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USE OF EXCESS HEAT FROM THE DATA CENTERS IN DISTRICT HEATING

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ABSTRACT

Excessive heat production from data centers can lead to energy efficiency improvements and reduce the costs of production and consumption. In the future, it is expected that waste heat recovery will become a trend, especially in countries such as Scandinavia.

The purpose of this thesis is to explain how this system works, collect various data and find out how effective it is from a practical and economic point of view. Another purpose of this work is to study and analyze the data and examine how effective and profitable this system is. It will be based on various scientific papers as well as numerous data from the Finnish energy industry.

The main result of this work is the proof that this system can seriously reduce emissions into the atmosphere, as well as reduce the cost of heat production.

In the conclusion of the work I have done, it can be seen that despite the many difficulties I have been able to achieve all the results, although there is still much room for improvement.

Keywords: district heating, data center, hvac, heat exchanger, excess heat usage

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1 INTRODUCTION

As technology and the modern world develop, the amount of information that needs to be stored somewhere increases in a direct proportion - which is why large companies are building large data centers in countries around the world. These data centres are rather energy demanding and require intensive cooling. This in turn produces a great deal of excess heat that must be cooled. Cooling equipment for server rooms by being included in the heating distribution system will allow to give off excess heat to heat residential buildings in cities and receive cold water which we are using for cooling air in data centres.

The main example of this system is the «Yandex» data centre in the city of Mäntsälä, Finland. In this city a reheating station was launched in 2018, which was built with funds from the MSOY energy sales company. After the facility's construction, a heat pump plant and equipment was installed, which allowed the recovery of a third of the data center's energy. In 2018, the facility's waste heat contributed to the total heat needs of the Mäntsälä municipality. The number of new data centers that will require electricity to operate in the Nordic countries will increase significantly by 2025. By utilizing the waste heat from these facilities, it could potentially reduce the country's fossil heat production by around 3.2 TWh and help cut down on emissions by around 1.1 MtCO2. [1]

Furthermore, it will help to use as less as possible natural resources for heat production in district heating systems, so it will have a positive effect on the environment and is also a very profitable solution from an economic point of view. I believe that the most modern solution is the conservation of the energy that we use and the creation of closed ring systems. Because they allow you to almost completely stop any emissions of processed resources, steam and water into the atmosphere.

This system uses absolutely all the principles that I study at the university. It uses ventilation, water supply and heating systems. Therefore, for me, the development of this thesis is the result of the knowledge gained in all sections of my profession.

2 AIMS AND METHODS

The aim of this thesis is to research the principles of combined heating and cooling systems in data centres and how we can use and combine it in district heating systems in towns as well as to understand how effective this system is, ss well as studying the data already available, measuring and analyzing the systems that are already in operation.

The first method which will be used is literature review. It is necessary to understand on what principles and laws this method of heat transfer is based. What devices and equipment are used in the system, how much excess heat is produced by the data center and how much of it can be recycled for district heating.

The second method is analysis of the data obtained. In this part of the thesis we will analyze and compare different data in order to clearly show the result and draw a conclusion.

The third method is the calculations about the benefits of data center heat recovery with heat pumps. Example calculations about district heating production cost are made (production cost €/MWh) with some assumptions. For the calculations the efficiency of the system (COP) and the average electricity price must be known. In this thesis, a graph showing costs €/MWh with a few different electricity prices and with many different COPs is presented.

The fourth method is the comparison. The results of our own calculations and data from various scientific literature will be compared and conclusions based on these data will be drawn.

3 THEORETICAL BACKGROUND

3.1 PRINCIPLES OF HEAT EXCHANGE

Understanding how heat exchange works will allow me to make informed decisions regarding the use of resources. The concept of heat exchange states that the body's heat loss is proportional to its gain when the cold body is exposed to it. The exchange of heat between the two objects will continue until a thermal equilibrium has been reached. [2]

The concept of energy conservation refers to the idea that the heat that the body produces is equal to the amount of energy that the cold body uses. When objects of opposing temperatures are kept in contact they absorb the temperature of the other object to reach an equilibrium (it is a state of balance among two opposite extremes). There will no more be an exchange if the objects are separated. [2]

The three types of heat transfer are convection, radiation, and conduction. Conduction is the process of transferring heat through solid materials. When it's hot outside, heat can enter buildings through their windows, roofs, and walls. Some ways to reduce heat transfer are by using insulation, energy-efficient windows, and heat reflective roofs. [2]

Convection, similar to that for liquids and gases, occurs when liquid molecules absorb heat. When hot air rises, it takes heat away from the walls and circulates inside the building. When a person feels or inhales this hot air, they begin to feel heat. [2]

The process of radiation involves transferring heat using electromagnetic waves. One of the easiest ways to reduce the heat transfer through windows is by blocking the radiation coming from the outside. This can be done through the use of low-emittance coatings. [2]

3.2 HEAT EXCHANGERS

A heat exchanger is a type of device that allows the transfer of heat from one type of liquid to another without the presence of either gas or liquids coming into contact with it. The principle of this type of device is that it does not transfer the heat from the fluid to the other. Figure 1 below illustrates the principle of operation of one type of heat exchanger. [3]

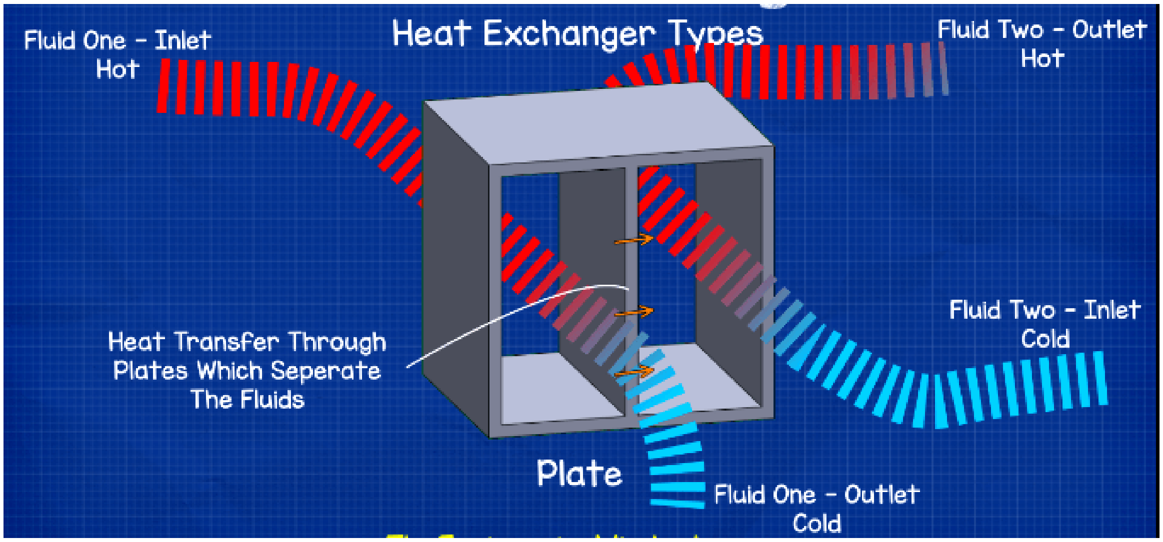


Figure 1. Basic plate heat exchanger [3]

Different types of heat exchangers are available depending on their design. Some of these include double pipe, shell and tube, plate, condensers, evaporators and boiler types. [3]

3.2.1 DUCT PLATE HEAT EXCHANGER

It is a component utilized in data center ventilation systems to exchange thermal energy with the air streams coming from the supply. It is made of thin aluminum sheets and has two fluids moving in opposite directions. Although air is usually used for both the flows, exhaust gases from CHP engines can be utilized. The heat from one stream flows through the metal sheets separating it and is forced into the other stream through convection. Figure 2 below shows us principles of work of duct plate heat exchanger. [3]

