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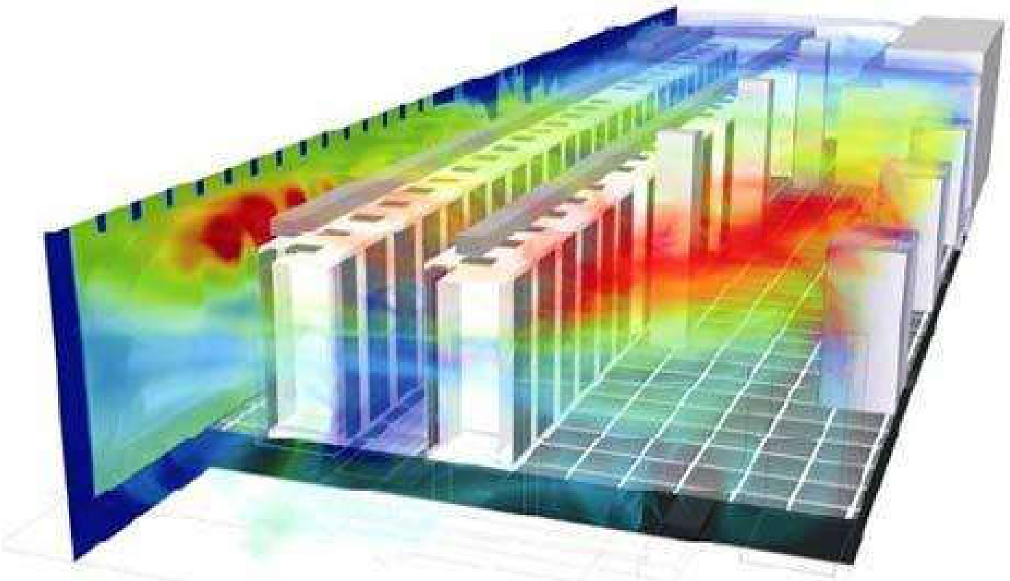
Energy and Environmental Technology

Utilization of excess heat from data centers



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Summary:

The rapid growth of technology and digitization lead to an increase in the number of data centers around the world. Data center facilities enable an organization to collect its resources and infrastructure for data processing, storage, and communication. In the meanwhile, the advancement of IT and telecommunications play an important role in the expansion of data centers. The main input energy of data center is electric power and because of facilities in a data center which are IT equipments, a large amount of heat is generated in the data center and the main energy output from the data center is heat. This work is about the utilization of excess heat which is produced in the data center and used for district heating. Typically, the quality of temperature heat from the data center is low and a heat pump might be necessary to improve the quality of heat by increasing the temperature. This work evaluates three alternatives heat pumps to improve the quality of heat and compare them to each other and with the case without a heat pump. Then, the payback period and economic potential for all conditions are evaluated.

Aspen HYSYS is used for simulation and economic optimization of this work. The first case is without heat pumps and three alternatives with heat pumps. Cooling water temperature from the data center is 45°C (in all conditions) and after using heat pumps the temperature increase to 60°C, 70°C, and 80°C respectively for the district heating network while in the first case without a heat pump the water 45°C is used for district heating network. The coefficient of performance (COP) of the heat pump for three alternatives is calculated and R-22 is used as the refrigerant in heat pumps in the simulation program, Aspen HYSYS.

In economic estimation, two methods are used. In the first one, the electricity cost is specified at 0.107 EUR/kWh in the winter season and 0.05 EUR/kWh in the summer season, and the district heat price is specified to 0.05 EUR/kWh during the year. In the second method the electricity price is assumed fixed and specified at 0.107 EUR/kWh. The investment cost for using heat pumps is specified at 0.7 MEUR/MW and since the Rjukan data center is 7 MW, the investment cost is 4.9 MEUR.

The payback period is calculated for three alternative heat pumps by two methods of economic estimation and there are 2.6, 2.9, 3.5 years and 3.1, 3.8, 5.3 years according to COP 5.45, 4.282 and 3.455 respectively. It is observed that the payback period increases by decreasing COP or increasing the temperature of the district heating network.

The economical potential of three alternative heat pumps and without heat pumps is calculated for 10 and 20 years with a discount rate of 0.7. The recovered waste heat of the Rjukan data center is calculated 60 GWh/year. It is observed that by increasing the temperature of district heating or decreasing COP, the economical potential is decreased and vice versa. Finally, the first method of economic calculation gives better economical potential.

Preface

I would like to express my profound gratitude to Prof. Lars Erik Øi for his continuous guidance, support, and, valuable direction throughout the thesis work. His door was always open for me and answers my question about the thesis. The professor always motivated me to handle my thesis. Also, I would like to appreciate the guidance of Mohammad Sharafdin during my master thesis.

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Vahid Zangeneh

Contents

Nomenclature

Abbreviations	Explanations
ICT	Information and Communication Technology
DC	Date Center
DH	District Heating
CRAC	Computer Room Air Conditioning
CRAH	Computer Room Air Handeler
ORC	Organic Rankine Cycle
ASHRAE	American Society of Heating, Refrigerating and Air conditioning Engineer
MED	Multiple Effect Distillation
CPU	Center Processing Unit
COP	Coefficient of Performance
HVAC	Heating Ventilation Air Condition
CFC’s	ChloroFluorohydroCarbons
EIA	Energy Information Agency
TEC	Thermoelectric Technology
ASHRAE	American Society of Heating, Refrigerating, and Air Conditioning Engineers
EPA	Environmental Protection Agency

1 Introduction

With the development of information in the technology these days, the need for using data centers has steadily increased which has led to an increase the electricity consumption. On a global scale, the data center electricity demand has risen from about 1.3% of the world's electricity use in 2010 to 2% in 2018 and is expected to keep growing to reach up to 13% in 2030. Due to its high energy consumption, the data center industry emits about as much CO_2 as the airline industry [1, 2]. Moreover, the demand for data processing will be increased day to day which means the consumption of higher energy and higher CO_2 emission into the environment and consequently global warming as well as the electricity consumed in a DC almost completely converts to heat. According to the reports of the US environmental protection agency (EPA), around 2% of the CO_2 is produced by information and communication technology (ICT) [3].

Date centers produce a considerable amount of heat because of their servers and a large number of electric components. There is a direct relationship between the amount of generated heat and the number of racks in the server room. Therefore, data centers need to have cooling systems and they should work full time (24 h a day, 7 days a week) throughout the year. The energy consumption of the cooling systems accounts for around 30-40% of the total energy consumption [4, 5]. In the meanwhile, the cold climate in Nordic countries is extremely suitable for DCs, by providing the much-needed cooling energy while there is a high demand for heat in these countries. Therefore, utilization of excess heat in DCs such as district heating (DH) plays an important role in energy efficiency.

