yearly saving in capacity demand costs of 1888 € for the example building. The cost reduction is not far from linear with the flow demand peak decrease in this building category. For the flow decrease of 30 %, the cost saving is 23 %. This represents a 4.1 % decrease in the overall annual district heating costs.

This function is also of high interest for the district heating supplier. As there is a decrease in capacity need, more heat can be sold with the same network by connecting more customers. For comparison, the 30 % saved flow demand in this case is sufficient to provide district heating capacity to a 15-apartment row house. This would mean approximately 150 MWh district heat worth more potential revenue for the supplier. (Energiateollisuus ry 2011) If the district heat supplier were to sell this freed capacity to a building with an hourly flow demand equal to the freed 0.8 m^3/h, a saving can be calculated for the supplier as follows, (prices without VAT for this calculation).

Change in income annually in capacity demand costs from example building due to lowered demand:

-1522 €

Change in income annually when freed capacity is sold to another building connected to network:

-1522 € + 2152 € = 630 €

Using the same network the supplier can earn 630 € more income annually as a result of the lowered capacity demand in the example building.

The pumping costs are also lowered for the supplier. The peaks in flow demand are what cause the highest pressure drops in the network and customer substations. If the same amount of energy can be pumped with a more even flow, the pressure drops are decreased and the electricity usage of the pump is lowered.

If applied to a larger scale the reduced peak load demand may also affect the district heat production positively. When the outdoor temperatures are cold, the electricity and heat demand is high. This is when primary energy sources are used most in the production in order to meet the needed capacities in the electrical grid and district heating network. Evening out the peaks in demand for district heating may decrease the need to use primary energy sources, which is directly linked to reduction in CO_2 emissions. (Lindén 2009, p.10)

Indoor temperature data

Most district heating substation controllers regulate the heating flow temperature with the control valve based on outdoor temperature, the relation between the temperatures form a heating curve. It is essential to indoor comfort and energy efficiency that this curve is set correctly. This can be difficult as the outdoor sensor does not consider internal energy sources in the building. Heat emitters such as residents, electronic devices, and sunlight from windows are causing temperature variation inside the building, while the outdoor temperature may remain the same. 5 EES points can be earned for the substation if the control system is equipped with a temperature sensor measuring indoor temperature and the controller is using it to regulate the heating flow water temperature.

The space heating usage in the example building was earlier in section 3.3.3 determined to 480 MWh/year. This is also the annual amount of energy lost through the building envelope excluding internal energy sources.

The annual mean outdoor temperature in Finland is 3 ºC, the ground temperature under a building can be considered 5 ºC warmer than the outdoor temperature (Ympäristöministeriö 2007b p.19). The building is considered cubical which means that 1/6 of the heat loss happens through the floor into the ground and the remaining 5/6 through walls and roof. With this correction, the T_{out} can be considered 3.8 ºC. The desired indoor temperature is considered 21 ºC. An estimation is made that during heating season (9 months) the indoor temperature in the building rises to 22 ºC 50 % of the time as the result of internal heat loads. This would make the annual average indoor temperature 21.5 ºC. Using a formula, we can determine the average annual heat transfer coefficient in kW/K for the entire building:

$$R_{\text{building}} = \frac{(\mathrm{T}_{\text{case}} - T_2)}{E/h}$$

where:

T_{case} is the indoor temperature in each case in ºC

T_2 is the average annual outdoor and ground temperatures at the respective building surface.

E is district heating space heating energy usage during heating period in kWh

h hours in heating period per year (from 1.9. to 1.6.).

$R_{building}$ is average thermal resistivity for the building in kW/K

Case 1.

$$R_{\text{building}} = \frac{(21.5\ ℃ - 3.8\ ℃)}{(480000\ \text{kWh})/(6552\ \text{h})} = 0.2416\ \text{kW/K}$$

For case 2, the $h_{building}$-value from case 1 is used to calculate the heat loss if the T_{case} temperature is kept at 21 ºC.

$$E = \frac{(21\ ℃ - 3.8\ ℃)\ 6552\ \text{h}}{0.2416\ \text{kW/K}} = 466450\ \text{kWh}$$

This results in an annual saving of 13550 kWh, or 2.8 % of overall district heating costs. This is in line with a generally considered energy saving potential of 5 % coming from dropping the indoor temperature 1 ºC. (MTV 2013)

Remote monitoring and control

7 EES points can be earned if the substation controller can be connected to remote communication, 15 points are earned if the controller can be controlled remotely. For both options, it is sufficient if this can be done with add-on modules to the controller. The maximum points in this category is 25 points, which can be earned if the substation can be monitored and controlled remotely and read data from the energy meter. (European Committee for Standardization 2015 p.28)

Remote monitoring is essential for optimizing the substation to work in the most economical way. If the settings can be modified remotely there is necessarily no need for a mechanic to visit the site physically. Remote monitoring contributes in helping detect faults in the entire heating and domestic hot water systems, and can indicate of incoming needed renovations to the substation and heating system. It is impossible to calculate how much saving these functions realistically may offer, but it is easy to understand that if the other energy saving functions in this section are implemented into the controller, it makes sense to monitor the functionality.

