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INSENERITEADUSKOND
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ENERGIATÕHUSUSE ARVUTUS REAALAJAS KASUTADES DÜNAAMILIST PRIMAARENERGIA KAALUMISTEGURIT ÜLIKOOLIHOONE NÄITEL

REAL-TIME ENERGY PERFORMANCE CALCULATION WITH DYNAMIC PRIMARY ENERGY FACTOR: APPLICATION TO UNIVERSITY BUILDING

MAGISTRITÖÖ

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Torino 2022

(*On the reverse side of title page*)

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THESIS TASK

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Thesis topic:
(in English) Real-time Energy Performance Calculation with Dynamic Primary Energy Factor: Application to University Building
(in Estonian) Energiatõhususe arvutus reaalajas kasutades dünaamilist primaarenergia kaalumistegurit ülikoolihoone näitel

Thesis main objectives:

1. Calculation of dynamic PEF for electricity and DH by hourly precision using data of national energy mix;
    1.1. Electricity and DH dynamic PEF comparison with Estonian static PEF based on national regulation;
2. Application of electricity and DH dynamic PEF for the evaluation of primary energy needs of case study building Mäepealse 3, Mustamäe, Tallinn, Estonia.

Thesis tasks and time schedule:

No	Task description	Deadline
1.	Submitting terms of reference, structure, literature review and brief description of methodology parts of the thesis	07.03.22
2.	Submitting 75% of the thesis and a poster	10.04.22
3.	Submitting final version of the thesis	16.05.22

Language: English **Deadline for submission of thesis:** "16" May 2022

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PREFACE

Present study is written while being on my exchange studies in Polytechnic University of Turin, Italy.

Firstly, I want to point out my supervisors and consultant. I am grateful for my supervisor in Estonia, Martin Thalfedt for being quick with all the answers and directing me to right people. Also for making it even possible to write my thesis in Italy. Thank you, Enrico Fabrizio, for keeping the pace up and asking right questions to improve the study. Also, I want to thank my consultant Matteo Bilardo, who helped me most with substantive work and was making sure I understand everything fully.

Secondly, I want to bring out people and companies without whom I would not have majority of my study. Thank you people from Taltech – Janar Küla, Reeli Kuhi-Thalfeldt, Jarek Kurnitski, Eduard Latõšov, also companies Enefit Power, Utilitas Tallinn and Enefit Green.

Keywords: static primary energy factor, dynamic primary energy factor, primary energy evaluation, EN17423, Master's Thesis

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List of abbreviations and symbols

CHP	Combined Heat and Power system
DH	District Heating
MP3	Mäepealse 3 building
nREN	non-renewable
PEF	Primary Energy Factor
PV	Photo Voltaic
REN	Renewable

Efficient DH – Following regulation [1] „..efficient district heating or cooling is a district heating or cooling system that uses at least 50% renewable energy, 50% waste heat, 75% cogeneration or 50% combinations of such energy and heat.‟

1 INTRODUCTION

1.1 Motivation

According to article about Energy Performance of Buildings Directive (EPBD) recast [2], energy performance of a building must show typical energy use of the building in calculated or actual energy use. Defining primary suitable primary energy factors (PEF) or weighting factors is a part of the process. European Member States (MS) are allowed to calculate their own PEFs based on national, regional, or local annual and also seasonal or monthly data. MS must make sure that buildings are working at optimal energy performance.

For 14 years, Estonian regulations [1], [3]–[5] has determined PEF as a constant for each energy carrier. However, [6] claims that single fixed PEF does not meet the PEF definition by European Union policy. A solution is needed for a more accurate PEF.

The aim of current study is to calculate DH and electricity PEFs by hour accuracy and compare the results to Estonian constant PEFs. As well as, apply these values to find primary energy need for case study building. In result, some indication will be present to improve Estonian PEF for electricity and DH.

1.2 Objective

The overall objective of this thesis is to find dynamic PEF for electricity and DH and apply these to evaluate Tallinn University of Technology building, Mäepealse 3 primary energy need. Also to compare Estonian legislative PEFs and calculated dynamic PEFs for electricity and DH. For clarification, two main objectives are formulated here:

1. Calculation of dynamic PEF for electricity and DH by hourly accuracy using data from national energy mix ;
    1.1. Electricity and DH dynamic PEF comparison with Estonian legislative PEF based on national regulations [1], [3]–[5];
2. Application of electricity and DH dynamic PEF for the evaluation of primary energy needs of case study building Mäepealse 3, Mustamäe, Tallinn, Estonia (hereinafter MP3).

1.3 Literature review

E. Latõšov, A. Volkova, A. Siirde, J. Kurnitski, and M. Thalfeldt article [6] collected data from EU member states that used adequate amount of district heating. Countries were separated by DH PEF determination procedure - single fixed DH PEF, differentiated DH PEFs and calculated DH PEF for each DH network separately. Regardless of preferred procedure in a country, PEF definition by European Union policy should have been confronted. However, study found that it is not true about single fixed DH PEF because combination of different fuels and technologies for heat production, renovated DH networks and waste water benefits were not taken into account. It is suggested to develop a common procedure to calculate PEF in all the EU member states.

M. Noussan, R. Roberto, and B. Nastasi article [7] made a data analysis of Italy's electricity production. Taking into account share of renewable energy sources and CO2 emissions based on primary energy consumption. The study showed a significant variation of power production seasonally and daily. There were also pointed out strict relation between PEF, renewable share and CO2 emission factor. The higher the percentage of renewable share the lower emission factor and PEF. Finally was compared electricity prices to the indicators. That analysis showed a weak relation between electricity prices and renewable share, also PEF.

In L. N. Troup, D. J. Fannon, and M. J. Eckelman article [8] were used two energy accounting practices to find out energy site-to-source conversion factors for North American Regions. Study found that currently used EnergyPlus factor is higher than calculated factors. Difference has a big influence on results of Building Energy Model.

E. Marrasso, C. Roselli, and M. Sasso article [9] four calculation methods for PEF are considered – first one in line with Eurostat primary energy calculation, second one most adequate for total use of non-renewable sources, third to analyze the different fuel input share for combined heat and power plants, last one modified third calculation by added life cycle perspective. Study showed that all calculated PEFs were lower than PEF 2,5. It was said that using constant values instead of time-varying values leads to inadequate energy and environmental analysis results.

1.3.1 Estonian legislative PEF

First Estonian PEFs appeared in regulation Energiatõhususe miinimumnõuded at year 2007 [3]. Today a regulatation from 2008 is still valid. Figure 1.2 shows that electricity PEF on has risen one time over the period 2007-2022. Being PEF 1,5 from 2007 – 2013 and after that PEF 2,0 till today [1].

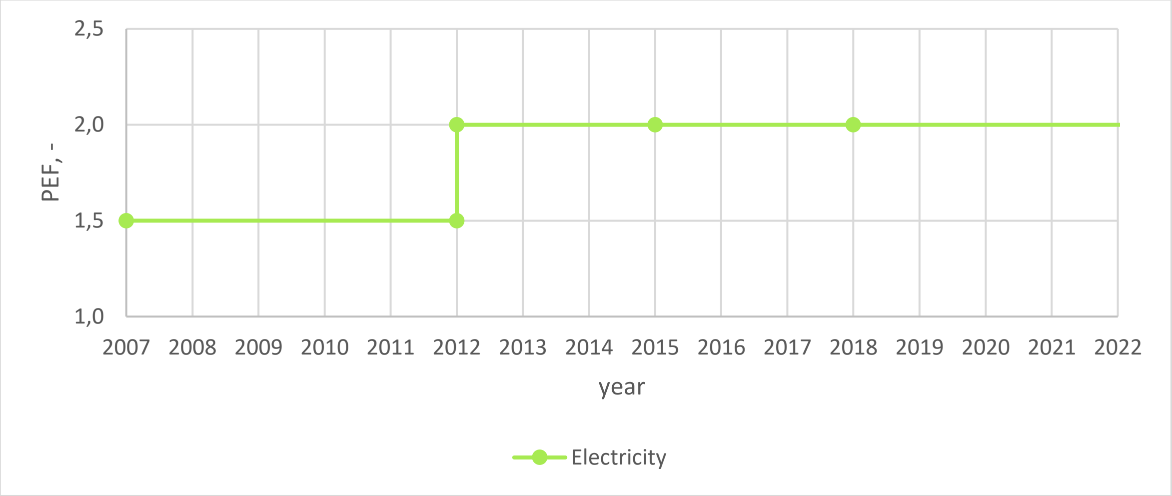

Figure 1.1 Estonian evolution of legislative PEF for electricity 2007-2022

As seen on the figure 1.1, regular DH has stayed the same PEF 0,9 for 14 years [3]–[5]. At 2018, efficient DH[1] was added and received lower PEF 0,65 [1].

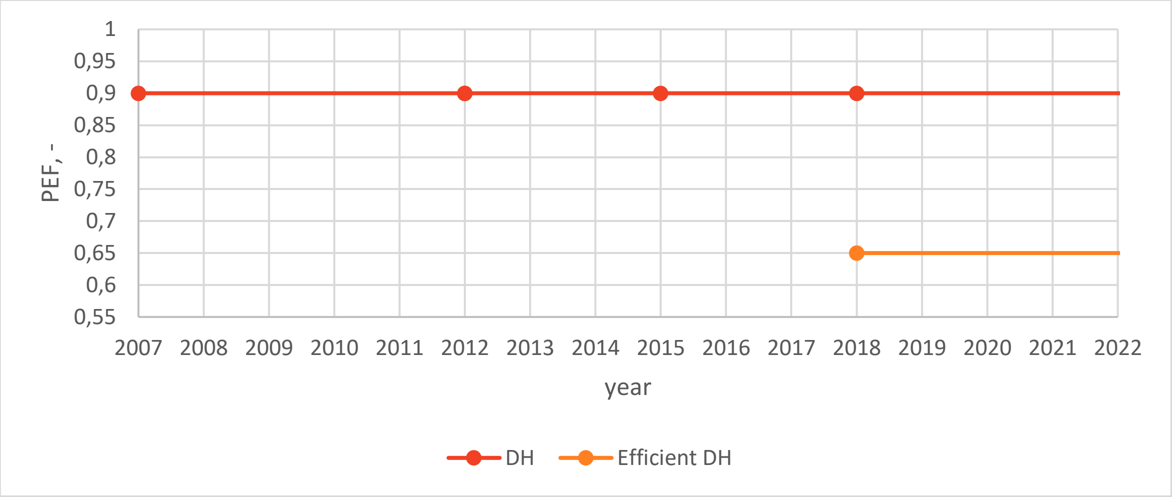

Figure 1.2 Estonian evolution of legislative PEF for DH 2007-2022

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[1] Following regulation [1] „..efficient district heating or cooling is a district heating or cooling system that uses at least 50% renewable energy, 50% waste heat, 75% cogeneration or 50% combinations of such energy and heat."

2 METHODOLOGY

Methodology divides into four smaller parts – Estonian legislative PEF, historical real PEF, dynamic PEF and primary enegy evaluation for MP3. In order to achive results, following steps were taken.

Estonian legislative PEF

1. Collecting data about Estonian electricity PEFs from all the regulations available [1], [3]–[5];
2. Collecting data about Estonian DH PEFs from all the regulations available [1], [3]–[5];

Historical real PEF - electricity

1. Finding annual electricity PEF for 2007-2020, using Eurostat data about Estonia energy balance and following EN17423 for calculation [10], [11];
2. Comparing Estonian legislative PEF and historical real PEF for electricity;

Historical real PEF - DH

1. Finding annual DH PEF for 2007-2020, using Eurostat data about Estonia energy balance and following EN17423 for calculation [10], [11];
2. Comparing Estonian legislative PEF and historical real PEF for DH;

Dynamic PEF

1. Choosing three weeks of the year to make all following calculations on. Basing on available data of MP3, season and PV production of MP3. Energy use data is from building management system website and PV production from SolarEdge [12], [13];

Dynamic PEF - electricity

1. Collecting general information about electricity generation in Estonia and data availability;
    - Deciding to use data only about electricity generation came from nREN sources, since Estonian legislative PEF is based on nREN source;
2. Collecting data about electricity generation per generation units in Estonia from Entso-e [14];

   - Using only electricity generation data from fossil oil shale plants that have capacity at least 100 MW since that data is available in Entso-e [15];

3. Receiving efficiency curves for each power plant unit working with fossil oil shale in Estonia from Enefit Power;
   - Assuming that CHP unit TG11 is generating 60 MW heat at the same time, resulting higher efficiency values;
4. Finding corresponding efficiency factor for every value of every unit within the time spans;
   - For generation values that are higher or lower than efficiency factors range, accordingly the lowest or highest efficiency factor is obtained;
5. Calculating average weighted efficiency factor for each hour, using formula (2.1)

$$\bar{\eta} = \frac{\sum_{i=1}^{n} \eta_i \cdot P_i}{\sum_{i=1}^{i} P_i} \tag{2.1}$$

Where $\bar{\eta}$ – average weighted efficiency factor, %

η - efficiency factor corresponding to electricity generated, %

P – Generated electricity, MW

6. Calculating electricity PEF for each hour, following formula (2.2);

$$PEF_{el} = \frac{1}{\left(\frac{\bar{\eta}}{100}\right)} \tag{2.2}$$

Where PEF_{el} – Electricity PEF, -

$\bar{\eta}$ – average weighted efficiency factor, %

Dynamic PEF - DH

1. Collecting general information about DH in Estonia;
   - Deciding to make DH PEF calculation only for Tallinn grid, since MP3 is located in Tallinn;
2. Obtaining data about DH load in Tallinn at 2021 and information about priority order, technology and capacity of plants from Utilitas Tallinn. As well as, dynamic efficiency factors about Iru waste burning block from Enefit Green and approximate average efficiency factors about rest of the plants, from AS Utiltias Eesti;

- Assuming that CHP plants 2-4 have allocation factor 0,5 that is divided with efficiency factors to get more accurate results;

3. Calculating average weighted efficiency factor for each hour, following formula (2.3);

$$\bar{\eta} = \frac{\sum_{i=1}^{n} \eta_i \cdot P_i}{\sum_{i=1}^{i} P_i} \tag{2.3}$$

Where $\bar{\eta}$ – average weighted efficiency factor, %

η - efficiency factor, %

P – Generated DH, MW

4. Calculating DH PEF for each hour, following formula (2.4);

$$PEF_{DH} = \frac{1}{\left(\frac{\bar{\eta}}{100}\right)} \tag{2.4}$$

Where PEF_{DH} – DH PEF, -

$\bar{\eta}$ – average weighted efficiency factor, %

Primary energy evaluation for MP3 - electricity

1. Obtaining electricity use data about MP3 building from building management system website [12];

2. Finding out how big percentage nREN source makes from the total electricity generation source for each hour of time spans;

    - Considering biomass, fossil coal-derived gas, fossil gas, fossil oil shale and fossil peat as nREN sources;

3. Calculating MP3 nREN electricity use based on national nREN source electricity percentage;

4. Calculating MP3 primary energy use with PEF and nREN electricity use;

Primary energy evaluation for MP3 - DH

1. Obtaining DH use data about MP3 building from building management system website [12];

2. Calculating MP3 primary energy use by multiplying PEF with DH use.

3 CASE STUDY BUILDING

Ehituse Mäemaja is one of Taltech’s buildings located at Mäepealse 3, Mustamäe district, Tallinn 12618, Estonia. It was partly renovated and rebuilt to become nearly zero-emission building. Mäepealse 3 is used as a research and study building including rooms like construction test hall, laboratories for construction, roads and traffic, building physics and indoor climate, water engineering, geotechnics, as well as stone cutting workshop and common classrooms. [16]

The structure of the building is combination of metal, concrete and wood. Water and sewerage are provided by grid, electricity is supplied by grid, as well as PV panels. PV panels are located on the roof of main building and awning, also on the wall. Heat supply comes from district heating. [17], [18]

Heating is divided between ventilation calorifiers, air curtain, radiators, radiant heating and floor heating. Cooling unit provides ventilation units cooling, fan-coils, cooling beams and panels, hydraulic station cooling, in addition split units are used for technical rooms. Ventilation is ensured with 8 different units including systems for air exchange with heat recovery, mechanical air supply and exhaust, air conditioning. [18]

More numerical data about the case study building can be found from the table 3.1 [17], [18].