All heat generated by the data centers can be used as a potential source of heating. Reusing the waste heat can improve the energy performance index of the data centers and is also useful from both economic and environmental points of view. The efficiency of an energy system and its processes can be increased using heat recovery. One of the existing methods for waste heat recovery is to use a heat pump which is explained in detail in the next parts.

1.1 Data centers (DC)

A data center is a place to keep information and communication technology (ICT) which includes components such as servers, switches, and storage facilities, and to control environmental conditions such as temperature, humidity, and dust to ensure that ICT systems operate in a reliable and safe mood. According to the scale of business, a data center might include a few or many racks and cabinets [5, 6]. In the rack, power distribution units, switches, rack-level air or liquid cooling and in some cases, the management units are placed. An alternative method of server arrangement with greater compactness and functionality can be provided features server blades housed in self-contained enclosures called chassis. Each chassis has its own power supply, fans, backplane interconnect, and management infrastructure. In figure 1.1, the physical organization of the data center is shown [7].

Figure 1.1: Physical organization of data centre [7]

1.2 Primary definitions

✓ Rack

A rack is a standardized metal frame or enclosure for inserting ICT components horizontally. A standards rack has a dimension of 78 inch height, 23-25 inch width, and 26-30 inch depth [5, 7].

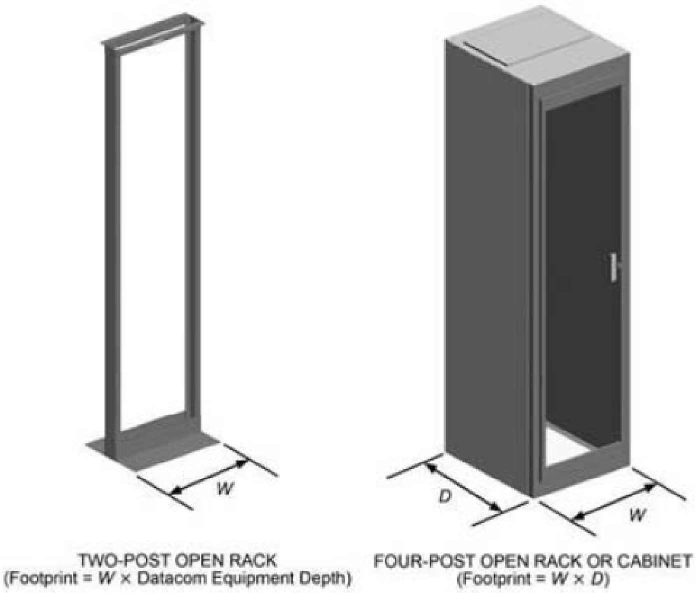

Figure 1.2: Typical rack and cabinet [8]

✓ Row and U

The standard racks are arranged in row at a pitch of approximately 2 m. the height and thickness of the components mounted in a rack is described by a unit of measurement which is called "U". The size of U is around 1.8 in and most of the servers have 1 U thickness. However, some of the servers have a thickness larger than 2U. A typical rack can take 42 1U [5, 8].

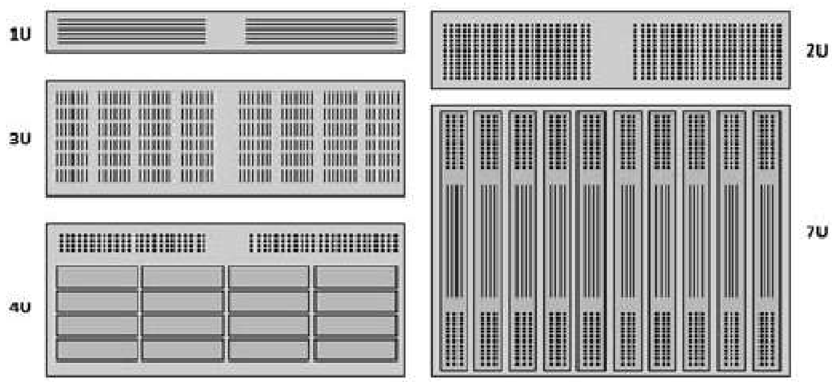

Figure 1.3: Typical computer servers packaging factor [8]

1.3 Thermal loads and temperature limits in Data Center

The increasing demand for information and communication technology services from one side and the direct proportionality between data center costs and area from the other side, has led manufacturers to design and produce more compact and higher power modules. In the traditional data centers the energy dissipation is in the range of 430-861 W/m^2 while in energy dissipation in the recent generation of them has been increased dramatically to 6458-10764 W/M^2 [9]. Moreover, by comparing this range with the conventional heating ventilation Air condition systems for a similar size of rooms (40-86 W/m^2) [5], the thermal management systems must be regarded as an important issue so that maintain the temperature of electronic components at a safe operational level. Therefore, for designing such systems having reliable and accurate thermal load and temperature limit in each component of a data center are necessary. Also, this information is essential for waste heat recovery. This information is shown as an example in table 1.1, table 1.2, and table 1.3 [5].

Table 1.1: Heat load and physical size of microprocessors/cores in some literature [5]

investigator	Microprocessor				Core		
	size	Heat load (W)	Heat flux (W/cm^2)	Number of core	size	Heat flux (W/cm^2)	Heat load (W)
Patel (2003) [10]	20×20 mm	100-125	NA	1	5×5 mm	200	50
Marcinichen et al. (20012) [11]	NA	150	100	2	NA	NA	NA
Campbell and Tuma [12]	NA	150	NA	2	0.51 cm^2	NA	NA

Table 1.2: Typical data center load limits [5]

Power load	
Component	values
Processor	65-75 W each (2 per server)
DIMM	6 W each
Auxiliary power per server	150-250 W
Total power per server	300-400 W
Rack capacity	1 U servers, up to 42 per rack Blade server at 10 U, up to 64 per rack
Total rack power	13-26 kW
Racks per data center	250
Total power per data center	3.2-6.5 MW

Table 1.3: Typical data center temperature limits [5]

Temperature limits	
Component	Values (°C)
Processor	85
DIMM	85
Disk drive	45

1.4 Cooling systems in the data centres

Higher overall data center energy demands have led to significantly increased energy consumed in data center facilities, reaching up to 35 kW per rack compared to about 1 kW per rack in the 1980s. Therefore, having an efficient cooling system in the data center becomes a more and challenged task. While the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) recommends a cooling temperature range between 18°C and 27°C for air-cooled data centers, most publications consider temperatures at the processor level of up to 85°C as reasonable. This makes it clear that higher cooling temperatures for data centers would be possible if the heat transfer between the processors and the cooling unit was improved [2].

Moreover, due to electronic equipment operate in a safe and efficient condition, the temperature and humidity of the data center should be controlled by the computer room air conditioning unit (CRAC). This unit plays a significant role in constructing and operating data center. In the newly data center with high power density, the forced air cooling system will not be able to handle the thermal loads in new data centers. Therefore, thermal management systems are shifting from traditional air cooling to liquid or two phases of cooling [13].