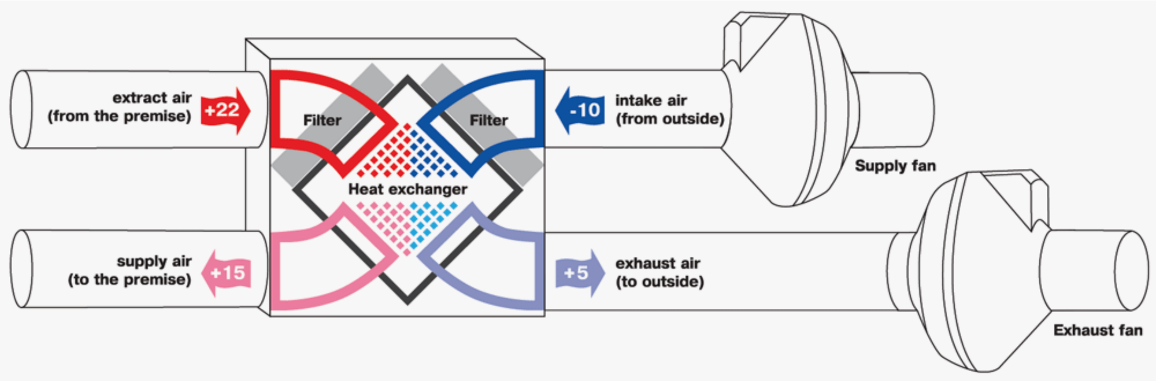


Figure 2. Duct plate heat exchanger [4]

3.2.2 ROTARY WHEEL HEAT EXCHANGER

These components are usually located in an air handling unit between the exhaust and supply ducts of a data center. They are powered by an electric motor and are designed to rotate a heat exchanger disc, which is located in the air flow between the fresh air intakes and the exhaust. Although the air passes through the disc, it is still in contact with the material. As the disc rotates, it releases heat energy into another air stream. [3]

The design of a heat exchanger allows little liquid to mix between the exhaust and intake air flow, which is a concern when used in areas that have strong fumes or strong odor. During the winter season, these units can be used to remove the heat from the building's exhaust. The heat is then transferred to the new air stream through the heat wheel. In the summer, these units can be utilized to remove the cold air coming from the exhaust of the building and use the collected air to cool the supply air. An example of the operation of this heat exchanger is shown in Figure 3. [3]

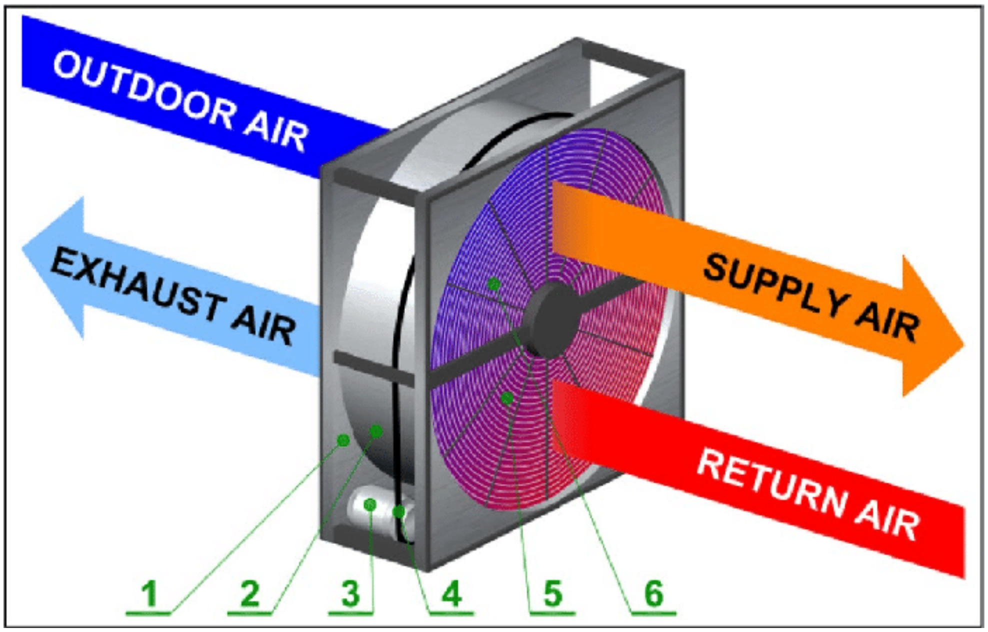


Figure 3. Rotary wheel heat exchanger [5]

3.2.3 TYPICAL PLATE HEAT EXCHANGER

Plate heat exchangers are generally categorized into two types: brazed and gasketed plates. These two works well at transferring heat, but they can also be used for other applications due to their compactness. [3]

One of the most important factors to keep in mind when it comes to the design and installation of heat exchangers is that they can be modified to increase or decrease their cooling or heating capacity by removing or adding plates. These are commonly used in commercial buildings to connect their cooling towers, chillers, and boiler systems to the district energy grid. [3]

A brazing plate heat exchanger is a sealed unit that can't be dismantled. It's mainly utilized in various applications, such as heat pumps and combination boilers. [3]

The units utilize the movement of fluids in adjoining ducts in the opposite direction. The heat is then transferred to the plate and then passes through the fluid before it can be carried away. An example of the operation of this heat exchanger is shown in Figure 4. [3]

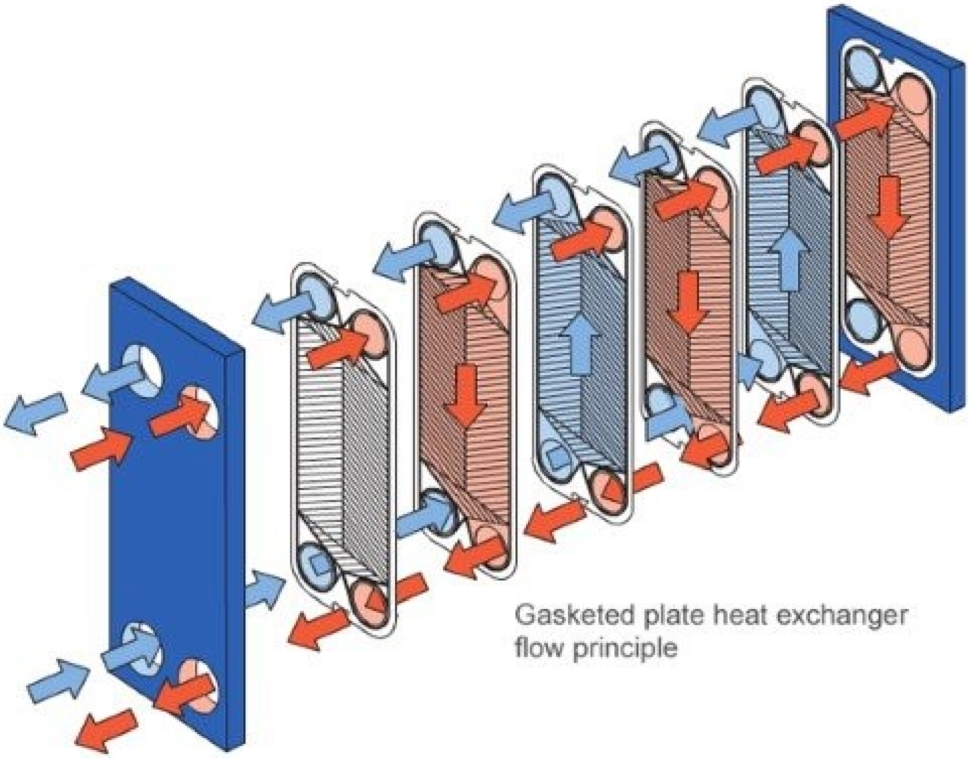


Figure 4. Plate heat exchanger [6]

3.3 DISTRICT HEATING

A district heating system is an engineering system that involves the generation of heat and the distribution of it through pipes to various facilities. A district heating system can provide hot water or space heating to residential and commercial buildings. This is a more cost-effective and environmentally-friendly alternative to the electricity generated by each building. This type of system commonly utilizes renewable energy sources to generate electricity for local businesses and neighborhoods. It can also capture waste heat. In Finland, district heating is a common form of heating. It is the largest producer of this type of heat supply in the Nordic countries. District heating is produced close to the consumers. [7]

3.3.1 REGULAR SYSTEM WITHOUT ALTERNATIVE HEAT SOURCES

Combined heat and power plants (CHPs) are systems that utilize both heat and power. In Finland, the main sources of fuel are wood, such as industrial wood residue and wood chips. Other sources include natural gas, coal, and peat. [8]

The district heating network delivers hot water to consumers through a plant that produces thermal energy. This energy is used to heat the water supply for domestic use and space/floor heating. [9]

Direct tap water heating can be used. Alternatively, a heat exchanger can circulate the heat to the interior part of the house. Once the supplied water is cold, the district heating plant returns the water to the supply. [9]

In a closed pipeline, district heating water can circulate for an indefinite period. Some systems utilize steam as their heating medium to achieve higher temperatures, which are required in certain industrial processes. However, this method has disadvantages, such as having higher heat losses. A graphic illustration of how this system works is shown in figure 5. [9]