One hypothetical situation where gathered data can be highly useful is the following example:

In March when the weather starts to warm, the building manager of the example building gets complaints of unnecessarily hot indoor temperatures from tenants. He proceeds to remotely check the temperature data from the heating flow sensor, it has been between 54.5 and 55.5 ºC for a week in a row and the trend curve is a straight line. He then checks the outdoor temperature trend and notices that it is stuck at exactly 0 ºC, also for a week. The actual outdoor temperature being 7 ºC, an assumption can be made that the outdoor temperature sensor is faulty and needs replacement. The manager manually sets the heating flow temperature to 46 ºC to reduce the unnecessary heat delivery to the residents. He orders a mechanic to change the outdoor sensor and the job is done immediately. Were it not for the remote controlling, the mechanic would first need to visit the site and figure out the problem, and only then could the replacement of the faulty sensor be done. All while the radiator system still heats the building unnecessarily. Taking the indoor temperature to be 26 ºC for three consecutive days if remote control would not be available, the cost of the district heating energy for the days can be calculated for each case with formula:

$$E = \frac{(T_{\text{case}} - T_2)h}{R_{\text{building}}}$$

where:

T_{case} is the indoor temperature in each case in ºC

T_2 is the outdoor temperature in this example (7 ºC) in ºC

E is district heating space heating energy during four days in kWh

h hours in examined heating period

$R_{building}$ is average thermal resistivity for the building in kW/K

Case 1

$$E = \frac{(26\ ℃ - 7\ ℃)72\ \text{h}}{0.2416\ \text{kW/K}} = 5662\ \text{kWh}$$

Case 2

$$E = \frac{(21\ ℃ - 7\ ℃)72\ \text{h}}{0.2416\ \text{kW/K}} = 4172\ \text{kWh}$$

1490 kWh in this example could have been saved in district heating energy with remote monitor and control. This example only shows one of the benefits of fault detection by monitoring. Fault-detection can often be complicated if data is not available, and man-hours are expensive. It is not uncommon that a building the size of the example building has maintenance costs of several hundred euros associated with the substation controller. The older the building is, the higher these costs tend to be. For the example building an estimation is made that 2/3 of the annual costs are caused by temporary temperature fluctuations causing controller alarms, while the remaining 1/3 are necessary in terms of the substation operation. Annually 3 instances occur, where in case 1, a service mechanic needs to be sent physically to the substation. Each instance cost 150 €, consisting of 2 man-hours and transportation compensation. In case 2, only 1 such instance occurs, as the other 2 can be eliminated with remote monitoring and control. The annual costs for these service calls for each case is:

Case 1. 450 €
Case 2. 150 €

A saving in service and maintenance costs of 300 € annually is highly likely with remote monitoring and control.
The remote-control functionality is also useful for optimizing the system even if all components are working. In single family houses this can be used to lower the indoor temperature while going away for a longer time. This way energy is saved, and the heating can be turned back on remotely a few hours before returning resulting in no lost comfort.

In an article by Henrik Gadd and Sven Werner from Applied Energy in 2015, a study of 140 substations located in Helsingborg and Ängelholm in Sweden shows that an annual 5 % fault frequency occurred in primary side temperature differences. The study included both old and new, large substations. The 5 % result comes from faulty system operating parameters, faulty components or wrongly dimensioned components in customer substations. The praxis when renewing a substation for old buildings is often to take dimensioning parameters from the old substation. This will result in possible dimensioning errors and poor component choices; it would be recommended to redesign the substation completely, based on energy meter readings, and keeping in mind energy efficient design. Follow up with remote monitoring should also be considered in all cases.
The authors of the Applied Energy article conclude the benefits of district heating remote monitoring perfectly in one sentence: “This [hourly meter readings] is a basic condition for more efficient district heating systems in the future.” (Gadd & Werner 2014).

ECO-function

If the substation controller has an ECO-function that closes the heating control valve and shuts off the heating circulation pump when the outdoor temperature exceeds a preset value 5 EES points are earned. A saving in pump energy can be achieved with this function. At the same time, it makes sure that no heat is delivered to the building unless it is needed. (European Committee for Standardization 2015 p.28)

Calculating the energy saving potential from the ECO-function is done in two parts, first the heating pump electricity savings are taken into consideration.

For calculating energy consumption and heating capacity demands in Finland a test year containing hourly temperature data from three different locations in Finland over a time between 1980 and 2009 has been produced. This data is meant to represent realistic average temperatures of different regions in Finland and is to be used when calculations of yearly energy consumption are done (Ympäristöministeriö 2007b p.56-64). The data used for the test year can be retrieved in excel format for each of the three locations.
Temperature data for each hour of the three years has been retrieved from the table and each hour the temperature exceeds 16 ºC has been counted, divided by three, and summed up to 939 h per year as an average in Finland. This figure will be used in the calculation.