1.4.1 Air-cooled systems

Most data centers use air cooling systems to remove the heat from their IT equipment via computer room air conditioners (CRACs). In the modern one, this method is divided into hot and cold aisles [13]. The front sides of server racks face to each other and the cold aisle provides the cooled air to each server. In the hot aisles where the rear sides of the racks exit hot exhaust each server. The chilled air produced by the computer room air conditioner unit which is shown in figure 1.4 is driven into the cold aisle and after cooling IT equipment the warm air goes to the hot aisle and it is captured and returned to the intake of the CRAC. This system of cooling in the data center is a design based on the rack’s maximum power dissipation and a typical temperature rise of 15 °C for the airflow passing through the high power density servers [5, 14].

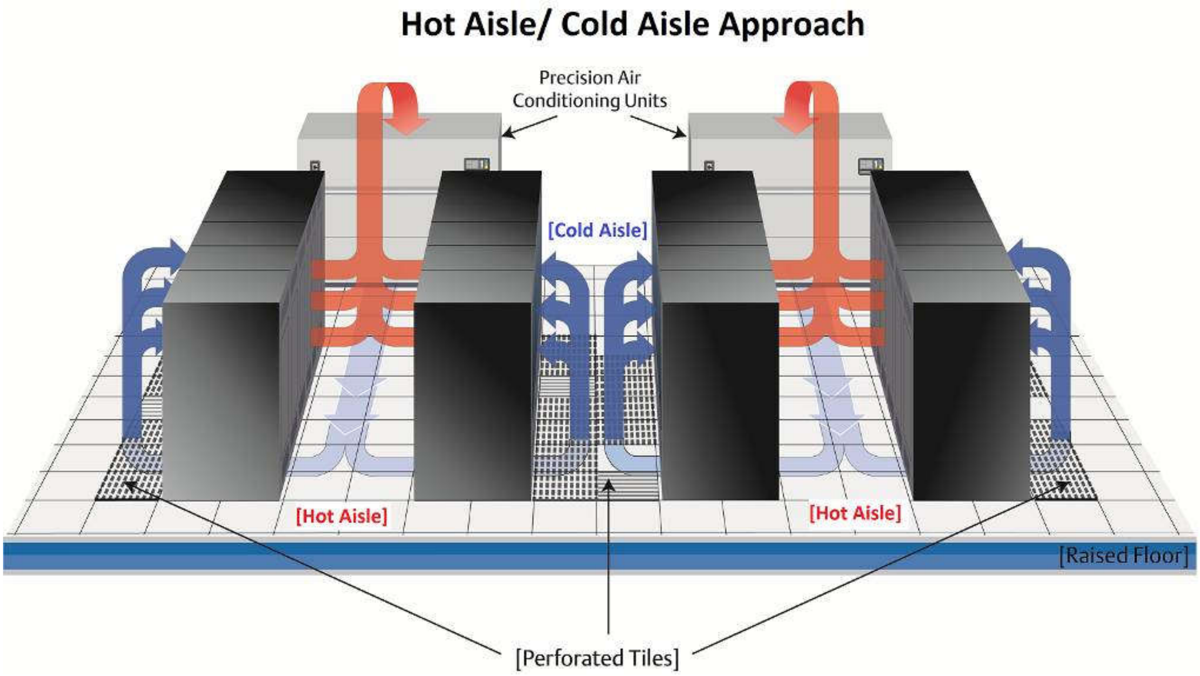

Figure 1.4: Hot and cold aisle configuration [14]

1.4.2 Water-cooled systems

By increasing the power load in the data centers CRACs cannot be enough for cooling. Therefore, due to cope with the increasing data center energy density, new cooling technologies such as water cooling will have become more important [5]. Water cooling has higher heat capacity and less thermal resistance than air cooling. Based on this benefit, water cooled data centres are able to deal with heat density at least 10 times higher than air-cooled. By using this technology, saving cooling energy demand is possible and at the same time, water cooling allows for high cooling inlet temperature of up 60 ℃ and provides new opportunities for waste heat utilization since the temperature of the outlet water is a key factor for such application [13].

1.4.3 Two-phased-cooled systems

In some data centers with high dissipation energy loads of more than 1000 W/m^2, two-phased cooling systems are essential. This cooling technology has been shown to remove heat flux in the range of 790W/cm2 up to 27000 W/m2 because of the advantages of the sharply increased convection heat transfer coefficient associated with nucleate boiling and using a micro-channel heat sink [5, 15].

1.4.4 Free cooling

In free cooling, the cooling capacity of ambient air, seawater or ground is done by chilled water to be used in cooling the Data center. If the temperature of ambient is too high free cooling is not possible and mechanical refrigeration should be added to the system due to produce more cooling energy. Free cooling is very common in Nordic DCs because the outside temperature is suitable for most of the year and makes it possible to direct free cooling of the server room which presents in figure 1.5 [16, 17].

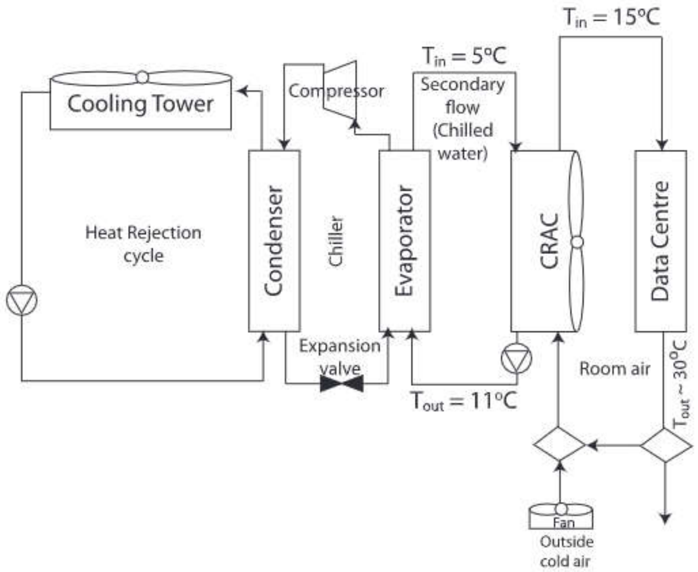

Figure 1.5: Schema of a direct air free cooling system for a data centre [17]

1.5 Room, row, and rack based cooling architectures

Every data center air conditioning has two key functions. Firstly, is to provide bulk cooling capacity and the second one is to distribute the air to the IT loads. The first function is the same for room row and rack architecture while the distribution of air to the loads is different in them. The 3 basic configurations are shown in figure 1.6. Black square boxes represent racks arranged in a row, and the blue arrows represent the computer room air handler (CRAH) units in the IT racks. It is shown that with room-based cooling, the CRAH units are associated with the room while in the row-based cooling the CRAH units are associated with rows or groups, and with rack-based cooling CRAH units are associated with the individual Rack [18].

