# Abstract

This analysis is part of the assessment of the possibilities for the application of efficient cogeneration and efficient district heating and cooling referred to in Article 14 of the Energy Efficiency Directive. In addition, issues related to the use of waste heat and cooling and their potential, as well as efficient district heating and cooling and their potential have been further analysed. This report deals with waste heat generated in housing, commercial real estate, service economy and industrial enterprises. The authors based the threshold on the capacity limit of the waste heat source starting from the capacity of 5 MW.

Major conclusions:

1. There are no simple and quick solutions for the use of waste heat sources in district heating and cooling, but today's fundamental decisions and long-term meaningful work will lead to this result. Solutions must be comprehensive, especially in terms of support measures, i.e. in addition to a suitable transmission infrastructure, the development of infrastructure capable of receiving low-temperature heat in housing should be encouraged.
2. The surveys and additional interviews revealed that district heating companies are probably in the best position for utilising the waste heat generated in the company, and investments are self-sustaining thanks to lower costs. The initial investment for the use of waste heat, converted into energy units, was in the range of EUR 60—80 (per MWh in the first year) for companies, while for industrial companies it was EUR 120—-300. District heating companies also had a good chance of benefiting directly (less frequently) or indirectly from the utilisation of waste heat. As a result of this analysis, the possibilities of district heating companies to utilise additional waste heat of 485 GWh/year have been assessed. The calculations performed in the studyshow that based on the unit price of energy, the implementation of flue gas condensers in district heating boiler houses and combined heat and power plants is cost-effective.
3. The extensive data collection carried out in this study was not sufficient to provide a nationwide assessment of the potential for untapped waste heat by sectors. Should detailed data prove necessary, this issue should be addressed in further analysis. In various other unspecified industries, an accurate assessment of the waste heat potential is not possible due to the absence of data, but is likely to exceed 400 GWh/a.
4. In individual cases, waste heat from companies has already been used or can be used in Estonia, where its parameters are suitable for transmission to the district heating network (either directly via a heat exchanger or heat pump), uniform and year-round availability is guaranteed and the company is located close to the district heating network. Collecting and utilising waste heat requires effort, work and financial resources, but it still has potential. Unfortunately, the availability of waste heat for use in district heating is often not continuous or sufficient, or it is technically difficult to route waste heat to the district heating network. In addition, it may not make economic sense because of the high investment cost and the remoteness of the network This makes is all the more important for waste heat to be used internally.
5. Wastewater treatment plants, data centres, flue gas condensing and the development of low-temperature district heating areas (islands) have the greatest potential for low-temperature waste heat if it is supplied from the return line of existing district heating networks.
6. It is more promising to develop low-temperature heat sources and to develop networks in housings. There are both final and transitional solutions for this. The wider use of waste heat in district heating systems requires the existence of a suitable infrastructure, i.e. a low-temperature district heating network. Reconstruction of existing district heating systems is

a lengthy but potentially positive process for society, which would require a separate, more detailed analysis of how to lower the network temperature on existing infrastructure, connect consumers to the return pipeline and build a low-temperature network in new development areas on the basis of existing pipelines. The analysis of the research confirmed that the existing housing stock, especially consisting of larger apartment buildings, is partly transferable to efficient solutions based on heat pumps (HP) (ventilation air HP). According to the present research, such a transfer could be undertaken gradually along with the reconstruction of buildings, during which the buildings will be insulated and modernised. Converting the existing housing stock to efficient heating would require a good deal of investment and would not be economically viable, the latter being primarily due to the reconstruction part of the building. Investments in heat pumps and associated equipment would theoretically be self-paying if the income target is the average price of heat (this is taken to be EUR 65 per MWh in this report) and the costs for modernisation of buildings are considered separately. Depending on how actively the investment is made, 39.7 to 85.21 MWh/a of primary energy could be saved by improving the efficiency of residential housing heating solutions. The investments are not cost-effective in any of the scenarios, and in the most aggressive scenario, the costs of district heating network and heat storage solutions have not been taken into account.
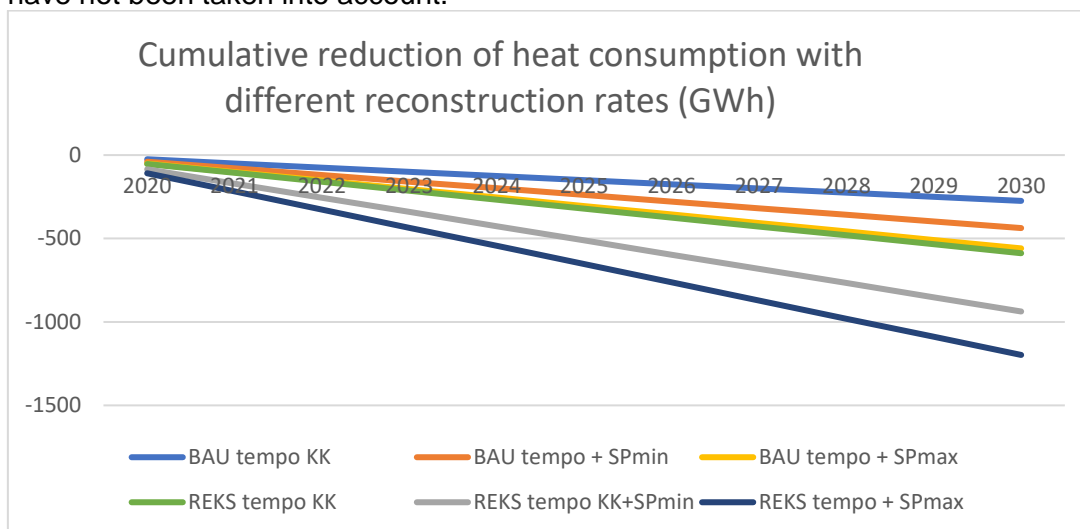
Figure. Cumulative reduction of heat consumption with different reconstruction rates (GWh)

This is a much simpler and more cost-effective situation for completely new residential buildings and for larger buildings for low-intensity economic activities. This work is based on research that thoroughly deals with heating solutions for one of Tallinn's new development areas and calculates that a high-efficiency heating solution based on a combination of gas heating and heat pumps is economically cost-effective. In the initial phase, more expensive 'smart heating' solutions as compared to classic heating systems, will become self-paying after a few years thanks to high fuel savings.

7. Low-temperature (below 100 °C) waste heat has mostly been unused or used to a lesser extent in industry, service companies and housing. The predominant uses are heat recovery for heating the ventilation air being sucked into the building, waste water heat recovery and domestic water heating. In this study, the use of certain high-potential low-temperature waste heat has been modelled and the resulting energy savings, cost-effectiveness and the impact on the share of CO_2 emissions and renewable energy have been assessed.

8. In connection with the resource efficiency measure, of which part (up to 50 %) of companies' resource efficiency projects are financed, waste heat has been used mainly internally.

9. Wood fuel boilers, starting with a capacity of 5.1 MW (all sectors combined), already use 253 GWh/a of waste heat and the theoretical total potential of free waste heat would be 234

GWh/a. It is known that 333 GWh/a of waste heat is already used in natural gas boilers, starting with a capacity of 5.1 MW (all sectors combined) and the theoretical total free waste heat potential would be 251 GWh/a. The amount of waste heat already obtained from the combustion of both fuels (from flue gas condensation) is estimated at 586 GWh and the total theoretical potential still available would be 485 GWh per year.

10. Theoretically, a total of 5,276 TJ/a or 1,466 GWh/a of waste heat could be obtained from Estonian wastewater treatment plants (the corresponding saving of wet wood chips would be estimated at 2.3 million pm^3 per year). Based solely on the quantities and properties of wastewater from Tallinna Vesi AS, up to 450 GWh/a of potential waste heat can be obtained, for example, to supply heat to nearby future residential development areas or to direct in the Tallinn district heating network. This is low-temperature waste heat that requires heat pumps. As for heat pumps in general, such projects can be considered cost-effective if the projects generate sufficient revenue. In this case, the average calculated wholesale heat price (estimated at EUR 20 to EUR 25 per MWh) is appropriate. In this case, the investment is economically viable without taking into account possible investments in the district heating network.

11. In terms of Estonia, a very large data centre (server park) will be built in Harju County. The initial electrical capacity is planned to be 6 MW (~50 GWh of waste heat per year if operating evenly at full capacity all year round), which will later be increased to 20 MW if necessary, with the possibility of further additions (up to 32 MW). In principle, it would be possible to direct this waste heat to the district heating network of the city of Tallinn (Õismäe) through almost 5 km of pipeline. The data centre presented one sample case, which shows that the amount of heat generated annually is 150 GWh/a, and the conditions are there for the establishment of such centres in the future. Based on the feasibility study shared with the authors of this report by the owner of the data centre, we find that the utilisation of the waste heat is self-sustaining. An NPV based on the data centre data is positive as long as the lack of connections to a suitable district heating network is ignored. In the feasibility study already mentioned, estimates of the costs of connecting to different district heating networks have been made and they show that the NPV is strongly negative in each scenario.

12. The approaches using the heat pumps described above, both in industry (water management, cloud data management) and in households (existing and new housing stock), allow the more efficient use of lower temperature heat sources and reduce energy consumption, but they do not necessarily reduce the share of renewable energy, because heat pumps have a significant electricity self-consumption ratio.

13. According to the current regulation, the addition of a waste heat source to the existing district heating network is considered as the purchase of heat by a heating company. This approach does not take into account the cross-economic need to increase the use of waste heat. The issue of waste heat should be reflected in more detail in the District Heating Act and/or related regulations, starting with the definition of waste heat in the legislation and the establishment of uniform and transparent basic principles for third parties to connect to the district heating network.

14. In order to increase the share of renewable energy/waste heat by at least one percentage point per year, consideration should be given, as a minimum, to designating a competent authority with limited powers to implement additional measures. This competent authority could also develop and publish the non-discriminatory and transparent criteria referred to in the previous point for connecting waste heat sources to the district heating network.

Waste heat utilisation technologies and equipment

Waste heat recovery/utilisation technologies can be classified into one of three groups:

- Direct use without upgrading

- Use after upgrading, through heat pumping

- Power generation

The use of waste heat and/or its products can take place inside or outside the company.

Direct use means that sensible or latent heat is used at source temperature without a heat pump. In this sense, direct use is not time-related and therefore a direct system may also involve the storage of heat.

In systems with fluctuating or alternating waste heat volumes, heat storage may be an interesting or necessary part of the waste heat utilisation system.

Electricity production includes variants of the main Rankine cycles (steam cycles, ORCs, etc.) and various thermoelectric devices.

In addition to improved heat exchange, industrial heat pumps are probably the most suitable way to utilise industrial waste heat. The possible temperatures of waste heat largely depend on the temperatures required in industrial processes. Typical possible temperature rises are 30-50 K, depending on the temperature level and, above all, the price level of electricity versus fuel.

The choice of heat recovery method depends on key factors such as temperature, phase of the substance (e.g. steam, water) and the chemical composition of the exhaust stream, as well as the nature of the desired end use of waste heat. Table 0.1. contains the comparison of conventional heat exchange technologies according to the applicable temperature ranges, waste heat sources, end use, type of heat exchange, moisture recovery, permissible temperature differences, cross-contamination resistance and corrosive gas adaptability.

KPMG

Table 0.1. Comparison of waste heat utilisation technologies[1].

Recovery Method	Temperature Range	Typical Sources of Waste Heat	Typical Uses	Type of Heat Exchange (Gas-Gas, Gas-Liquid, etc.)	Recovers Moisture	Large Temperature Differentials Permitted	No Cross-Contamination	Corrosive Gases Permitted with Special Construction
Radiation Recuperator	H	Soaking or annealing ovens, melting furnaces, incinerators, radiant-tube burners, reheat furnace	Combustion air preheat	G-G		X	X	X
Convection Recuperator	M-H	Soaking or annealing ovens, melting furnaces, incinerators, radiant-tube burners, reheat furnace	Combustion air preheat	G-G		X	X	X
Metallic Heat Wheel	L-M	Boiler exhaust, curing and drying ovens	Combustion air preheat, space heat	G-G	b		c	x
Hygroscopic Heat Wheel	M	Boiler exhaust, curing and drying ovens	Combustion air preheat, space heat	G-G	X		c	X
Ceramic Heat Wheel	M-H	Large boilers, incinerator exhaust, melting furnaces	Combustion air preheat,	G-G		X		X
Plate-type Heat Exchanger	L,M	Exhaust from boilers, incinerators, & turbines	Combustion air preheat, space heat	G-G, L-L		X	X	
Heat Pipe	L-H	Drying, curing, and baking ovens Waste steam, air dryers, kilns (secondary recovery), reverberatory furnaces (secondary recovery) Drying, curing & baking ovens	Combustion air preheat, boiler makeup water preheat, domestic hot water, space heat	G-G,G-L		d	X	X
Finned-tube Heat Exchanger	L,M	Boiler exhaust	Boiler feedwater preheat	G-L		X	X	e
Waste-heat Boilers	L-H	Exhaust from gas turbines, reciprocating engines, incinerators, furnaces	Hot water or steam generation	G-L			X	e
Tube Shell-and Tube Exchanger	L,M	Refrigeration condensates, waste steam distillation condensates, waste steam distillation condensates, coolants from engines, air compressors, bearings & lubricants	Liquid feed flows requiring heating	G-L, L-L		X	X	

a. Sources: W. Turner. *Energy Management Handbook,* 2007; *PG&E Energy Efficiency Information* "Industrial Heat Recovery Strategies," 1997
b. claimed by some vendors
c. with a purge section added, cross-contamination can be limited to less than 1% by mass
d. allowable temperatures and temperature differential limited by the phase equilibrium properties of the internal fluid
e. can be constructed from corrosion-resistant materials, but consider possible extensive damage to equipment caused by leaks or tube ruptures

Table 0.2 contains the possibilities for heat recovery (equipment, processes) and the feasibility of utilisation and its condition (commercial, technical and economic) in different industries (steel and aluminium industry, glass industry, cement industry, etc.).

[1] U.S. Department of Energy, "Waste Heat Recovery: Technology and Opportunities in U.S. Industry," U.S. Department of Energy, Industrial Technologies Program, Washington DC, 2008

KPMG

Table 0.2. Comparison of waste heat utilisation technologies in selected areas[2]

Device/equipment	Coke Owen Gas (C)	(T)	(E)	Waste gas (C)	(T)	(E)	Blast Furnace Gas (C)	(T)	(E)	Hot Blast Stove Exhaust (C)	(T)	(E)	Basic Oxygen Furnace Gas (C)	(T)	(E)	Electric Arc Furnace Off-gas (C)	(T)	(E)	Gas-fired Melting Furnace (C)	(T)	(E)	Oxyfuel Melting Furnace (C)	(T)	(E)	Cement Kiln (C)	(T)	(E)	Hall-Heroult Cells (C)	(T)	(E)	Melting Furnaces (C)	(T)	(E)	Iron Cupola (C)	(T)	(E)	Steam Boiler (C)	(T)	(E)
Regenerator	-	-	-	+	+	+	-	-	-	n	n	-	x	x	x	x	x	x	+	+	o	-	o	-	n	n	n	-	-	-	+	+	o	n	n	n	-	+	-
Recuperator	-	-	-	n	-	-	-	-	-	n	n	-	x	x	x	x	x	x	+	+	+	-	o	-	n	n	n	-	-	-	+	+	o	+	+	+	+	+	+
Heat Wheel	-	-	-	n	m	-	n	n	n	+	+	+	x	x	x	x	x	x	o	o	-	n	o	-	n	n	n	-	-	-	o	+	o	n	n	n	+	+	+
Passive Air Preheater	-	-	-	-	o	o	n	n	n	+	+	+	x	x	x	x	x	x	n	n	n	-	o	-	n	n	n	-	-	-	n	n	n	n	n	n	+	+	+
Thermal Medium System	o	o	-	n	m	-	n	n	n	+	+	+	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	-	-	-	n	n	n	n	n	n	+	+	+
Waste Heat Boiler	-	-	-	-	-	-	n	-	n	n	-	-	o	+	o	n	-	n	o	+	-	o	+	-	+	+	+	-	-	-	n	n	n	n	n	n	x	x	x
Low Temperature Power Cycle	-	-	-	n	m	-	-	n	n	-	m	n	x	x	x	x	x	x	x	x	x	x	x	x	o	+	o	-	-	-	x	x	x	n	n	n	-	m	n
Solid State Generation	-	-	-	-	m	-	-	-	-	-	m	-	-	-	-	-	-	-	-	m	-	-	m	-	-	m	-	-	m	-	-	m	-	-	m	-	-	m	-
Load preheat	-	-	-													+	+	o	n	m	n	o	o	o	+	+	+	n	n	n	+	+	o				+	+	+
Process Specific/Other[1]	o	o	-	o	o	-	o	+	-																+	+	+												

[1] – Process Specific – includes coal moisture control for coke making, dry-type top pressure recovery turbines for blast furnaces and recovery of cement clinker cooler

Explanation for Table 0.2:

Commercialisation Status	Technical Feasibility	Economic feasibility
+ – Frequently used in US o – Limited commercialisation - – Not deployed	+ – Not technical barriers o – Proven in limited applications m – May be feasible, but not demonstrated - – Not technically feasible	+ – Cost effective o – Application specific - – Cost-Prohibitive
N – Not addressed in available literature X – Not applicable		

KPMG

1.1   Overview of waste heat utilisation technologies

Temperature is the most important criterion for whether waste heat is itself a valuable heat source for use directly in technological processes or can be used as an energy source for further conversion. High temperature waste heat (T> 400 °C) generally has a higher recovery potential compared to medium temperature (100—400 °C) or low temperature (T<100 °C) waste heat. High temperature waste heat is generated primarily in the metal and mineral materials industry.