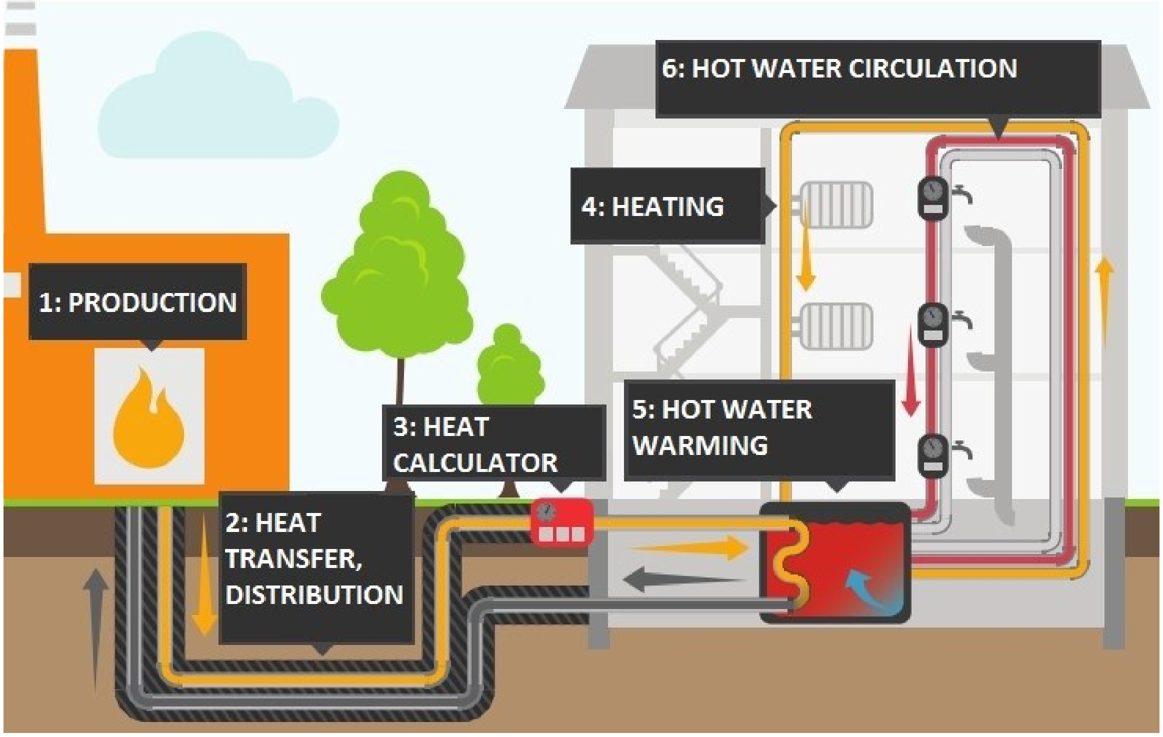
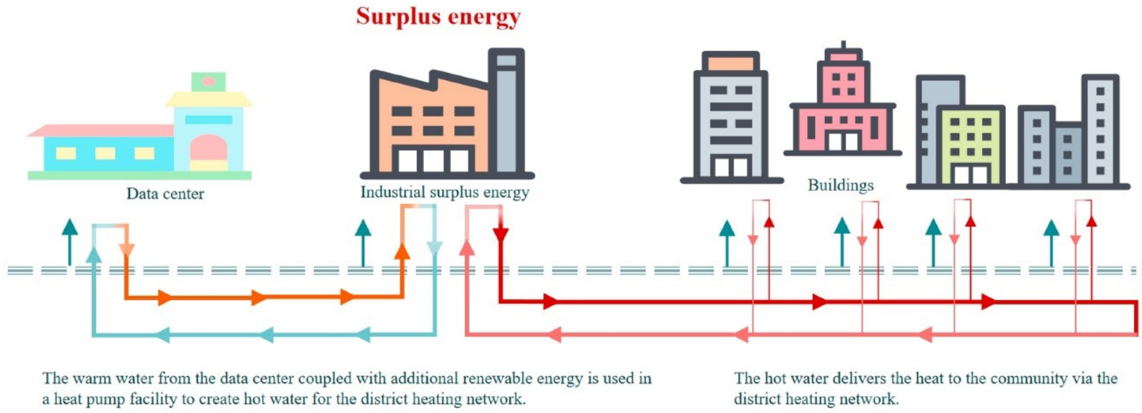


Figure 5. How district heating works. [10]

3.3.2 SYSTEM USING SUPPLEMENTARY HEAT

Data centers are one of the primary sources of heat, along with nuclear power plants, natural gas fired generators, solar thermal water, and air or geothermal-heated liquid. Those in urban areas can benefit from the clean and efficient heat that data centers provide. Data centers can also help lower their energy bills by selling surplus heat to the district heating network. This type of energy-saving practice can be beneficial for the local heating networks. Moreover, waste heat from plants can be utilized in industries that are heavily affected by heat. A graphic illustration of how this system works is shown in figure 6. [11]



The warm water from the data center coupled with additional renewable energy is used in a heat pump facility to create hot water for the district heating network.

The hot water delivers the heat to the community via the district heating network.

Figure 6. Example of system using supplementary heat [11]

3.4 HVAC SYSTEMS IN DATA CENTERS

A mechanical system that provides heating, ventilation, and air conditioning is known as an HVAC system. It is utilized in data centers to control the environment, such as temperature, humidity, and air filtration. Besides the equipment used in computing systems, other components of the data center include security systems, cables, storage systems, power, and fire protection.

Most physical devices come with certain environmental requirements that are designed to ensure that they meet the standards of their environment. These requirements can be described in a physical planning guide or in a specification document. A plenum is often used to allow air to circulate cables and other electrical equipment in a space between a raised floor and a structural ceiling. A graphic example of one possible HVAC system for data centers is illustrated in figure 7. [12]

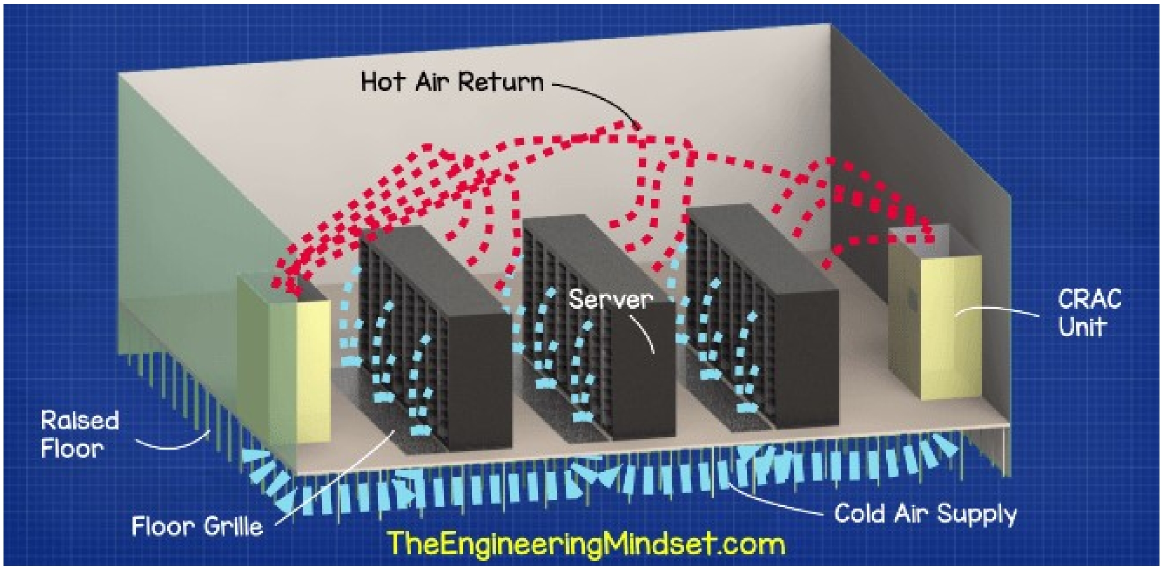


Figure 7. HVAC system in data center [13]

3.5 HEAT PUMP

A heat pump is a type of device that uses a refrigeration cycle to transfer heat energy from a cold space to a warm one. It can be used in combination with other devices to provide heating and cooling to a building. Some types of heat pumps are air source, ground source, and water source. [14]

Although heat pumps are commonly used in homes, they can also be used in commercial establishments. There are two main kinds of heat pumps that are used in homes: an air source and a ground source. An air source is used to heat the air inside a house, while a ground source usually provides the heat to water. [15]