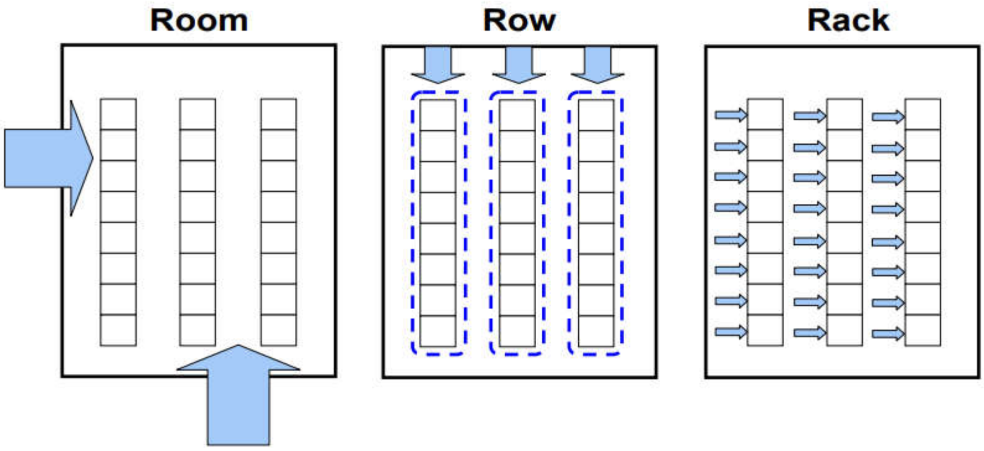

Figure 1.6: The basic concept of room, row and rack-based cooling [18]

✓ Room-based cooling

This cooling system is designed and implemented for data center and server rooms according to the structure of the room and ceiling height to balance the ambient air temperature by combining hot and cold air. This type is heavily affected by constraints of the room. Such as the ceiling height, the room shape, obstruction above and under floor, rack, CRAH location and distribution of IT loads. Therefore, the performance of this type is poor, particularly when the power density is increased. In figure 1.7 a traditional contained room-based cooling is shown [18].

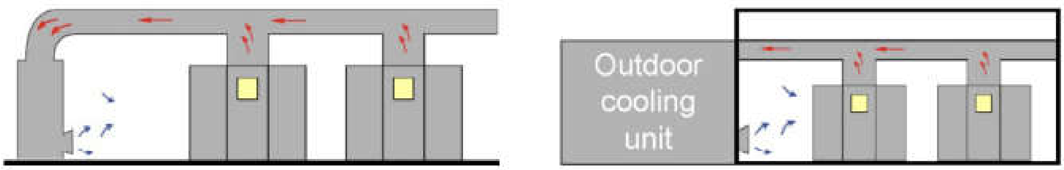

Figure 1.7: Next generation contained room-based cooling [18]

✓ Row-based cooling

In this type of cooling system, racks at the top and bottom of the false floor or in the row between, where more capacity racks are run in one row and fewer capacity racks in the other row. Row-based configuration has many benefits such as reduction CRAH fan power because of reduction of airflow path length, increasing the efficiency. In figures 1.7a and 1.7 b to the type of this configuration is shown.

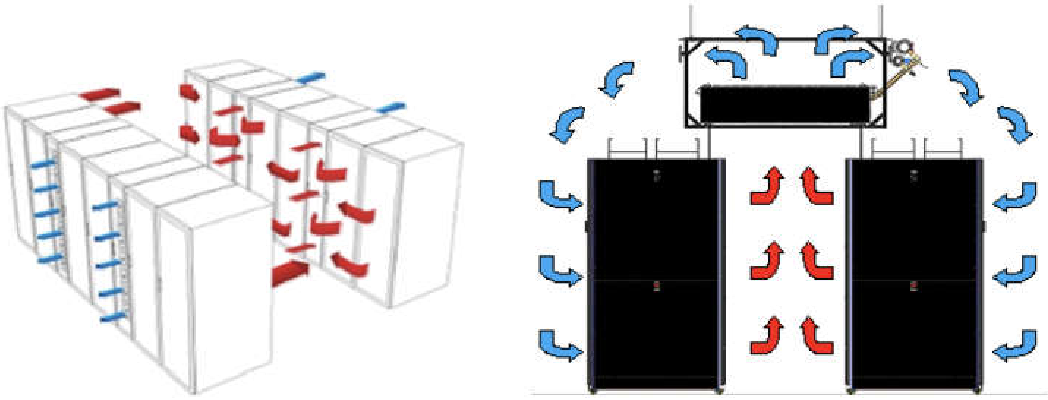

Figure 1.7: Floor-mounted and overhead row-based cooling (a is right side and b is left side) [18]

✓ Rack-based cooling

In this type of cooling system, the CRAH units are directly mounted to or within an IT racks. Airflow paths are even shorter compare to room-based and row-based cooling. Airflow is immune to any installation, variation or room constraints. Therefore, the capacity of CRAH can be utilized and the higher power density is achievable. An example of this configuration is shown in figure 1.8 [18].

Figure 1.8: Rack cooling system with cooling completely internal to rack [18]

1.6 District heating (DH)

The fundamental idea of district heating is to utilize local resources that would be wasted [19]. Suitable resources are waste incineration, geothermal energy, solar thermal energy, and waste heat. Waste heat plays a significant role in DH systems. Around 72% of the heat supply comes from waste heat in European countries [19]. Waste heat generates from an industrial process, heat and power plant, and large electricity users.

Waste heat from data centers is a promising heat resource especially in the Nordic Countries because for many reasons, such as most of the electricity is converted into waste heat and these countries because of cold weather need more heat. Also, data centers are reliable heat source and many DCs are built close to an existing DH network.

1.7 Objectives

The prime goal of this Master thesis is to utilize excess heat from data centers. Achieving the goal required five main objectives. They are as follows:

1- Literature search on cooling principles in computers. Of special interest is to find the maximum or optimum temperature on cooling air or cooling water.
2- Process description of cooling processes for a large data center. One case should be for traditional cooling technology, and another should be a case with a high outlet temperature.
3- Calculation of a material and energy balance of the cooling process for at least one large data center. Also, the calculation of the payback period and economic potential for specific energy recovery solutions.
4- Evaluations of possible ways to utilize waste heat from a data center. The possibility of district heating should be evaluated. Possibilities including heat pumps should also be evaluated
5- Simulations and economical optimization at different conditions in Aspen HYSYS.