Waste heat utilisation technologies (see also Figure 0.1) may in turn be classified into two groups:

1. Active technologies
2. Passive technologies.

The classification depends on whether the waste heat is used directly at the same or lower temperature level or is converted to another form of energy or to a higher temperature level.
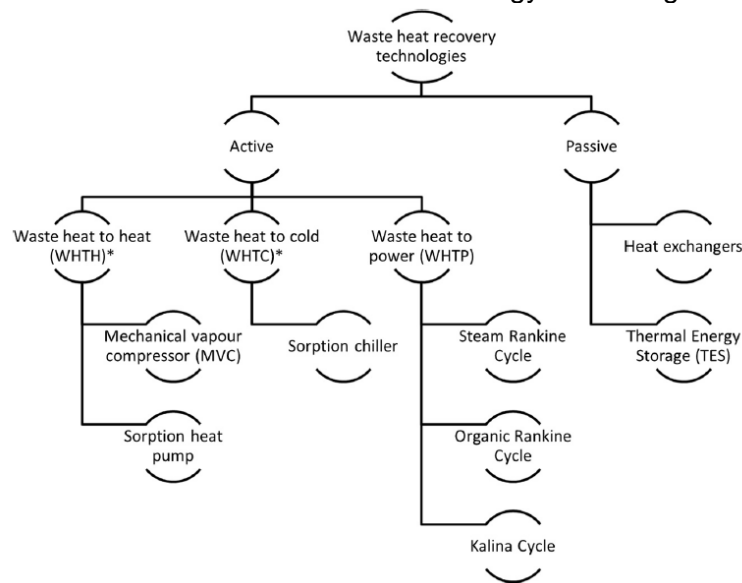

Figure 0.1. Overview of waste heat utilisation technologies[3]

1.1.1   Passive technologies
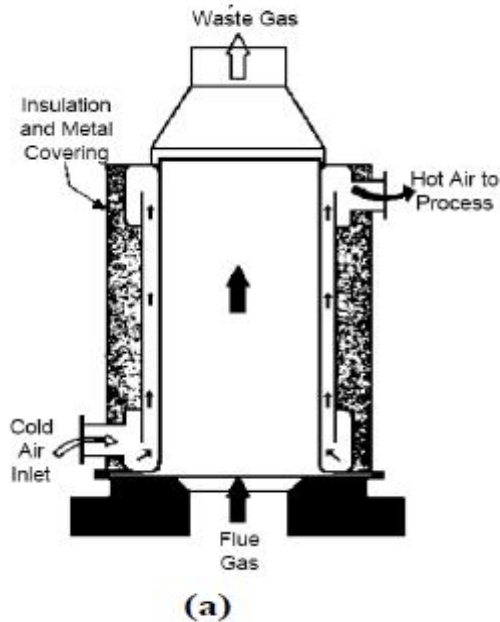
Heat exchangers

The most used passive technologies are heat exchangers and heat storage. These technologies are used in industry to carry out other processes, such as for heating (domestic water) or preheating (boiler air preheater) heat-carrying fluids.

---

[3] Sarah Brückner, Selina Liu, Laia Miró, Michael Radspieler, Luisa F. Cabeza, Eberhard Lävemann.Industrial waste heat recovery technologies: An economic analysis of heat transformation technologies. Applied Energy 151 (2015) 157–167

One area of application of heat exchangers is the transfer of heat from a waste heat carrying fluid with a relatively high temperature (primary heat-carrying fluid) to a heat-receiving thermodynamic body or secondary heat-carrying fluid (e.g. water, air, oil). As a general rule, the temperature of the waste heat carrying fluid should be above 100 °C.

Heat exchangers can be used to utilise combustion gas, hot air or similar waste heat generated in several processes, see also Figure 0.2Figure 0.2. .

Figure 0.2. (a) Hot medium (e.g. combustion gas) heat exchanger working principle; (b) Heat exchanger mounted on a glass furnace[4]

If the medium does not contain solid particles, such as spent air, a rotary heat exchanger (regenerative heat exchanger) is often used for the transfer of heat, see also Figure 0.3.
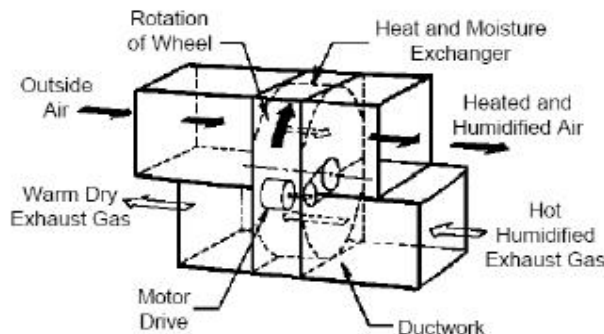
Figure 0.3. Rotary heat exchanger working principle (left) and rotary heat exchanger on a metal melting furnace (right) [5]

When a rotary heat exchanger is used, the heat is transferred through a porous filling. The porous filling is disk-shaped and rotates. The medium passing through it either heats it on one side or cools it on the other side. It is mainly used for low or medium temperature waste heat.

[4] Waste Heat Recovery: Technology and Opportunitirs in U.S. Industry.U.S. Department of Energy. 2008

[5] Waste Heat Recovery: Technology and Opportunitirs in U.S. Industry.U.S. Department of Energy. 2008[6] H. Arro, A. Koni, A. Kull, I. Mikk, A. Ots, A. Poobus, H. Roolaid, L. Õispuu. Soojustehnika käsiraamat. Tallinn Valgus 1977

At high temperatures, problems occur with the thermal expansion and contraction of the metal in the device and the associated malfunctions. The rotary heat exchanger also allows for the recovery of moisture.

Regenerative heat exchangers have both the periodic (cyclic) and continuous operating mode (Figure 0.4).
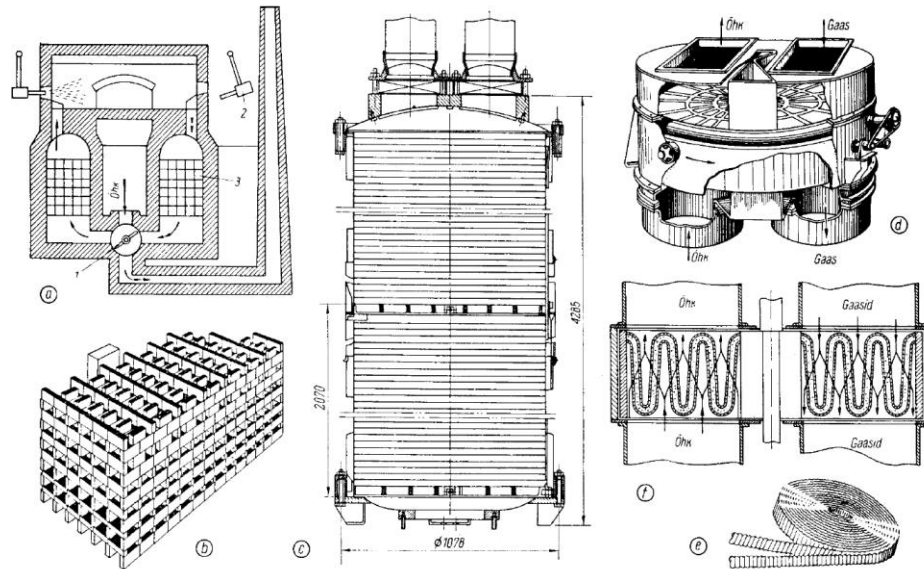
a regeneratiivõhusoojenditega tööstusahju skeem,
b – tulekindlatest tellistest regeneraatori täidis, *c* – liikumatu metalltäidisega regeneraator,
d – Ljungström õhueelsoojendi, *e* – metalltäidise element, *f* – kuultäidisega õhueelsoojendi;
1 – pöörd-siiber regeneratiivsoojusvahetite ümberlülitamiseks, *2* – põleti, *3* – täidis

a – diagram of an industrial furnace with regenerative air heaters, *b* – regenerator filling made of fire bricks,
c – regenerator with fixed metal filling, *d* – Ljungström air preheater, *e* – element of metal filling,
f – air preheater with ball filling, *l* – rotary damper for switching regenerative heat exchangers,
2 – burner, *3* – filling

Figure 0.4. Regenerative heat exchangers[6]

Recuperative heat exchangers are used where the mixing of gases is not permitted, e.g. see also Figure 0.5, Figure 0.6, Figure 0.7).
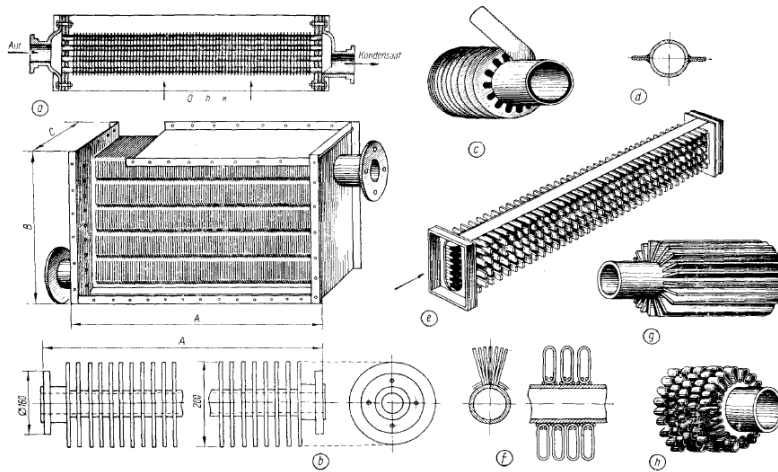
---

[6] H. Arro, A. Koni, A. Kull, I. Mikk, A. Ots, A. Poobus, H. Roolaid, L. Õispuu. Soojustehnika käsiraamat. Tallinn Valgus 1977
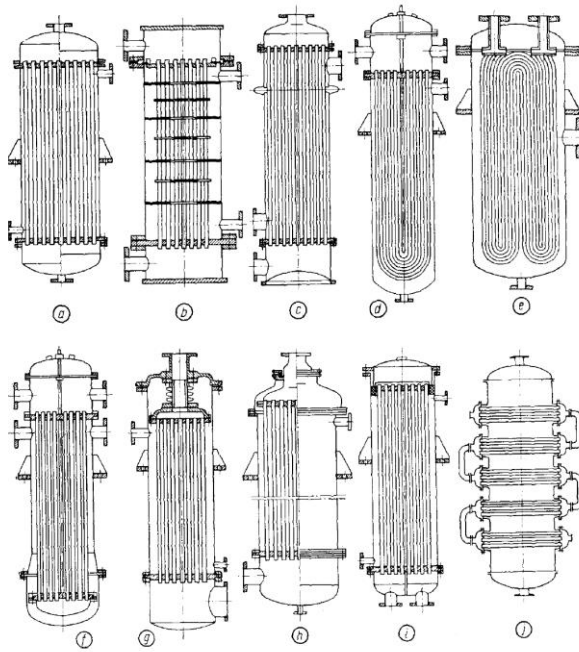
a – with fixed tube sheets, *b* – with baffles in the space between tubes and with the membrane compensator of the upper tube sheet, *c* – with lens compensator on the body, *d* – with V-shaped tubes, *e* – with W-shaped tubes, *f* – with floating chamber (tube sheet), *g* – with bellows compensator of main tube, *h* – with connector tube gasket, *i* – with body gasket, *j* – with cross tubes

Figure 0.5. Jacketed heat exchangers[7]

a – tubes finned with plates, *b* – cast iron tube with round fins. *c* – spiral-finned element, *d* – finned tube, *e* – cast iron tube with double needle fins, *f* – finned tube with wire spirals (bispiral). *g* – tube with longitudinal fins, *h* – tube with fins folded from metal tape

---

[7] H. Arro, A. Koni, A. Kull, I. Mikk, A. Ots, A. Poobus, H. Roolaid, L. Õispuu. Soojustehnika käsiraamat. Tallinn Valgus 1977

Figure 0.6. Finned tube heat exchangers[8]
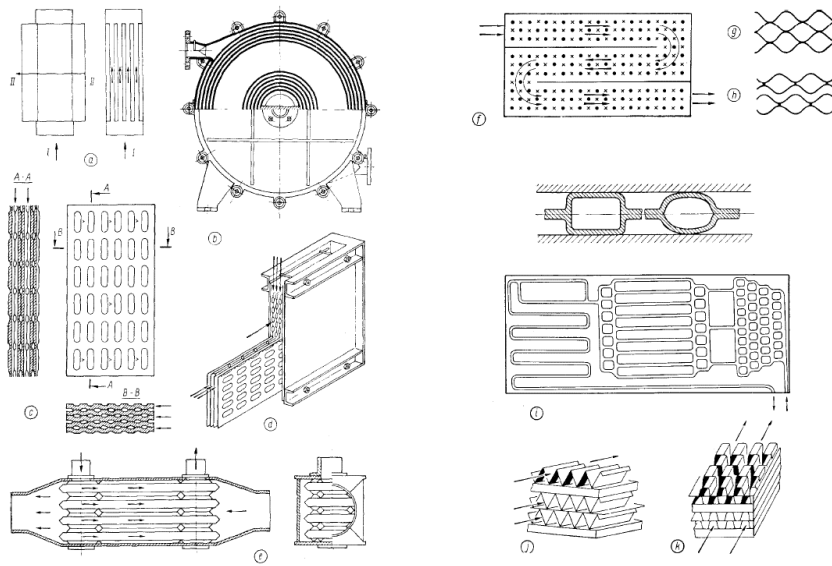
Figure 0.7. Plate heat exchangers[9]

Figure 0.8. Recuperative gas-gas heat exchanger for heating air[10]

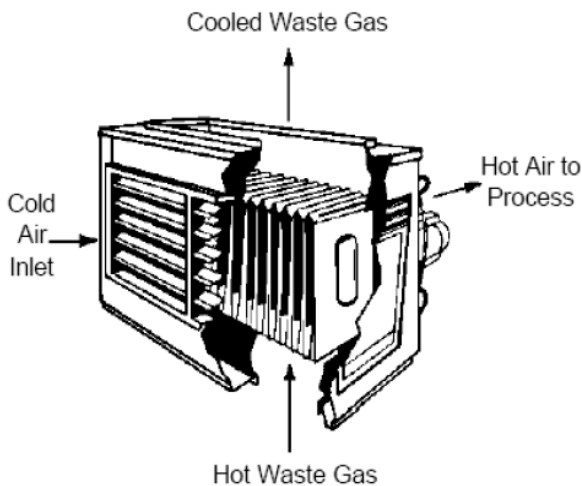Recuperative heat exchangers (Figure 0.8) are mostly used for low or medium temperature waste heat. Areas of application include furnaces, steam boilers, combustion gases in gas turbines and heat recovery of indoor air.

Heat exchangers with finned tubes are used with gas-liquid media, for example, a boiler economiser, where the heat of the combustion gases is transferred to the boiler feed water. The gas may be any hot gas and the liquid may be any warm water or oil used for any purpose.