Table 3.1 Numerical data about Mäepealse 3 building

Floors	4 (1 underground + 3 above the ground)
Lenght	50,1 m
Width	43,1 m
Height	17,7 m
Depth	3,5 m
Heated area	3406,2 m^2
Volume	20328 m^3
Heating total power	268,6 kW
Cooling total power	250 + 22 kW
PV panels total power	48,7 kW
Energy performance index[2]	100 kWh/m^{2}y (class A)

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[2] „Calculated total weighted delivered energy use for typical use of a building, reflecting complex energy use for indoor climate, heating of domestic water as well as using household and other electrical equipment by heated space square meter with typical use of a building and is expressed in kilowatt-hours for a heated space square meter of a building per year.‟ [2]

On photo 3.1 Mäepealse 3 case study building is showed.

Photo 3.1. Mäepealse 3 building, author Karl-Kristjan Nigesen

4 RESULTS AND DISCUSSION

Present chapter includes four main sections – historical real PEF, dynamic PEF, primary energy evaluation for MP3 and comparison between Estonian legislative PEF and calculated dynamic PEF. All these sections include two subsections, one for electricity and other for DH.

First section, historical real PEF shows yearly PEF factors from 2007 to 2020, calculated with Eurostat data by normative EN17423 [10], [11]. Second section, dynamic PEF includes several figures leading to dynamic PEF. In electricity part data was collected from Enefit Power and Entso-e [14], [15], [19]. DH part data came from Utilitas Tallinn and Enefit Green. Third section, primary energy evaluation for MP3 shows figures leading to MP3 primary energy use. Data was obtained from MP3 building management system website and from Entso-e [12], [20]. Fourth section, comparison between Estonian legislative PEF and calculated dynamic PEF contains previously obtained information.

4.1 Historical real PEF

Historical real PEFs were found using annual data about Estonian energy balance, provided by Eurostat [11]. Calculation followed European normative EN17423 [10]. Beginning of time span was chosen 2007 because first Estonian legislative PEF values were declared that year and comparison will be made between real historical and legislative factors. End of time span is 2020, since that is latest annual data available in Eurostat.

4.1.1 Electricity

Historical real PEF change for electricity during 2007-2020 can be seen on figure 4.1. From 2007 to 2011 PEF was almost stable around 2,6. 2012 showed a drop to 2,4 and from 2013 PEF lowered each year from 2,6 to 1,8 in 2020. In comparison with Estonian legislative values, historical real was sam or lower only last two years of the time span.

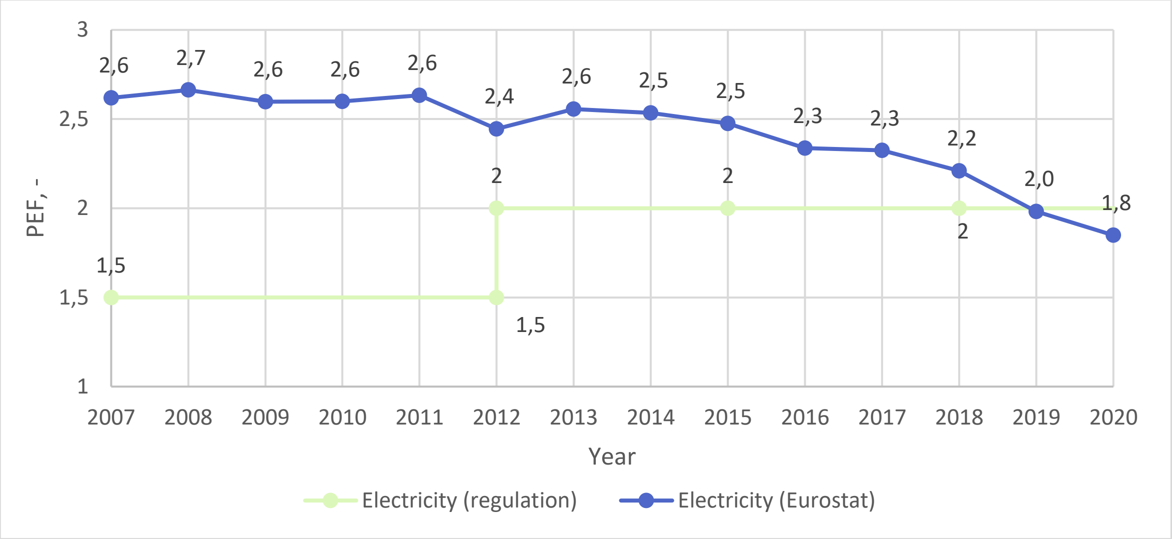

Figure 4.1 Historical real and Estonian legislative PEF for electricity 2007-2020

4.1.2 DH

Historical real PEF values for DH are shown on figure 4.2 and compared with legislative PEFs. From 2007 to 2013 real factors are higher than legislative DH PEF. From 2014 calculated PEF is lower than DH legislative with one exception in 2016. Calculated PEF lowest value appears on years 2017-2020 at 0,8, being still higher than efficienct DH PEF.

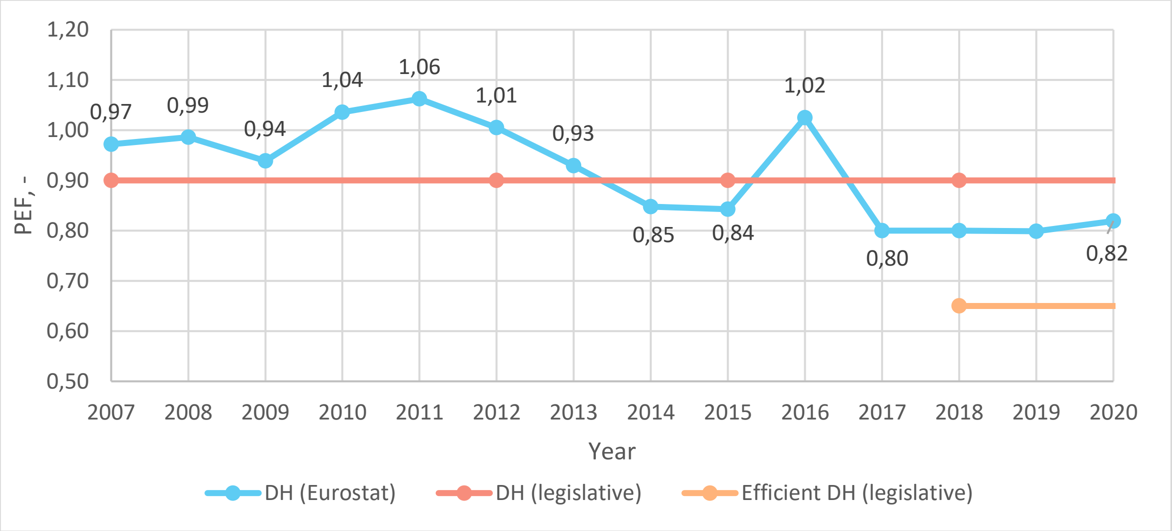

Figure 4.2 Historical real and Estonian legislative PEF for DH 2007-2020

4.2 Dynamic PEF

Before making any calculations a suitable time period was decided on. Since these dynamic PEFs will be also applied to evaluate MP3 energy performance, available MP3 data was a starting point to choose time spans. 2021 is the year where MP3 shows energy data whole time. Next it was suggested to choose three weeks from a year – one typical winter (December-January-February), spring (March-April-May) and summer (June-July-August) week, meaning accordingly little or no sun, medium quantity of sun and lots of sun. PV production values about MP3 are available in SolarEdge website [13]. To find suitable weeks first monthly data was evaluated to choose one month from each given season that matches sun light requirements the best. Secondly, daily data of the chosen month was looked at to find one week from Monday to Sunday that meets requirements. To be clear, chosen time spans are shown in Table 4.1.

Table 4.1 Overview of time spans and requirements

Season	PV production	Date range
Winter	Low	06.12.21-12.12.21
Spring	Medium	12.04.21-18.04.21
Summer	High	14.06.21-20.06.21

4.2.1 Electricity

To calculate electricity PEF two kinds of data must be known. Output electricity amount and efficiency factor of generation unit or input energy amount. In this thesis efficiency factors are used since it was available data. Before starting any calculations some research and assumptions were made.

Estonian electricity comes from different nREN and REN sources. For this caculation only nREN was considered since Estonian legislative PEF is based on nREN source and these two will be compared at the end. Biggest source with available data in nREN share is fossil oil shale. Entso-e provides hourly data for each power plant unit generating electricity from fossil oil shale [14]. It must be mentioned, that the source only takes into account plants, that have installed capacity at least 100 MW [15].

Table 4.1 shows all the power plants units that were working on any three time periods. Units are from three power plants and have one of three kind of technology used. Installed capacity ranges from 140 to 270 MW. Only one unit TG11 is CHP meaning that also heat was generated with electricity. This unit's efficiency curve was chosen with assumption that at the same time 60 MW of heat is generated.

Table 4.2 Power plants units overview

Unit	**Name of the power plant**	**Technology**	**Installed capacity, MW** [19]	**CHP**
G1	Auvere elektrijaam	CFB boiler[3]	270	
TG3	Eesti Elektrijaam	PC[4]	164	
TG4	Eesti Elektrijaam	PC	164	
TG5	Eesti Elektrijaam	PC	173	
TG6	Eesti Elektrijaam	PC	173	
TG8	Eesti Elektrijaam	CFBC[5]	194	
TG11	Balti Elektrijaam	CFBC	140	Yes

Figure 4.3 shows efficiency curves for each technology used in power plant unit. In the intrest of Enefit Power, full data about each unit's efficiency curve could not be shared. In result, these three curves are each technology averages, shown as trendlines.

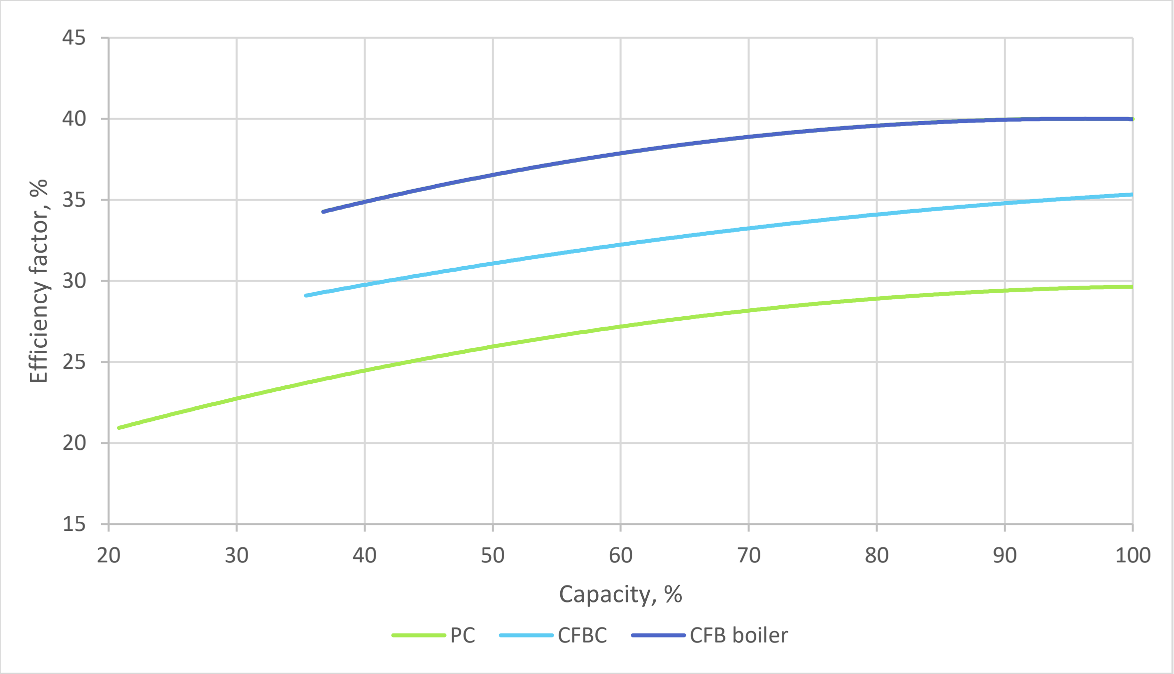

Figure 4.3 Efficiency curves per technology (source: Enefit Power)

All the following figures have colored edge to indicate winter (blue), spring (green) or summer (orange) time span. On the top of the figure days of the week are listed and in the bottom hours 1, 7, 13 and 19 are indicating time of the day. Lines indicating units are the same color as used technology efficiency curves on figure 4.2.

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[3] CFB boiler - Circulating fluidized bed boiler

[4] PC - Pulverized combustion

[5] CFBC - Circulating fluidized-bed combustion

4.2.1.1 Electricity generation per unit

First step finding dynamic PEF was getting hourly delivered electricity data from Entso-e [14]. Next three figures are data representation of electricity generation per generation unit for chosen time spans 06.12.21-12.12.21, 12.04.21-20.04.21 and 14.06.21-20.06.21.

Figure 4.4 shows that 6 units are working all week between 100 and 200 MW, making total electricity generation about 1000 MW per day.