2 Literature review

2.1 Literature review on energy recovery from data centers

All the heat generated by the data centers can be used as a potential source of heat up the office building and clients exit often near data centers. Reusing the waste heat improves the energy performance index in data center and is also useful economically and environmentally. There are a lot of studies on Data centers and waste heat. According to the review by Ebrahimi et al. [5]. there are different techniques for recycling waste heat for low temperatures. they suggested that a simple way to reuse low-quality energy is in HVAC or hot water production systems. The temperature of heat waste from air-cooled servers is around 35-45°C. This range is sufficient for reuse heating needs such as domestic heating [5]. Also, Energy Information Agency shows that 6% of total US energy usage is in terms of home heating [20]. Therefore, reusing data center waste heat for domestic heating can provide significant energy savings during the cold months. An estimated saving of between 280$ and 325$ per server per year was calculated when using data furnaces in the US domestic sector [21].

By using liquid cooling in data centers it is possible to provide a slightly higher quality of waste heat up to 50-60°C which can be used in district heating. Also, this heat provides an income for the data center. District heating is used in Europe more than in the US, particularly in Nordic countries. As an example, a 2 MW data center in Helsinki Finland provides enough water heated by waste heat for 500 homes or 1000 apartments [22]. Moreover, this waste heat can be used for preheating domestic hot water which can lead to energy saving and emission reduction by reducing the use of fossil fuels. Ebrahimi et al [5] say that the optimal location for installing a heat exchanger to extract waste heat of a legacy air-cooled data center and use it in district heating or hot water production is at the return of CRAC unit or at the chiller water return. They show that the temperature in this design is around 35°C which is appropriate for preheating hot water, space heating. When air side economization is used in cold weather sites, waste heat can be used to increase the temperature of the outside before entering the data center due to prevent freezing or moisture condensation. However, if a higher temperature is required for DH, there is necessary to use heat pumps due to the increase in the temperature of waste heat [5].

The cold loop heat exchanger is the easiest location to capture waste heat in water-cooled data center systems. The output temperature can be higher than in the range of 60-70 °C which is appropriate for district heating. Also, by two-phase cooling systems, the temperature is as high as 70-80 °C which is more than sufficient for any heating or hot water application [5].

The next heat recovery technique that Ebrahimi and at [5] investigated is the heating of water in the thermal Rankine cycle of a power plant. The waste heat from the data center is used to preheat boiler feed water which can reduce the consumption of fossil fuel and pollution. They show that it will be more beneficial if a two-phase data center cooling system is used because of higher temperature [5].

Mercinichen et al. [13] investigated waste heat of a data center for preheating the water in a coal-fired power plant. In this configuration, which shows in figure 2.1, the data center waste heat is added into the cycle after the condenser and before the feed water heater. Data center contains 100000 servers, and each server has dissipated heat 325 W. the power plant cycle is a 175 MW coal-fired plant and other information about the power plant is shown in figure 2.1. The investigation shows that by using waste heat the efficiency of the power plant is up to 2.2% under certain optimized conditions and this performance can lead to a huge saving in fuel cost and decrease carbon emission [13].

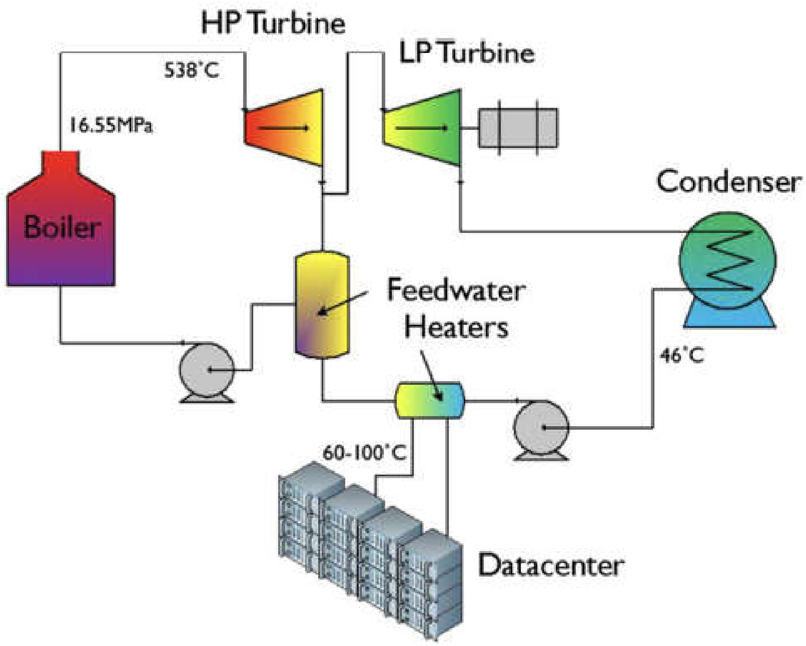

Figure 2.1: Data center integrated in power utility [13]

Absorption cooling cycle is another technology due to the use of waste heat in data center which is shown in figure 2.2 and investigated by Ebrahimi et al [5]. Since liquids have a much higher specific volume than vapours, the vapour compression system (compressor) is replaced with an absorption refrigeration system. Using absorption cooling utility not only reduces the power necessary to run the system but also has the benefit of using the data center waste heat as the absorption generator heat source which provides a significant economic benefit. The operating temperatures in the generator are between 70-90 °C which is consistent with available waste heat from water-cooled and two-phase cooled data center while this method is not suitable for air-cooled data centers and there may be a challenge about space issue when retrofitting systems to existing data centers [5].

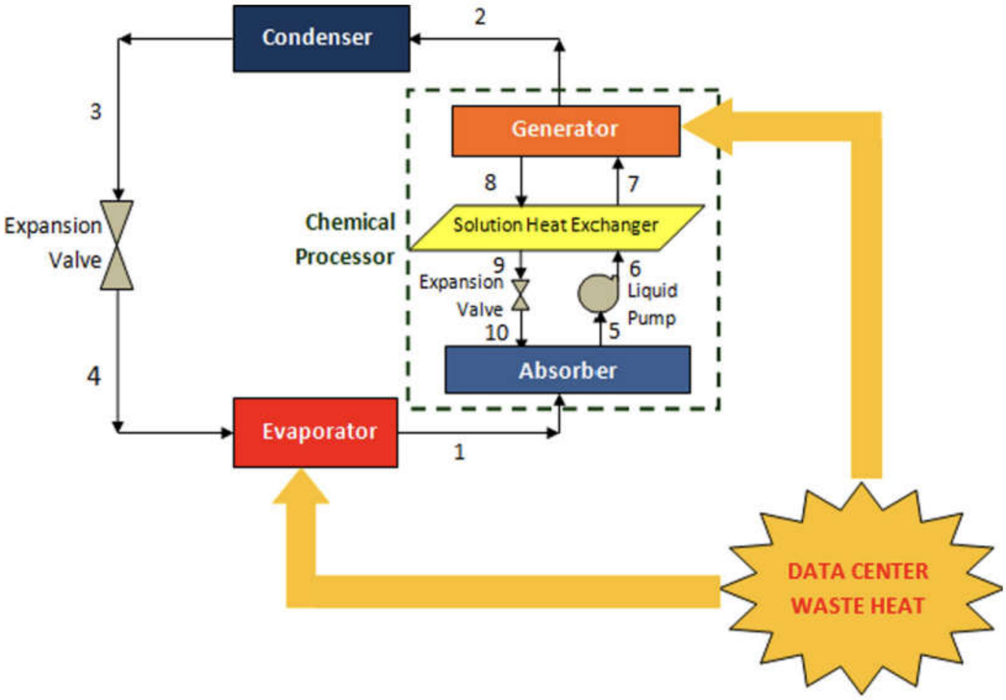

Figure 2.2: A schematic of a simple absorption refrigeration system driven by data center waste heat [5]