The heating pump was earlier in section 3.3.2 specified. The secondary side combined pressure loss is considered 55 kPa. The ECO-function is to be set to turn off the pump when outdoor temperature exceeds 16 ºC, which is when the demand for space heating is nonexistent in most cases.

Using the following formula, the energy consumption of the heating pump during the whole year for each case can be determined:

$$E = \frac{hP}{\varphi}$$

where:

P is pump output power in kW

φ is circulation pump electrical efficiency factor

h is hours

E is pump electrical energy usage in kWh/year

Case 1.

$$E = \frac{(8760\ \mathrm{h})(0.177\ \mathrm{kW})}{0.99} = 1566\ \mathrm{kWh}$$

Case 2.

$$E = \frac{(8760\ \mathrm{h} - 939\ \mathrm{h})(0.177\mathrm{kW})}{0.99} = 1398\ \mathrm{kWh}$$

168 kWh saving in electrical energy from having an ECO-function in the substation controller is achieved.

The other potential saving is in district heating energy. By optimizing the set point for the ECO-function, a saving can be achieved from preventing any heating energy from being delivered to the heating circuit when it is not needed. As the heating pump is stopped, no excess heat is delivered from the substation when the function is active. If the heating pump would still be operating, the water circulating in the system would still to some amount be heated from leakage in the heating control valve. If the ECO-function set to 16 ºC, the control valve will shut completely when that outdoor temperature is exceeded, preventing the heating network from causing the indoor temperature to rise higher than the desired 21 ºC. For calculations, an assumption is made that when the outdoor temperature exceeds 16 ºC, the indoor temperature rises to 22 ºC. The heating control valve is considered be closed completely whether there is an ECO-function or not when the outdoor temperature exceeds 19 ºC. On average these conditions, where the outdoor temperature is 16-19 ºC, apply 487 h in Finland and the average temperature during those hours is 17,3 ºC. Calculations for the cases can be done with formula:

$$E = \frac{(T_{\mathrm{case}} - T_2)h}{R_{\mathrm{building}}}$$

where:

T_{case} is the indoor temperature in each case in ºC

T_2 is the outdoor temperature in this example (16 ºC) in ºC

E is heat loss through building envelope during the examined conditions in kWh

h hours in examined heating period

$R_{building}$ is average thermal resistivity for the building in kW/K

Case 1.

$$E = \frac{(22\ ^\circ\mathrm{C} - 17.3\ ^\circ\mathrm{C})(487\ \mathrm{h})}{0.2416\ \mathrm{kW/K}} = 9474\ \mathrm{kWh}$$

Case 2.

$$E = \frac{(21\ ^\circ\mathrm{C} - 17.3\ ^\circ\mathrm{C})(487\ \mathrm{h})}{0.2416\mathrm{kW/K}} = 7458\ \mathrm{kWh}$$

2061 kWh can be saved in district heating energy with the ECO-function in the example case. To utilize the ECO-function to its full potential, it is recommended the controller also has access to indoor temperature data. This way the ECO-function can be turned on when the indoor temperature rises above 21 ºC, or, whenever the outdoor temperature exceeds a set point as a preventive measure before the indoor temperature gets to rise unnecessarily high.

3.4 Conclusion of calculations

To get a better picture of the results the potential savings in all categories would need to have a common unit of measurement. On top of this the savings affect both the district heating supplier and the customer. The control and limitation of max capacity / primary flow function affects the capacity demand costs and influence the overall district heating price per unit in doing so. Some of the functions and specifications resulting in savings partially overlap each other and of course, vary from case to case. Some of the categories for savings also contribute to larger saving potential in another category. All this considered there is still undeniable saving potential in both electricity and district heating energy as well as in costs, for both the customer and the supplier. In the example case the total saving potential in energy efficient design of district heating substations in annual energy consumption is 3.3 %. The annual cost saving for the costumer is 8.6 %. In energy the saving annually is 20.09 MWh. In table 10 the savings are summarized. It is important to consider that this calculation was done for a new building. Old buildings use more energy per square meter, the substation technology may be outdated or faulty, and thus affecting the efficiency of the heating system and district heating network. Therefore, the saving potential in renewing an old substation is generally significantly higher.

Table 10. Summary of calculations.