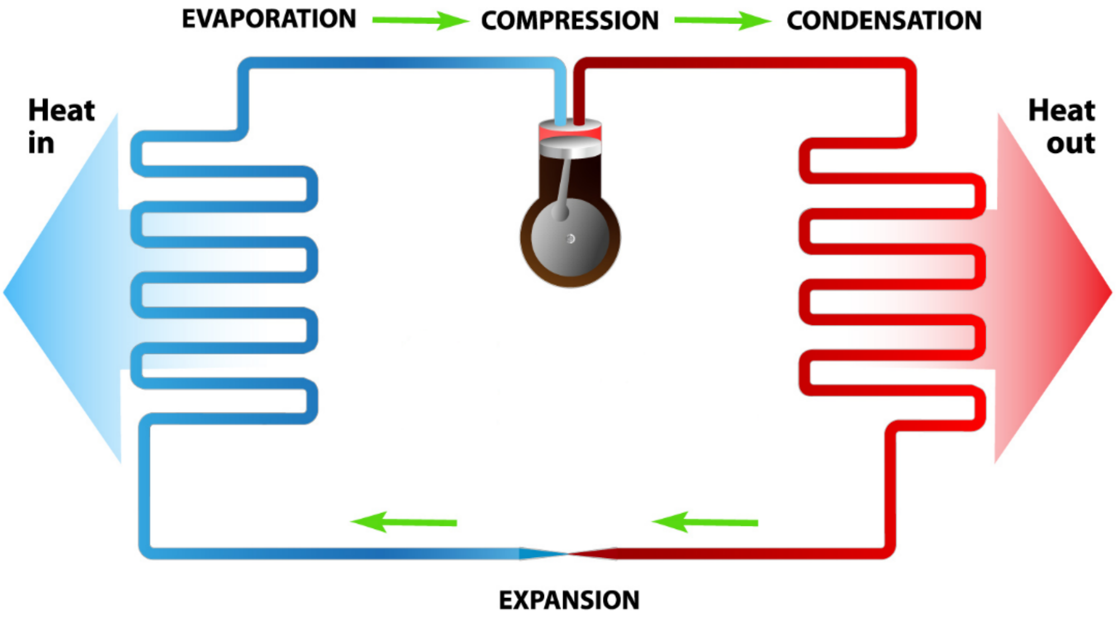


Figure 8. The basic principle of the heat pump [15]

An air-source heat pump can help cool or heat an indoor space even in extremely cold environments. Its efficiency depends on the room's temperature difference and the street's temperature. the higher the efficiency of this heat pump, the lowest efficiency indicator will be at a temperature of about 0 degrees Celsius In addition, this type of heat pump can be used to cool water.There are two basic types:

Air to air heat pumps, uses the air from the outside to heat a room, then moves it through the house's fan system. An example of this system we can see in figure 9.

Air to water heat pumps, converts the air from the outside into water that's used to heat the radiators or other similar equipment.

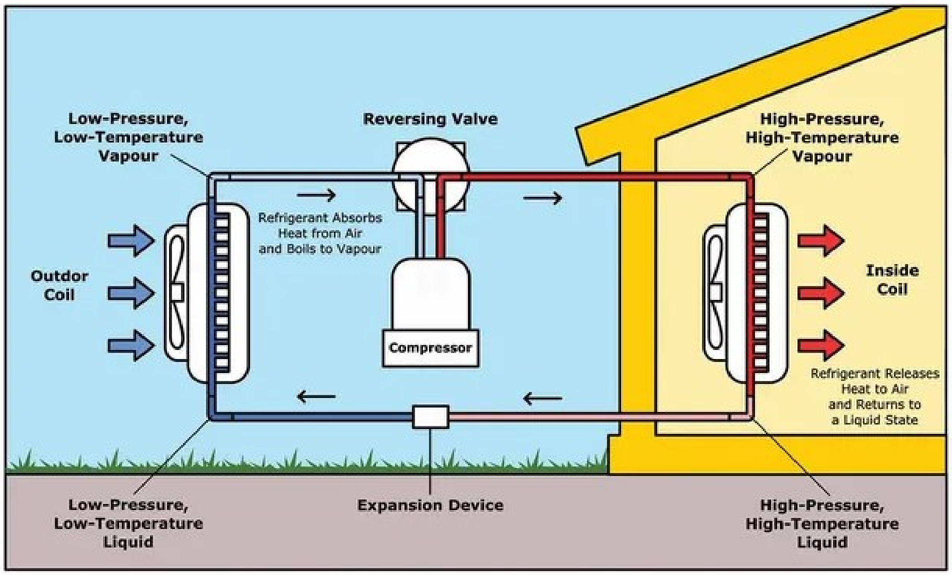


Figure 9. Air source heat pump [14]

A ground-source heat pump works differently. It draws heat from the ground through pipes that are filled with water and antifreeze. This mixture then goes through a cycle of refrigeration before it is transferred to another brazed plate exchanger. This process then transfers the heat to a hot water tank. A graphic illustration of this type of heat pump is shown in figure 10. [16]

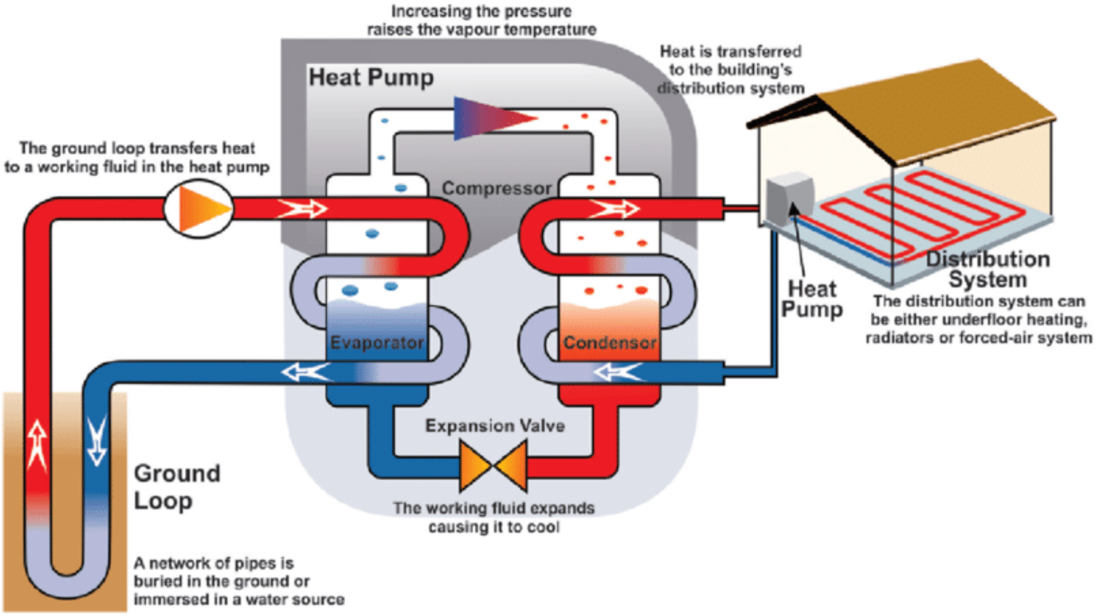


Figure 10. Ground source heat pump [16]

3.6 REFRIGERANTS

The thermodynamic properties of certain chemical compounds are responsible for the performance of certain refrigeration processes. They play a crucial role in the design and selection of new or improved refrigeration systems, and their impact on the environment and operational efficiency is also acknowledged. [17]

R134a, R404a/R407a or R410A refrigerants are now widely used in the industrial refrigeration and heat pump market. These HFCs have zero ODP, non-flammability, very low toxicity, non-corrosivity and good thermodynamic properties, but there is a problem - their high GWP. [17]

4 EXPLANATION OF THE SYSTEM

This section of the thesis explains the basic requirements of this system, as well as parts of the excess heat utilization system, their types and principle of operation.

Based on Fig.11, it is possible to simplify the basic principle of this system. The data center consists of server equipment (computers), they consume electricity and emit heat it is necessary to remove, because overheating of this equipment causes its failure. The easiest way to remove the heated air is to extract it outdoors, but because of this a huge amount of energy is lost and as a consequence, money, and the emissions of carbon dioxide into the atmosphere increase as well.

Therefore, the way of reuse of this heat was invented, and now it will be considered. In this example the ventilation is an indirect cooling system, the exhaust and heated air enters the heat exchanger where it transfers heat and energy to the refrigerant, which subsequently enters the heat pump, where it is heated to the required heating network temperature, this happens because the heat pump has a COP of around 4-7. After heating in the heat pump, it gets water with a temperature of about +85 degrees, which is then used in the district heating system. After that the waste water returns back to this system and continues to participate in the process. Thus, it was possible to create a closed system, in which the leakage of heat and carbon dioxide is practically zero. An illustration is shown in figure 11.