electricity can also be generated by data centre waste heat directly through Organic Rankine cycle (ORC) which is investigated by Ebrahimi et al [5]. this technology work on as same as the steam Rankine cycle, but only use organic fluid with a lower boiling point instead of working fluid. R-134, Benzene, Toluene, and propane are appropriate organic working fluids with a temperature range of 65-350 °C. They presented that lower temperature has lower efficiency than higher temperature. Figure 2.3 depicts ORC consisting of a turbine, condenser, pump evaporator, and superheater. The super heater is only necessary when the fluid is wet [5, 23].

They suggested that the temperature range for ORC is available by waste heat streams from water-cooled or two-phased cooled data centers. Also, by adding a secondary heat source air-cooled data center it is possible to use ORC technology. The most advantages of this technology is on-site electricity production from waste heat of data center and no specific place needs and making ORC more suitable for a wide range of data centers. However, the efficiency of the organic Rankine cycle is low at around 5-20% according to the operating temperature.

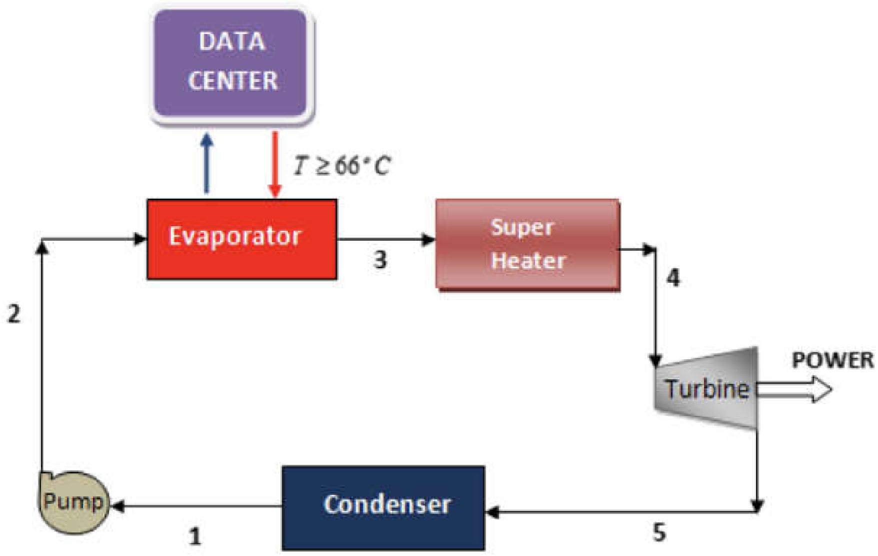

Figure 2.3: Schematic diagram of organic Rankine cycle [5]

Piezoelectrics is another method to use data center waste heat. In this method, turbulent oscillation in the data center cooling air flow is converted to electricity. In this method piezoelectric material is under mechanical stress and strain, then there is a change in its internal field and electricity is produced.

Piezoelectric technology is only suitable for an air-cooled data center because worked by turbulence in the CRAC airflow. Although this method electricity can be generated for a small power need, this method has very low efficiency and high costs [5].

Another method that Ebrahimi et al [5] investigate is thermoelectric technology (TECs). By this method, data center waste heat is directly to convert electricity. Seebek effect is based on thermoelectric technology which explains when two different materials with different conduction energy level (such as semiconductor) are subjected to a temperature difference, electricity is created, and vice versa. This method has low efficiency of about 2-5 % and is very costing so it is not widespread today. Also, this method is only usable with a higher temperature difference between 80-175°C which will be available only by an advanced two-phase flow cooling system in the data center.

Another technology that Ebrahimi et al [5] suggested is multiple effect distillation (MED) which can use data center waste heat for producing clean water from seawater. Figure 2.4 shows conventional MED systems. In the first stage, water is boiled to become steam and then used as a heat source to boil saltwater. Water vapour in the first stage acts as medium heating for the second stage and the process continues till the last stage. MED method is based on the capture of the waste heat from each stage until the quality of heat has dropped too low for using. Since the input temperature for MED system is 75 °C and higher, this technology is only available by advanced two-phase flow cooling system in the data center and it is not possible for air-cooled data centers and in most data center production of clean water is not a priority need [5].

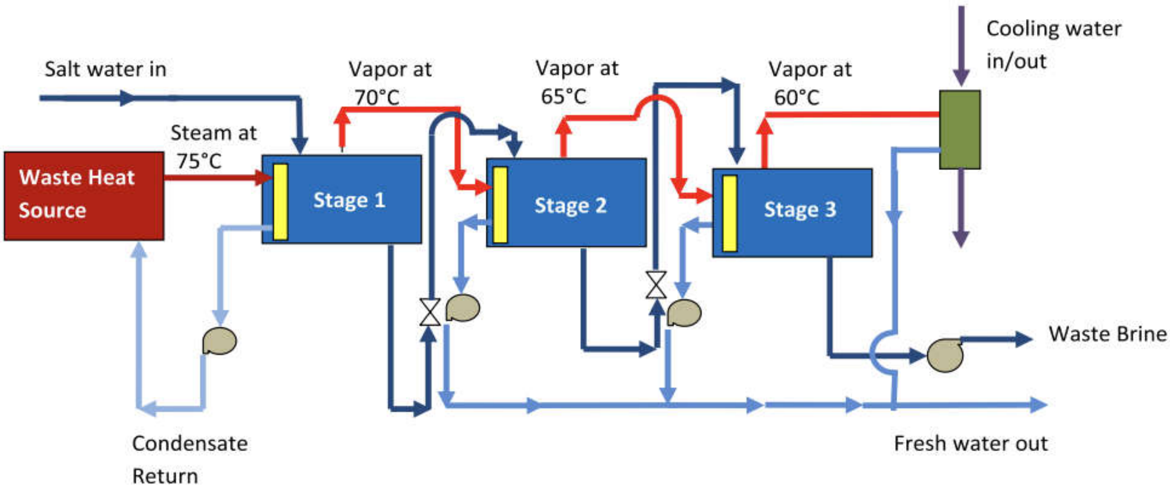

Figure 2.4: A three stage MED with the first stage energized by data center waste heat [5]

Li et al. investigated [24] a 4 stage MED system. The first stage of MED system is the absorber/heat pump as the heat source. The saturated temperature is 70 °C based on a salt content 3.8% and the absorber temperature is 75 °C. Industrial waste water in 90 °C is entered into the system and the output temperature is around 75 °C. This steam is the heat source for the second stage and water after four stages has cooled to 27 °C at the end of the process. The process depicts in figure 2.5 and there is no necessity for a chiller since hot water is absorbed during the desalination process.