Summary of calculations

Category of energy saving measure / function	Energy saving in MWh	Cause of difference	Beneficiary and saving object	Annual saving for customer	Annual saving for supplier
Heat losses (from primary side piping)	1.33	Better piping insulation reduces heat losses.	Customer in district heating energy	107.33 €	- €
Pressure losses in secondary side heating	0.19	Lower pressure drop in secondary side heating heat exchanger reduces pump electricity usage.	Customer in electricity	18.80 €	- €
Cooling of the return temperature, domestic hot water	0	No difference, K1 minimum requirements entitle to max. EES points.	Supplier in district heat	- €	- €
Cooling of the return temperature, heating	0.77	Lower return temperature reduces heat losses for district heating return pipe.	Supplier in district heat	- €	53.71 €
	0.04	Better cooling of the district heating water means less required flow and pumping electricity consumption is reduced.	Supplier in district heat	- €	4.10 €
	0.49	Improved efficiency for combined heat and power electricity production caused by lower return temperature.	Supplier in district heat	- €	49.30 €
	0	Less required flow for heating results in lowered district heating flow demand tariff. *	Customer in district heating cost per unit	467.00 €	- €
	0	Less required flow for heating means capacity can be sold to other customers using same network. *	Supplier in district heat income	- €	397.00 €
Control and limitation of max capacity / primary flow	0	Less required max capacity results in lowered district heating flow demand tariff. *	Customer in district heating cost per unit	1 888.00 €	- €
	0	Freed capacity can be sold to other customers using same network. *	Supplier in district heat income	- €	630.00 €
Indoor temp	13.55	Controlled indoor temperature reduces heat loss from building.	Customer in district heating energy	1 094.30 €	- €
Remote monitoring+control	1.49	Fault detection reduces possibility of system functioning improperly.	Customer in district heating energy	120.33 €	- €
	0	Fault detection reduces costs in service man-hours.	Customer in maintenence costs	300.00 €	- €
Eco function, electricity	0.17	Heating pump automatic shut-off when flow is not required reduces pump electricity usage.	Customer in electricity	16.80 €	- €
	2.06	No heat is delivered into circulation when not needed, reduces heat losses from building.	Customer in district heating energy	166.45 €	- €
SUM:	**20.09**		**SUM:**	**4 179.01 €**	**1 134.11 €**

Energy prices (based on average 1.1.2017)

District heating energy	69.66	€/MWh
Capacity demand cost	11.1	€/MWh
Electricity (including distribution)**	100	€/MWh

* Savings based on capacity demand costs (Prices from Helen Oy 2017)
** Estimation of average in Finland

4 SOFTWARE FOR TENDER SPECIFICATION DOCUMENT

The Alfa Laval Eco-efficient substation tool was developed for consultants to use when compiling tender specifications to Alfa Laval's heat exchanger system sales company, Armatec OY. It is intended to be uploaded once EES labelling is officially released. This software is important in driving the customers towards greener solutions and investing in a higher quality product that will run more ecologically throughout its lifespan.

The benefits of having a software to do the calculation is that it helps the customer and consultants easily see which functions and performance standards influence the EES-label. It minimizes the possibility for misinterpretation of the substation manufacturers in the tendering process, and may help reduce instances where the contents of the offers differ between manufacturers. As the tool calculates a saving potential in percent, it may also help consultants to justify to the end customer to choose a more energy efficient product. As the software is meant to be used in Finland first, it is entirely in Finnish, however it is designed so that once finalized and released, multiple language versions may be developed with the same concept.

4.1 Starting a project

After registering and logging in to the web-page, the user is directed to a personal project page. On this page, new projects can be started and old projects are listed and can be opened, modified, printed or removed. A search field helps to navigate the project page and the user can search for projects based on multiple inputs such as contractor, project name, address or project number. To start a new project, the user will need to specify a project name, a contractor and a unique project number. Once this is done the new project can be started by clicking a button.

The new project template is opened and the user can now fill out more project related information, specify dimensioning values and choose options that influence the EES-label and add additional components that may be needed in the substation. A flowchart is also displayed that updates automatically based on component choices, connection types and number of circuits.