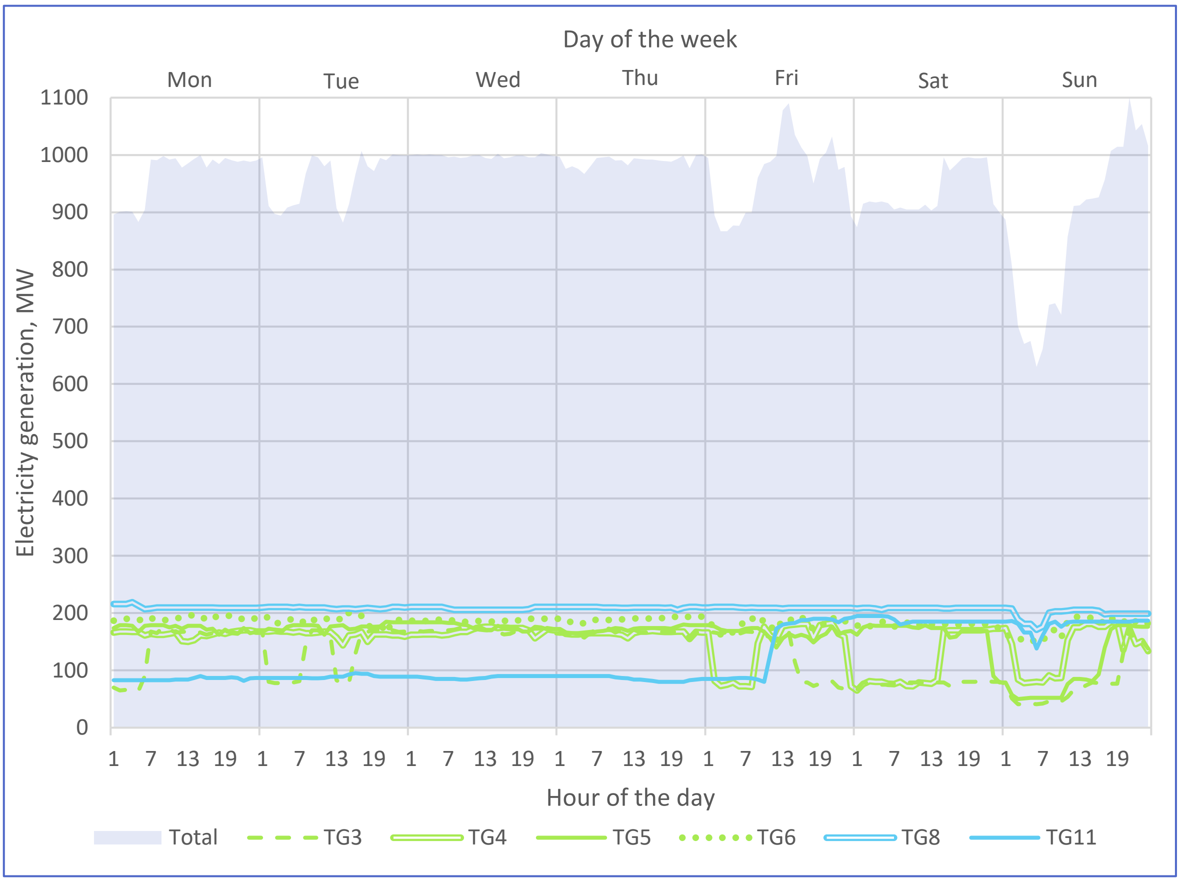

Figure 4.4 Electricity generation per unit 06.12.21-12.12.21

Since G1 unit is out order other units must be working on full power [21]. Decreases of electricity generation can be seen on night times due to lower electricity use at households.

Figure 4.5 shows that four units (G1, TG5, TG8, TG11) are represented in the week and are working abruptly. Highest generation of the week, near 600 MW is on Wednesday.

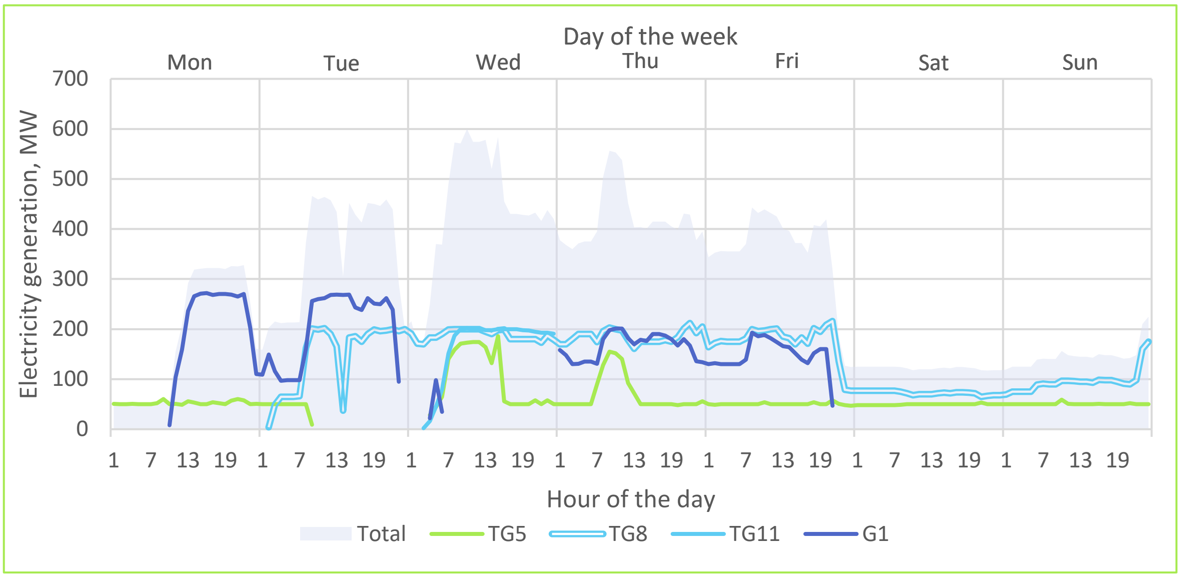

Figure 4.5 Electricity generation per unit 12.04.21-18.04.21

Lower values can be seen on nighttime and highest from mid-day to evening because of people’s daily rythm.

Figure 4.6 shows that mostly three units (G1, TG8, TG11) are working during the week, fourth (TG5) adheres on Sunday. Highest generation can be seen in the middle of the week with values about 650 MW.

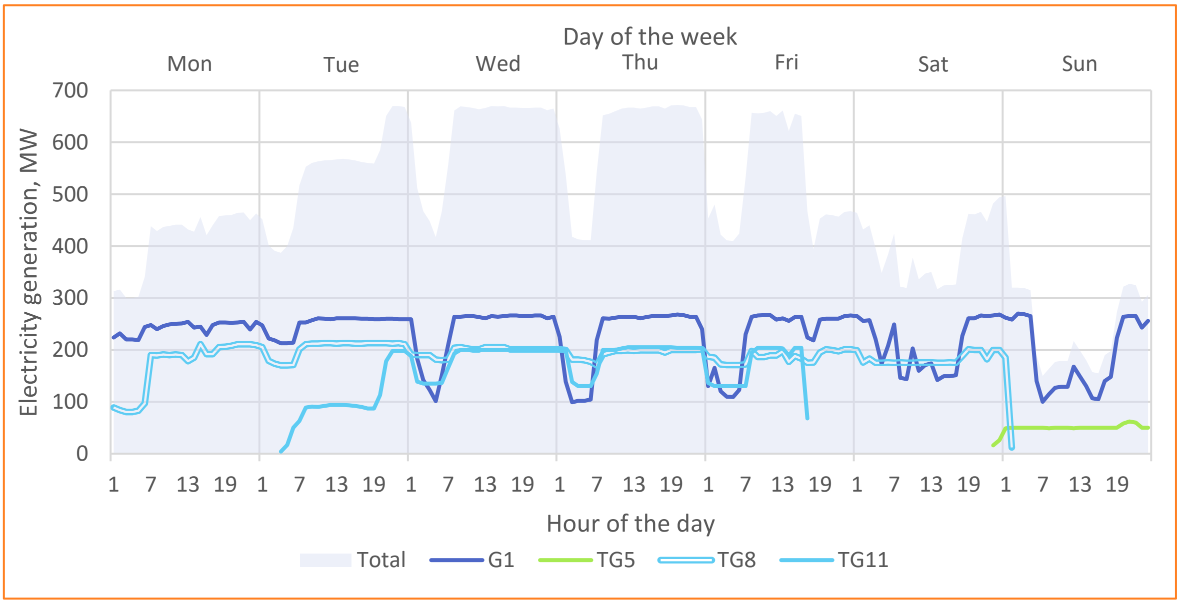

Figure 4.6 Electricity generation per unit 14.06.21-20.06.21

All three figures showed higher electricity generation in the middle of the week when people are more actively using electricity

4.2.1.2 Efficiency factor per unit

Efficiency factors per unit were found using real efficiency curves corresponding to the unit. For every unit hourly electricity generation was matched with efficiency factor, resulting a dynamic efficiency factors for each unit at given week.

For TG11, that is a CHP unit, an assumption were made that with the electricity 60 MW heat is also generated along with electricity. This resulted as higher efficiency factor values.

Figures 4.7, 4.8 and 4.3 show dynamic efficiency factors per unit for time spans 06.12.21-12.12.21, 12.04.21-20.04.21 and 14.06.21-20.06.21.

At winter week six units were working as seen on figure 4.7. TG6 and TG8 have almost constant efficiency for entire period, TG3-5 show some lower values, TG11 rises at the end of the week.

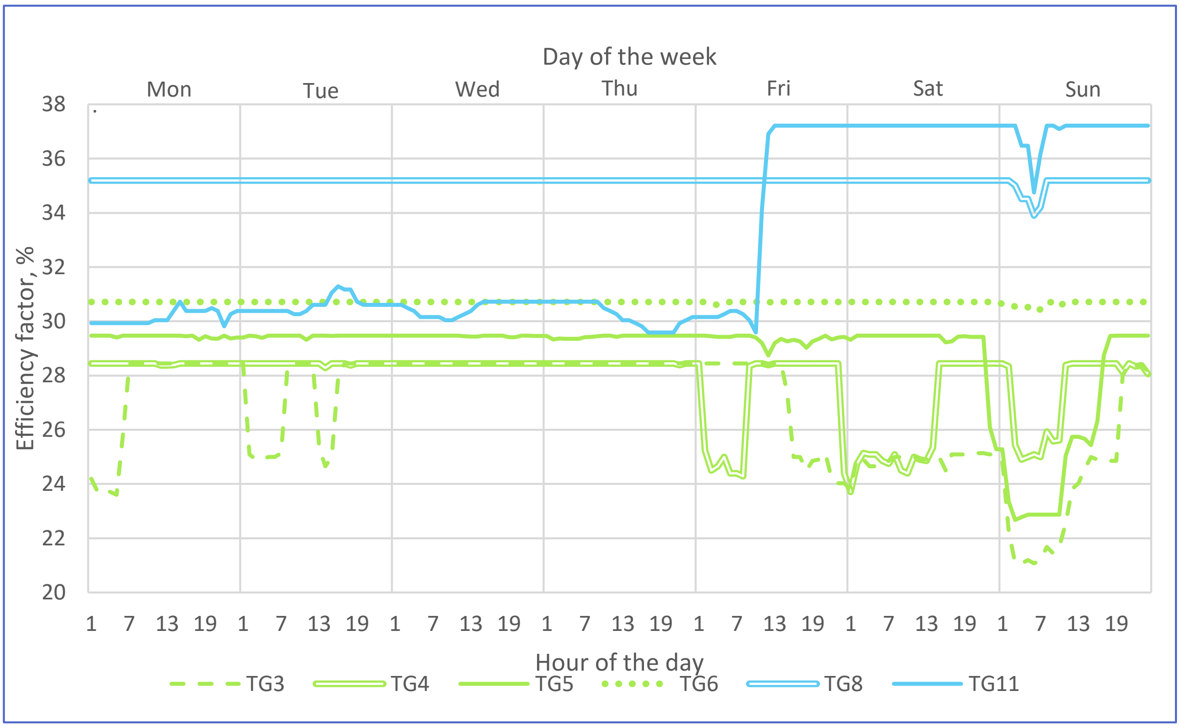

Figure 4.7 Efficiency factor per unit 06.12.21-12.12.21

Spring period figure 4.8 shows hectic efficiency factors from four units. Values change in about 6% range for each unit.

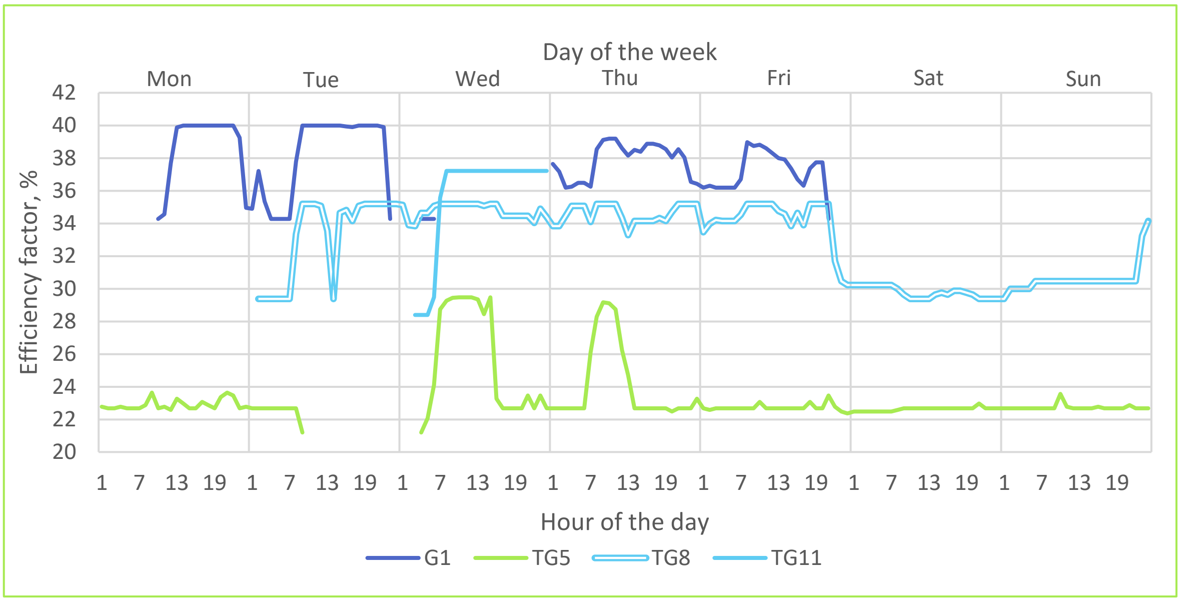

Figure 4.8 Efficiency factor per unit 12.04.21-18.04.21

In summer period as seen on figure 4.9, four units (G1, TG5, TG8, TG11) are working mostly in range of 30-40% efficiency. In the middle of the week there are recognizable drops each night.

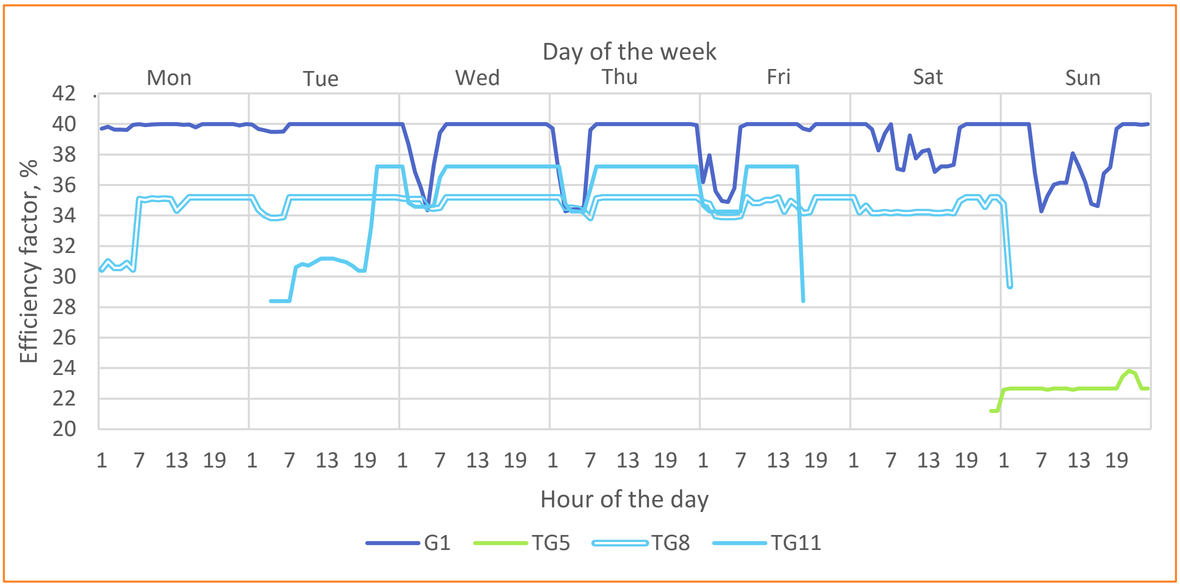

Figure 4.9 Efficiency factor per unit 14.06.21-20.06.21

Efficiency values follow the same line as electricity generation, higher generation means higher efficiency factor. Reasons behind the changes are same as with electricity generation. According to these time spans, unit TG8 is the most reliable unit, working most of the time.