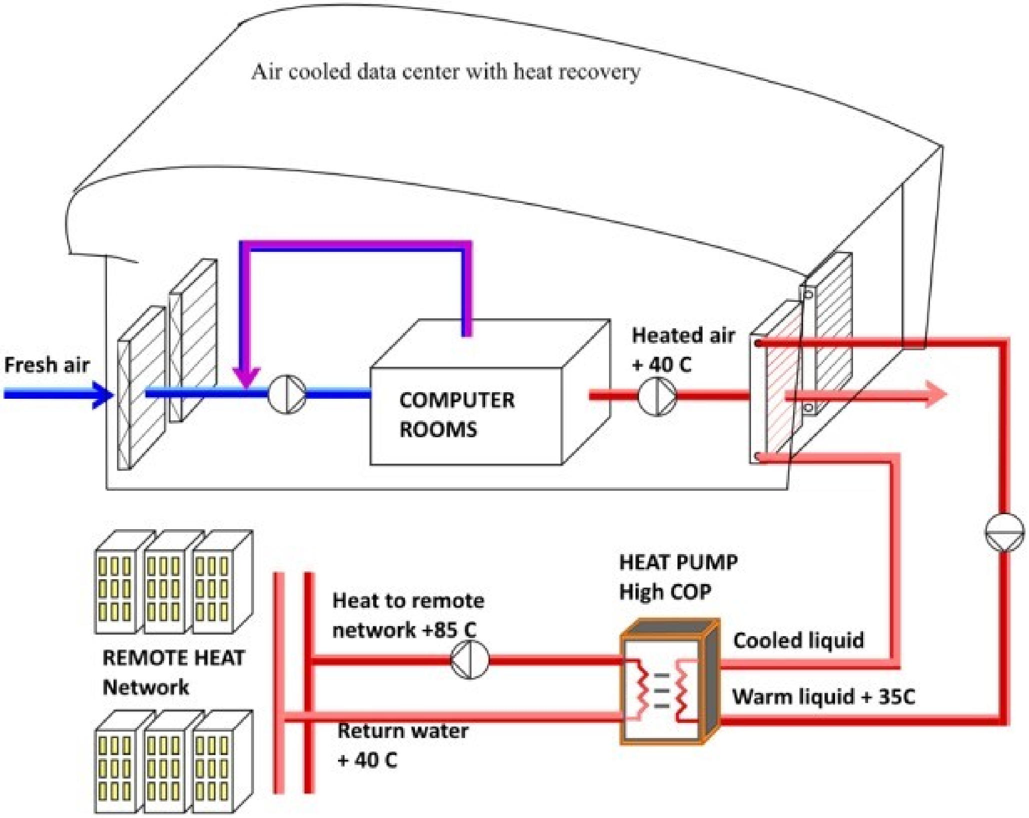


Figure 11. Data center connected with district heating network [18]

4.1 GEOGRAPHICAL LOCATION

The geographic location of the data center is important because it sets the parameters and prerequisites for various factors, including cooling methods, heat recovery, energy distribution, and power. How much of the year free cooling can be used depends on the region and climate. During most of the year, another type of cooling is required that can be used for free, which can reduce the cost of cooling.

The ability to use excess heat is another issue that depends on the specific region. In addition to being used in commercial and industrial facilities, excess heat can also be used in district heating systems to provide additional heat to areas with a high demand for it. An advantage for many data centers may be the ability to work more closely with customers who use the services provided by a densely populated area.

The availability of power sources depends on the location of the data center. A high level of grid reliability is an advantage because it can reduce the need for a backup power system. It can reduce installation, purchase and maintenance costs.

4.2 COMMON SYSTEM CONNECTION ARCHITECTURE

A heat pump is a simple and effective way to integrate district heating with data centers, as shown in Fig 12. The heat pump takes in the low-grade heat that was collected from the data facility. It then passes this thermal energy to the district heating company's end users. [19]

The initial cost of this technique is relatively low, but it'll be important to keep in mind the waste heat must come from a consistent supply to the district heating network. Otherwise, the additional heat will be released. The connection’s performance rating can reach as high as 4.3 based on its efficiency. [19]

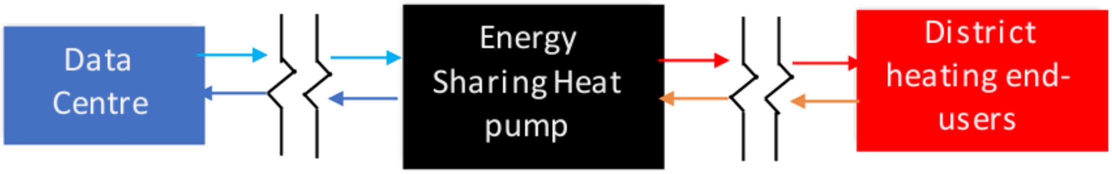


Figure 12. Energy exchange between systems [19]

4.2.1 COOLING SYSTEMS AND LOCATION OF WASTE HEAT RECOVERY IN DATA CENTERS

Once the electricity used by data centers has been converted into heat, it's necessary to remove the excess heat to ensure that the operating temperatures of their facilities stay below their recommended levels. The most common method for cooling data centers is through the use of air handlers. [20]

While the cooling units are situated within a room, they must be kept refrigerated so that the air can stay cool. The servers are placed in various configurations within the data center, and the air is conveyed to these rooms from a raised surface. The warmed air is then re-radiated through the hot aisle to the cooling units, which can save up to 40% of electricity usage. [21]
In order to cut down on energy consumption, data centers have started to implement more sustainable cooling methods. These techniques can help them save a huge amount of energy. These methods can help them save a huge amount of energy:

- Various containment techniques can be utilized to keep hot and cold air streams from colliding in an aisle. These include recirculation and bypass.
- In order to cool an area, fresh air can be utilized;
- Indirect and direct evaporative cooling can be used to cool incoming air.

This method involves utilizing water- and close-coupled air-cooling systems. Although electronic components remain air-cooled, the heat is then transferred to a cooling unit situated close to the racks, which eliminates the need to cool the entire building.

In direct liquid cooling, water, or dielectric fluids can be utilized. This method is commonly used to cool electronic components, such as processors and memory chips. It uses air to cool the lower-temperature components. In addition, it can be done completely immersing the entire server board in dielectric fluid. The two-phase and the one-phase systems are commonly used. New cooling systems are more energy-efficient and can reduce the operating costs of a facility. However, their various cooling techniques have varying temperature ratings. Figure 13 presents a summary of the four major cooling techniques. [22]