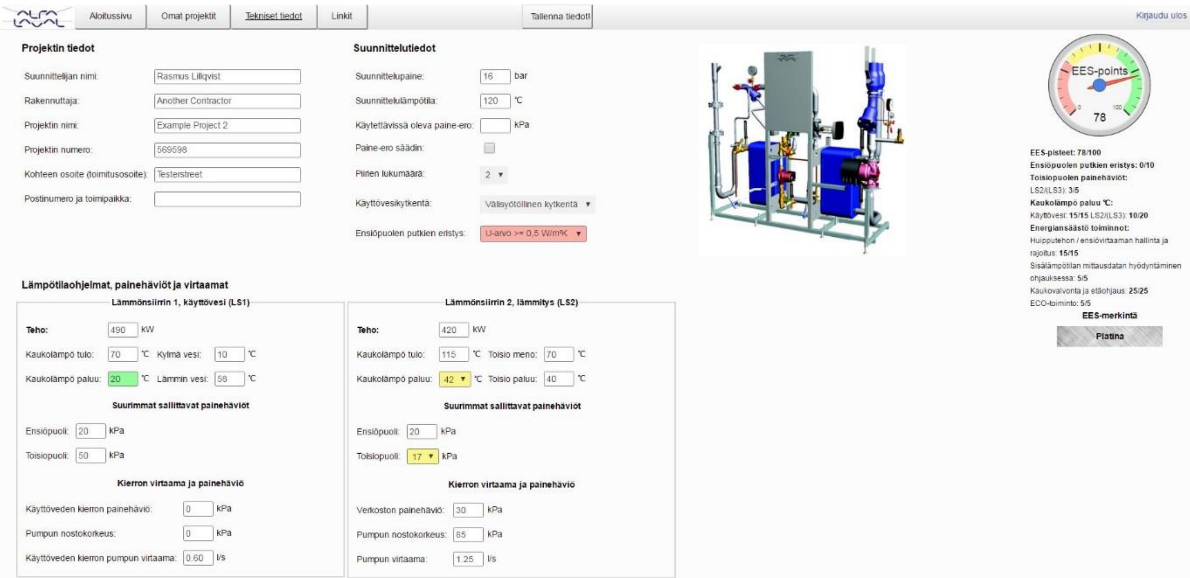

Figure 4. Screenshot from software, basic project information data form.

In figure 4 the design and layout of the project page can be seen. The colored input boxes all influence the EES-label. Green represents best level, yellow and orange the middle levels and red indicates no points in that category is earned with the present value. On the right is a summary of points in different categories, with a gauge displaying current point status. The EES-label is also displayed here and changes dynamically. In figure 5 the flow chart can be seen. The checkboxes represent some common additional components that may be needed in the substation, the flow chart is dynamic and displays the components of the boxes that are checked.

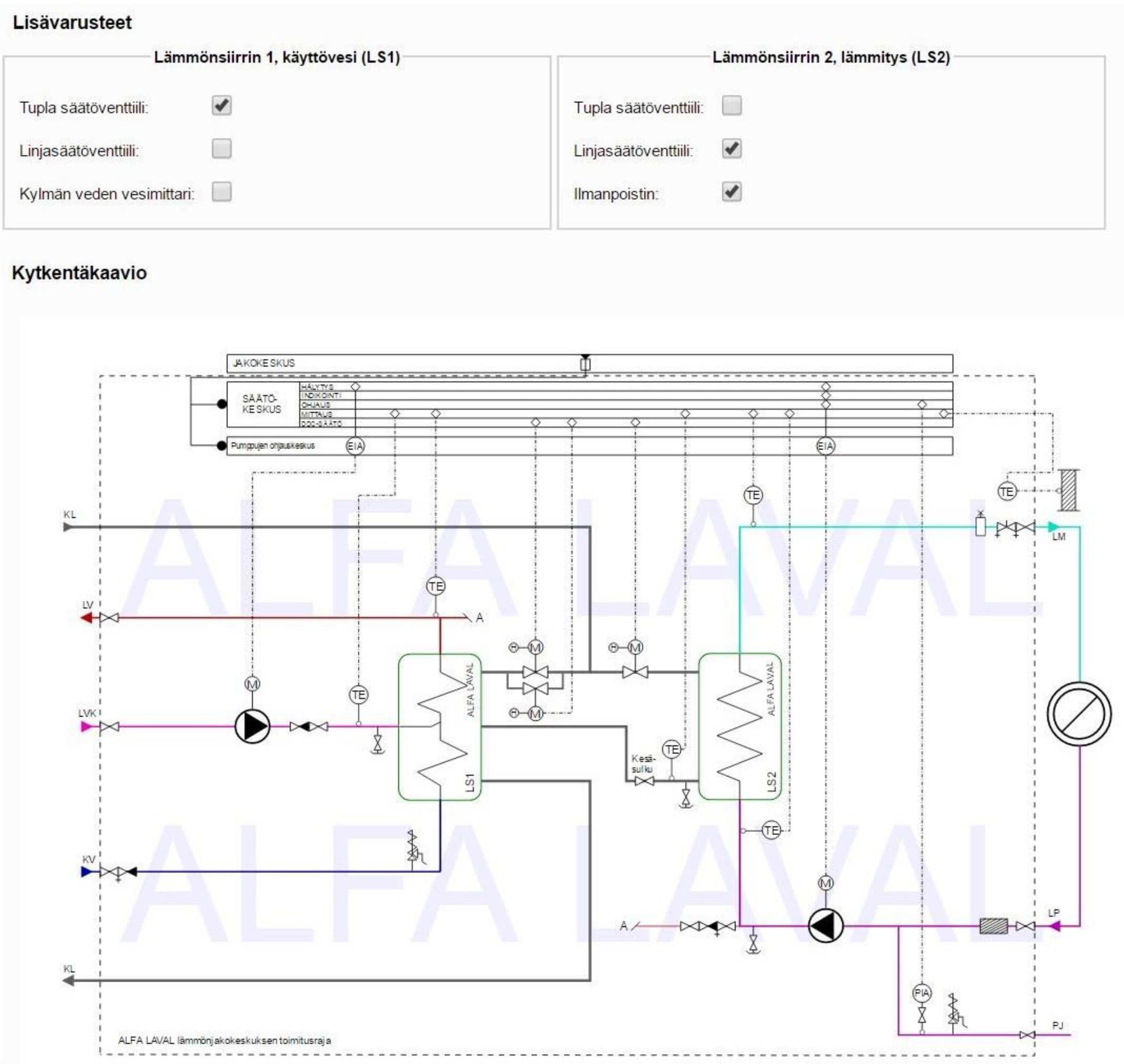

Figure 5. Screenshot of dynamic flow chart.