4.2.1.3 Electricity PEF

Electricity PEF calculation started with finding average weighted efficiency factor for each hour, following formula (2.1) For this calculation, real efficiency factors for each unit were used, provided by Enefit Power and not displayed in the study. Electricity PEF calculation followed with formula (2.2) for each given hour.

Next three figures show electricity PEF change on time spans 06.12.21-12.12.21, 12.04.21-20.04.21 and 14.06.21-20.06.21.

On figure 4.10 PEF varies from 3,14 to 3,29. Being higher in the beginning of the week and lower at the end of the week with one spike on Sunday morning.

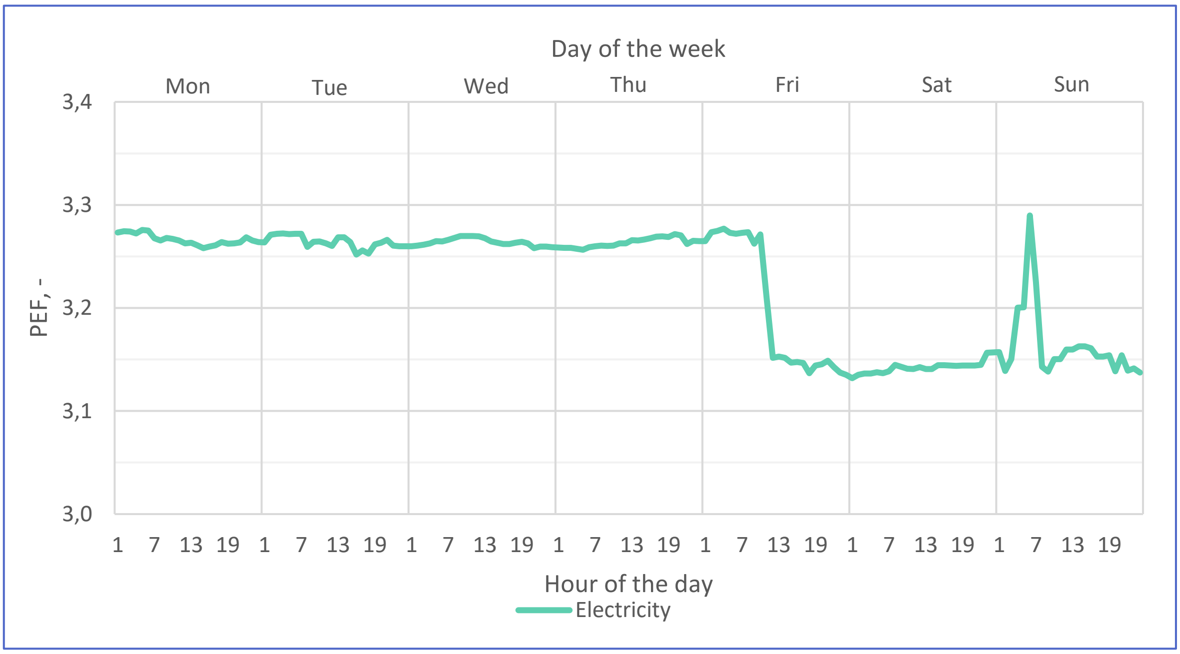

Figure 4.10 Electricity PEF 06.12.21-12.12.21

0,1 decline at the end of the week is caused by unit TG11 with increasing the efficiency factor, average factor and therefore lowering PEF.

On Figure 4.11 PEF shows bigger difference in range. Weekly value varies from 2,6 to 4,4 being higher in the beginning and in the end of the time span.

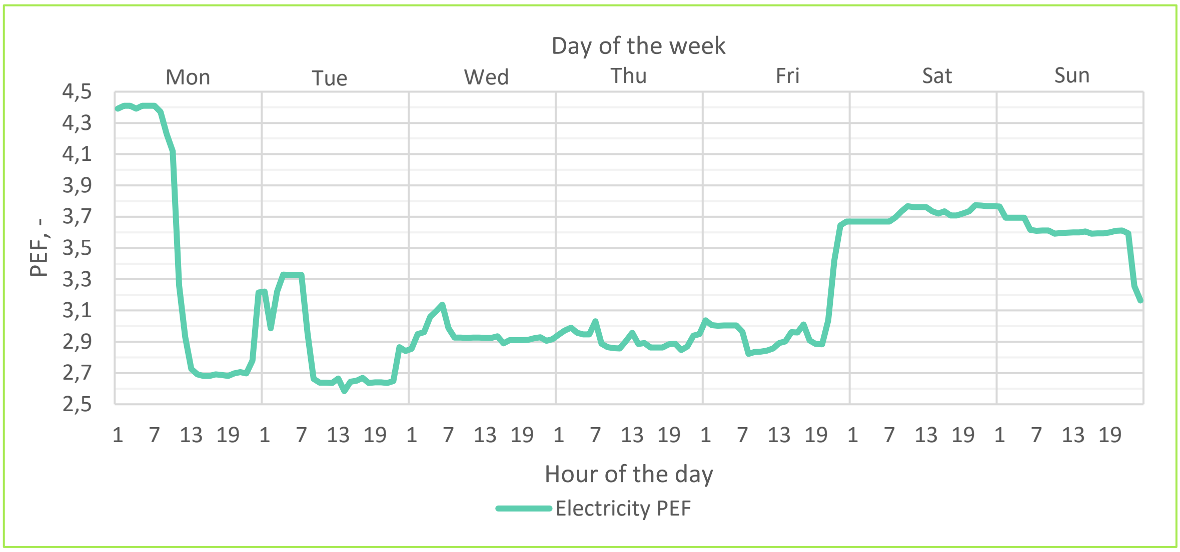

Figure 4.11 Electricity PEF 12.04.21-18.04.21

This very high 4,4 PEF at the beginning of the week is caused by one unit that is working on a low efficiency alone, bringing the average efficiency down and PEF up. End of the week shows also higher PEF values since unit G1 stopped and left two units with lower efficiency working.

Figure 4.12 represents PEF from 2,65 up to 3,3. Spikes are seen Wednesday, Thrusday and Friday nights and also on Sunday.

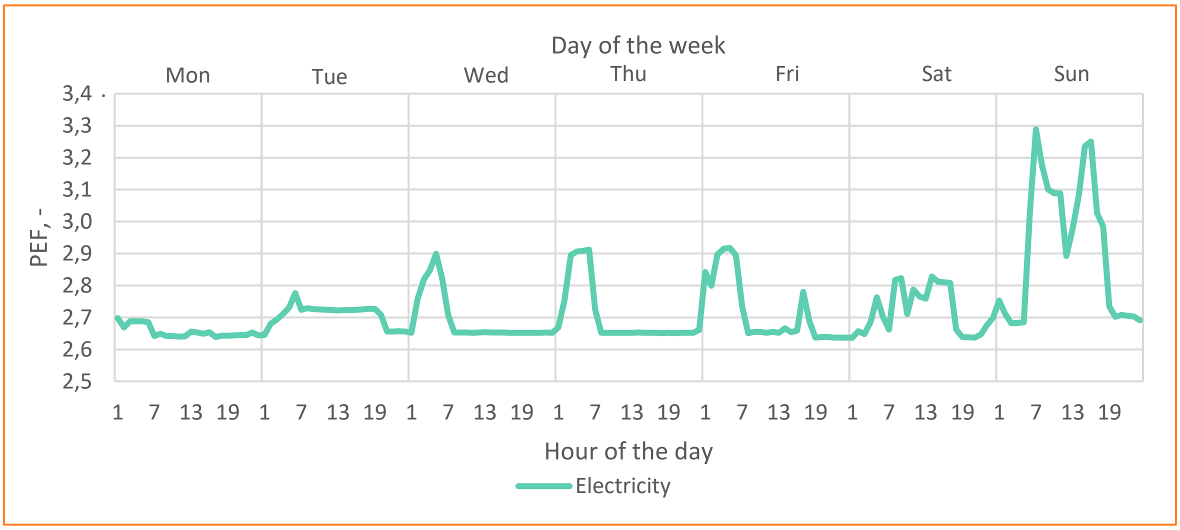

Figure 4.12 Electricity PEF 14.06.21-20.06.21

These spikes on Wednesday, Thursday and Friday nights are cause by collective decrease in units generation. Rise on Sunday is beacuse only two units out of four were left working.

4.2.2 DH

DH calculations were similar to electricity calculations. To calculate PEF two things must be known - delivered DH and plant input energy or efficiency factor of the plants.

Utilitas Tallinn provided information about heat generating plants in Tallinn grid shown in table 4.3. Plants are in order of priority, first marked with 1. Most of the names have index of (a) or (b) to distinguish different units with the same name. For CHP plants 2-4 an allocation factor was assumptioned as 0,5. For these plants, given efficiency factor was divided with allocation factor to get more accurate percentage of efficiency. Same three plants also have flue gas condensers installed, that are not working in summer, resulting lower efficiency values at summer time, shown in the last column.

Efficiency factor for Iru plant is based on 2022 average and already considering cogeneration of electricity. Data was obtained from Enefit Green.

Table 4.3 Tallinn DH plants overview (source: Utilitas Tallinn and Enefit Green)

Priority	**Name**	**Installed capacity, MW**	**CHP**	**Efficiency factor, %**	**Efficiency factor (summer), %**
1	Iru	50		81	
2	Tallinn (a)	76	Yes	206	170
3	Mustamäe (a)	38	Yes	206	170
4	Tallinn (b)	67	Yes	206	170
5	Spordi	16		101	
6	Kristiine (a)	100		98	
7	Mustamäe (b)	150		93	
8	Kristiine (b)	Remaining capacity		93	
	Ülemiste*	100			

* Ülemiste is a backup plant for when any of the foremost plants is not working. It was not considered in the study.

4.2.2.1 DH generation per plant

DH generation per plant data came from combining plants order of priority and capacity with Tallinn DH total load hourly values, provided by Utilitas Tallinn. Next three figures show DH generation per plant for three time spans 06.12.21-12.12.21, 12.04.21-20.04.21 and 14.06.21-20.06.21.

Figure 4.13 shows DH load about 650 MW in the beginning of the week to lowering about 400 MW in the end of the week. All 8 plants are working.

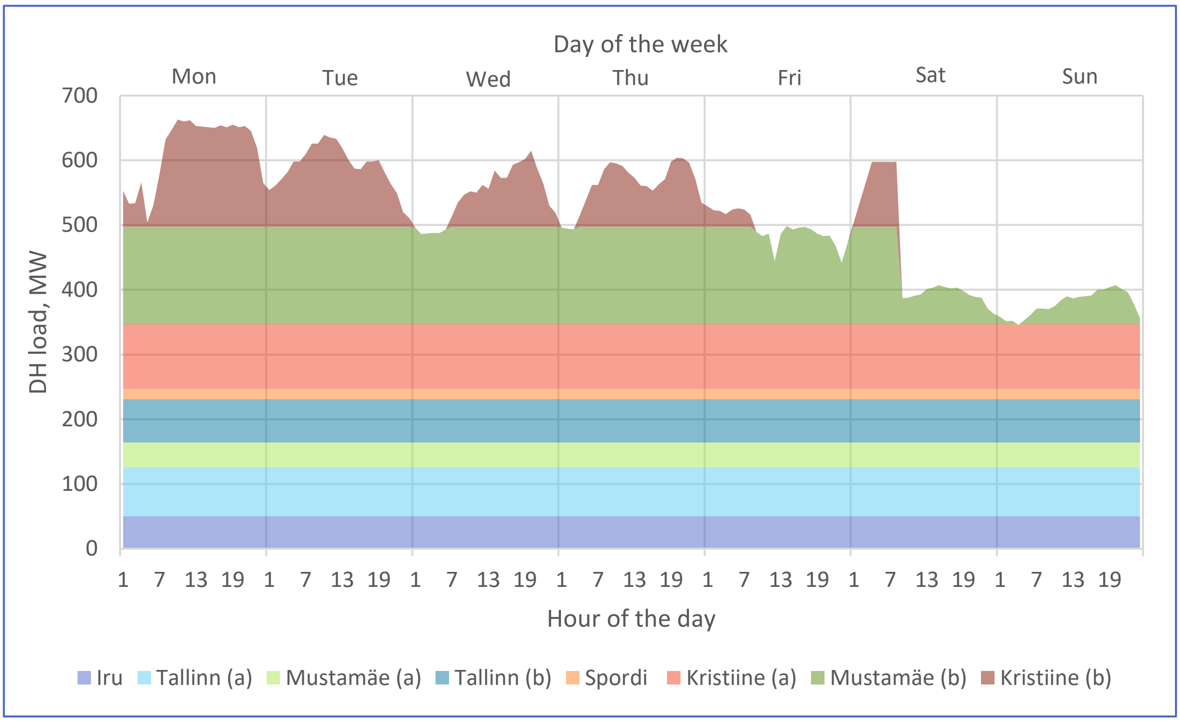

Figure 4.13 DH generation per plant 06.12.21-12.12.21 (source: Utilitas Tallinn)

High DH generation is probably a sign of colder weather.

Figure 4.14 shows that all plants except Kristiine (b) are working whitin spring time span. Highest values around 300 MW can be seen in the middle of the week, as well as one spike on Sunday.

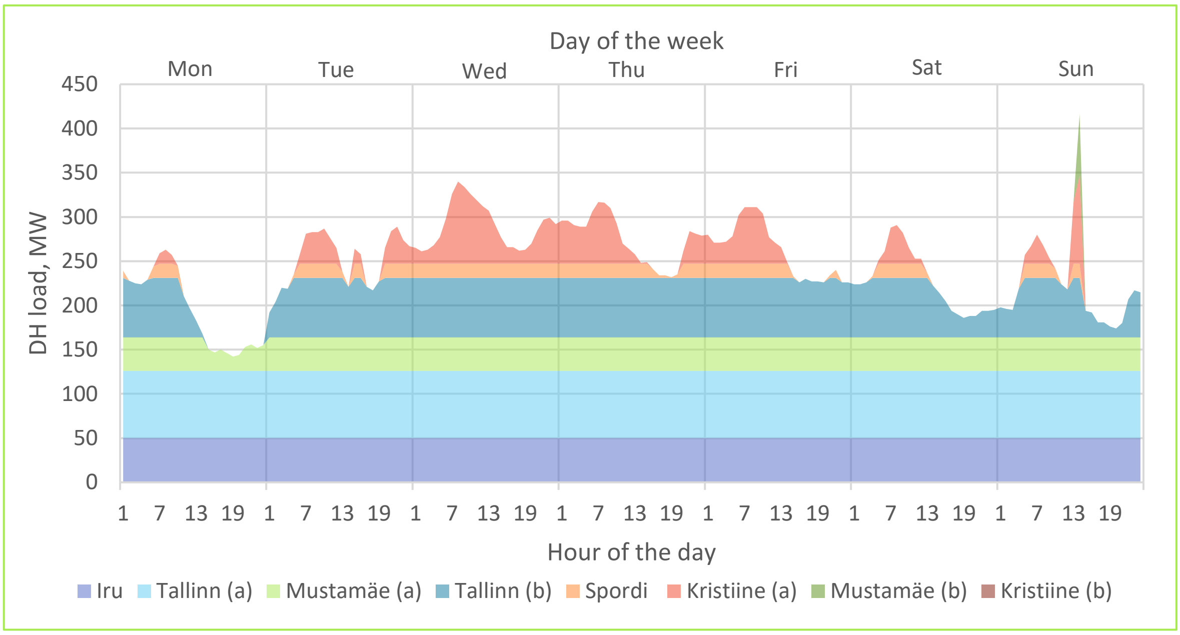

Figure 4.14 DH generation per plant 12.04.21-18.04.21 (source: Utilitas Tallinn)

Figure 4.15 shows almost stable DH generation for whole week, being around 70 MW. One spike occurs on Wednesday, resulting total of three plants working during the week.