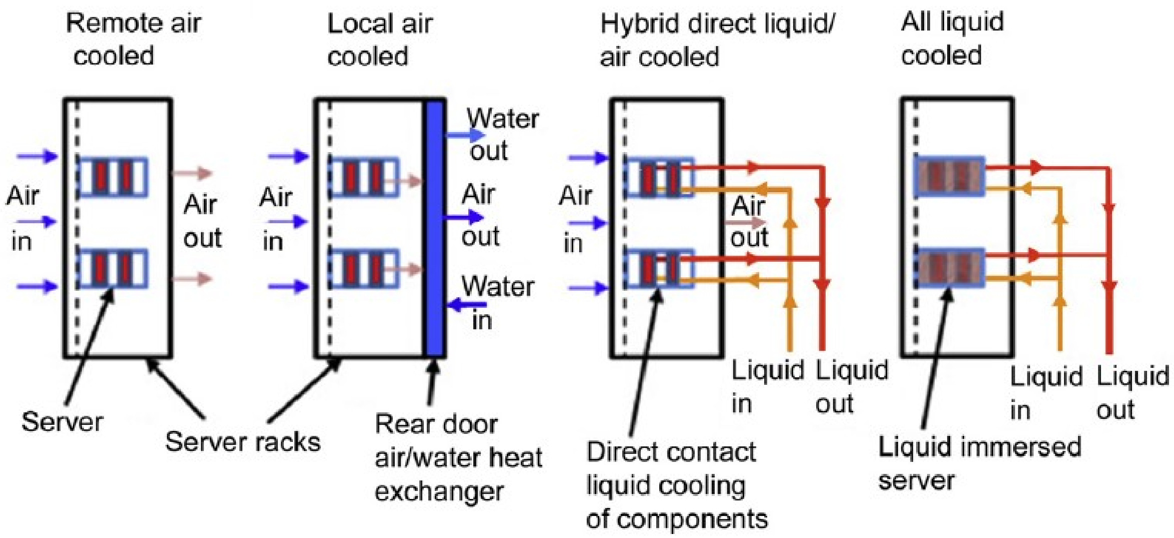


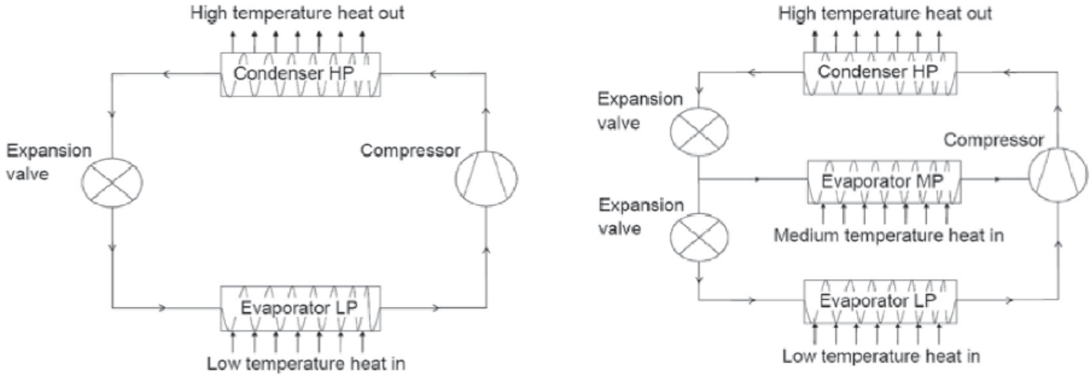
Figure 13. Data center cooling approaches [22]

4.3 USE OF HEAT PUMPS FOR UPGRADING WASTE HEAT

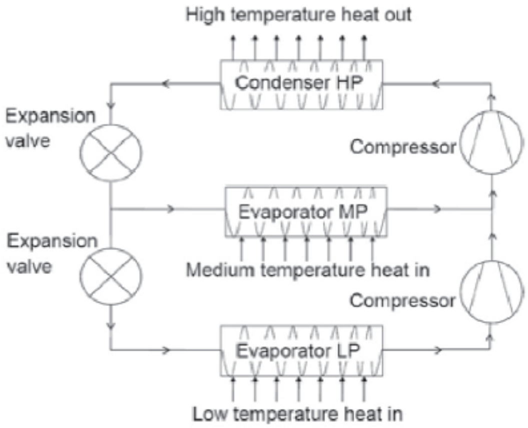
Heat pumps can convert low-grade heat into high-grade energy by utilizing a two-phased refrigerant. This process works by absorbing low-temperature heat and then vaporizing it. After it has been vaporized, the refrigerant is then heated and pressed to a higher temperature before it is transferred to a condenser. [22]

Following the expansion valve, the liquid refrigerant returns to the evaporator with a reduced pressure (and temperature). Various thermodynamic cycles can be utilized to achieve certain temperature increases or upgrades. These include those that involve several stages and multiple compressors.

For certain applications, the optimal cycle is dependent on the specific temperature and range of the elements involved. Also, the availability of additional heat in different streams at varying temperatures is crucial. In data centers, for instance, the cooling systems can allow the recovery of waste heat at varying temperatures. This allows for more efficient multistage cycles and also enables two or more evaporators to operate at different temperatures. A cycle that consists of multiple heat pumps can provide a substantial increase in efficiency. It can also upgrade the existing heat from the data center and deliver it to a specific application at a high ambient temperature. Examples of these can be seen in Figure 15. They can be used to upgrade the waste heat in data centers. Other configurations can also be utilized. [22]



(A) Single stage, single compressor cycle (B) Two stage, single compressor, two cycles



(C) Two stage, two compressor cycles

Figure 15. Potential thermodynamic cycles for upgrading data center waste heat [22]

A bore field system and a ground source heat pump are two components that can be integrated to address the issue of mismatched waste heat supply and demand in data centers. The connection between the two components can provide a total COP of up to 8.2 and heating output of 3.5. [23]

Adding a bore field can help improve the efficiency of the ground source heat pump and provide free cooling for data centers. The connection can reach a maximum COP of 40 in the cooling mode and 4.1 in the heating mode. But, due to the installation of two bore fields, the total capital investments of such system are quite high. An illustration of how this system works is shown in figure 16. [24]

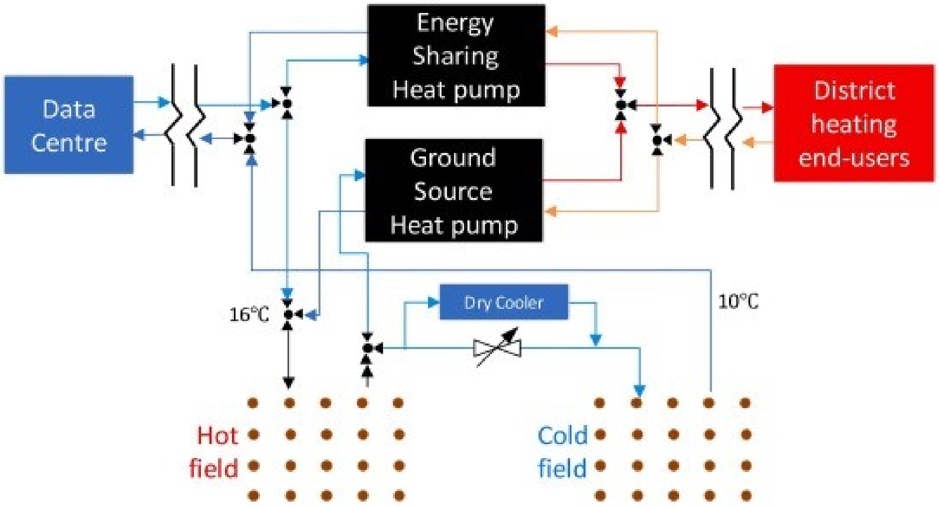


Figure 16. Ground source heat pump with a two bore field system [24]

5 COP AND PRODUCTION COST CALCULATIONS

5.1 PRICE DEPENDING ON COP

The relationship between the amount of power that's supplied to a compressor and the amount of power that's extracted from a heat pump is called COP. [25] The cost of a heat pump depends on various parameters, one of these is its coefficient of performance. Figure 17 shows the effect of this on the cost of production. In DCs, the average COP ranges from 3.0 to 6.3. [22]