The EES-points are also compiled into a table dynamically as seen in figure 6. A factor of points compared to annual saving potential has been determined based on the calculations done for the example building. This is displayed as an estimation of annual running-cost saving potential below the score-table.

Alfa Laval lämmönjakokeskuksen Eco-efficient Substation piteytys

Pistekategoria	Minimipisteet hopea-taso	Minimipisteet kulta-taso	Minimipisteet platina-taso	Maximi pisteet	Saavutetut pisteet
1. Ensiöpuolen putkien eristys	0	0	0	10	0
2. LS2/(LS3) toisiopuolen painehäviöt	0	0	3	5	3
3. Kaukolämpöveden jäähtyminen, LS2/(LS3)	0	10	10	20	10
4. Kaukolämpöveden jäähtyminen, käyttövesi LS1	0	7	7	15	15
5.1 Huipputehon / ensiövirtaaman hallinta ja rajoitus	0	0	0	15	15
5.2 Sisälämpötilan mittausdatan hyödyntäminen ohjauksessa	0	0	0	5	5
5.3 Kaukovalvonta ja etäohjaus	0	7	15	25	25
5.4 Eco-toiminto	0	5	5	5	5
YHTEENSÄ	16	45	70	100	78

Eco-efficient Substation-merkintä

Platina

Arvioitu vuosittainen säästö kaukolämpöön liittyvissä kustannuksissa: 6.3 %

Vertaus tehty K1 minimivaatimuksiin nähden pisteiden ja kustannusten välisellä kertoimella.

Figure 6. EES-points and label screenshot.

When the user is done with inserting project information and dimensioning values the project can be saved from a button in the navigation bar.

4.2 Tender specification output

After saving the project, the software redirects the user back to the personal project page. From there, a print-page with compiled project information can be opened. On this page a technical specification with a summary of the EES-labelling points, EES-label and flow chart can be printed to a file or on paper using the browsers own print function. A tender specification for the example building with full 100 EES points has been generated with this software (Appendix 1).

Usually consultants also provide a written specification along with the flow chart and dimensioning values. In the written specification is often described certain additional requirements that the substation must fulfill. On the print page in the software, a box is displayed which will not print. But it has certain texts that the user may copy into their own written specification to ensure that the specification is in unison to fulfill the EES label requirements. This way the consultant can ensure that all manufacturer offers uphold a certain standard and that the EES-label will be the same for all offered substations.

5 NEED FOR EES-LABELLING

The calculations clearly show a potential environmental, customer and supplier benefit in energy efficient design of substations. In this section the need for labelling is discussed from market fairness, consumer and environmental point of view.

5.1 Market fairness and transparency

From a market fairness perspective, it seems reasonable to be able to assure the substation customer of a superior performance compared to the minimum requirements. The EES-label works as a tool for this, and represents a high-quality standard, that will result in better energy efficiency of the product. As a certification is needed to have the right to use the EES-label, the consumer is made aware that the product has been thoroughly tested and approved by the certification board. It levels the playing field between manufacturers as the same standard for the label is applied for all manufacturers and substations in the EES range.

EES-labelling could also benefit the competition between district heating and other forms of heating. Compared to ground heating, district heating is, in the core, very reliable and simple technology with clear dimensioning parameters. The energy consumption is also highly predictable for a substation. For ground heating, a label would not work as well, since it is hard to predict the ground properties and amount of energy that can be extracted per well and meter depth. If the dimensioning of ground heating is done improperly and the heat extraction is too low, the electricity usage rises as the peaks in heat demand are taken care of by electric heaters. In case of over dimensioning, the investment cost is unnecessarily high for the case in question. Ground heating system manufacturers use their own dimensioning parameters and therefore the needed well-depth and count varies between competitors (Kilpijärvi 2015). This is not possible for district heating as the temperature programs are set. But if even higher standards, and stricter dimensioning parameters than the minimum requirements are used, to improve the product, the EES-label is a fitting tool to use to ensure the customer of the quality.

If the substation manufacturer has an EES-certificate, the risk of dimensioning errors for substation components are lowered substantially even further, as the process of dimensioning must be done per both EES specification and local regulations. The EES-certification can thus further strengthen the benefits, reliability and consumption predictability, of district heating compared to other forms of heating. The running cost savings gained from an EES platinum label may also contribute to the cost competitiveness of district heating.