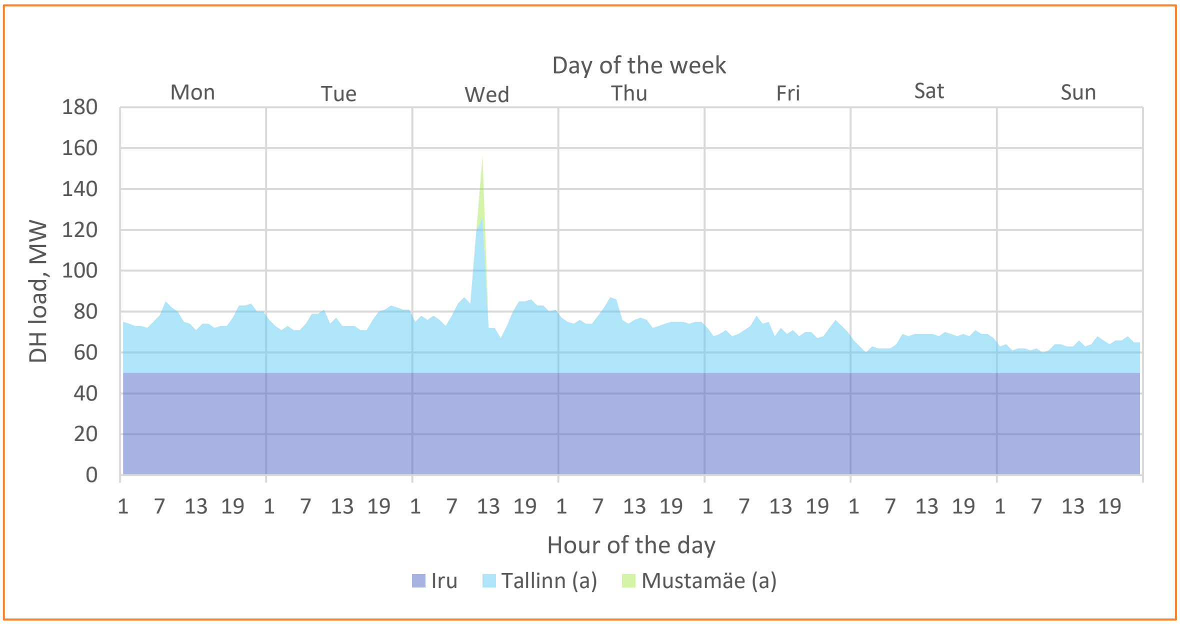

Figure 4.15 DH generation per plant 14.06.21-20.06.21 (source: Utilitas Tallinn)

All figures indicate that there is a connection between outside temperature and DH load. Also lower values at the end of the week are spotted due to weekend.

4.2.2.2 Dynamic PEF for DH

Here are three DH PEF figures, one for each time span. Figure 4.16 shows PEF from 0,8 to 0,65. Starting higher in the beginning of the week and coming gradually down.

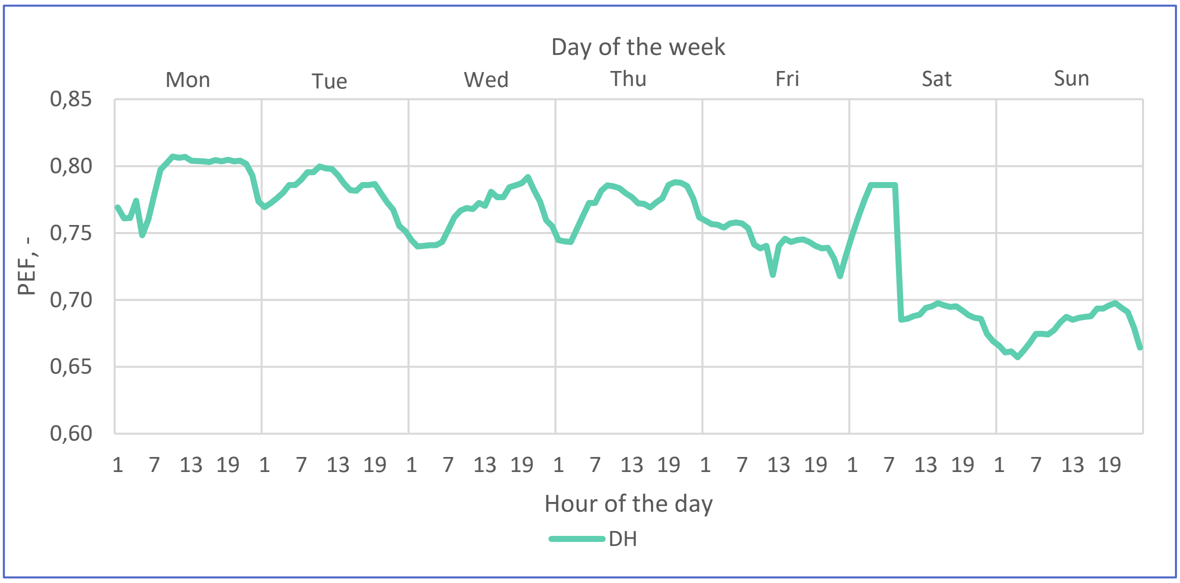

Figure 4.16 DH PEF 06.12.21-12.12.21

Figure 4.17 shows that PEF is staying mostly between 0,55-0,65. One higher spike occurs on Sunday.

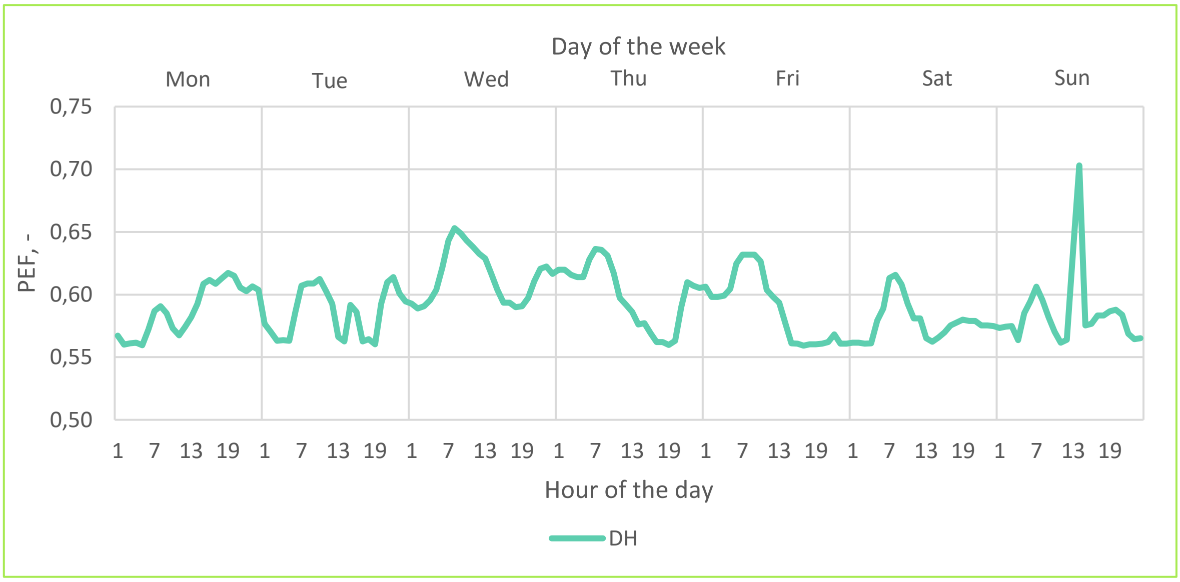

Figure 4.17 DH PEF 12.04.21-18.04.21

On figure 4.18 PEF stays between 0,8 and 0,85 for first two days and then starts to rise till 0,9 for the end of the week.

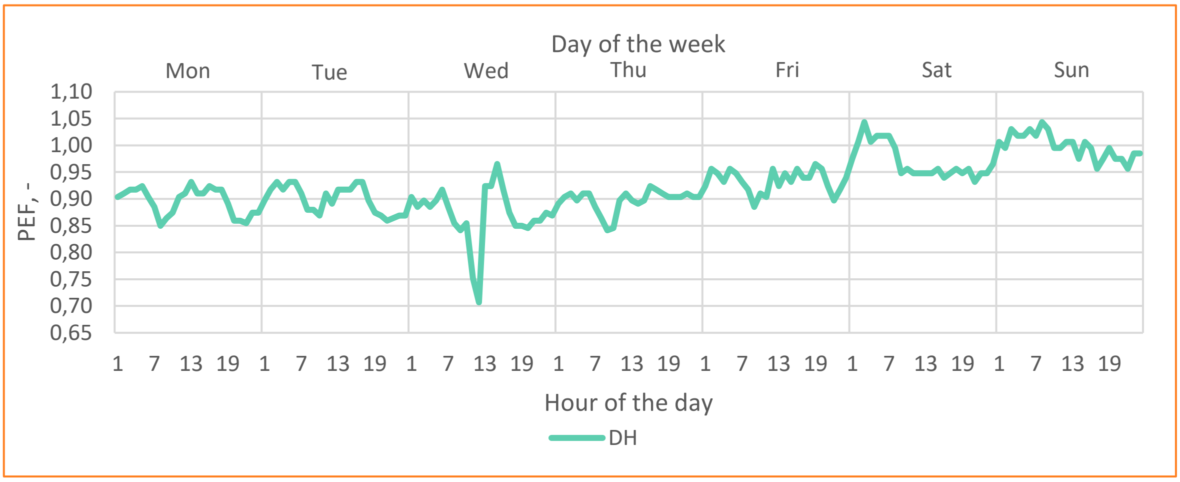

Figure 4.18 DH PEF 14.06.21-20.06.21

Because of static efficiency factors, PEF is following the same line as DH generation. Reasons for change are the same.

4.3 Primary energy evaluation for MP3

Source data for this section were taken from previous PEF calculations, from Entso-E and MP3 building management system website [12], [20]. Primary energy evaluations were made separately about electricity and DH use in MP3 building for three chosen time periods.

4.3.1 Electricity

In order to find MP3 electricity primary energy use, three kinds of data were needed. MP3 total electricity use, electricity division between nREN and REN sources in Estonia and previously calculated dynamic PEF.

4.3.1.1 Electricity generation from nREN and REN sources

Since calculated PEF only considers nREN source, a nREN part of MP3 total electricity must also be known. To get the percentage of nREN share, national data was used. Entso-e provides data of electricity generation per production type, considering all the nREN and REN sources used to generate electricity in Estonia [20]. Biomass, fossil coal-derived gas, fossil gas, fossil oil shale and fossil peat were considered as a nREN source. Hydro run-of-river and poundage, other renewable, solar, waste and wind onshore were considered as REN sources. Combining these values a percentage of nREN was found for Estonia boundary.

Next three figures show electricity generation from nREN and REN sources in percentages within three different time spans. On figure 4.19 can be seen that nREN source makes 85-95% of the total.

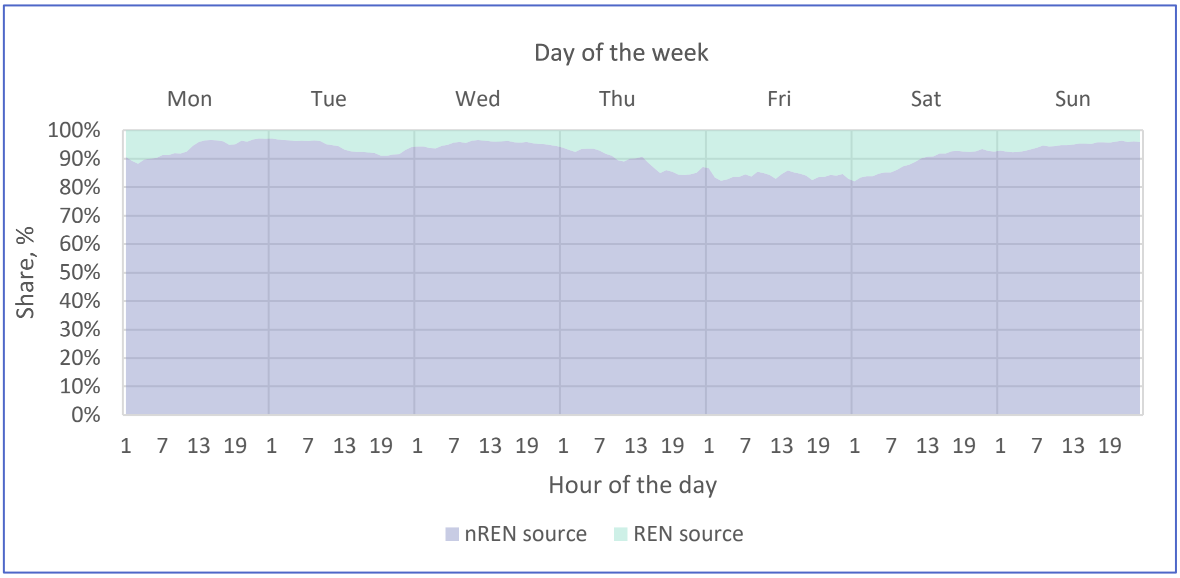

Figure 4.19 Electricity generation from nREN and REN sources 06.12.21-12.12.21

Highest nREN share percentages can be seen winter time. Reason could be smaller REN sources availability, for example solar energy.

Figure 4.20 shows that nREN share start at about 40% at the beginning of the week, then rises to 90% and after starts to gradually come down.

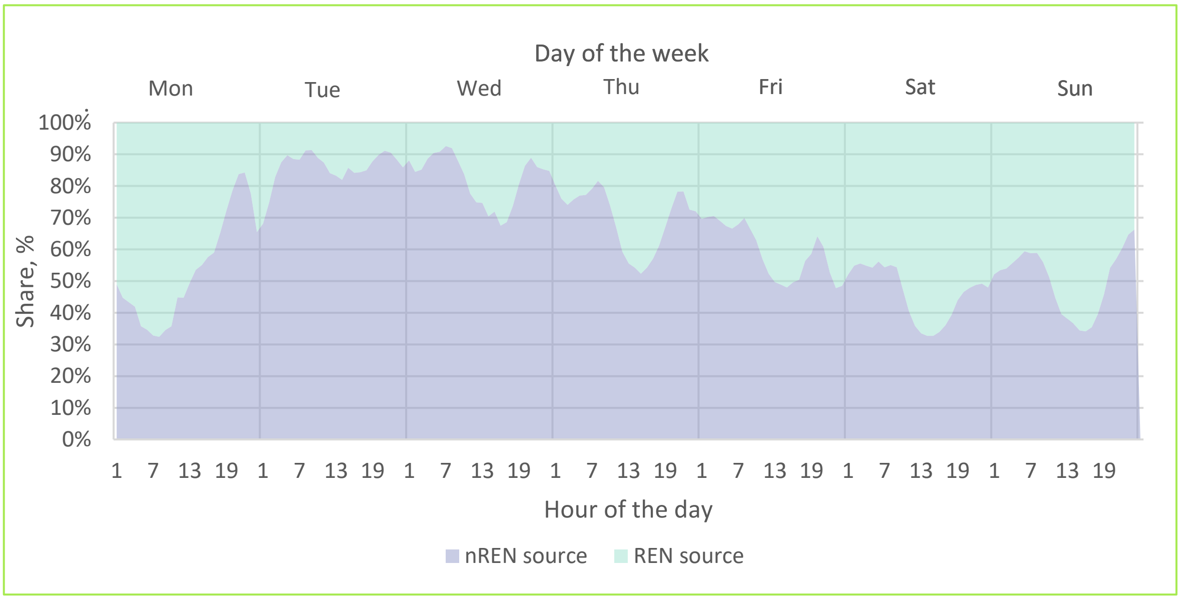

Figure 4.20 Electricity generation from nREN and REN sources 12.04.21-18.04.21

Spring time source distribution has so big variation probably beucause of changable weather and therfore REN sources availability.