---

[8] H. Arro, A. Koni, A. Kull, I. Mikk, A. Ots, A. Poobus, H. Roolaid, L. Õispuu. Soojustehnika käsiraamat. Tallinn Valgus 1977

[9] H. Arro, A. Koni, A. Kull, I. Mikk, A. Ots, A. Poobus, H. Roolaid, L. Õispuu. Soojustehnika käsiraamat. Tallinn Valgus 1977

[10] Waste Heat Recovery: Technology and Opportunitirs in U.S. Industry.U.S. Department of Energy. 2008

If the temperature of the gas containing the waste heat is high enough and the consumer needs steam, a waste heat boiler or utilisation boiler is used for the transfer of waste heat, see also Figure 0.9.
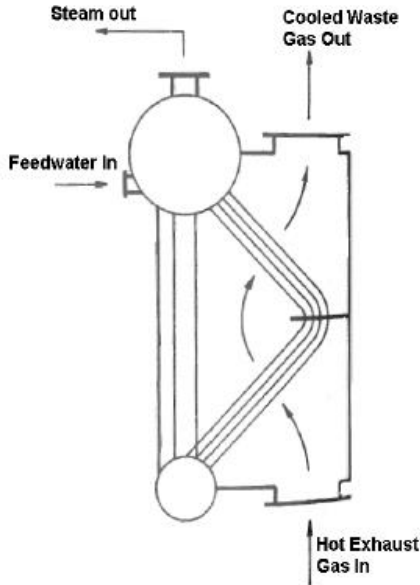
Figure 0.9. Waste heat steam boiler or utilisation boiler[11]

Additional burner(s) may be installed on waste heat boilers with the purpose of burning additional fuel in the boiler, if necessary for generating heat in a situation where waste heat is not sufficient to generate steam with the desired parameters (pressure, temperature).

Heat storage

One way to store heat is to heat the material being processed. One of the most common examples is the preheating of the boiler feed water by means of a heat exchanger. The same principle can be applied for storing the heat from the combustion gases of the furnace to preheat the material fed into the furnace and heated there. For example, the aluminium industry uses the preheating of the material to be melted, see also Figure 0.10.

---

[11] Waste Heat Recovery: Technology and Opportunitirs in U.S. Industry.U.S. Department of Energy. 2008

Figure 0.10. Stack melter preheating the aluminium before melting[12]

A vertical tube furnace is the preferred technology for melting and casting aluminium compared to flame furnace, as the former can reduce energy consumption by up to 47 % compared to the latter.

Storage in liquid, steam

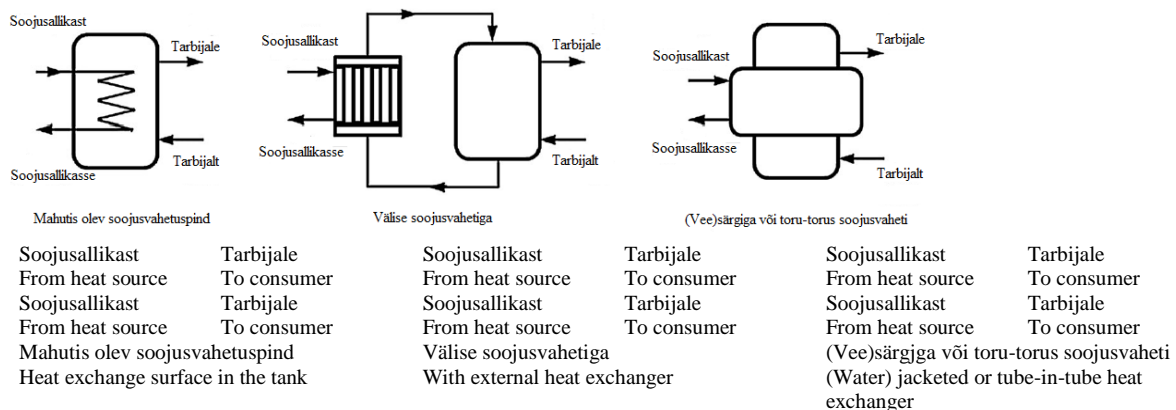There are situations where waste heat is left over for a certain period of time or there is no consumption at some point in time. At some other point in time, however, there is consumption, but the amount of waste heat is insufficient or not available at the required time. Heat storage can be used in such cases. Storage of low and medium temperature energy by heat transfer is predominantly used at temperatures up to 200 °C. It has been extensively studied and is also used in the heating and cooling systems of buildings. Medium and high temperature storage is done above 200 °C and is utilised e.g. in industry, power plants (incl. solar power plants, concentrated solar power (CSP) plants, where heat is stored for use as steam in a steam turbine so that the plant can operate 24 hours a day and when there is no sun).[13]

Water is suitable for storing energy as heat in the temperature range of 5 °C to 95 °C and water has a relatively high thermal capacity, high thermal break (4.18 kJ/(kg K)) and it can be considered relatively inexpensive.

The use of water requires tanks, which can be made of metal or concrete or natural cavities may be used (granite). Water in the tank may be used for storage, being also the substance to be stored (active system), or any other liquid that passes through the heat exchanger installed in the tank (passive system) (Figure 0.11).

Soojusallikast	Tarbijale	Soojusallikast	Tarbijale	Soojusallikast	Tarbijale
From heat source	To consumer	From heat source	To consumer	From heat source	To consumer
Soojusallikast	Tarbijale	Soojusallikast	Tarbijale	Soojusallikast	Tarbijale
From heat source	To consumer	From heat source	To consumer	From heat source	To consumer
Mahutis olev soojusvahetuspind		Välise soojusvahetiga		(Vee)särgjga või toru-torus soojusvaheti	
Heat exchange surface in the tank		With external heat exchanger		(Water) jacketed or tube-in-tube heat exchanger	

**Figure 0.11. Energy storage in tank using heat transfer[14]**

Storage in soil does not look at the traditional storage of energy in the rocky soil, but the rock layer (mineral layer) prepared for energy storage. When storing in the rock layer (Figure 0.12) either e.g. water or air passes through the rock layer as heat-carrying fluid.

In the case of storage in the soil (including rock), the main costs to be taken into account are the costs of the installation of systems (soil removal, backfilling, drilling, etc.), as the soil itself is relatively cheap. Both vertical boreholes (Figure 0.13) as well as horizontal tubes are used (Figure 0.14).

[12] Waste Heat Recovery: Technology and Opportunities in U.S. Industry.U.S. Department of Energy. 2008

[13] A. Rosin, S. Link, H. Hõimoja, I. Drovtar. Energy storage devices and storage technologies. 2015.

[14] Y.M. Han, Y.M., R.Z. Wang, R.Z., Y.J. Dai, Y.J. (2009). Thermal stratification within the water tank. – Renewable and Sustainable Energy Reviews, 13 (2009), 1014–-1026.
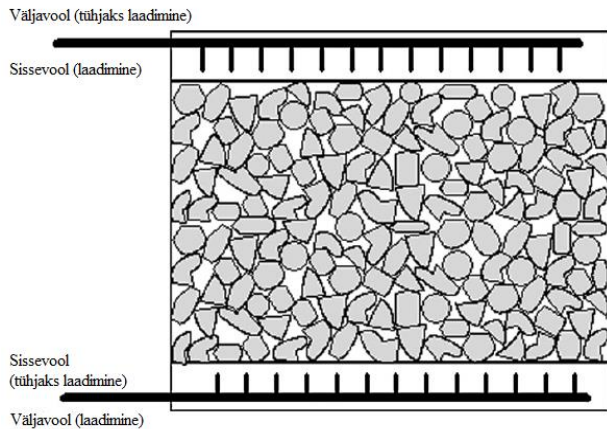
Väljavool (tühjaks laadimine)
Outflow (emptying)
Sissevool (laadimine)
Inflow (filling)
Sissevool
(tühjaks laadimine)
Inflow
(emptying)
Väljavool (laadimine)
Outflow (filling)

Figure 0.12. The working principle of storage in the rock layer[15]
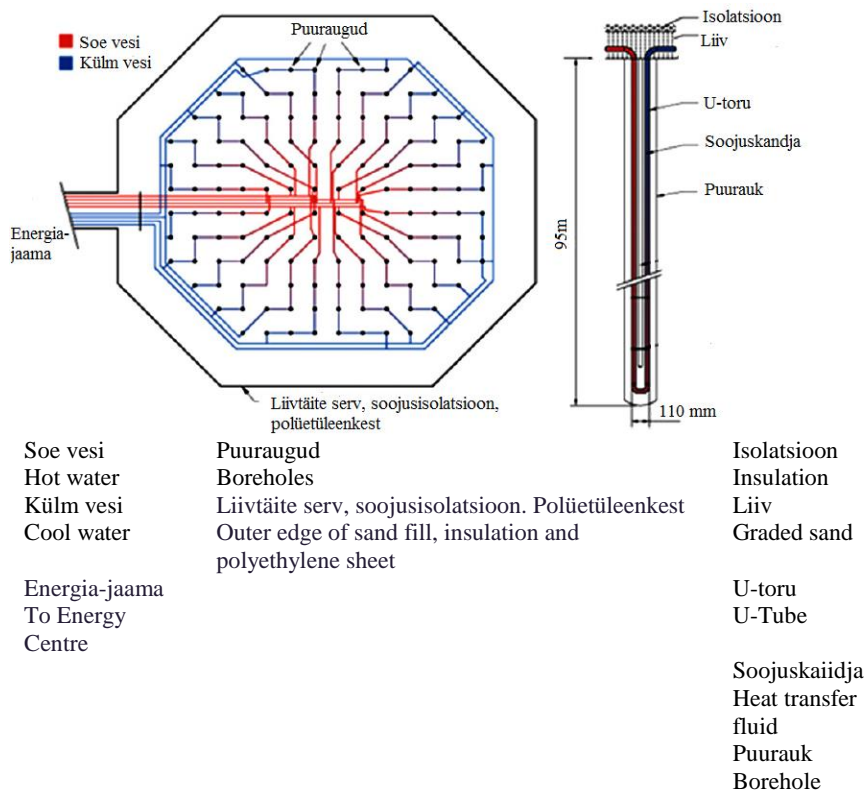
Soe vesi	Puuraugud	Isolatsioon
Hot water	Boreholes	Insulation
Külm vesi	Liivtäite serv, soojusisolatsioon. Polüetüleenkest	Liiv
Cool water	Outer edge of sand fill, insulation and polyethylene sheet	Graded sand
Energia-jaama		U-toru
To Energy Centre		U-Tube
		Soojuskaiidja
		Heat transfer fluid
		Puurauk
		Borehole

[15] P. Pinel, P., C.A. Cruickshank, C.A., I.Beausoleil-Morrison, I., A. Wills, A. (2011). A review of available methods for seasonal storage of solar thermal energy in residential applications. – Renewable and Sustainable Energy Reviews, 15, (2011) 3341– 3359.

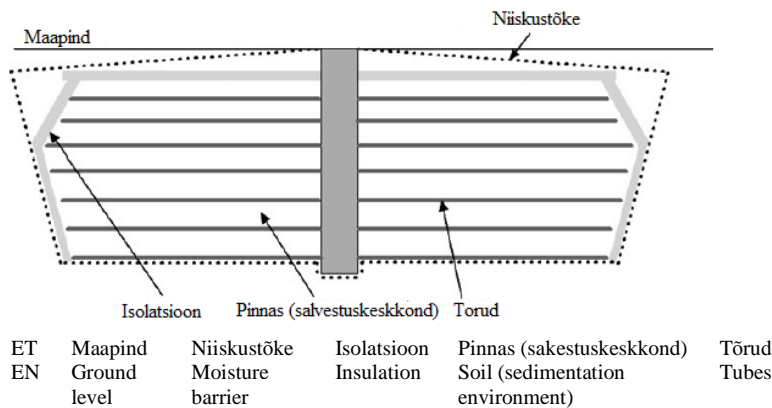**Figure 0.13. Drake Landing Solar Community seasonal thermal storage[16]**

ET	Maapind	Niiskustõke	Isolatsioon	Pinnas (sakestuskeskkond)	Tõrud
EN	Ground level	Moisture barrier	Insulation	Soil (sedimentation environment)	Tubes

Figure 0.14. Vaulruz system[17]

Oils and chemicals (e.g. salts) are also used as substances storing energy. Oil and chemicals are more expensive than water and are used when higher temperatures are required, i.e. to store heat at higher temperatures. Different blocks, slabs, etc. made of various materials such as concrete, graphite, iron and iron oxide pellets, round granules, etc. can also be used as a storage medium for storing energy without phase change. Such solutions are, however, more expensive compared to the use of rock, soil or water. On the other hand, they allow for the use of higher temperatures.

Storage with stratification

One important aspect of storage without phase change is the so-called thermal stratification (Figure 0.15). Stratification helps to increase 'energy quality' (exergy). Stratification increases the energy used from the storage compared to the non-stratification situation, due to the temperature differences required for heat transfer (Figure 0.15Figure 0.15).

(a)		(b)		(c)	
Kuum tsoon	Hot zone	Kuum tsoon	Hot zone	Ühtlane temperatuur	Uniform temperature
Üleminekutsoon	Transition zone	Üleminekutsoon	Transition zone		
Külm tsoon	Cold zone	Külm tsoon	Cold zone		
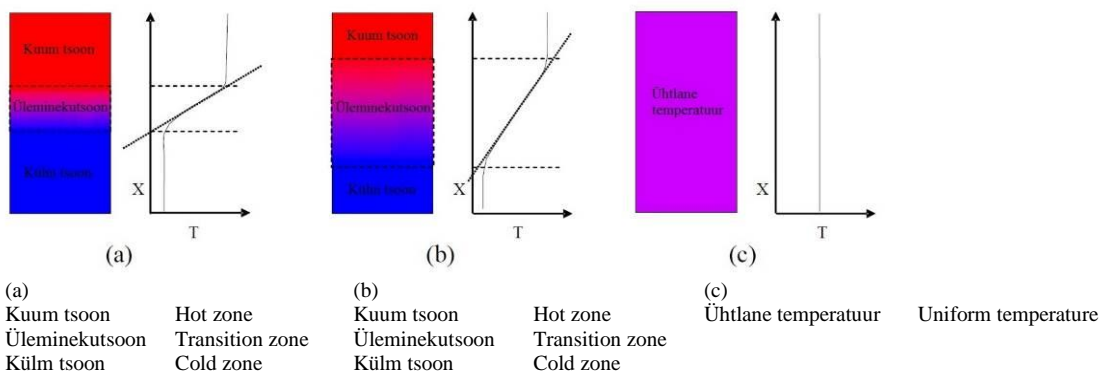
Figure 0.15. Different levels of stratification: (a) good stratification, (b) medium stratification, (c) mixed (non-stratified)[18]

Figure 0.16 illustrates a possible design of a stratified storage device.

---

[16] Drake Landing Solar Community. Borehole thermal energy storage (BTES). http://www.dlsc.ca/borehole.htm.

[17] Chuard, P., Chuard, D., Gilst, van J., Hadorn, J.C., Mercier, C. (1983). IEA Task VII Swiss project in Vaulruz – design and first experiences. – International conference on subsurface heat storage in theory and practise.

[18] . Cruickshank, C.A. (2009). Evaluation of a stratified multi-tank thermal storage for solar heating applications :. PhD Thesis., Queens University, Canada[19] Buderus.
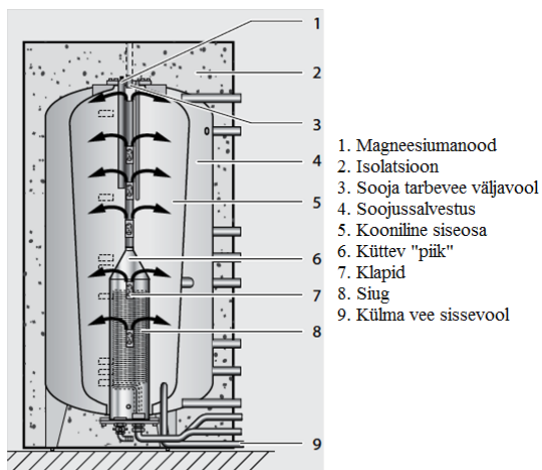
ET		EN	
1.	Magneesiumanood	1.	Magnesium anode
2.	Isolatsioon	2.	Insulation
3.	Sooja tarbevee väljavool	3.	Domestic hot water outflow
4.	Soojussalvestus	4.	Heat storage
5.	Kooniline siseosa	5.	Conical inner part
6.	Küttev "piik"	6.	Heating 'peak'
7.	Klapid	7.	Valves
8.	Siug	8.	Snake
9.	Külma vee sissevool	9.	Cold water inflow

Figure 0.16. A design of stratified storage device[19]

Energy storage by phase change

The thermochemical process is based on storing energy by breaking the water bonds of a substance with heat (desorption[20]), on the evaporation and condensation of one product for later use. The heat is recovered when the condensed substance is re-evaporated and re-bound (sorption) to another substance. Some molecules (sorbent) have a high affinity[21] for water (sorbate) and form a strong bond with it. Disruption of this bond (desorption) and subsequent evaporation is an endothermic reaction. The opposite reaction (sorption) is an exothermic reaction. Sorption possibilities are shown in Table 0.3.