5.2 Benefits for the consumer and environmental impact

Designing a product, more energy efficient than mandatory, will without consumer awareness of the benefits in doing so, have no environmental impact. This is since without a document, or label, pointing out the differences in performance and quality the average consumer will likely choose the cheaper one. Company branding may distort this statement to some extent, but a label proving the values the branding is based on, may contribute to the impact.

From an environmental point of view, the EES-labelling is therefore needed to help the consumer make greener choices. Generally, a substation saving 8.6 % in running costs annually has a very short payback time, which would be the case in the example calculation. This is a clear benefit for the consumer when the whole lifespan of a substations costs is examined. There is also no other energy labelling system for district heating substations in Finland, so for the consumer to know the performance they would need to have extensive knowledge of the subject. Almost all components in a substation has their own data-sheet with figures contributing to the overall efficiency of the substation. But there is no data-sheet that presents the energy efficiency performance of the complete substation. When buying a refrigerator, the layman is not interested in the electrical efficiency of the individual components, but rather of the whole product. For refrigerators in EU, an energy label is required by law, why should heating substations be any different?

The EES-label provides the consumer an easy access, and uncomplicated tool for making environmental-friendly choices, at a cost that is payed back within the first half of the product lifespan.

REFERENCES

European Committee for Standardization 2015, *Cen Workshop Agreement CWA16975, Eco-efficient Substations for District Heating*, Danish Standard Foundation, 47 p.

Energiateollisuus ry 2013, *Rakennusten kaukolämmitys Määräykset ja ohjeet Julkaisu K1/2013 Päivitetty 9.5.2014.* Energiateollisuus ry, 106 p.

Energiateollisuus ry 2011, *Kaukolämmön hintatilasto - tyyppitalot Määräytysmisperusteet.* Energiateollisuus ry, Available:
http://energia.fi/files/1196/Kaukolammon_hintatilasto_tyyppitalomaarittelyt.pdf
Retrieved: 20.4.2017

Energiateollisuus ry 2014, *Teho ja vesivirta kaukolämmön maksuperusteina Suositus K15/2014.* Energiateollisuus ry, 36 p.

Energiateollisuus ry 2006, *Kaukolämmön käsikirja.* Kirjapaino Libris OY Helsinki, 566 p.

Energiateollisuus ry 2016, *Kaukolämpötilasto 2015.* Energiateollisuus ry, 80 p.

Ympäristöministeriö 2007a, *D1 Kiinteistöjen vesi- ja viemärilaitteistot MÄÄRÄYKSET JA OHJEET 2007*, Ympöristöministeriö Asunto- ja rakennusosasto, 64 p.

Cengel, Yunus A. 2002, *HEAT TRANSFER A Practical Approach, second edition,* Mcgraw-Hill, Texas, 874 p.

Armacell 2010, *AP Armaflex Technical Information*, Armacell LLC, 2 p. Available:
http://www.armacell.com/www/armacell/ACwwwAttach.nsf/ansFiles/003-003-004-NA(NA).pdf/$File/003-003-004-NA(NA).pdf
Retrieved: 5.3.2017

Grundfos product center 2017, (*Magna 3 25-120 page displayed with given input values for flow and lifting height)*, Available: https://product-selection.grundfos.com/front-page.html?custid=GMAtotal&lang=FIN&time=1493747192280&qcid=168152152
Retrieved: 2.5.2017

Frederiksen & Werner 2013, Frederiksen, Svend & Werner, Sven, *District Heating and Cooling*, Studentlitteratur AB Lund, 585 p.

Euroheat & Power 2008, *Guidelines for District Heating Substations*, Euroheat & Power, 68 p.

Masatin 2016, Masatin, Vladislav & Latosev, Eduard & Volkova, Anna. Evaluation facto for district heating network heat loss with respect to network geometry, *Energy Procedia 95*, p. 279-285.

Tilastokeskus 2015, *Liitekuvio 2. Asumisen energiankulutus käyttökohteittain vuonna 2015 (Kuviota korjattu 8.12.2016)*, Available:
http://www.stat.fi/til/asen/2015/asen_2015_2016-11-18_kuv_002_fi.html
Retrieved: 15.3.2017

Piippanen 2015, Piippanen, Timo, *Paljonko maksaa yhden asteen nousu kaukolämmön paluuveden lämpötilassa?*, Elenia, Power point presentation 28.5.2015.

Helen Oy 2017, *Kaukolämmön energia- ja vesivirtamaksut, 1.5.2017 alkaen*, Available:
https://www.helen.fi/globalassets/hinnastot-ja-sopimusehdot/lampo-ja-jaahdytys/kotitaloudet/energia--ja-vesivirtamaksut.pdf
Retrieved: 18.4.2017

Lindén 2009, Lindén, Anders & Eriksson, Kristoffer & Sjöholm, Björn, *Metoder för att sänka effektbehovet vid fjärrvärme*, Svensk Fjärrvärme AB, 56 p.