On figure 4.21 highest points are located at the day shifts, reaching 90% at the middle of the week. Fluctation is 30-50% per day.

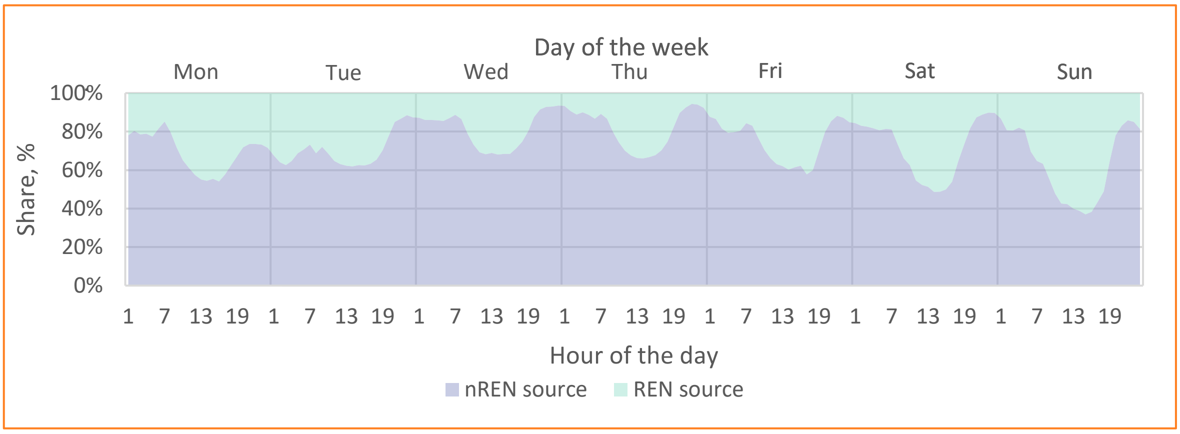

Figure 4.21 Electricity generation from nREN and REN sources 14.06.21-20.06.21

Drops in the middle of the days are caused of higher solar and onshore wind generation leaving less room for nREN generation.

4.3.1.2 MP3 nREN electricity use

MP3 electricity use data was available in building management system website [12]. Total electricity use was multiplied with electricity nREN source share of total to find MP3 nREN electricity use. Next three figures show MP3 total and nREN electricity use in kWh and within three chosen time spans.

Figure 4.22 shows that MP3 nREN electricity use is very close to total and follows the same line. Values range about 30 to 70 kWh.

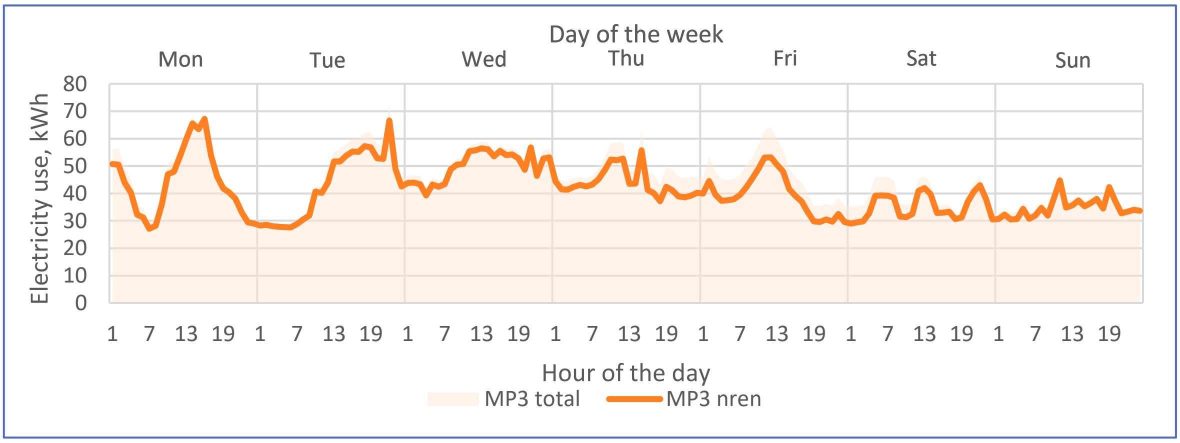

Figure 4.22 MP3 nREN and total electricity used 06.12.21-12.12.21

MP3 electricity use is higher in the day time when everybody is working. That also explains why weekend shows lower and more stable use. Total and nREN lines are very close beacuase nREN share is high.

Figure 4.23 shows bigger differences in total and nREN lines mostly at the beginning and end of the week. nREN values range from about 5 to 65 kWh.

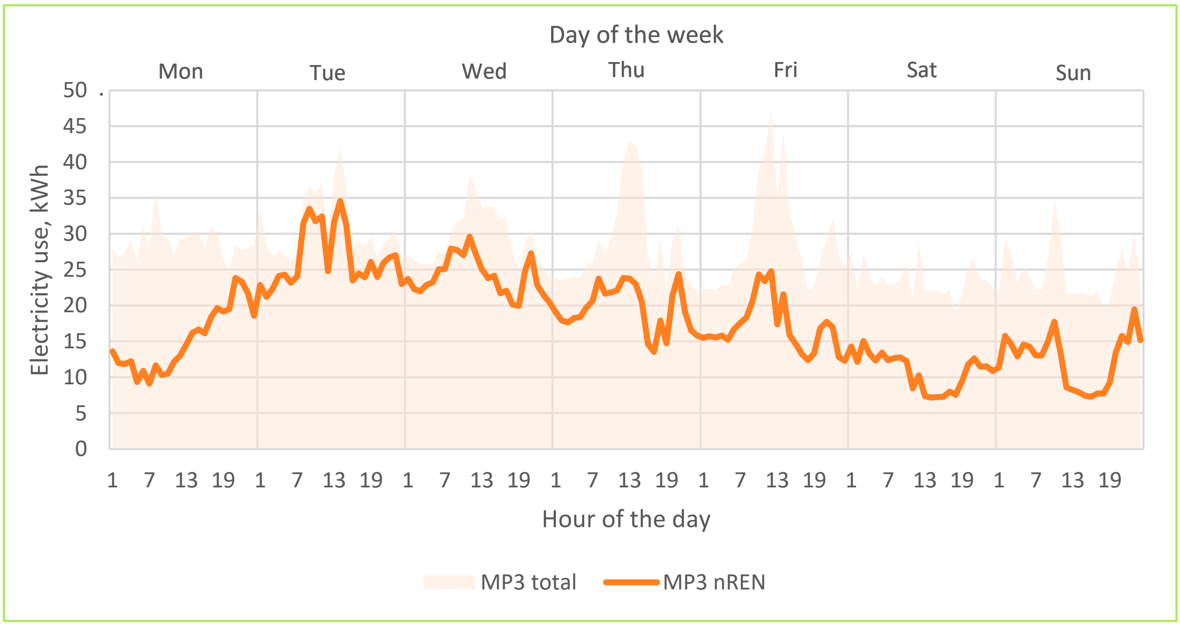

Figure 4.23 MP3 nREN and total electricity used 12.04.21-18.04.21

Highest values can be seen in the middle of the week, when people are most active.

Figure 4.24 shows slowly rising nREN line starting from 20 and ending at 30 kWh. Higher spikes appear on nights of Friday, Saturday and Sunday.

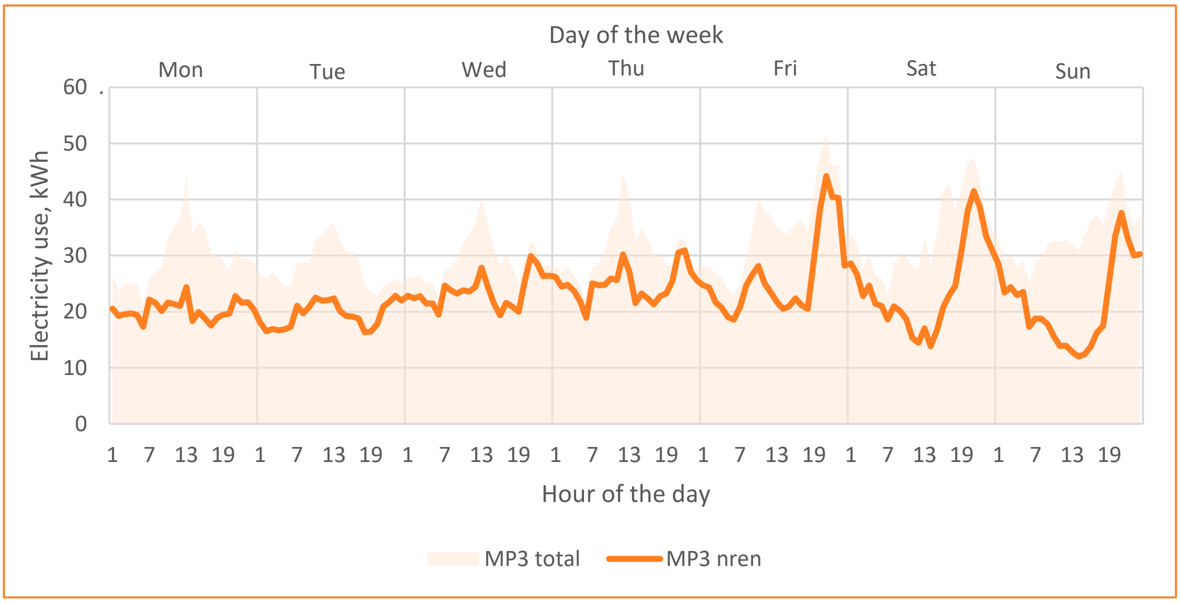

Figure 4.24 MP3 nREN and total electricity used 14.06.21-20.06.21

Here are unusual values that not quite correlaeate with basic work week rythm. It might be that some mainteance was done.

4.3.1.3 MP3 primary energy use

MP3 primary energy use was found by multiplying nREN electricity use with PEF factor for each hour within given time spans. Three figures were generated for this purpose.

On figure 4.25 primary energy line starts with bigger fluctuation at the beginning of the week ranging from 90 to 220 kWh. End of the week shows less fluctuations and lower use around 120 kWh.

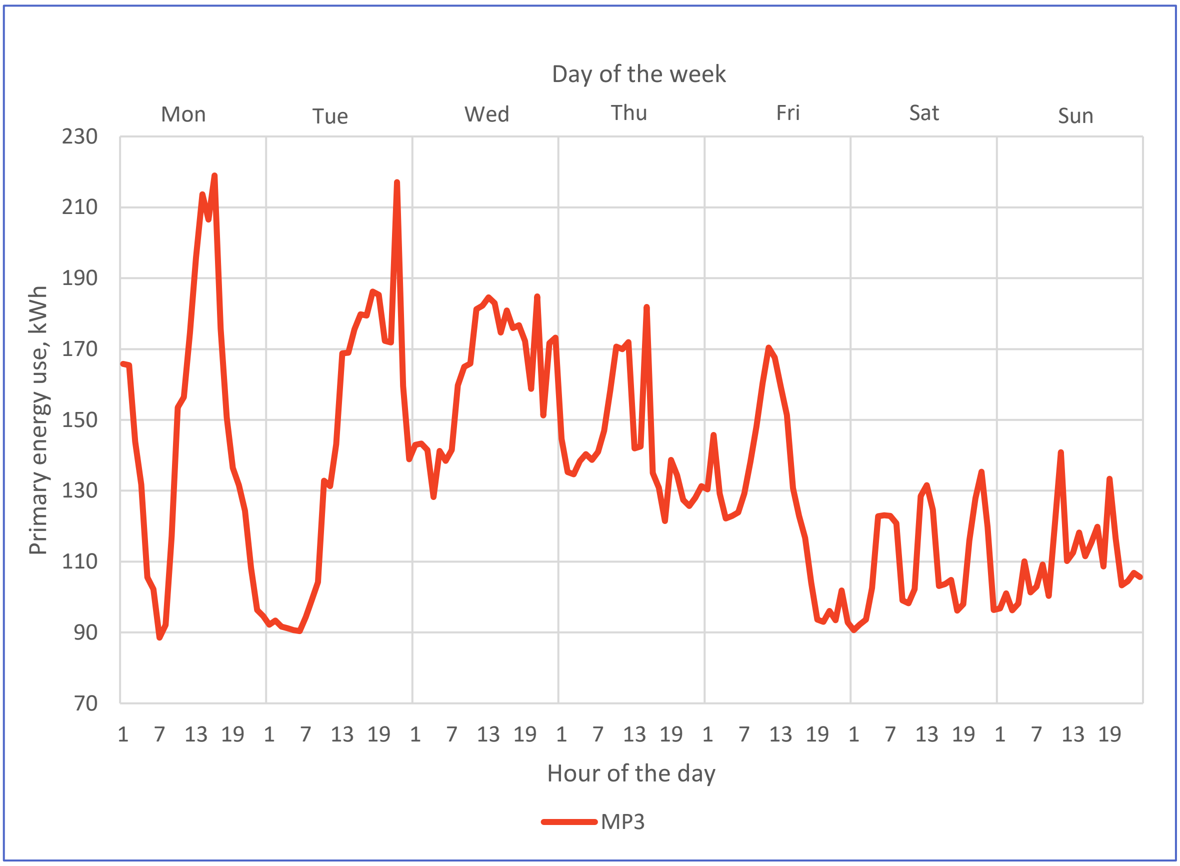

Figure 4.25 MP3 primary energy use from electricity 06.12.21-12.12.21

Two high spikes in the beggining of the week can be caused by MP3 electricity use and PEF being high at the same time.

On figure 4.26 highest primary energy use is over 90 kWh on Tuesday morning. After that average value starts to come down, being around 45 kWh on Friday.