Table 0.3. Sorption possibilities[22]

Absorption	Adsorption	Solid-gas reaction
NH_3-H_2O (0.40 GJ/kg)	H_2O-zeolite 4A (0.08 GJ/kg)	H_2O-Na_2S (1.27 GJ/kg)
H_2O-NaOH (1.00 GJ/kg)	H_2O – silica gel (0.14 GJ/kg)	H_2O-$MgCl_2$ (0.84 GJ/kg)

[19] Buderus.

[20] Desorption is the opposite process to adsorption. Adsorption is the adhesion of atoms, ions, biomolecules, gaseous, liquid and dissolved molecules to a surface.

[21] Affinity in chemistry characterises the ability of a substance or functional group to react with another substance.

[22] Bales, C., P. Gantenbein, P., A. Hauer, A., H.-M. Henning, H.-M., D. Jaenig, D., H. Kerskes, H. et al. (2005). Thermal properties of materials for thermo-chemical storage of solar heat. Report B2-IEA SHC Task 32 :. International Energy Association., 2005.

-	-	H_2O-$CaCl_2$ (0.98 GJ/kg)
-	-	H_2O-LiCl (0.71 GJ/kg)

When energy is stored based on the closed-loop sorption principle (Figure 0.17), heat exchange with the external environment takes place, as a result of which the sorbate (water) is condensed in the filling phase. In the emptying phase, it evaporates. The evaporation process requires low temperature heat (≥5 °C) for the water to evaporate in the emptying phase. Such low temperature heat can be generated by cooling the building, from outside air or from another 'free' source. The heat generated during the exothermic process can be used e.g. to heat a building. Thus, this option of energy storage may also be used for both heating and cooling.
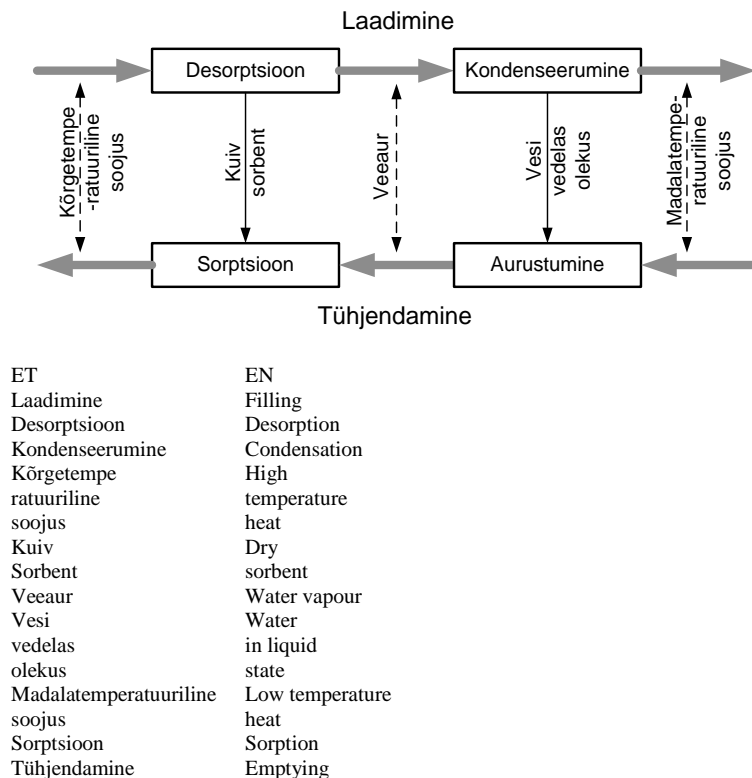

ET	EN
Laadimine	Filling
Desorptsioon	Desorption
Kondenseerumine	Condensation
Kõrgetempe	High
ratuuriline	temperature
soojus	heat
Kuiv	Dry
Sorbent	sorbent
Veeaur	Water vapour
Vesi	Water
vedelas	in liquid
olekus	state
Madalatemperatuuriline	Low temperature
soojus	heat
Sorptsioon	Sorption
Tühjendamine	Emptying

Figure 0.17. Storage based on closed-loop sorption[23]

1.1.2   Active technologies

Active technologies are sorption systems, mechanically operated heat pumps and the organic Rankine cycle (ORC). Active applications can be used to produce heat (WHTH), cold (WHTC) or electricity (WHTP). WHTH and WHTC are technologies of heat transformation - the temperature of the incoming heat transfer medium is changed to either lower or higher.

The most common solutions are:

- Compressor heat pump - for the production of heat (150—500 EUR/kW),

- Absorption heat pump - for the production of heat (330—830 EUR/kW),

- Absorption refrigeration plant - for the production of cold (800—2,000 EUR/kW),

---

[23] Bales, C., P. Gantenbein, P., D. Jaenig, D., R. Weber, R. (2007).. Laboratory prototypes of thermo-chemical and sorption storage units. Report B3-IEA SHC Task 32 :. International Energy Association, 2007

- Rankine cycle - for the production of steam (1,100—1,400 EUR/kW),

- Organic Rankine cycle (1,500—3,500 EUR/kW),

- Kalina cycle (1,100—1,500 EUR/kW).

Unlike the Rankine cycle, the ORC and Kalina cycle can be applied to waste heat at 100 to 200 °C (hot liquids, exhaust gases, etc.). The Kalina cycle is suitable for use at the lower end of this temperature range. The Rankine cycle is more suitable for high temperature waste heat.

Compressor heat pump

In nature, heat spreads spontaneously from a body with higher temperature to a body with lower temperature. The opposite process can only take place with an artificial heat transformer. A heat pump (see also Figure 0.18) is a heat transformer as it transfers heat from an environment with lower temperature to an environment with higher temperature. Heat pumps are used in heating and air conditioning systems, as well as technological processes.
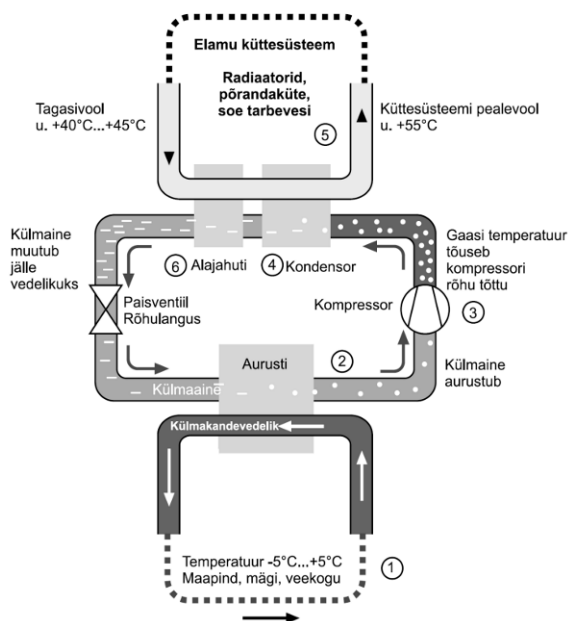
1. Temperature -5 °C …+5 °C Ground level, mountain, body of water
2. Compressor
3. The temperature of the gas rises due to the pressure of the compressor
4. Capacitor
5. Radiators, floor heating, domestic hot water
6. Subcooler

ET	Tagasivool u.+40°C...+45°C	Elamu küttesüsteem	Küttesüsteemi pealevool u. +55°C	Külmaine muutub jälle vedelikuks	Paisventiil Rõhulangus	Külmaine
EN	Return flow Approx. +40 °C …+45 °C	Residential heating system	Heating system inflow approx. +55 °C	The refrigerant becomes a liquid again	Expansion valve Pressure drop	Refrigerant
ET	Aurusti	Külmaine aurustub	Külmakandevedelik	Temperatuur -5°C...+5°C Maapind, magi, veekogu		
EN	Evaporator	The refrigerant evaporates	Brine	Temperature - 5 °C …+ 5 °C Ground level, mountain, body of water		

Figure 0.18. Working principle of heat pump[24]

The working principle of heat pumps is similar to that of refrigeration units (e.g. home refrigerators), but they have different temperature levels: refrigeration units transfer heat from the object to be cooled (frozen) to the environment, in a heat pump, however, usually from an external environment (low temperature heat source, which may be waste heat) to an object to be heated (for heating buildings, process heat, etc.). The heat pump is a universal device - it can be a heater and a cooler at the same time.

The operation of a heat pump is characterised by the Coefficient of Performance (COP) - the ratio of the heat output to the energy consumed by the heat pump for operation (see also Figure 0.19):

$$\varphi_0 = \frac{q_2}{l} \geq 1$$

kus: q_2 – ringprotsessist eemaldatav soojushulk kJ/kg;
l – ringprotsessi kulutatud töö kJ/kg.

where: q_2 - the amount of heat kJ/kg removed from the cycle;

l - the work spent on the cycle kJ/kg.

In other words:

$$COP = \frac{Soojuspumba\ soojustoodang}{Soojuspumba\ poolt\ tarbitud\ energia\ (elekter)}$$

[COP = heat generated by the heat pump/energy consumed by the heat pump (electricity)]
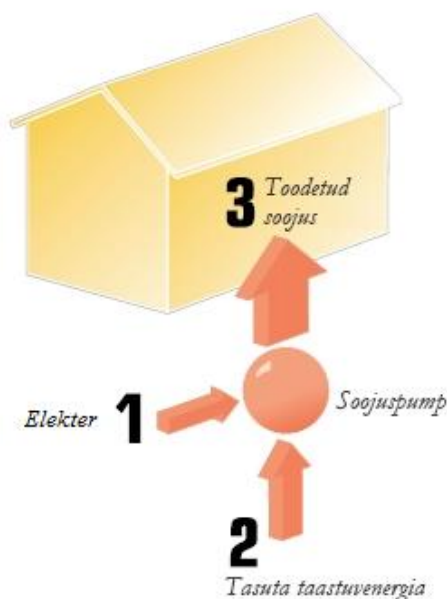
1. Electricity
2. Free renewable energy
3. Heat generated
4. Heat pump

Figure 0.19. Simplified energy balance of heat pump

Compression

[24] Thermia.

The compressor is the 'heart' of the heat pump, and thus close attention is paid to both compressors and compression. Compression raises the pressure of the evaporated refrigerant, which allows the refrigerant to condense at a higher temperature and transfer heat after compression. Multi-stage compression involves more than one stage of compression, e.g. in a cascade (see also

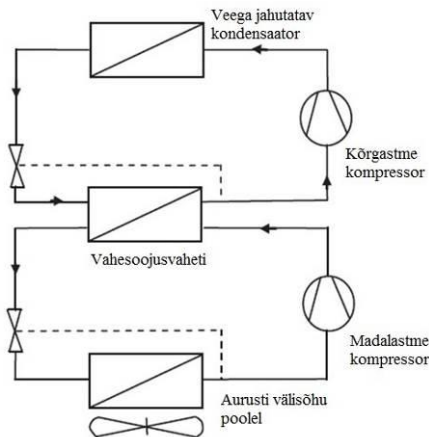| EN	Water-cooled condenser	High ratio compressor	Intermediate heat exchanger	Low ratio compressor	Evaporator on the ambient air side

Figure 0.20). Compared to single-stage compression, multi-stage compression has a smaller pressure ratio and, at the same time, a higher overall compression efficiency.

ET	Veega jahutatav kondensaator	Kõrgastme kompressor	Vahesoojusvaheti	Madalastme kompressor	Aurusti välisõhu poolel
EN	Water-cooled condenser	High ratio compressor	Intermediate heat exchanger	Low ratio compressor	Evaporator on the ambient air side

Figure 0.20. Multistage compression heat pump connected to a cascade[25]

Absorption device

In an absorption heat transformer, heat is used to transform heat. The difference from the working principle of the compressor described above is that absorption devices use thermochemical compression to increase the pressure of a thermodynamic body. Heat from a heat source with a temperature higher than the ambient temperature is used for this purpose. Binary solution is a thermodynamic body, being a mixture of two substances with different thermodynamic properties.

The absorption device uses the property of the solution to absorb steam. Unlike a pure substance, a solution has the ability to absorb steam of a certain composition from a solution of a different composition if the temperature of the former is higher than that of the latter.

The constant boiling point of a binary solution consisting of two substances with different boiling points depends on the ratio of the components in the solution. The higher the concentration of the substance with a higher boiling point in the solution, the higher the boiling point of the solution. It is also important that the concentration of the component with a lower boiling point in the steam generated during boiling is always higher than in the boiling liquid.

Aqueous solutions, such as aqueous ammonia, are usually used as thermodynamic bodies. The boiling point of water is 100 °C and for ammonia -33 °C.

The diagram of the absorption cooling machine is presented in Figure 0.21.

---

[25] K.J. Chua, S.K. Chou, W.M. Yang. Advances in heat pump systems: A review. Applied Energy 87 (2010) 3611-3624.

The figure contains the following labels:

Jahutatav meedium ehk eemaldatav soojus — q_a

kuiv küllastunud aur — NH_3

Pump — p_1

p_2 Da p_1

p_2 Dr p_1 — T_2 T_1

Aurusti

Jahutatud meediumi tagastus

Absorber

Aurugeneraator NH_3

q_k

Soojendatud väliskeskkond (vesi, õhk) ehk eemaldatud soojus — q_0

q_1

T_0

Kondensaator

Väliskeskkond (vesi, õhk)

ET	Jahutatav meedium ehk eemaldatav soojus	Absorber	Soojendatud väliskeskkond (vēsi, öhk) elik eeinaldatud soojus	kuiv küllastunud aur	Pump
EN	Cooling medium, i.e. heat to be removed	Absorber	Heated external environment (water, air), i.e. removed heat	Dry saturated steam	Pump
ET	Aurugeneraator	Aurusti	Kondensaator	Jahiitatud meediumi tagastus	Väliskeskkoud (vesi, ölik)
EN	Steam generator	Evaporator	Capacitor	Return of cooled medium	External environment (water, air)

Figure 0.21. Diagram of an absorption refrigerator

An amount of heat q_k is channelled to the steam generator from outside, in order to evaporate ammonia from the binary solution in the steam generator. The resulting ammonia vapours are condensed in a capacitor at ambient temperature (T_0). To evaporate the liquid ammonia, the liquid ammonia leaving the capacitor is throttled in the throttle valve (Dr) from pressure p_1 to pressure p_2. In the throttling process, the ammonia temperature drops from T_1 to the cooling chamber or evaporator temperature T_2 and moist steam is formed. In the evaporator, a quantity of heat q_a is transferred from the environment to be cooled to the ammonia, and in the isobaric-isothermal evaporation process at temperature T_2 dry saturated (or slightly moist) ammonia vapour is obtained from the moist ammonia vapour. The dry saturated ammonia vapour is then fed to the absorber. At the same time, an aqueous solution with low ammonia concentration is introduced into the absorber from the steam generator via the throttle valve Da. The pressure of the solution decreases from p_1 to p_2 during the throttling.

The vapour condenses (absorption). As this is an exothermic process, it is accompanied by a rise in temperature, i.e. the condensation releases heat q_0, which is directed to the surrounding environment so that the absorption capacity of ammonia into the solution is not reduced. The concentration of the component with a lower boiling point in the liquid increases as a result of the absorption process.

The pressure of the liquid with elevated concentration is raised from pressure p_2 in the pump to pressure p_1 and channelled to the steam generator. Throttling between the steam generator and the absorber through the throttle valve Da balances and keeps the concentration of

components with different boiling points constant in both the steam generator and the absorber.

The absorption device is more complex than a steam compressor unit, but lacks a compressor. On the other hand, the cooling factor is relatively small (1.5). It is expedient to use the device if it is possible to obtain cheap (waste) heat (ventilation heat, solar heat), especially compared to the price of electricity. It is usually used for large devices.