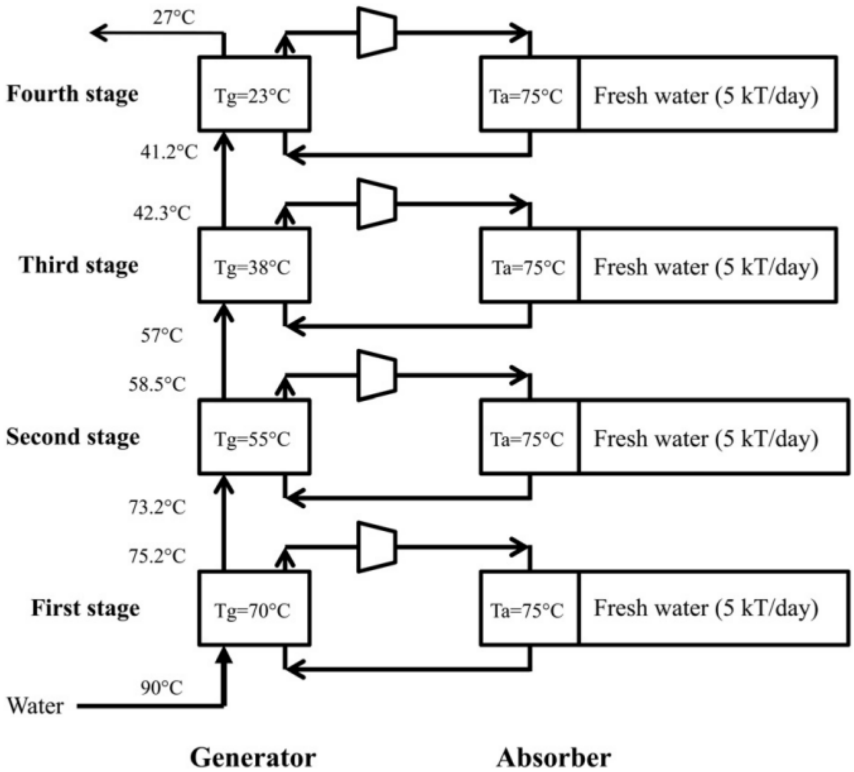

Figure 2.5: Schematic diagram of four-stage heat-pump operations used for MED [24]

Finally, Ebrahimi et al [5] investigate using data center waste heat for biomass. Biomass production from organic plant and animal materials provides a renewable energy source that can reduce carbon emissions. Recent investigation shows growing interest in the co-location of data centers with biomass facilities [25]. Due to producing power from the plant material and bio-solid waste, the heat source is required, and data center waste heat is used for that. Plant materials such as grass algae or bio materials such as manure is dried and burned by data center waste heat and produce steam in a power plant cycle. 60℃ temperature is most efficient in drying biomass, but this process can be complete with temperatures as low as 45℃. Another way to utilize data center waste heat in the biomass sector is to use this heat source to keep the anaerobic digestion reactor warm and to reduce moisture content in the biomaterial prior to the anaerobic process. A temperature above 60 ℃ is required for this purpose. This method is not suitable for air-cooled data center systems. And specific sitting needs of this technology are necessary.

Based on the literature review, a summary of waste heat technologies and their suitability for three main data center cooling systems (air-cooled, liquid-cooled and two-phase) is presented in table 2.1 by Ebrahimi et al. It is observed with liquid and two-phase cooling system, higher quality of waste heat is provided which can lead to many possible ways to reuse waste heat. Some scenarios technologies need co-location siting conditions such as biomass processing and it is not suitable for the existing data center.

Also, in terms of operational thermodynamic conditions and the operational requirements of the utilization of waste heat in data centre it is illustrated that absorption refrigeration and organic Rankin cycle technology are most beneficial for the recovery of waste heat in data center. Absorption refrigeration offers a source of chilled water which provide additional cooling load and reduce the CRAC load. And ORC technology generates electricity from waste heat stream [5].

Table 2.1: Suitability of each waste heat technology for retrofit and new data center designs [5]

Technology	Retrofit	New siting	Co-location required
HVAC/domestic hot water	Yes	Yes	No
District heating	Maybe	Yes	Yes
Boiler feedwater preheating	No	Yes	Yes
Absorption refrigeration	Yes	Yes	No
Organic Rankine Cycle	Yes	Yes	No
Piezoelectric	Yes	Yes	No

Thermoelectric	Yes	Yes	No
Desalination	No	Yes	Yes
Biomass processing	No	Yes	Yes

Oltmanns et al. [2] investigated the utilization of excess heat of a data center in the technical university of Darmstadt, Germany, they present that the electric energy demand of data center has grown rapidly and on average 25% of electricity in data center is used for cooling demand. TU Darmstadt applies a new cooling concept in the next generation of the high-performance computing data center which called "Lichtenberg II" due to increasing energy efficiency. Direct hot-water cooling for the high-performance computers is provided in the new data center at a temperature 45 °C instead of the current air-cooled servers with water-cooled rear doors at 17-24 °C in the old one. The high-temperature waste heat will be utilized for heating the university's campus Lichtwiese. For waste heat utilization, two concepts are presented, either heat integration in the return line of the district heating network or utilizing it locally in buildings situated near the data center which depict in figure 2.6. The project shows that between 20%-50% of the waste heat generated by high-performance computers can be utilized for heating purposes while the remaining heat is wasted by free cooling without any energy demand for mechanical equipment. Also, there is 4% CO_2 emission reduction in the campus Lichtwise.