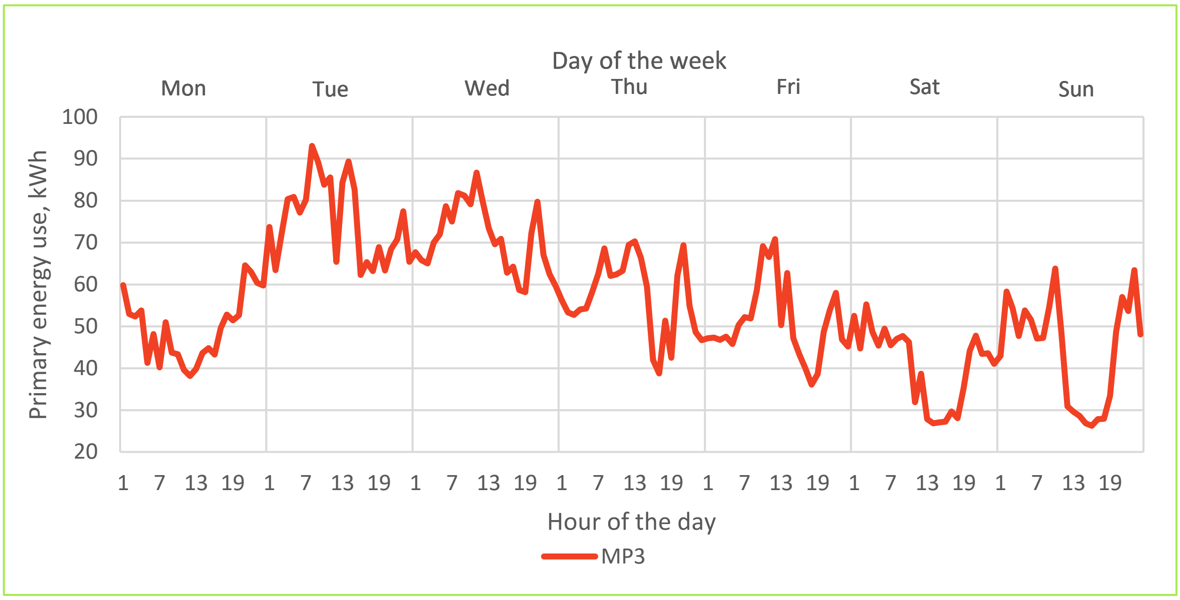

Figure 4.26 MP3 primary energy use from electricity 12.04.21-18.04.21

Very high PEF value at the beggining of the week is balanced with medium total electricity use and low nREN percentage.

On figure 4.27 primary energy need stays between 40-80%. From Friday to Sunday nights spikes rise above 100 MW.

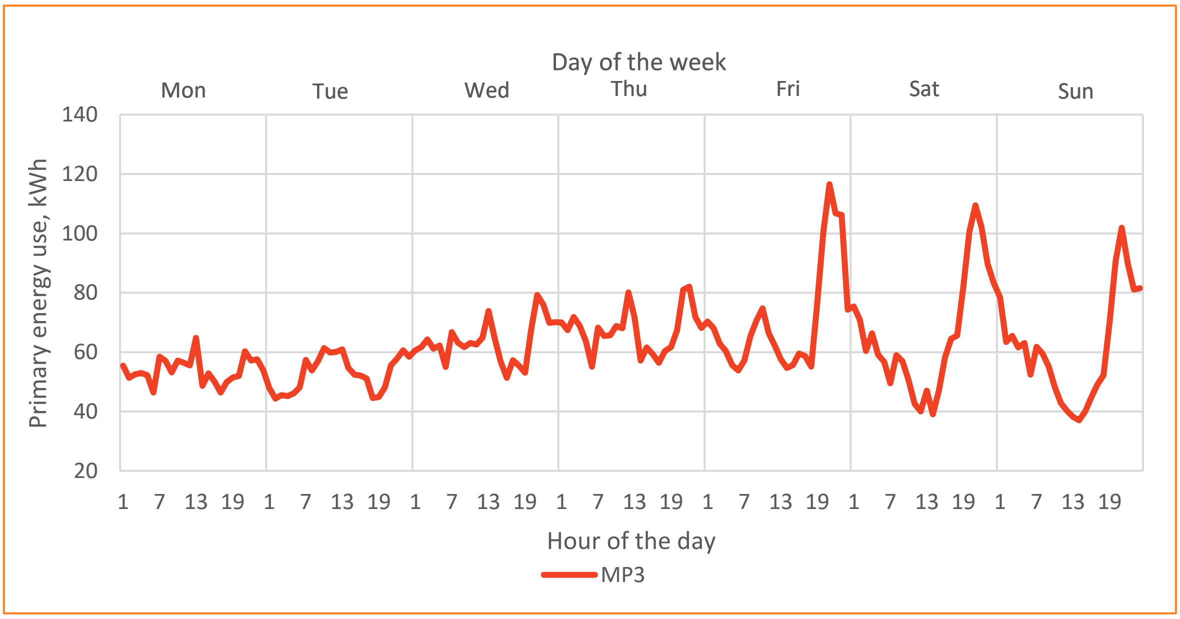

Figure 4.27 MP3 primary energy use from electricity 14.06.21-20.06.21

This primary energy use line shows same patterns as MP3 nREN electricity use. Meaning that PEF and MP3 use have similar trends.

4.3.2 DH

To evaluate MP3 DH primary energy use, MP3 DH use and previously calulated PEF data is needed.

4.3.2.1 MP3 DH use

Due to MP3 heat meter settings a value is shown when difference with previous reading is at least 0,5 MWh. Meaning that DH value is not shown every hour. Next three figures show MP3 DH use within chosen weeks.

On figure 4.28 can be seen most frequent DH use. Monday and Tuesday four times a day and rest of the week three times. All values range from 0,5 to 0,57 MWh.

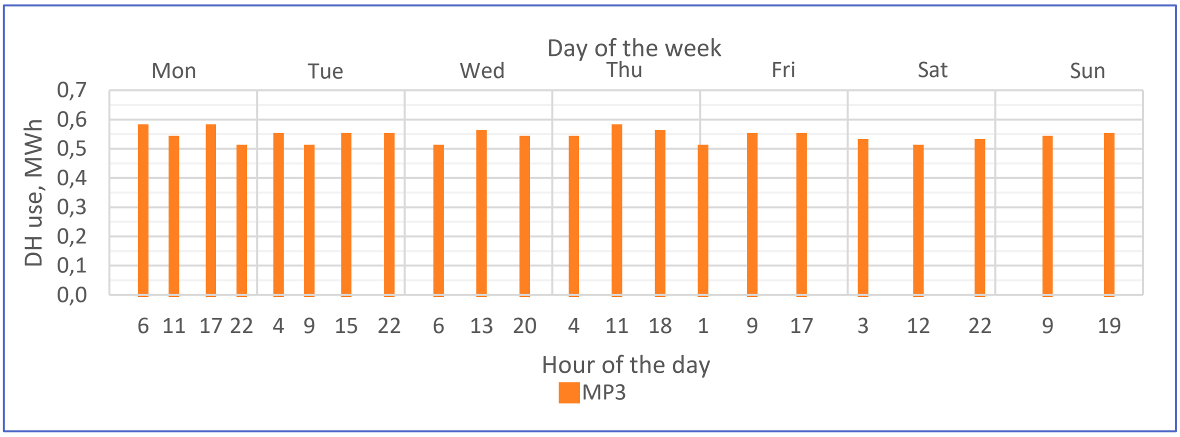

Figure 4.28 MP3 DH use 06.12.21-12.12.21

Figure 4.29 shows less frequent DH use. One for every day except Thursday that has two values.

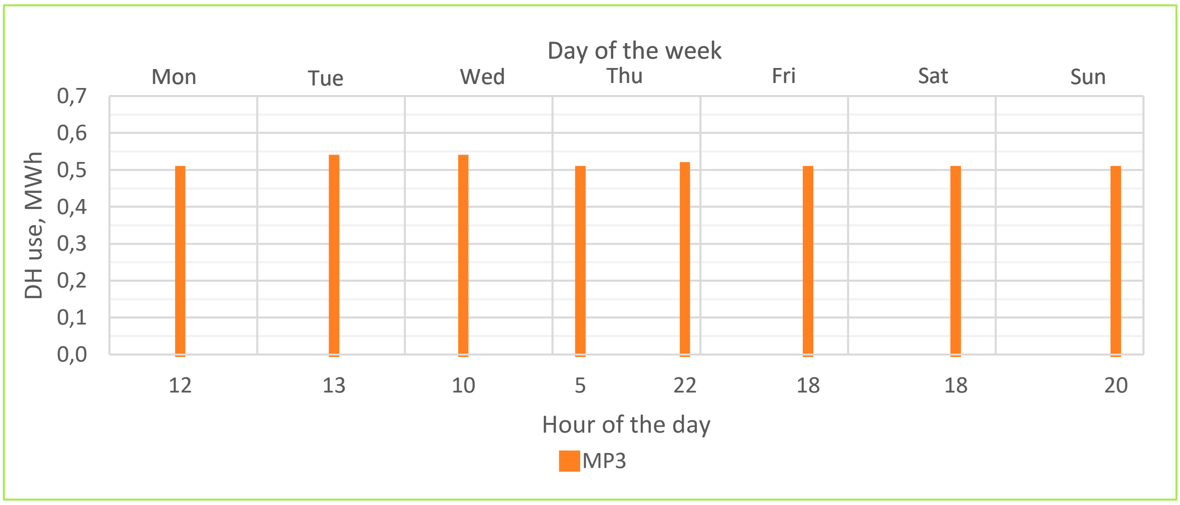

Figure 4.29 MP3 DH use 12.04.21-18.04.21

Figure 4.30 shows only two uses of DH during the week. 0,5 MWh use on Wednesday and on Saturday.

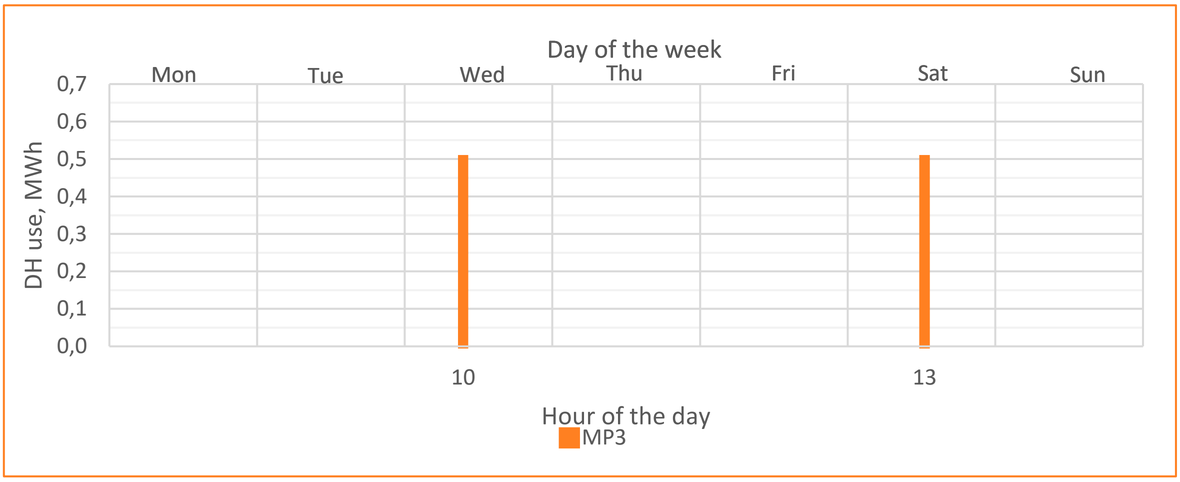

Figure 4.30 MP3 DH use 14.06.21-20.06.21

MP3 DH use is probably related to weather and specifically outside temperature. As seen on previous three figures DH use changes to more infrequent as the weather gets warmer.

4.3.2.2 MP3 DH primary energy use

MP3 DH primary energy use was achieved multiplying DH use with DH PEF. Results are shown on following three figures covering chosen three time spans.

On figure 4.31 can be seen that primary energy use starts at around 0,45 and lowers by 1 MWh till the end of the week.

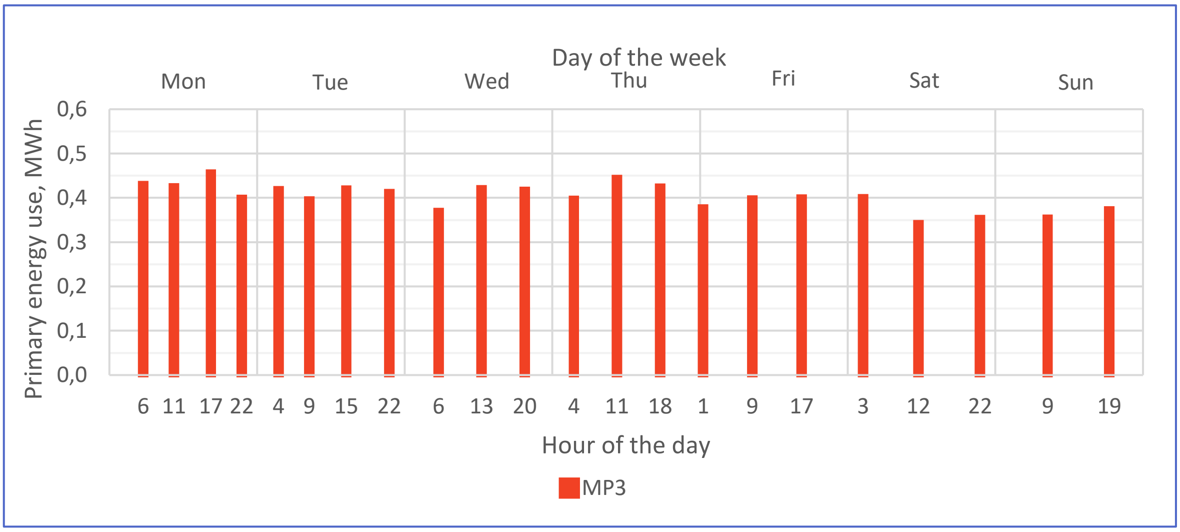

Figure 4.31 MP3 primary energy use from DH 06.12.21-12.12.21

Figure 4.32 shows almost constant primary energy use around 0,51 MWh.

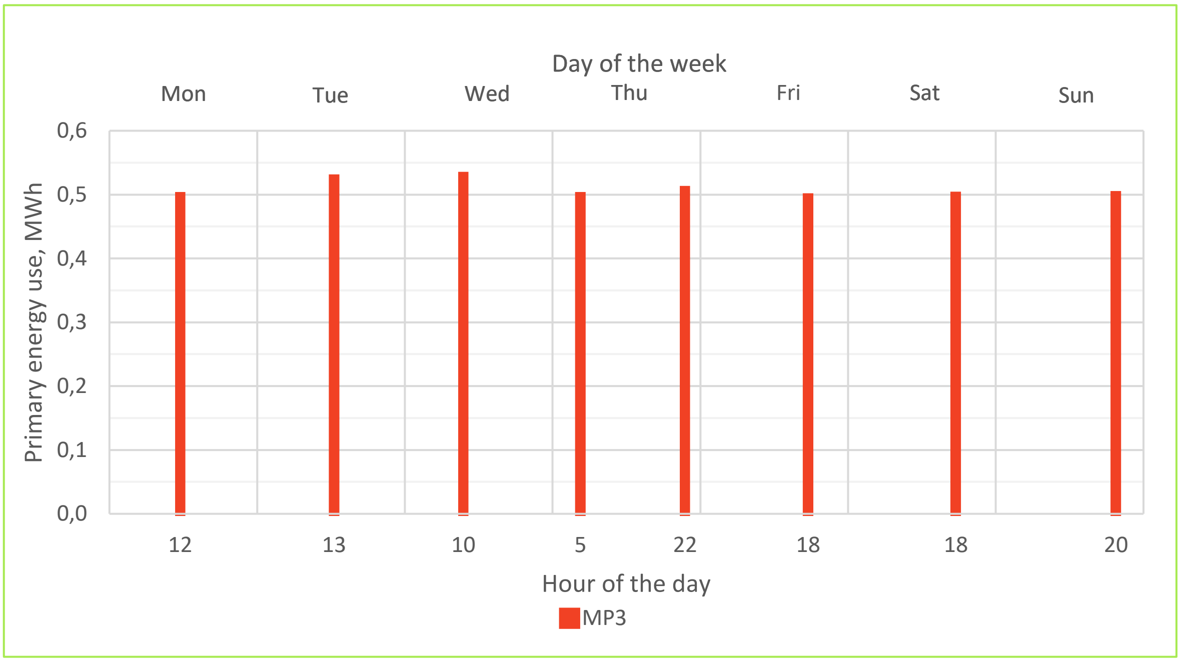

Figure 4.32 MP3 primary energy use from DH 12.04.21-18.04.21

Figure 4.33 shows only two uses of DH primary energy use with values 0,55 MWh.