In combined heat and power systems, the use of absorption cooling enables the heat remaining in the cogeneration process in the summer to be used for cooling (trigeneration), see also Figure 0.22.
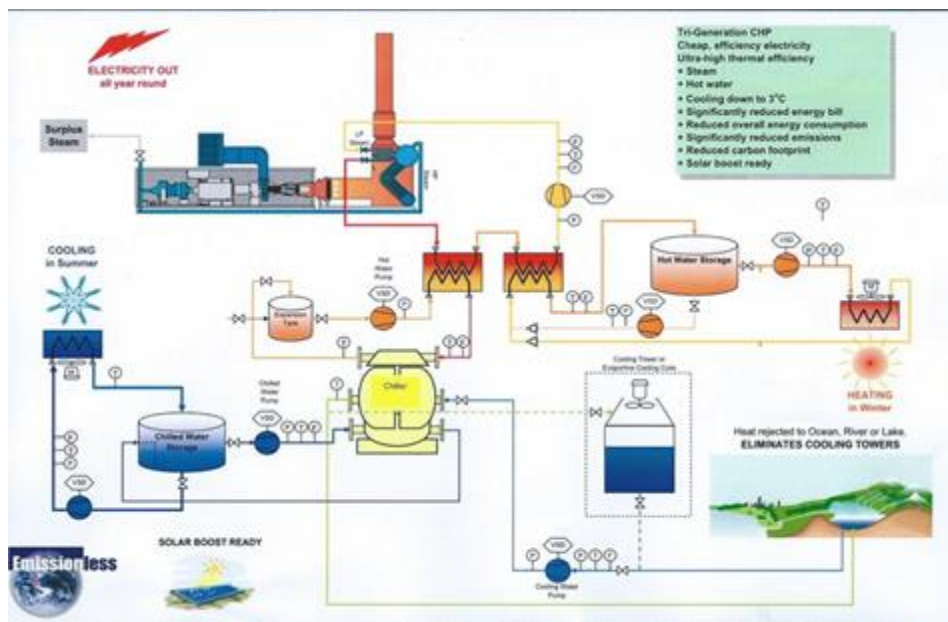
Figure 0.22. Sample diagram of the cogeneration of cold, heat and electricity

Rankine cycle

Today, the majority of electricity (~80 %) is generated by steam. Steam power plants are used for this purpose. Steam generators are used to produce water vapour. The diagram of an elementary steam power plant is shown in Figure 0.23.

AG – aurugeneraator,
ÜK – auruülekuumendi,
AJM – aurujõumasin,
KO – kondensaator,
TP – toitepump,
G – elektrigeneraator
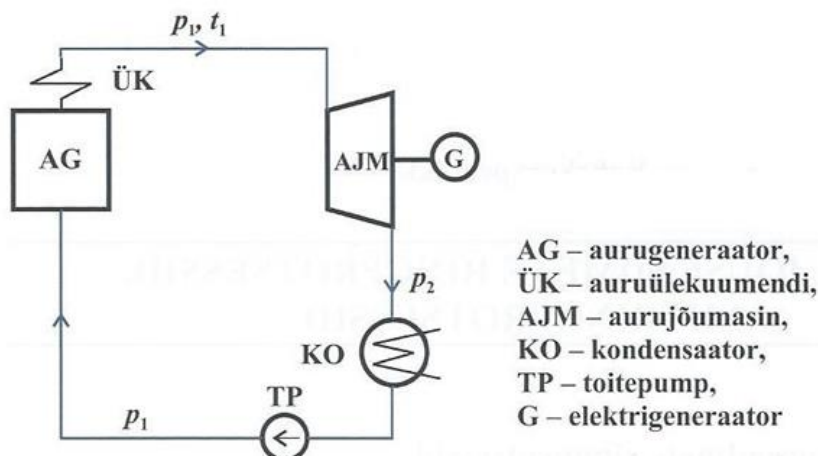
SG - steam generator, SSH - steam superheater, SPP - steam power plant, C - capacitor, FP - feed pump, G - electric generator

Figure 0.23. Diagram of steam power plant

The water pumped to the steam generator turns into dry saturated steam in an isobaric heating and evaporation process. The steam temperature is raised to the required level in the steam superheater. As a result of the processes taking place in the steam generator, the thermodynamic body receives an amount of heat q_1. From the steam superheater, the steam goes to the steam power plant (usually a turbine but also steam engine), where it expands from adiabatic pressure p_1 to pressure p_2. The useful work done during the expansion of the steam in the turbine is used to run the electricity generator. The steam leaving the steam power plant condenses in the capacitor, releasing the amount of heat q_2. The condensate is pumped back to the steam generator by means of a feed pump. The capacitor is cooled either with natural water or a closed cooling system (air or water).

The average cycle efficiency is in the order of 30–40 %. Efficiency depends on the size of the appliance and the steam parameters. The higher the steam pressure and temperature, the bigger the efficiency.

Organic Rankine cycle (ORC)

The organic Rankine cycle is basically the same as the conventional water-based process, but the thermodynamic body or heat-carrying fluid is an organic liquid instead of water. For ORC, waste heat starting from 66 °C can be used.

The average cycle efficiency is in the order of 10–20 %.

Kalina cycle

The Kalina cycle is a further development of the Rankine cycle. The heat-carrying fluid here is e.g. aqueous ammonia. For a single-phase heat-carrying fluid, e.g. water, the boiling temperature is constant until the water has evaporated, whereas in the case of a binary solution, the temperature rises as the mixture evaporates. The substances in the solution have different boiling points. This allows better use of waste heat at the appropriate temperature. Therefore, the cycle efficiencies are also 10 % higher compared to the conventional Rankine cycle. The Kalina cycle diagram is depicted on Figure 0.24.
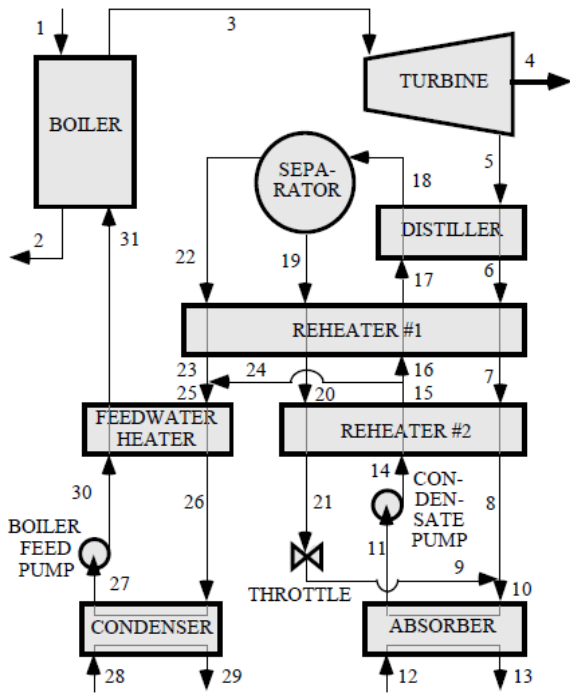
Figure 0.24. Simplified Kalina cycle diagram[26]

Waste heat can be obtained e.g. from combustion gases (1–2). Overheated ammonia-water vapour (3) is channelled to the turbine (4), where expansion takes place and work is performed. The medium (5) leaving the turbine is cooled (6, 7, 8), diluted with ammonia-poor liquid (9, 10) and condensed (11) in the absorber with cold water (12, 13). The saturated liquid leaving the absorber is compressed (14) to intermediate pressure and heated (15, 16, 17, 18). The saturated mixture is passed to a separator, where the liquid phase and vapour phase are separated. An ammonia-poor liquid (19) exits the separator, it is cooled and depressurised by throttling (20, 21). The ammonia-rich steam (22) is cooled (23) and the original condensate (24) is added to make a mixture with an ammonia concentration of 70 %. The mixture is then cooled (26), condensed (27) with cooling water (28, 29), compressed (30) and returned to the boiler (31).

The temperature range of the Kalina cycle heat source is 100–140 °C (e.g. Húsavík geothermal power station in Iceland).

---

[26] G. Wall, C-C. Chuang, M. Ishida. Exergy Study of the Kalina Cycle. Published in: R. A. Bajura, M. R. von Spakovsky and E. S. Geskin Eds., Analysis and Design of Energy Systems: Analysis of Industrial Processes, AES-Vol. 10-3, pp. 73-77, ASME

Options for the use of waste heat and cold in the heating and/or cooling sectors
and the assessment of the efficient district heating and cooling potential in Estonia
ANNEX 3

1. Examples of waste heat use in other countries

This chapter describes the examples of the utilisation of waste heat in other countries in addition to Estonia: Denmark, Germany, Norway and Sweden.

1.1 Denmark

In Denmark, the industrial waste heat is mostly used as a heat source in district heating systems, that is the waste heat is used for heating rooms and domestic water.[1] The relatively high price of natural gas and the low price of the electricity fed into the grid have pushed for the more active use of industrial waste heat, making the CHP plants operating on natural gas economically inefficient.

Denmark is developing low temperature 'fourth generation' district heating systems enabling one to make more extensive use of waste heat. The lower the parameters of a heat-carrying fluid in the district heating network, the lower the temperature of the waste heat that may be received and used (without having to raise the temperature with a heat pump).

In Denmark, projects on waste heat utilisation have been carried out in the aluminium industry, metalwork industry, pump manufacturing, paper industry, glass industry, production of potato crisps, packaging industry and shopping malls (the heat from the cooling compressors is fed into the district heating network).

The Kalundborg Eco-Industrial Park, which is an industrial symbiosis network located in Kalundborg, is one of the most well-known circular economy regions in Denmark, in which companies in the region collaborate to use each other's by-products and otherwise share resources (

Figure 1.1).

---

[1] IETS. Industrial Energy-Related Technologies and Systems. An Implementing Agreement established Under the auspices of the International Energy Agency. Annex XV: Industrial Excess Heat Recovery – Technologies and Applications. Phase 1. Country Reports

KPMG

Options for the use of waste heat and cold in the heating and/or cooling sectors
and the assessment of the efficient district heating and cooling potential in Estonia
ANNEX 3
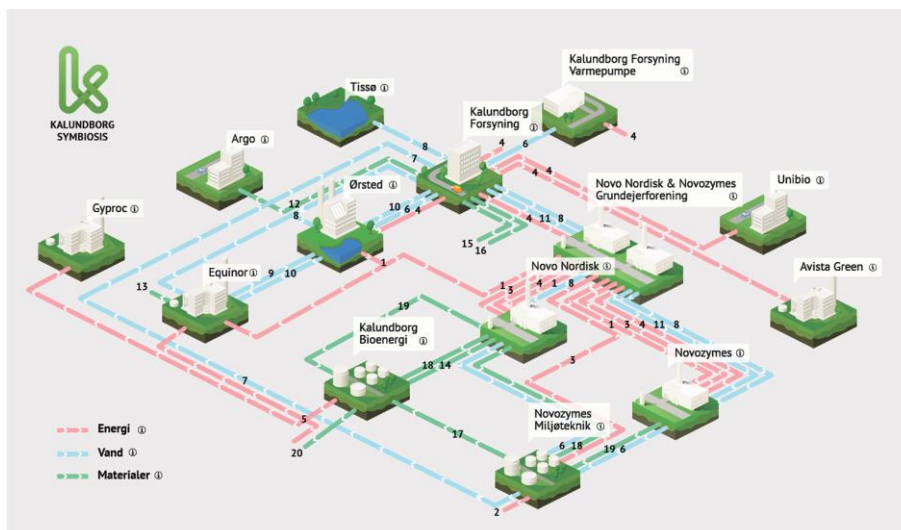
Figure 1.1. Denmark, Kalundborg Eco-Industrial Park. Example of the world's first industrial symbiosis[2]

The collaboration and its environmental implications in Kalundborg Eco-Industrial Park arose through private initiatives, as opposed to government planning, making it a model for the private planning of eco-industrial parks. At the centre of the exchange network is the Asnæs Power Station, a 1500 MW coal-fired power plant, which has material flow and energy supply links with several other companies and the community. Surplus heat from this power plant is used to heat 3,500 local homes in addition to a nearby fish farm. The sludge left over from ash discharge is then sold as a fertiliser. Steam from the power plant is sold to Novo Nordisk, a pharmaceutical and enzyme manufacturer, in addition to the Statoil oil refinery. Such use of heat reduces the amount of thermal pollution discharged to a nearby fjord. Additionally, a by-product from the power plant's sulphur dioxide scrubber contains gypsum, which is sold to a wallboard manufacturer. Almost all of the manufacturer's gypsum needs are met in this way, which reduces the amount of open-pit mining needed. Furthermore, fly ash and clinker from the power plant is used for road building and cement production. These exchanges of waste, water and materials have greatly increased environmental and economic efficiency, as well as created other less tangible benefits for these actors, gained through the sharing of personnel, equipment and information.[3]

1.2 Germany

1.2.1 Ventilation aggregate with heat recovery from indoor air in paper industry[4]

One German company in the paper industry has been using the heat present in spent air for preheating the incoming ventilated air since 2013. The amount of air needed is 75,000 m^3/h. The ventilation aggregate contains a water heating calorifier in addition

---

[2] Red lines depict the movement of energy, blue lines the movement of water and green lines the movement of materials. /http://www.symbiosis.dk/en//

[3] Kalundborg Eco-industrial Park. On the web: https://en.wikipedia.org/wiki/Kalundborg_Eco-industrial_Park

[4] Erfolgreiche Abwärmenutzung im Unternehmen. Energieeffizienzpotenziale erkennen und erschließen. Deutsche Energie-Agentur, 2019.

Options for the use of waste heat and cold in the heating and/or cooling sectors
and the assessment of the efficient district heating and cooling potential in Estonia
ANNEX 3

to the rotary heat exchanger. A natural gas boiler house provides the necessary heat for the water calorifier.

The invested amount was EUR 113,000. The yearly savings on gaseous fuel were 8,400 EUR/y (price of natural gas was 40 EUR/MWh). The natural gas saving is 210 MWh/y and CO_2 saving 42 h/y. The lifetime of the investment is considered to be 15 years, which is longer than the simple payback period of 13.5 years.

1.2.2 Reuse of process exhaust heat by means of a heat pump[5]

Roth Werke GmbH manufactures energy and sanitation systems. The company has c. 1,100 employees. The company uses oil-fired boilers for heating. In the tank manufacturing process, waste heat is produced during cooling, its temperature is raised to 50 °C using three heat pumps (so-called ground source heat pumps) and it is used for heating the production hall. The existing oil-fired boilers are used as peak-load boilers.

As a result of the project, the energy need for heating was reduced by 1.7 GWh/y. The cost of the solution EUR 250,000 and the yearly financial saving is 150,350 EUR/y. CO_2 saving is 590 t/y.

1.2.3 Operation of absorption refrigerator using the heat contained in flue gas[6]

Molkerei Gropper is a manufacturer of milk and juice products and drinks with ca. 500 employees. Since 2012/2013, the company uses two gas engines for the cogeneration of heat and electricity. The waste heat from the engines' combustion gases is used to preheat feedwater and produce steam. The residual heat and the heat generated by the cooling of the body are used for operating two ammonia/water absorption cooling devices. The resulting cooling capacity is 500 to 800 kW and the yearly production of cold is 9.6 GWh.

The cost of the project was EUR 1,700,000 and the company saves 515,000 EUR/y. The gas engines and cooling devices in total produce 34 GWh of electricity, 19 GWh of steam and 9.6 GWh of cold. 86 GWh of natural gas is used for this. CO_2 saving is 930 t/y.

1.2.4 Utilisation of waste heat from a metal heat treatment furnace to generate electricity[7]

The Volkswagen AG (approx. 16,000 employees) plant in Kassel manufactures metal components for vehicles. The waste heat from the metal heat treatment furnace is used to produce steam at a temperature of 400 °C. The steam is used in a specially developed steam Rankine cycle unit (SRC unit), see also Figure 1.2. The steam expands in a piston-expansion

---

[5] Erfolgreiche Abwärmenutzung im Unternehmen. Energieeffizienzpotenziale erkennen und erschließen. Deutsche Energie-Agentur, 2019.

[6] Erfolgreiche Abwärmenutzung im Unternehmen. Energieeffizienzpotenziale erkennen und erschließen. Deutsche Energie-Agentur, 2019.

[7] Erfolgreiche Abwärmenutzung im Unternehmen. Energieeffizienzpotenziale erkennen und erschließen. Deutsche Energie-Agentur, 2019.