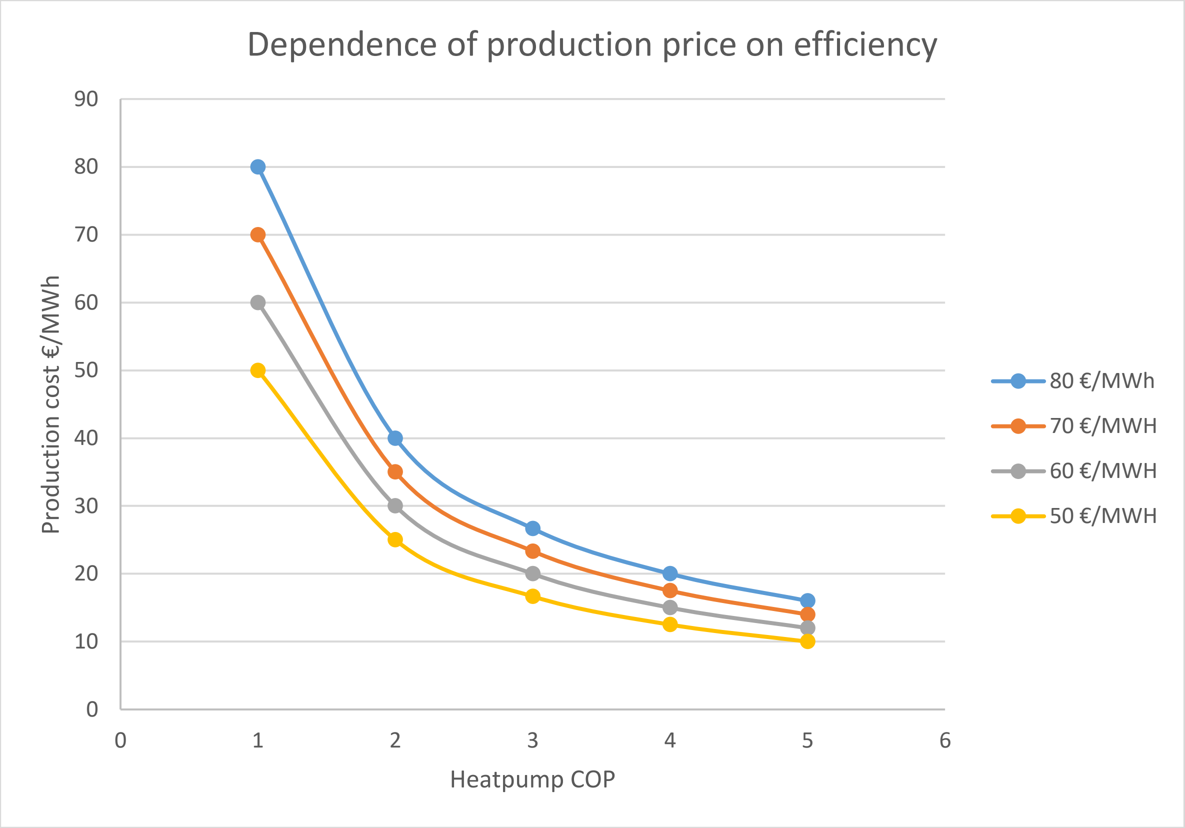


Figure 17. Dependence of production price on efficiency

5.2 PRICE AND COP DEPENDING ON THE TEMPERATURE

The COP is dependent on several parameters, one of the main ones being the required outlet temperature. The COP decreases when the desired temperature is increased as we can see in Figure 18.

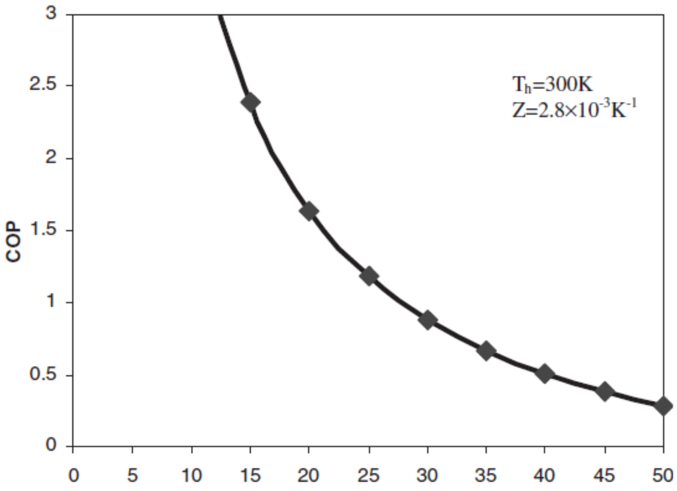


Figure 18. COP as a function of temperature difference across the module at hot side temperature [27]

When it comes to investing in a heat pump, one of the most important factors that you should consider is the long-term perspective of the project. This is because, in addition to increasing energy consumption, a heat pump also requires a large investment. If the equipment is not integrated into the district heating system, the operator will most likely make the investment.

Buying waste heat from an external source can be advantageous for the District Heating network operator. It can lower their production costs and lessen their reliance on peak load generation, which typically utilizes fossil fuels. In certain scenarios, utilizing waste heat can help replace the need to install new heat production capacity. However, in these instances, the reliability of the waste heat source is important. [26]

The price of district heating is currently $€_e$ = 83.91 €/MWh. The price includes electricity, transmission charges and taxes. The data for the price is based on the average electricity price for January-May 2020 from the electricity price statistics of Energia Finland. [28]

The price paid for energy supplied to the district heating network varies dynamically in the calculation model depending on the outdoor temperature on the upstream side between 50 and 10 €/MWh for the consumer side and between 25 and 5 €/MWh for the producer side, as shown in Figure 19. It is also assumed that the prices for energy that will be supplied to the district heating network will be similar to those for the market.

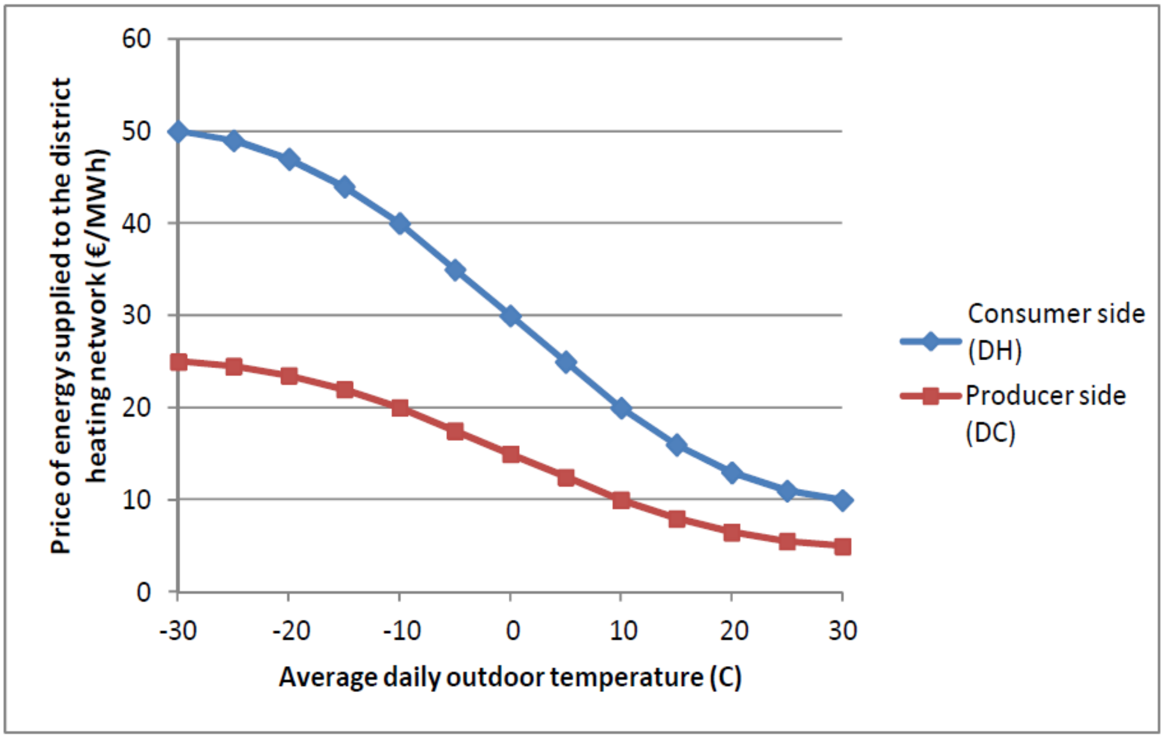


Figure 19. Price of energy supplied to the district heating network in relation to the daily outdoor average temperature [26]

The price of district heat supplied to the supply side is formed by the energy company from the estimated monthly consumption of district heat in the metropolitan area and the Helsinki 2012 set tariff. The price of energy supplied to the return side is estimated by the energy company at 50% of the price of energy supplied to the supply side, due to the need to prioritize return energy. Thus, the model provides the monthly average and annual average as shown in the Table 1 and Figure 20. The full year average is 27 €/MWh. [26]

Table 1. The cost of heat relative to the month. [26]

Month	**Supply side (DH) (€/MWh)**	**Return side (DC) (€/MWh)**
January	40.2	20.1
February	40.4	20.2
March	38.6	19.3
April	27.0	13.5
May	19.2	9.6
June	16.0	8.0
July	13.8	7.0
August	14.6	7.3
September	19.2	9.6
October	24.0	12.0
November	32.8	16.4
December	38.0	19.0
Whole year	**27.0**	**13.5**