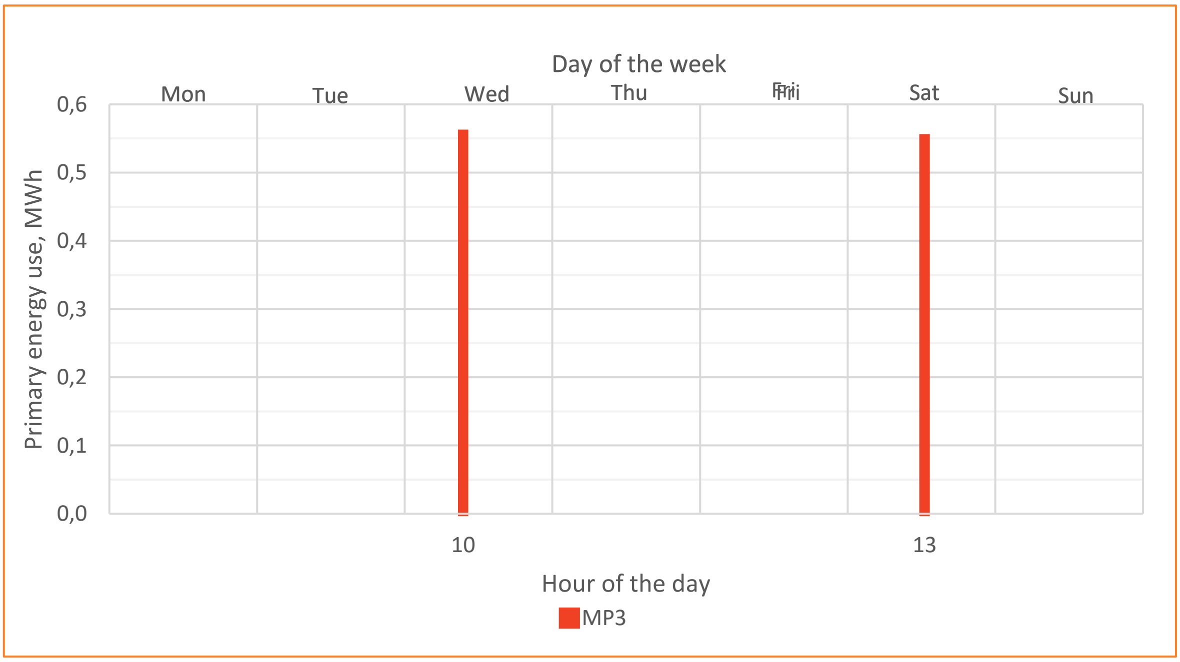

Figure 4.33 MP3 primary energy use from DH 14.06.21-20.06.21

Because of constant efficiency values and DH use values between 0,5-0,6, primary energy need is also quite stable. Depending only on DH use little variations.

4.4 Comparison between legislative and dynamic PEF

This chapter covers comparison between Estonian legislative PEF and calculated dynamic PEF for electricity and DH. Since latest data about energy balance in Estonia is from 2020 according to Eurostat, historical real PEF could not be taken into comparison [11].

Figure 4.34 shows Estonian legislative PEF and dynamic PEF for winter, spring and summer week in 2021. All the dynamic values are at least 0,5 higher than legislative values. Per hour, smallest gap is with summer time PEF and biggest with spring time line, being over 2,0.

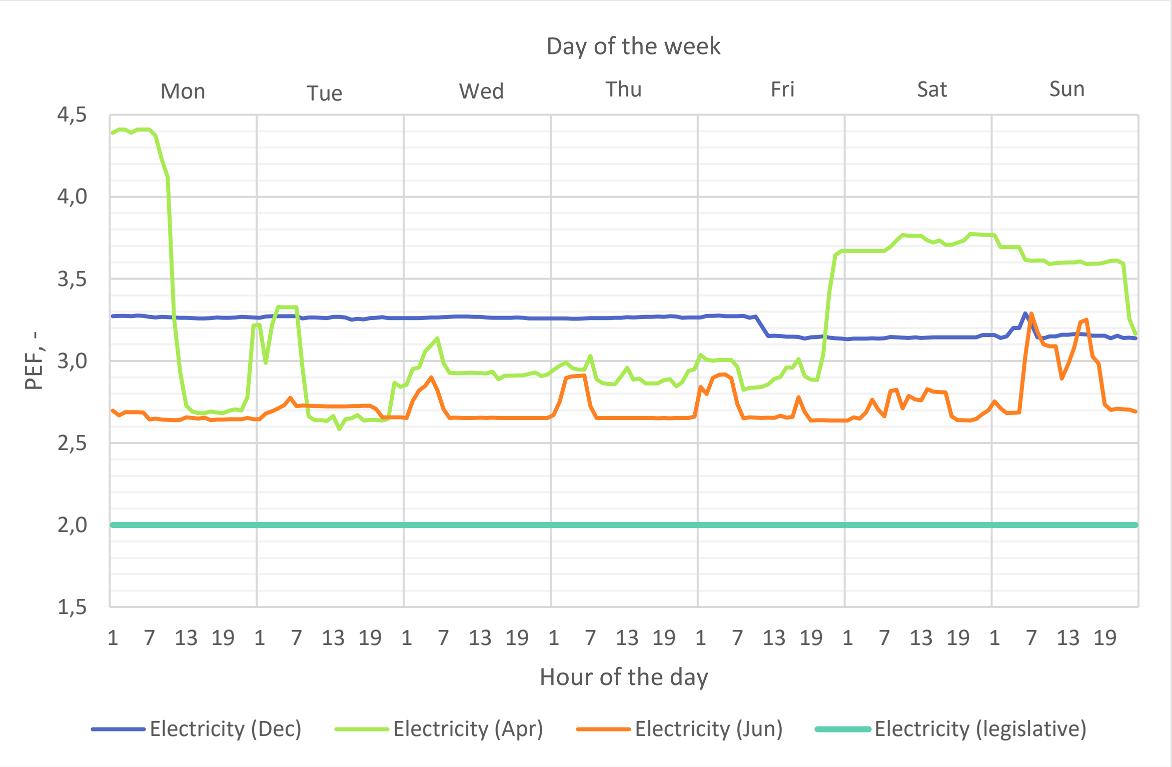

Figure 4.34 Legislative and dynamic PEF for electricity

These higher dynamic PEF values could be result of data accuracy – not taking some other nREN source electricity generations into consideration and assuming that TG11 plant cogenerates only 60 MW of heat.

Figure 4.35 shows DH and efficient DH legislative PEFs and dynamic PEFs for winter, spring and summer time spans (defined in the chapter 4.2). All calculated PEF values stay below legislative DH, except June PEF on weekend nights. December week PEFs are between two of the legislative PEF lines. Only April PEFs shows lower values of DH PEF with one exception on Sunday afternoon.

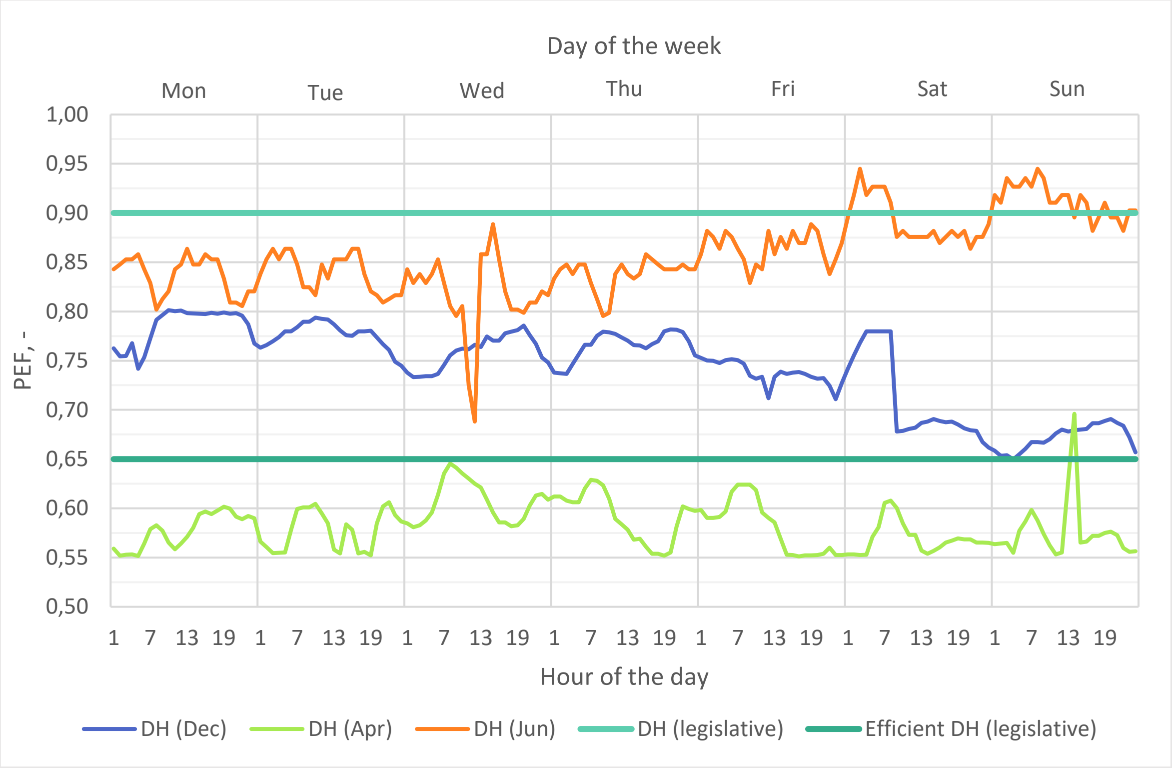

Figure 4.35 Legislative and dynamic PEF for DH

Summer time high PEF can be explained with low DH generation that means mostly Iru waste burning plant is working, that has lower efficiency than next ones in the priority list. Resulting lower average efficiency factor and higher PEF. On the other hand, spring period PEF is lowest, because 250 MW load is just the right amount to keep most efficienct plants working, leaving almost completely out two last ones, Mustamäe (b) and Kristiine (b). Winter week PEF is in the middle because all plants are in the use.

It must also be mentioned that Estonian PEFs are based also on energy-political aspect that were not considered in current thesis.

5 SUMMARY

Current thesis focused on calculating PEF for electricity in Estonia boundary and PEF for DH in Tallinn boundary with hourly accuracy. Second main objective was to apply calculated dynamic PEFs to Taltech’s building Mäepealse 3 electricity and DH use to find primary energy need. These objectives were done on three weeks on year 2021 - 06.12.21-12.12.21, 12.04.21-20.04.21 and 14.06.21-20.06.21. Side focus was to find Estonian legislative PEF, historical real PEF for interval 2007-2020 and compare acquired data.

Main methodologies were research, data collecting and calculations. Research part focused on finding common information about Estonian electricity grid and DH systems and about case study building. This part was done mostly by exchanging emails with Utilitas Tallinn and Enerfit Power, for Mäepealse 3 by looking through project documentation [17]. Data collecting was based on knowledge from research part. Base sources for electricity data were Entso-e and Enefit Power [14], [15], [19], [20]. DH data came mainly from Utilitas Tallinn as well as from Enefit Green. Case study building electricity and DH use is available from building management website with [12]. Calculations based on EN17423 [10].

Results of electricity side shows higher dynamic PEF than legislative PEF during all time periods. Gap between legislative and dynamic lines varies from 0,5 to exeptionally 2,5 for spring time values. DH dynamic PEF is more close to legislative PEFs. Spring representing line is highest of the three dynamic PEFs exceeding even basic legislative PEF value on some cases. Winter time PEF stays in between two legislative values DH and DH efficient. Summer time span PEF is located below efficient DH value with lower values of 0,55.

During this study some assumptions and simplifications were made, therefore final conclusion about electricity and DH valid PEF accuracy in Estonia could not be made. At the same time this thesis includes valuable information and sources for further study.

6 KOKKKUVÕTE

Käesolev lõputöö keskendus primaarenergia kaalumisteguri leidmisele elektrile Eesti piires ning kaugküttele Tallinna piires. Teine peamine eesmärk oli kasutada leitud kaalumistegureid Taltech-i Mäepealse 3 hoone elektri ja kaugkütte primaarenergia vajaduse leidmiseks. Need arvutused tehti kolmel nädalal 2021 aastast - 06.12.21-12.12.21, 12.04.21-20.04.21 and 14.06.21-20.06.21. Kõrvalsihiks oli leida Eesti määrusejärgsed primaarenergia kasutegurid, ajaloolised arvutatud kasutegurid ajaperioodil 2007-2020 ning neid omavahel võrrelda.

Peamised kasutatud meetodid olid info otsimine, andmete kogumine ning arvutused. Info otsimine seisnes üldiste teadmiste kogumises Eesti elektrivõrgu ning kaugkütte süsteemide kohta, samuti uuritava hoone kohta. Selles osas oli peamine osa meilide vahetusel Utilitas Tallinn-iga ja Enefit Power-iga, Mäepealse 3 info saadi tööprojekti dokumentatsioonist [17]. Andmete kogumine põhines juba teadmistel, mis tekkisid info kogumise käigus. Põhiallikad elektriandmetele olid Entso-e ja Enefit Power [14], [15], [19], [20]. Kaukütte andmed tulid peamiselt Utilitas Tallinn-lt, aga ka Enefit Green-i poolt. Mäepealse 3 hoone elektri ja kaugkütte tarbimise andmed on saadaval hoone automaatikasüsteemi veebillehel [12]. Arvutused põhinevad normatiivil EN17423 [10].

Elektri poole pealt on tulemustes näha kõrgemaid kaalumistegurite väärtusi kui Eesti määruses. Vahe seadusliku ja dünaamilise teguri vahel varieerub 0,5 kuni erandlikult 2,5-ni kevadiste väärtuste puhul. Kaugkütte dünaamiline kaalumistegur on lähemal määruses näidatud väärtusele. Kevade kõver on kõrgeim kolmest dünaamilises, ületades isegi tavalise kaugkütte väärtust mõnel juhul. Talvine kaalumisteguri kõver jääb kahe seadusliku kõvera vahele. Suvine kaalumistegur asub enamus ajast madalamal seaduslikust efektiivsest kaugkütte kaalumistegurist, madalaimate väärtustega kuni 0,55.

Töö jooksul tehti mõningaid eeldusi ja lihtsustusi, seega lõplikku kokkuvõtet elektri ja kaugkütte kaalumistegurite täpsuse kohta Eestis pole võimalik teha. Samas see magistritöö sisaldab väärtuslikku informatsiooni ja allikaid järgnevateks teadustöödeks.

7 REFERENCES

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