KPMG

Options for the use of waste heat and cold in the heating and/or cooling sectors
and the assessment of the efficient district heating and cooling potential in Estonia
ANNEX 3

engine, the shaft of which causes the generator to rotate and thus generate electricity. The excess heat is used to heat rooms.
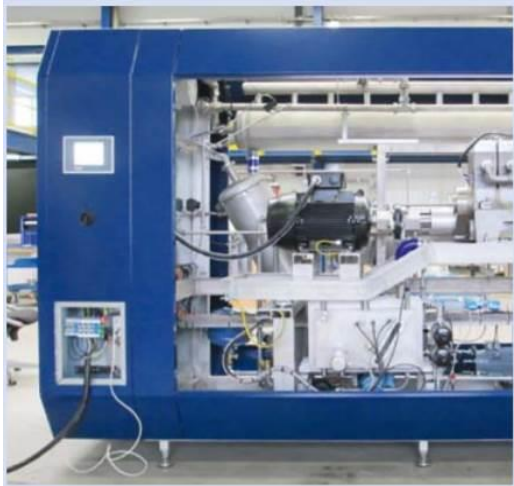

Figure 1.2. SRC unit

The SRC unit produces 5 GWh of waste heat per year for the process, 0.5 GWh of electricity and 4.3 GWh of useful heat. The cost of the project was EUR 768,000 and the financial savings are 230,000 EUR/y. CO_2 savings are 394 t/y.

1.2.5 Utilisation of waste heat from the ceramics industry by the ORC process[8]

Conrad Liphard & Söhne GmbH (approx. 80 employees) is a ceramics factory producing stones for industry and for the manufacture of tile stoves, as well as technological ceramics for gas turbines. The company generates waste heat from three ceramic kilns. To use this waste heat, two ORC Modules ('e-Pack', see also Figure 1.3) were installed with a total power of 40 kW$_{el}$. They help produce at least 0.32 GWh of electricity per year.

Figure 1.3. Example of an e-Pack ORC unit[9]

The cost of the project was EUR 160,000 and the annual financial savings are EUR 51,200. CO_2 savings are 196 t/y.

---

[8] Erfolgreiche Abwärmenutzung im Unternehmen. Energieeffizienzpotenziale erkennen und erschließen. Deutsche Energie-Agentur, 2019.

[9] http://effguss.bdguss.de/?wpfb_dl=174

Options for the use of waste heat and cold in the heating and/or cooling sectors
and the assessment of the efficient district heating and cooling potential in Estonia
ANNEX 3

1.2.6   Utilisation of waste heat from the metal industry by the ORC process[10]

In 2012, a metal factory in Germany installed an ORC system to utilise the waste heat from metal heating furnaces. The temperature of waste heat is 550 °C. The total capacity of the ORC station is 200 kW_{el} and 1.4 GWh_{el} is produced yearly. The investment will reduce the amount of electricity used for operating metal heating furnaces.

The cost of the project was EUR 790 000 and the cost savings are 238,000 EUR/y. CO_2 savings are 901 t/y.

1.2.7   Utilisation of waste heat from the cement industry by the ORC process[11]

HeidelbergCement AG cement factory in Lengfurt has been using waste heat at 275 °C generated by the cooling of clinker air (150,000 m^3/h) in an ORC process to generate electricity since 1999. After the heat exchanger, the air temperature is 125 °C. The oil temperature is 85/230 °C. The thermal capacity of the heat exchangers is 12.8 MW. The thermal capacity of the ORC unit is 8.2 MW_s and the electrical capacity is 1.95 MW_{el}. The annual production is 7.2 GWh_{el}. CO_2 savings are 7 000 t/y.

The ORC unit covers ca. 12 % of the factory's annual electricity consumption.

The cost of the project was EUR 4,000,000, of which EUR 2,650,000 was spent on the development of the unit. At an electricity price of 80 EUR/MWh, the simple payback period is 7 y.

1.2.8   Utilisation of waste heat from the metal and chemical industries in district heating[12]

Niederrhein Duisburg Dinslaken district heating network (see also Figure 1.4) uses waste heat from the metal and chemical industries. The main pipeline of the district heating network is 29 km long, there are 15 boiler stations in the network with a connection capacity of 550 MW for the transfer of heat to the Niederrhein and Duisburg distribution networks.

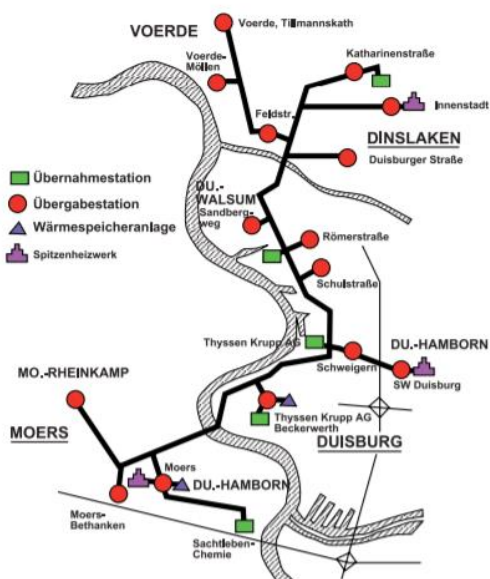[10] Erfolgreiche Abwärmenutzung im Unternehmen. Energieeffizienzpotenziale erkennen und erschließen. Deutsche Energie-Agentur, 2019.

[11] Industrielle Abwärmenutzung. Beispiele & Technologien.Dr. Brandstätter Sachverständigenbüro. Land Oberösterreich, 2008.

[12] Industrielle Abwärmenutzung. Beispiele & Technologien.Dr. Brandstätter Sachverständigenbüro. Land Oberösterreich, 2008.

Options for the use of waste heat and cold in the heating and/or cooling sectors
and the assessment of the efficient district heating and cooling potential in Estonia
ANNEX 3

Figure 1.4. Niederrhein Duisburg Dinslaken district heating network

The Niederrhein network connects consumers with a capacity of 800 MW, the length of the network is 500 km and its supply area has 500,000 inhabitants. Annually, 1,100 GWh of heat is fed into the network, of which 350 MWh is waste heat. Industrial waste heat is obtained from the Thyssen-Krupp AG metal factory and Sachleben Chemie GmbH chemical plant. The combustion gas temperature of Thyssen-Krupp AG is 250 °C and is used to heat the district heating network water (Duisburg-Schwelgern plant). The Beeckerwerth plant produces effluent gases at temperatures of 450-600 °C. The annual heat transfer from both plants to the district heating network is 250 GWh.

The Sachleben Chemie GmbH sulphuric acid plant in Duisburg-Homberg can supply 100 GWh of heat per year to the district heating network. The waste heat is generated in the production of titanium dioxide necessary for the sulphuric acid production process. The waste heat temperature at the Sachtleben thermal power plant is raised to 140 °C to ensure the temperature required for the district heating network.

The use of waste heat saves 90,000 t/y of CO_2.

Georg Fischer Automobilguss GmbH (Singen, Baden-Württemberg) manufactures metal components for the automotive industry. At the neighbouring Maggi food factory, the waste heat generated in the metal melting process has been used since 2008.[13]

1.2.9 Utilisation of waste heat from the metal industry in the food industry

The heat contained in the furnace exhaust air (1,200 °C) is transferred to thermal oil with a temperature of 280 °C. The thermal oil is pumped along a 200 m long pipeline (see also Figure 1.5) to the Maggi factory, which has a heat exchanger. The heat exchanger transfers the heat from thermal oil to water and produces steam. The steam is used to sterilise, cook and dry fresh products containing moisture, e.g. ravioli, freeze-dried soups and sauces.

---

[13] IETS. Industrial Energy-Related Technologies and Systems. An Implementing Agreement established Under the auspices of the International Energy Agency. ANNEX XV: Industrial Excess Heat Recovery – Technologies and Applications. Phase 1. Country Reports

Options for the use of waste heat and cold in the heating and/or cooling sectors
and the assessment of the efficient district heating and cooling potential in Estonia
ANNEX 3

The thermal capacity of the connection is 20 MW. Waste heat replaces 50 GWh/y worth of natural gas according to the required process heat. The annual amount of CO_2 saved is estimated at over 11,000 t/y.

Figure 1.5. Thermal oil pipeline between Georg Fischer Automobilguss GmbH and Maggi

1.3 Norway

In Norway, Finnfjord AS (see also Figure 1.6) is one of the largest producers of ferrosilicon (100,000 t/y) and microsilicon (20,000 t/y), whose production covers 15 % of the steel industry needs.[14]

---

[14] IETS. Industrial Energy-Related Technologies and Systems. An Implementing Agreement established Under the auspices of the International Energy Agency. ANNEX XV: Industrial Excess Heat Recovery – Technologies and Applications. Phase 1. Country Reports

Options for the use of waste heat and cold in the heating and/or cooling sectors
and the assessment of the efficient district heating and cooling potential in Estonia
ANNEX 3

Figure 1.6. Finnfjord AS

Ferrosilicon production is energy-intensive. The temperature of the combustion gases leaving the furnace is >600 °C. The heat recovery is a complicated task, because the combustion gas contains silicon dust. Special steam boilers have been designed for this purpose, which are connected to a 40.5 MW turbine. The heat in the combustion gases is used to produce steam, which is channelled to the steam turbine, producing approximately 340 GWh electricity per year.

In addition to Finnfjord AS, there are other companies that have created an analogous solution:

1. Elkem, Thamshavn – 195 GWh/y;
2. Elkem, Bjølvefossen – 50 GWh/y;
3. Hønefoss, kaugküte – 4x375 kW.

Lerøy Seafood (fish industry) at the Skjervøy plant and Fatland Jæren (meat industry) have implemented waste heat recovery from an ammonia-based cold plant.

Skretting Fish Feed utilises the recovery of heat generated from the condensation of moisture from the exhaust air in fish drying. A hybrid heat pump has been installed for this purpose. The heat released during the condensation of moisture is converted by a heat pump into heat with higher parameters, which is used in air dryers to preheat air. The capacity of the heat pump is 1,600 kW, which raises the waste heat temperature from 27–42 °C to 85 °C. The measured coefficient of performance is estimated at 5.5. The estimated annual energy savings are 5 GWh.

In-house waste heat recovery has become popular in Norwegian industrial companies. There are at least three companies in Norway that develop heat pumps for high temperature applications - from domestic water heating to steam production. In Norway, hybrid heat pumps (aqueous heat pumps) of at least over 6.5 MW have been installed. Epcon manufactures heat pumps for steam production.

One of the renewable heat projects is a 13.2 MW heat pump station completed in Norway in 2010, which uses cold water as a heat source and supplies heating and hot water to the city of Drammen's industry and local building stock with 63,000 inhabitants. The heat pump uses water from a local fjord (waste water could be used just as well) with a temperature of about 8 °C and which the heat pump returns at 4 °C. On the outlet side, the temperature of the water is initially raised to 60 °C in the district heating system. After bringing the water to 60 °C, a three-stage cycle follows, bringing the water to 90 °C in the district heating system. The payback period of such a 13 MW heat pump with a coefficient of performance of 3.05 and an initial investment of EUR 5.8 million is 4 years. This project is made more profitable by the fact that it benefits from Norway's low electricity price. The heat-carrying fluid used in the heat pump is ammonia, which is more efficient than other synthetic heat-carrying fluids and does not contribute to global warming. In this project, the heat pump is able to supply 85 % of the heat demand of the district heating network, and the remaining 15 % is covered by boilers running on fuel oil during peak loads. Using such a solution will reduce CO_2 emissions by approximately 15,000 t/y, given that electricity comes from a renewable energy source and up to 6.7 million litres of fuel is saved annually. [15] [16]

---

[15] Heat Pumps & Energy Efficiency Influencers - Making the right choice. [Võrgumaterjal]. Saadaval: http://www.star-ref.co.uk/smart-thinking/how-to-choose-an-efficient-heat-pump-large-scale-heat-pumps-and-district-heating-making-the-right-choice.aspx.

[16] Large scale heat pumps in Europe. [Võrgumaterjal]. Saadaval: https://www.ehpa.org/fileadmin/red/03._Media/03.02_Studies_and_reports/Large_heat_pumps_in_Europe_MDN_II_final4_small.pdf.

KPMG

Options for the use of waste heat and cold in the heating and/or cooling sectors
and the assessment of the efficient district heating and cooling potential in Estonia
ANNEX 3

1.4 Sweden

1.4.1 Utilisation of waste heat from a cardboard mill in district heating[17,18]

Waste heat from Krosnäs Frövi is channelled to Lindesberg (23,500 inhabitants) district heating system (see also Figure 1.7). Approximately 86 GWh of waste heat per year is supplied to the district heating network from the industry, which makes up 92 % of the district heating network's need. 4,500 apartments, schools, industrial facilities and public buildings are connected to the district heating network. A new pipeline with a length of 18 km and a capacity of 20 MW was built for the utilisation of waste heat. The waste heat is taken from the process steam at a temperature of 480 °C.
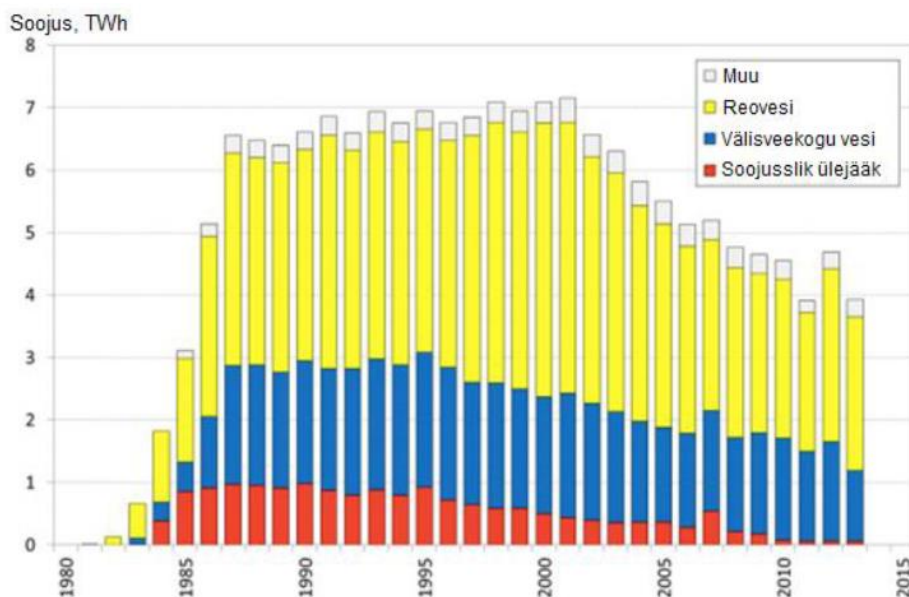

Figure 1.7. Krosnäs Frövi mill

As a result of the project, 40-60 new properties (buildings) will be connected to the district heating network annually (each apartment might be considered a separate consumer). An estimated 100-150 m^3 of fuel oil and 400 MWh of electricity have been replaced by waste heat. CO_2 savings are estimated at 16,000 t/y. As a result of the project, the use of a heat pump was also abandoned, meaning that 5 tonnes of freon are out of use. Electricity consumption also decreased by 11 GWh, which is estimated to be equal to the consumption of 550 private houses. The operating costs of the district heating network are low, comprising only the cost of electricity for pumping.

The main heat sources may be divided into four groups based on the Swedish example. Surrounding (external) water, waste water, additional heat from industry and other sources are mainly used. Surrounding water is mainly salty sea water, river water, lake water or groundwater. Water temperatures vary from 2 to 14 °C in different seasons. Industrial waste heat means low temperature heat generated as a result of industrial processes and the temperature range is 15–40 °C. Waste water includes effluent generated as a result of human activities with a temperature in the range of 12–20 °C. Other sources include flue gases and geothermal water. As shown in Figure 1.9, the most used heat source is waste water, followed by water from an external body of water. The use of industrial waste heat as a heat source has decreased the most, giving rise to the conclusion that waste water and water from natural bodies of water can be regarded as a stable heat source for heat pumps in the long run. Figure 1.8 is a graph describing the annual heat production by heat pumps between 1981 and 2013, depending on the heat source used.

Industrielle Abwärmenutzung. Beispiele & Technologien.Dr. Brandstätter Sachverständigenbüro. Land Oberösterreich, 2008.