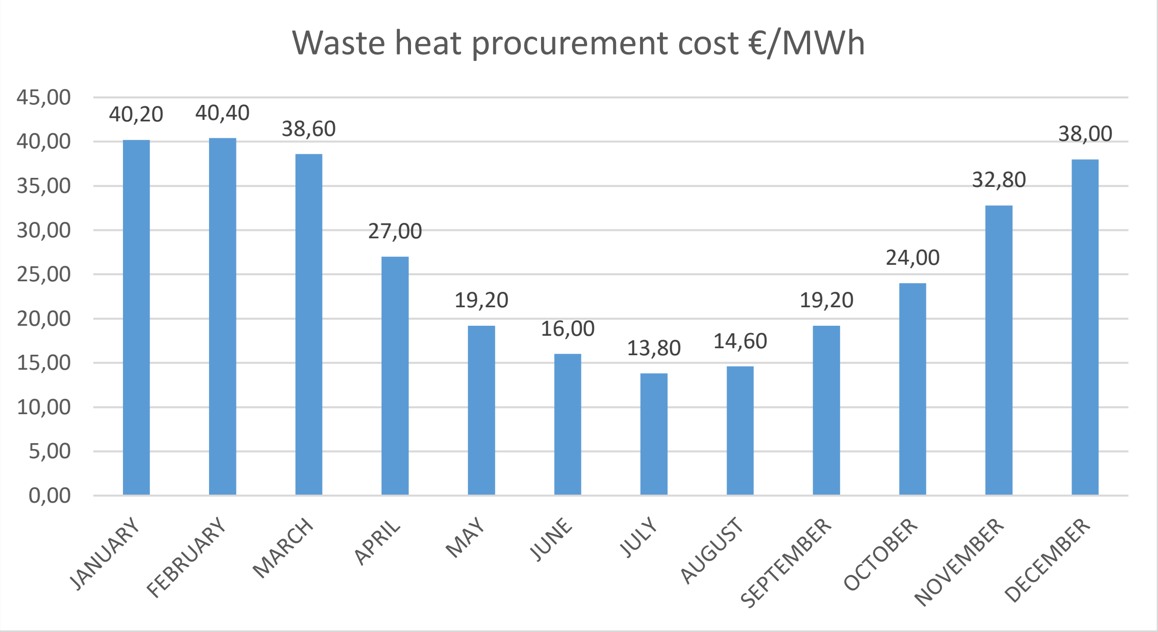
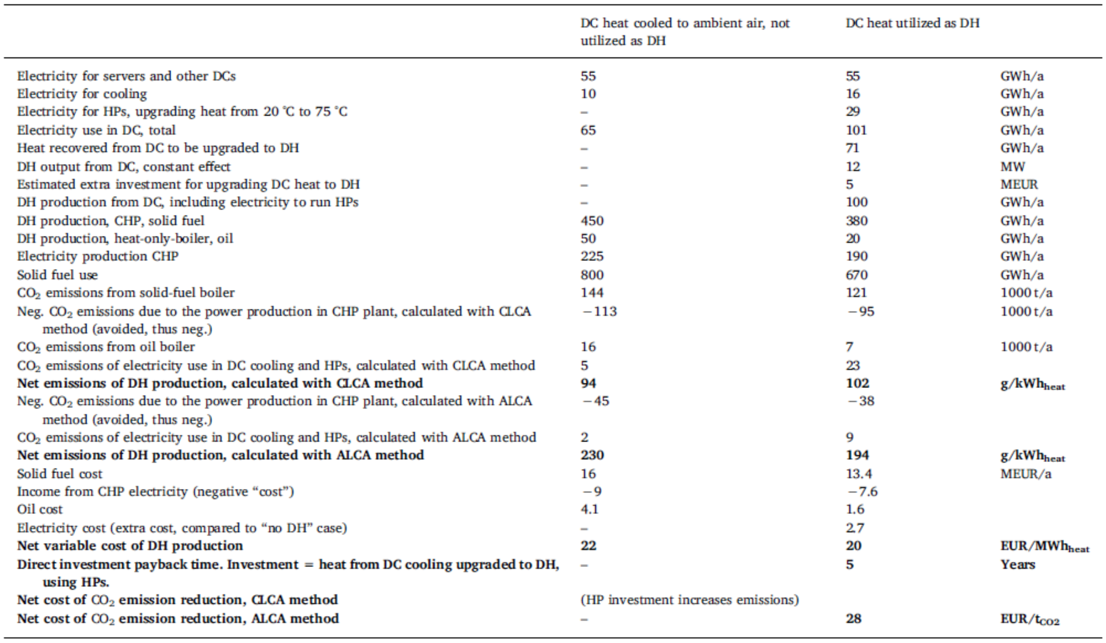


Figure 20. Table 1 in a graph.

6 ECONOMIC AND EMISSION EVALUATION OF WASTE HEAT

In this section electricity consumption, heat production, and CO2 emissions in the atmosphere with one simple example listed in Table 2 will be discussed. Although this estimate is only a rough guide, the results may differ due to the varying factors such as the district heating system's properties, the plant portfolio, and the climate.

Table 2. Economic and emission evaluation [29]



	DC heat cooled to ambient air, not utilized as DH	DC heat utilized as DH	
Electricity for servers and other DCs	55	55	GWh/a
Electricity for cooling	10	16	GWh/a
Electricity for HPs, upgrading heat from 20 °C to 75 °C	–	29	GWh/a
Electricity use in DC, total	65	101	GWh/a
Heat recovered from DC to be upgraded to DH	–	71	GWh/a
DH output from DC, constant effect	–	12	MW
Estimated extra investment for upgrading DC heat to DH	–	5	MEUR
DH production from DC, including electricity to run HPs	–	100	GWh/a
DH production, CHP, solid fuel	450	380	GWh/a
DH production, heat-only-boiler, oil	50	20	GWh/a
Electricity production CHP	225	190	GWh/a
Solid fuel use	800	670	GWh/a
CO_2 emissions from solid-fuel boiler	144	121	1000 t/a
Neg. CO_2 emissions due to the power production in CHP plant, calculated with CLCA method (avoided, thus neg.)	−113	−95	1000 t/a
CO_2 emissions from oil boiler	16	7	1000 t/a
CO_2 emissions of electricity use in DC cooling and HPs, calculated with CLCA method	5	23	
Net emissions of DH production, calculated with CLCA method	**94**	**102**	**g/kWh$_{heat}$**
Neg. CO_2 emissions due to the power production in CHP plant, calculated with ALCA method (avoided, thus neg.)	−45	−38	
CO_2 emissions of electricity use in DC cooling and HPs, calculated with ALCA method	2	9	
Net emissions of DH production, calculated with ALCA method	**230**	**194**	**g/kWh$_{heat}$**
Solid fuel cost	16	13.4	MEUR/a
Income from CHP electricity (negative "cost")	−9	−7.6	
Oil cost	4.1	1.6	
Electricity cost (extra cost, compared to "no DH" case)	–	2.7	
Net variable cost of DH production	**22**	**20**	**EUR/MWh$_{heat}$**
Direct investment payback time. Investment = heat from DC cooling upgraded to DH, using HPs.	–	**5**	**Years**
Net cost of CO_2 emission reduction, CLCA method	(HP investment increases emissions)		
Net cost of CO_2 emission reduction, ALCA method	–	**28**	**EUR/t$_{CO2}$**

In this table we can clearly see how the use of a heat recovery system in district heating systems reduces the amount of emissions into the atmosphere from 230 g/kWh$_{heat}$ to 194 g/kWh$_{heat}$. Also the price of heat production decreases from 22 EUR/MWh$_{heat}$ to 20 EUR/MWh$_{heat}$, which in the long run makes it possible to greatly reduce the cost of heat both for the producer and for the consumer. The long-term use and investment in these systems can seriously reduce the amount of excessive heat emissions into the atmosphere and CO2 emissions, as well as reduce the cost of electricity.

7 CONCLUSION

I can say with confidence that I was able to achieve all of my goals in this thesis. I managed to explain the essence, purpose, principle of work and benefit of using this system in a simple language with the help of the tools I have. I believe that my thesis can be a very useful document for all kinds of readers and researchers who would like to understand and study how systems of using excess heat for central heating work, as well as how systems of energy reuse work in general and on what physical laws such projects are based, what equipment they already use.

In my thesis I faced many difficulties. Starting with the fact that I had to search for all the literature myself, because at the time of writing this work there were not so many ready-made scientific projects on these topics from which I could learn. Therefore, the main difficulty was to find the necessary information among the vast amount of information, it took me many days, but I think I was able to cope with it.

But I cannot say that I was completely satisfied with this work, there are a few things that I had to leave out due to various factors. At the beginning of writing this work I had a goal to get on a tour to a company in Finland, where they use such installations in practice, but unfortunately for many reasons I have not been able to, and it could be a very important and extremely interesting part of my thesis. I am very sorry that I was not able to get acquainted with this system in practice. I hope that in the future I will be able to do it.

I would also like to summarize briefly the work done. Nowadays, it is becoming very important to use energy as efficiently as possible. Natural resources are not infinite and we cannot afford to waste them. That is why systems such as the one described in this thesis are being invented and become more popular every day. This system has a considerable number of possibilities and prospects for the future. Most of the aspects and devices can be improved while increasing the efficiency of the entire system. There are also many variations of this system, depending on the country in which it is located, the climate or the country as a whole. In this thesis work I have studied the basic principles of the system of using excess heat from data centers. I have studied some varieties of this system and possibilities to improve it. It was found how profitable the existence of such a system is, how much it costs to produce and sell this heat, and on what factors it all depends.

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