Ympäristöministeriö 2007b, *Rakennuksen energiankulutuksen ja lämmitystehontarpeen laskenta Ohjeet 2007*, Ympöristöministeriö Asunto- ja rakennusosasto, 72 p.

Ekokumppanit Oy, MTV 2013, *Tiesitkö: Asteen pudotus huonelämpötilassa – viisi prosenttia säästöä laskussa!* Published: 28.09.2013, Available:
http://www.mtv.fi/lifestyle/koti/artikkeli/tiesitko-asteen-pudotus-huonelampotilassa-viisi-prosenttia-saastoa-laskussa/3201216
Retrieved: 18.4.2017

Gadd & Werner 2014, Gadd, Henrik & Werner, Sven, Achieving low return temperatures from district heating substations, *Applied Energy 136*, p. 59-67

Kilpijärvi 2015, Kilpijärvi, Aki, *Maalämpöpumppujen mitoituksien vertailu*, Degree Thesis Talotekniikankoulutusohjelma, Oulun ammattikorkeakoulu, 42 p. Available:
http://docplayer.fi/1897573-Aki-kilpijarvi-maalampopumppujen-mitoituksien-vertailu.html
Retrieved: 22.4.2017

APPENDIX 1, printed software output document

Alfa Laval Kaukolämpö lämmönjakokeskus

Suunnittelijan nimi:	Rasmus Lillqvist
Rakennuttaja:	ExampleContractor
Projektin nimi:	Thesis Example Building
Projektin numero:	559977
Kohteen osoite (toimitusosoite):	Project address here
Postinumero ja toimipaikka:	00000 Helsinki
Malli:	
Tarjousnumero:	

Tekninen erittely

LÄMMÖNSIIRTIMET		Lämmönsiirrin 1, käyttövesi (LS1)		Lämmönsiirrin 2, lämmitys (LS2)	
Valmistaja		Alfa Laval		Alfa Laval	
Tyyppi		-Ei määritetty-		-Ei määritetty-	
Tehot	kW	345			
		Ensiö	Toisio	Ensiö	Toisio
Lämpötilat	℃	70 - 20	10 - 58	115 - 43	40 - 60
Virtaamat	l/s	-	-	-	-
Painehäviöt	kPa	50	20	20	20
PED-kategoria					
Materiaali		AISI 316		AISI 316	
Serifiointi		AHRI 400		AHRI 400	
SÄÄTÖLAITTEET					
Säädin					
Säätöventtiilien valmistaja					
Säätöventtiili 1		✔		✔	
Säätöventtiili 2		✔			
Virtaama	l/s				
Painehäviö	kPa				
koko/kvs SV1	DN/kvs				
Toimlaitteiden valmistaja					
Toimilaite 1		✔		✔	
Toimilaite 2		✔			
PUMPUT					
Pumppujen valmistaja					
Tyyppi		Yksöispumppu		Yksöispumppu	
Virtaama	l/s	0.37		1.91	
Nostokorkeus	kPa	40		55	
Teho/virta	W/A				
Jännite	V				
TOISIOPUOLEN VENTTIILIT					
Tyyppi		Sulkuventtiili		Linjasäätöventtiili	
VERKOSTO, PAISUNTA-JA VAROLAITTEET					
Verkoston tilavuus / verkoston painehäviö			l/kPa		35
Paisunta-astian tilavuus / esipaine			l/kPa		
Varoventtiilin koko / avautumispaine			DN/bar		
PUTKIKOOT					
Kaukolämpö tulo / paluu			DN		
Kylmä vesi / lämmin vesi			DN		
Lämpimän käyttöveden kierto			DN		
Lämmitys meno / paluu			DN		

02.05.2017 kl. 11.27.57
Sivu 2/2

Alfa Laval Kaukolämpö lämmönjakokeskus

Malli:
Kohde: Thesis Example Building
Tarjousnumero:

Tekninen erittely

LISÄKOMPONENTIT (piirikohtaiset)	Käyttövesi	Lämmitys
Kylmän veden vesimittari		-
Ilmanpoistin	-	
LISÄKOMPONENTIT (yleiset)		
Paine-ero säädin		

ECO-EFFICIENT SUBSTATION PISTEET	Pisteet
1. Ensiöpuolen putkien eristys	10
2. LS2/(LS3) toisiopuolen painehäviöt	5
3. Kaukolämpöveden jäähtyminen, LS2/(LS3)	20
4. Kaukolämpöveden jäähtyminen, käyttövesi LS1	15
5.1 Huipputehon / ensiövirtaaman hallinta ja rajoitus	15
5.2 Sisälämpötilan mittausdatan hyödyntäminen ohjauksessa	5
5.3 Kaukovalvonta ja etäohjaus	25
5.4 Eco-toiminto	5
YHTEENSÄ	100
LÄMMÖNJAKOKESKUKSEN EES-MERKINTÄ	**Platina**

Kytkentäkaavio