[18] https://www.naturvardsverket.se/Documents/publikationer/978-91-620-8400-4.pdf?pid=4084

Options for the use of waste heat and cold in the heating and/or cooling sectors
and the assessment of the efficient district heating and cooling potential in Estonia
ANNEX 3

Key: Soojus, TWh - Heat, TWh; Muu – Other; Reovesi – Waste water; Välisveekogu vesi - Water from external body of water; Soojusslik ülejääk - surplus heat
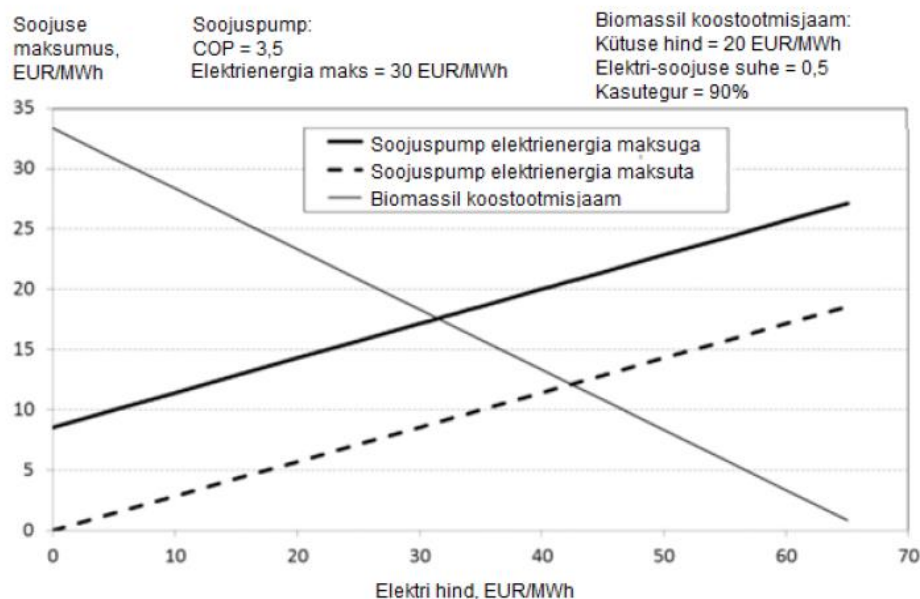
Figure 1.8. Heat production by heat pumps in Sweden between 1981 and 2013, depending on the heat source [19]

The next Figure 1.9

Soojuse maksumus, EUR/MWh	Cost of heat, EUR/MWh
Soojuspump: COP = 3.5 Elektrienergia maks = 30 EUR/MWh	Heat pump: COP = 3.5 Electricity tax = 30 EUR/MWh
Biomassil koostootmisjaam: Kutuse hind = 20 EUR/MWh Elektri-soojuse suhe = 0.5 Kasutegur = 90%	Biomass cogeneration plant: Fuel price = 20 EUR/MWh Electricity-heat ratio = 0.5 Efficiency = 90 %
Soojuspump elektrienergia maksuga	Heat pump with electricity tax
Soojuspump elektrienergia maksuta	Heat pump without electricity tax
Biomassil koostootmisjaam	Biomass cogeneration plant
Elektri hind, EUR/MWh	Price of electricity, EUR/MWh

shows the comparison of the price of heat produced in a biomass cogeneration plant and with heat pumps for Sweden. We see that the cheaper the price of heat, the more cost-effective it is to generate heat with heat pumps, and the more expensive the price of electricity, the more cost-effective the heat from cogeneration plants. If the price of electricity is considered with taxes, the price cap is approximately 32 EUR/MWh (32 euro cents/kWh), above which it is worth producing heat in CHP plants running on biomass.

---

[19] H. Averfalk, P. Ingvarsson, U. Persson, M. Gong, S. Werner, "Large heat pumps in Swedish district heating systems". [Võrgumaterjal]. Saadaval: https://www.sciencedirect.com/science/article/pii/S1364032117307839

Options for the use of waste heat and cold in the heating and/or cooling sectors
and the assessment of the efficient district heating and cooling potential in Estonia
ANNEX 3

Soojuse maksumus, EUR/MWh	Cost of heat, EUR/MWh
Soojuspump: COP = 3.5 Elektrienergia maks = 30 EUR/MWh	Heat pump: COP = 3.5 Electricity tax = 30 EUR/MWh
Biomassil koostootmisjaam: Kutuse hind = 20 EUR/MWh Elektri-soojuse suhe = 0.5 Kasutegur = 90%	Biomass cogeneration plant: Fuel price = 20 EUR/MWh Electricity-heat ratio = 0.5 Efficiency = 90 %
Soojuspump elektrienergia maksuga	Heat pump with electricity tax
Soojuspump elektrienergia maksuta	Heat pump without electricity tax
Biomassil koostootmisjaam	Biomass cogeneration plant
Elektri hind, EUR/MWh	Price of electricity, EUR/MWh

Figure 1.9. Cost of heat production in Sweden for heat pumps and biomass cogeneration plants depending on the price of electricity [108]

There are a number of other projects based on heat pumps (HP), some of which use waste heat and which have already been implemented and are in operation in the Nordic countries. These are described in Table 1.1.

Options for the use of waste heat and cold in the heating and/or cooling sectors
and the assessment of the efficient district heating and cooling potential in Estonia
ANNEX 3

Table 1.1. HP projects implemented in the Nordic countries [20]

City	Company	Heat output capacity of heat pumps (cooling capacity)	Heat source
Akaa	Elenia Lämpö	0.6 MW (0.5 MW)	Flue gases
Espoo	Fortum	2x20 MW (2x7.5 MW)	Waste water
Helsinki	Helen	5x18 MW (5x12 MW)	Waste water, cooling water
Riihimäki	Ekokem/HLV	2x4.5 MW (2x2 MW)	Flue gases, District heating return water
Mäntsälä	Mäntsälän Sähkö (Nivos)	3 MW	Data centre
Turku	TSE	2x20 MW (2x14 MW)	Waste water
Gothenburg	Göteborg Energi (Rya verket)	2x50 MW + 2x30 MW	Waste water
Lund	Lunds Energi	3.6 MW	Particle accelerator, geothermal
Stockholm	Fortum Sverige	4x27 MW + 2x24 MW+ 4x25 MW	Sea water
Drammen	Drammen Fjernvarme	3x4.5 MW	Sea water
Oslo	Oslofjord Värme (Sandvika)	2x6.5 MW (2x4.5 MW)	Waste water
Trondheim	NTNU	1.1 MW	Data centre
Dronninglund	Dronninglund Fjernvarme	3 MW	Stored solar energy

1.4.2 Stockholm district heating and cooling network

As of 2005, the Stockholm district heating system had heat pumps with a total capacity of 420 MW.

The total heat capacity of the heat pump station in Värtan Ropsten (see also Figure 1.10) using seawater is 180 MW. The station has 6 Friotherm Unitop 50FY heat pumps, which were installed in 1984-1986 (refrigerant R22). The transfer of heat pumps to another refrigerant R134a was started in 2003. Water intake is from a depth of 15 m, where water temperature is permanently +3 °C.

---

[20]   Large heat pumps in district heating systems. [Web material]. Available at: https://energia.fi/files/976/Large_heat_pumps_in_district_heating_systems_Summary.pdf.

Options for the use of waste heat and cold in the heating and/or cooling sectors
and the assessment of the efficient district heating and cooling potential in Estonia
ANNEX 3

Figure 1.10. Värtan Ropsten pump station building21

Two water intake pipes are installed on each pump. By today, more devices have been added. There are a total of 12 heat pumps and 4 refrigerators and the heat output is 300 MW. According to data from literature, the coefficient of performance of the station is 3,22. Heat pumps allow the transfer of water with a temperature of 80 °C to district heating. Seawater-based free cooling capacity is 74 MW.

At Nimrod station (Figure 1.11), four Unitop Turbo units of 12 MWj each were installed in 2000-2001, which can operate in different modes according to the situation.
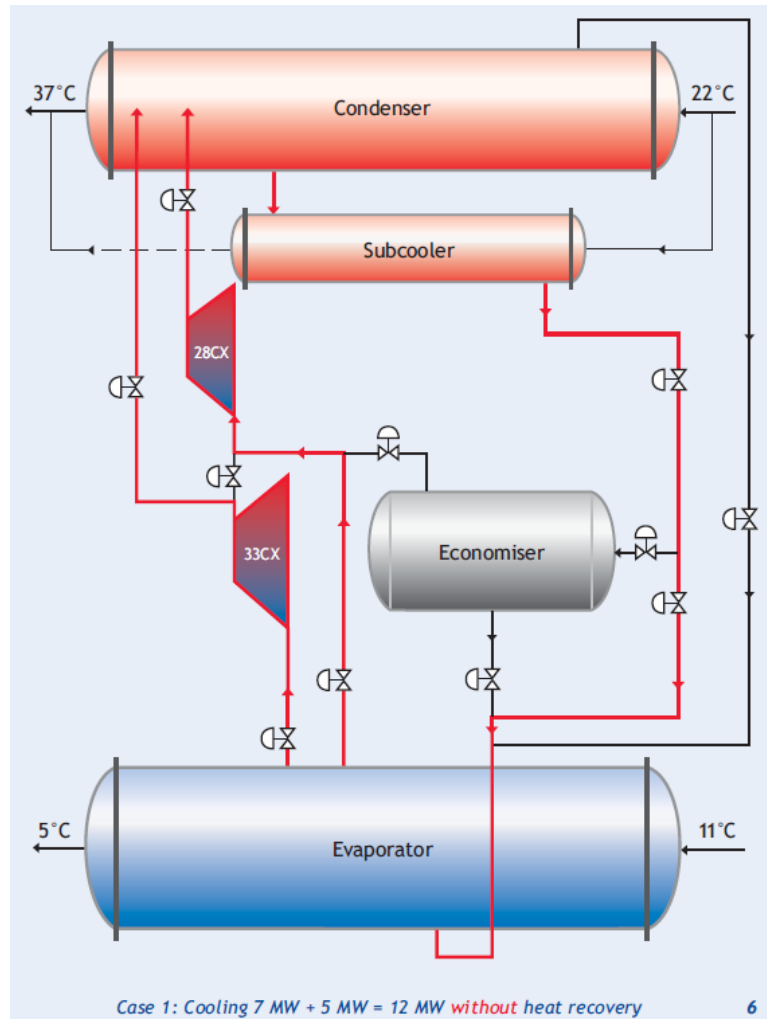

Figure 1.11. Nimrod station

Each unit has two compressors 28CX (5 MWj) and 33CX (7 MWj). In the summer, both compressors run in parallel (see also Figure 1.12), allowing for a maximum cooling capacity of 12 MW. At lower cooling loads, the compressor load is reduced by 20 %. In the summer, the waste heat is transferred from the capacitor to the sea with seawater.

---

[21] Friotherm AG

[22] https://www.gshp.org.uk/DeMontfort/LargeWaterSourceHeatPumpsSwedish.pdf

Options for the use of waste heat and cold in the heating and/or cooling sectors
and the assessment of the efficient district heating and cooling potential in Estonia
ANNEX 3

Figure 1.12. Operation in cold production mode only

In the spring, autumn, winter - sometimes also in the summer - combined cold and heat production is possible (see also Figure 1.13). In this case, the 33CX and 28CX compressors run in sequence. The first is a larger compressor 33CX and the second is a smaller 28CX.
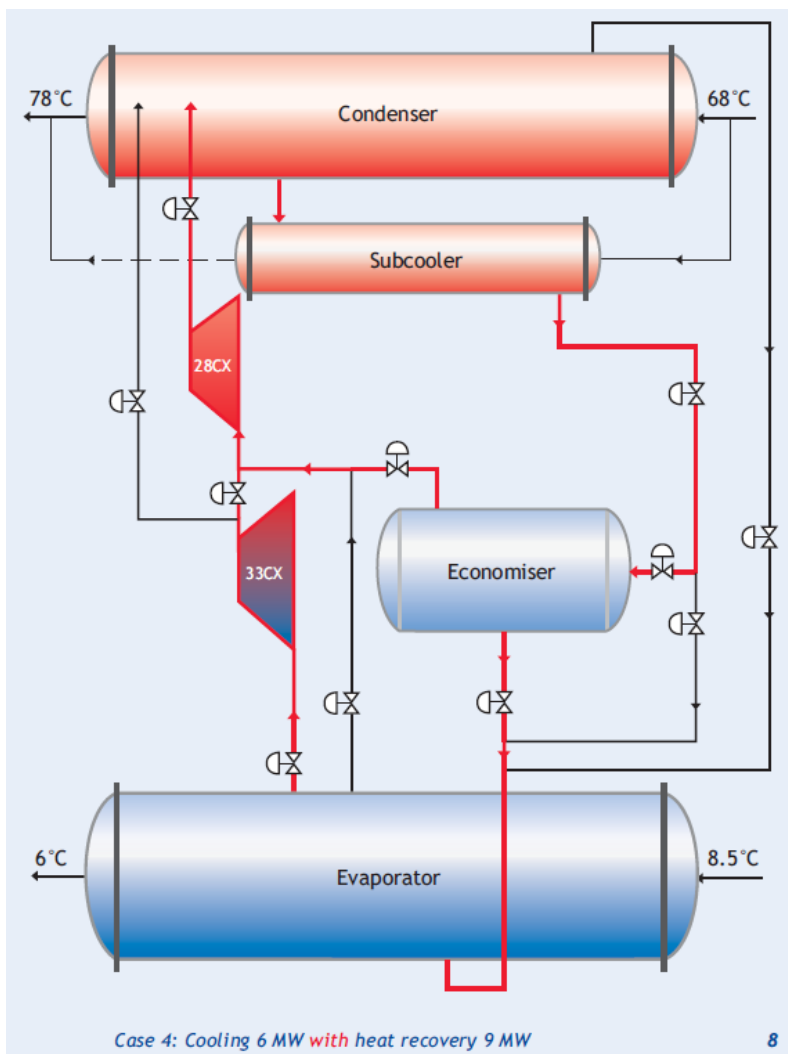
Options for the use of waste heat and cold in the heating and/or cooling sectors
and the assessment of the efficient district heating and cooling potential in Estonia
ANNEX 3

Figure 1.13. Operation in heat and cold production mode

1.5 Estonia

The following descriptions are based on the experience and knowledge of experts.

In Estonia, heat from the compressors of grocery store refrigerators has been used to heat the buildings, and large retail chains are increasingly using it in their stores.

One Estonian brewery is utilising the waste heat generated during the drying of the air of the finished products warehouse. Air is removed from the finished product warehouse, it is cooled to condense the moisture and the dry air is returned to the warehouse. The heat generated during the operation of the refrigeration compressor is recovered to raise the temperature of that air.

In the dairy industry, the waste heat generated in the process has been utilised either to heat the building, ventilation air, water or another process. Heat is transferred with both heat exchangers and heat pumps. The dairy industry needs to cool the processed milk and products. Refrigeration equipment is used to produce ice water. Waste heat from refrigeration equipment can be e.g. recovered.

Options for the use of waste heat and cold in the heating and/or cooling sectors
and the assessment of the efficient district heating and cooling potential in Estonia
ANNEX 3

In Estonia, the waste heat of glass tempering furnaces is still largely unused. During tempering, glass is heated and cooled. The capacity of the engines of the air fans are ca. 300 kW. Natural gas is used to heat glass. All of this energy is eventually contained in the cooling air of the glass, which is channelled to the atmosphere.

1.5.1 Utilisation of waste heat from the printing industry

The temperature of offset printing machines may reach up to 55 °C. In order for the colour pigments to crystallise, it is necessary to cool the printing rollers with water. Infrared dryers are also used, accounting for 40 % of the device's electricity consumption.[23]

Of the printing houses in Estonia, AS Kroonpress located in Tartu has utilised the channelling of waste heat to the network. The waste heat from the industry is transferred to the district heating network via a plate heat exchanger.

1.5.2 Utilisation of waste heat from the metal industry

In a company producing metal parts, whole metal parts are treated with heat. The heating is done with an inductor and the energy source used is electricity. To prevent the inductor from overheating, it is cooled with water. The maximum temperature of the water passing through the inductor is 40 °C. The circulating water is cooled and the heat is stored in storage tanks. The stored heat is used for heating rooms.

The industry applies measures with a payback period not exceeding 5 years, but more often 3 years. In order for companies to be interested in investing, support mechanisms are likely necessary to bring the payback period to the level expected by the industry. In the case of new industries, the development of waste heat recovery is a lot cheaper than reconstructions in the industry. It is therefore advisable to consider whether it would be possible to provide investment support for obtaining waste heat utilisation equipment for new industries.

Table 1.2 shows that Estonia ranks 9th from the bottom among the listed countries in terms of the industrial waste heat ratio to total energy used by industries, which stands at 11.9 %. This means that we should be able to recover 11.9 % of the energy used by industries as waste heat. The used industrial waste heat ratio to energy used in the whole country is 2.5 %. Lithuania stands out positively from the other Baltic states.

---

[23] M. Blesl, A. Kessler. Energieeffizienz in der Industrie. Springer Vieweg, 2017.

Options for the use of waste heat and cold in the heating and/or cooling sectors
and the assessment of the efficient district heating and cooling potential in Estonia
ANNEX 3

Table 1.2. Ratio of industrial waste heat to energy used by industries and ratio of industrial waste heat use to energy used country by country[24]

	Industrial Waste Heat per Energy Consumed by the Industry (%)	Industrial Waste Heat per Energy Consumed by the Country (%)
Japan	1.0	0.4
Latvia	3.0	0.6
US	4.0–4.2	1.5
Sweden	5.5–18.4	2.0–6.7
UK	5.5–21.3	1.1–4.2
Slovenia	7.3	1.9
Korea	8.0	4.7
EU	9.1–22.2	2.3–5.6
Estonia	11.9	2.5
Denmark	12.9	2.0
Luxembourg	13.6	2.2
Norway	15.4	5.7
Ireland	16.3	2.6
Finland	16.9	7.4
Czech Republic	17.4	6.0
Germany	18.8–20.7	5.2–5.8
France	19.8–26.0	5.0–6.5
Austria	20.4	6.4
Bulgaria	21.0	6.0
Hungary	22.2	3.9
Spain	23.1	6.0
Poland	23.1	5.4
Portugal	23.4	7.0
Italy	24.2	6.0
Belgium	24.5	7.5
Romania	26.0	8.0
Netherlands	26.7	7.1
Slovak Republic	27.7	10.5
Greece	38.2	7.0
Turkey	46.9	17.4
Cyprus	47.8	5.0
Lithuania	55.7	10.4
Canada	71.0	26.4

---

[24] Laia Miró, Sarah Brückner, Luisa F. Cabeza. Mapping and discussing Industrial Waste Heat (IWH) potentials for different countries. Renewable and Sustainable Energy Reviews 51 (2015) 847-855. (Ingl k Industrial Waste Heat per Energy Consumed by the Industry and Industrial Waste Heat per Energy Consumed by the Industry ratios)

KPMG

These worksheets are a part of the analysis carried out on behalf of the Ministry of Economic Affairs and Communications 'Heitsoojuse- ja heitjahutuse kasutamise võimalused kütte- ja/või jahutussektoris ning Eesti tõhusa kaugkütte ja -jahutuse potentsiaali hindamine'

Colour codes

The relevant input data are highlighted with light orange colour in the spreadsheet (the relevant inputs must be adjusted when new updated data are created)

The relevant data that need emphasis or the results of calculations are highlighted with intensive orange colour in the spreadsheet

The relevant data created as a result of calculations are highlighted with light blue colour in the spreadsheet (updated automatically, do not change unless necessary)

Worksheet

● 'Eeldused ja sisendid' - reflects a) the macroeconomic indicators in use, such as inflation rate, b) sector-specific indicators, such as the discount rate used as the basis for NPV calculations and c) the inputs of NPV calculations of specific projects, e.g. The lifetime of the investment
● 'NPV Arvutus' - shows the NPV calculations for specific projects
● 'Elamumajanduse BaasStse' - shows the inputs and assumptions of the scenarios regarding the reconstruction of the existing building stock and the modernisation of heating systems systems
● 'Madalatemp. küttevõrk' - shows the inputs and assumptions of the low temperature heating network scenario
● 'Prognoos' - addresses the forecasts based on different sources up until 2050
● 'CO2' - concerns the direction to which the alternatives of the scenarios impact the CO2-eq of emissions
● 'Stsenaariumid'rt - shows the sector-specific generalisations based on the scenarios

Sectors covered in the Directive

(a) industrial waste heat and cold

(b) waste incineration

(c) high efficiency cogeneration

(d) renewable energy sources (such as geothermal, solar thermal and biomass) other than those used for high efficiency cogeneration

(e) heat pumps

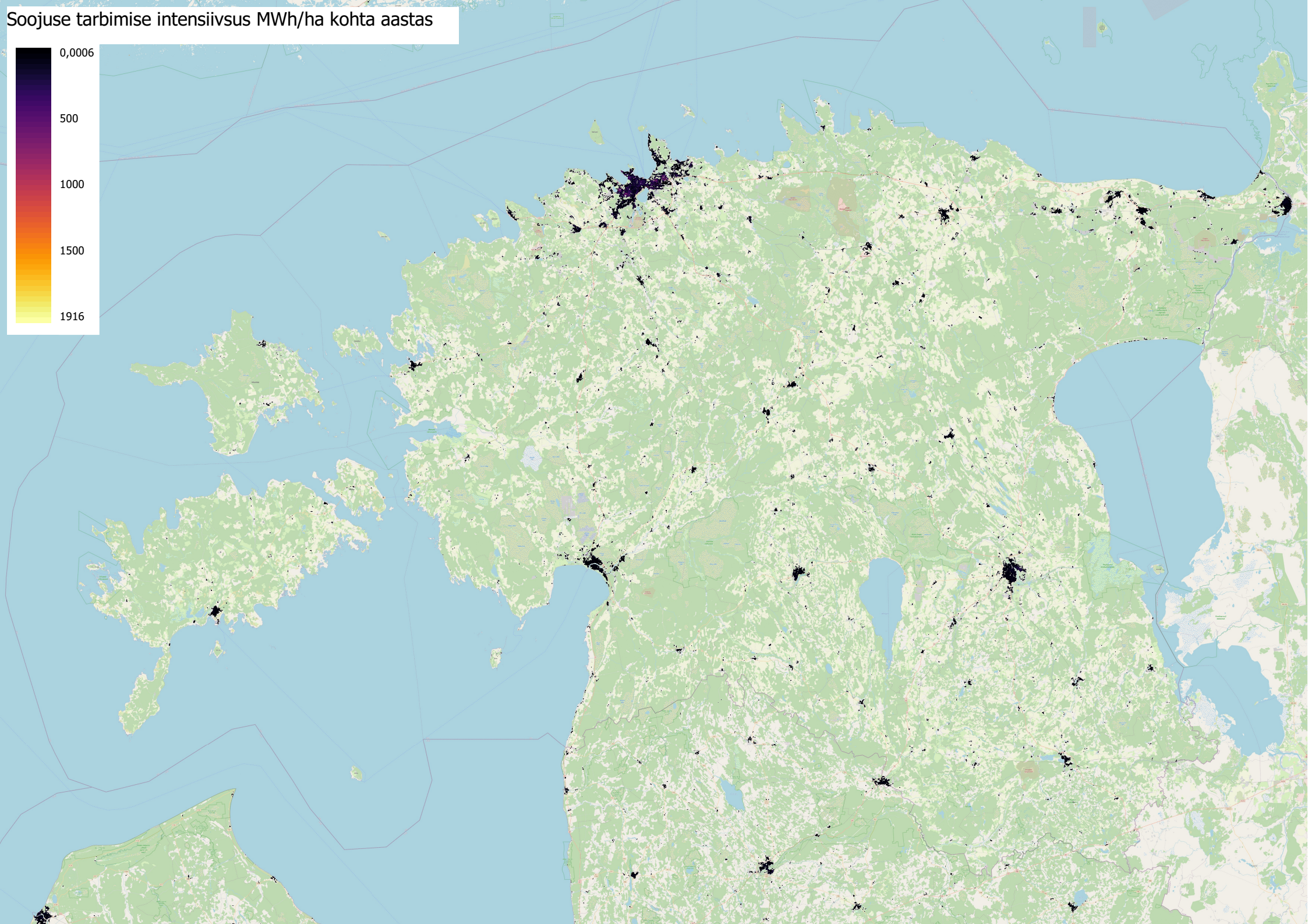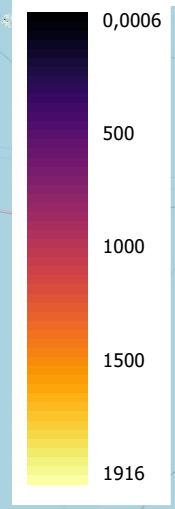(f) reducing heat and cold losses from existing district heating networks
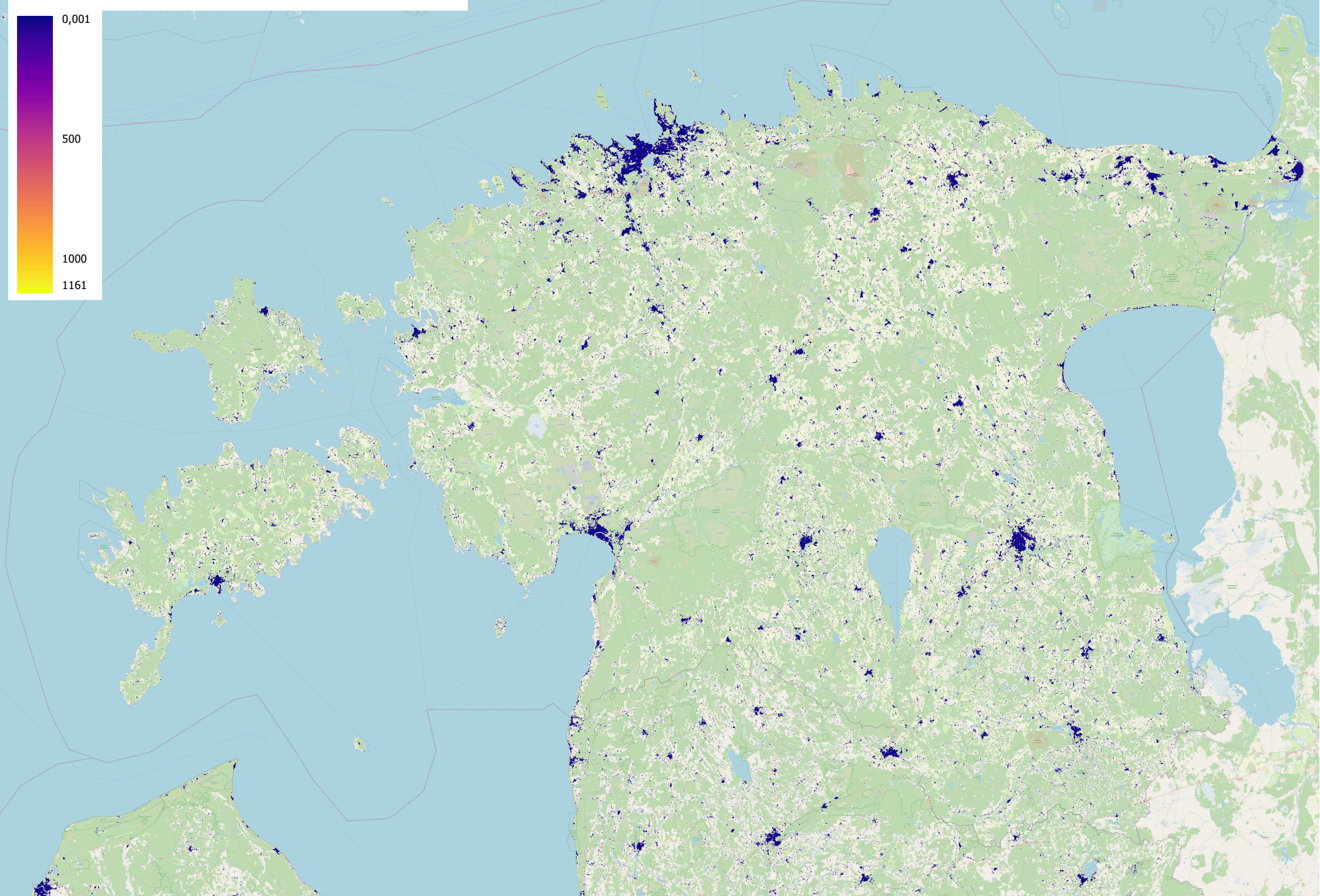
Soojuse tarbimise intensiivsus MWh/ha kohta aastas
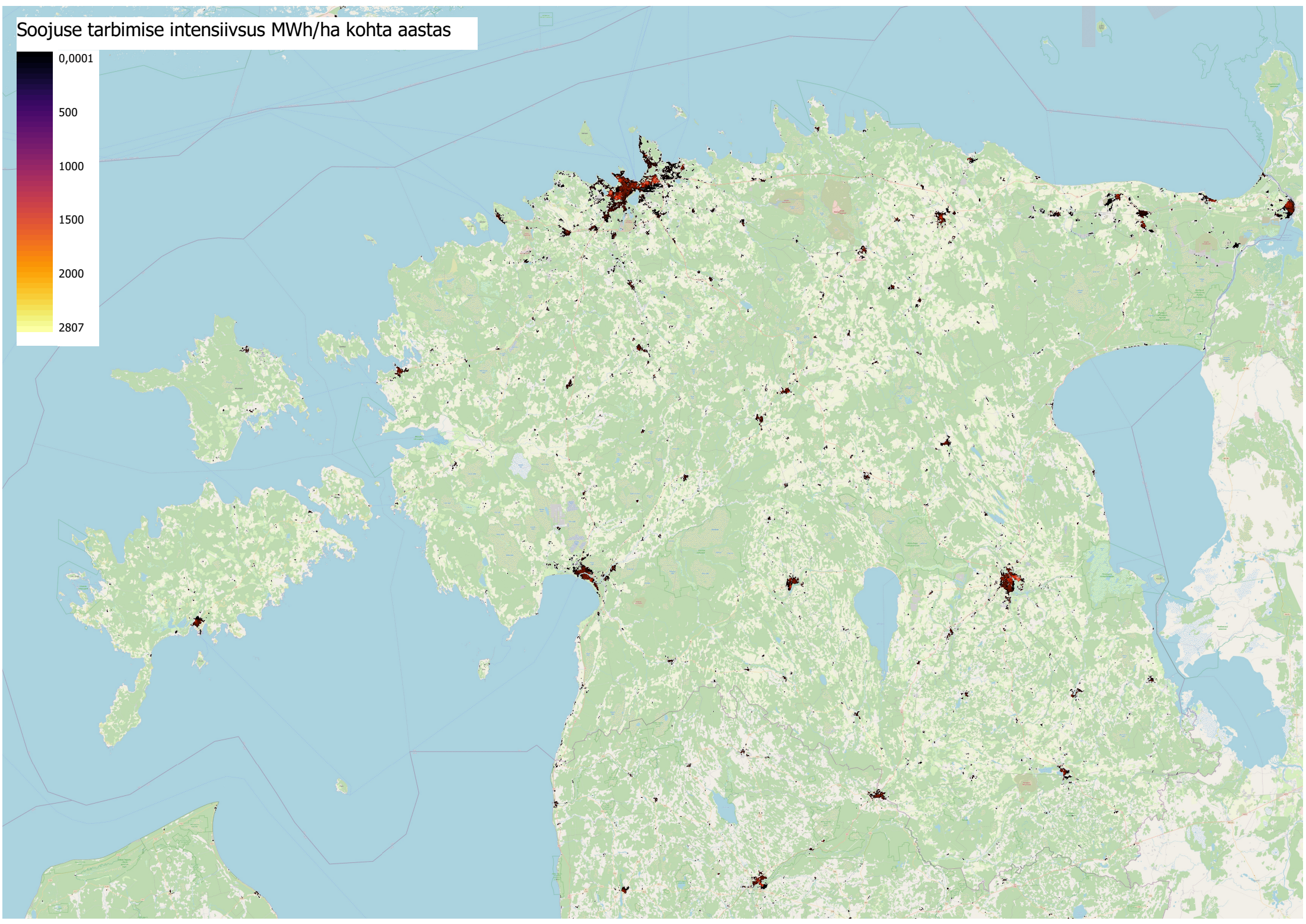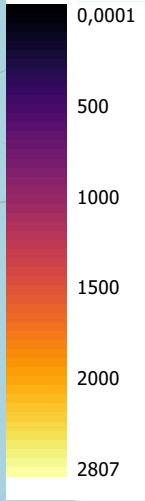
Soojuse tarbimise intensiivsus MWh/ha kohta aastas

Arvutuslik jahutusenergiavajadus MWh/ha kohta aastas

0,001
500
1000
1161

Hinnanguline heitsoojusallika
võimsus (MW)
(alumisel kihil elamusektori soojustarbimine)

- 0 - 16
- 16 - 80
- 80 - 200

AS Tallinna Vesi
Electroälr
AS ELVESO
AS Estonian Cell
VKG Energia OÜ
Fortum Eesti AS
AS ESRO
Saint-Gobain Glass Estonia SE; äriüksus SEKURIT
UPM Kymmene Otepää OÜ