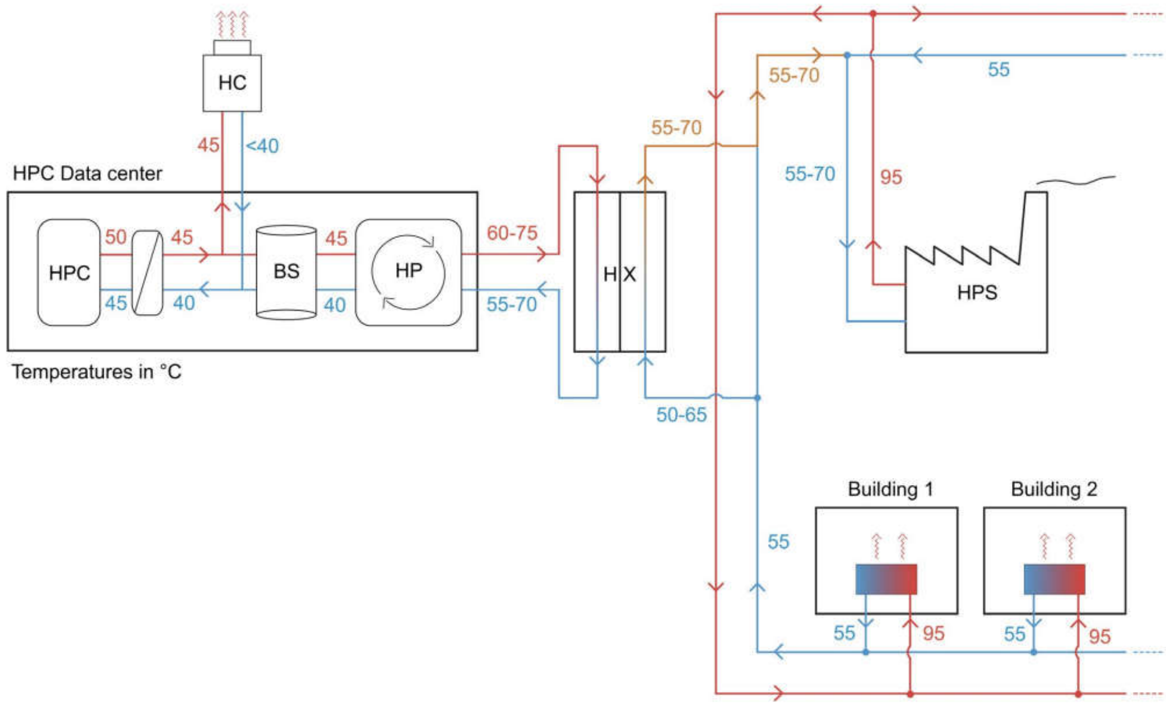

Figure 2.6: Functional diagram of the hot-water cooling and district heating waste heat integration [2]

Ore et al. [26] study utilization of data center waste heat for an indoor swimming pool in Barcelona. Each rack in the data center contains 48 shelves and each shelf has two servers with a maximum power consumption of 246 W. Therefore, there is 23.6 kW demand for each rack and different scenario of data center are considered. They show that liquid-cooled data centers can reduce energy consumption up to 30% in comparison to air-cooled data centers. Also, they investigated numerically different liquid cooling configurations of on-chip servers in the swimming pool as a case study which is shown in figure 2.7. The result shows that the operational cost of the data center is decreased, and surplus income is generated by selling excess heat, achieving a net present value after 15 years of 330,000 €. Moreover, the operational cost of the swimming pool is reduced up to 18 % and associated CO_2 emission up to 60 %.

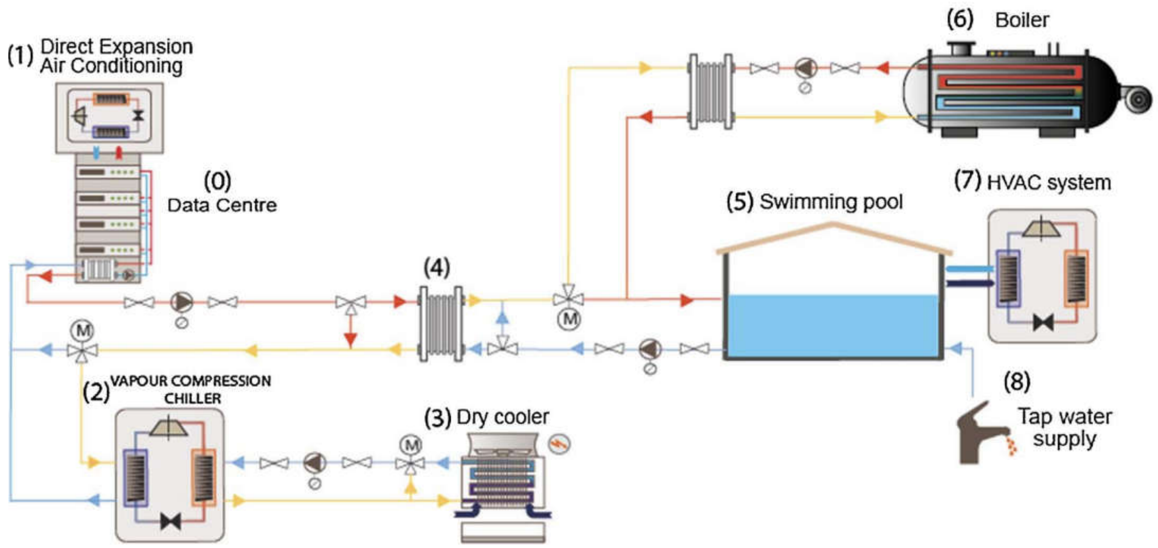

Figure 2.7: Schematic overview of the data centre connexion to the indoor swimming pool [26]

2.2 Possible temperatures in cooling principle in data centers

Due to proper and efficient utilization of data center waste heat, the temperature of the cooling system not only is very essential but also very sensitive. The quality of heat recovery can be evaluated by the temperature range. Thus, there is some guideline and investigation about the temperature.

One of the most references to determine the favorable environment and temperature and also standards range for data centers is provided by the American Society of Heating, Refrigerating, and Air Conditioning Engineers (ASHRAE) [8]. The technical committee recommends that data center equipment should maintain in the temperature range 17-27°C to fit the manufacturer's provided criteria and also give some information about the allowable range of equipment environmental specifications which shows in table 2.1 and figure 2.8. In addition to this, the guideline classy data center to four classes from A1 to A4.

Class A1 is a data computer room with tightly controlled environmental parameters such as temperature, dew point, and relative humidity. Most of the enterprise servers and storage products are designed in this type.

Class A2/A3/A4 is an information technology space with some controlled environmental parameters. Volume servers, storage products, personal computers, and workstations are designed according to these classes.

Table 2.1: ASHRAE Thermal Guidelines [8].

classes	Equipment Environmental Specifications							
	Product operation					Product power off		
	Dry-bulb Temperature (°C)	Humidity Range, non-Condensing	Maximum Dew Point (°C)	Maximum Evaluation (m)	Maximum rate of Change (°C/hr)	Dry-bulb Temperature (°C)	Relative humidity (%)	Maximum Dew Point (°C)
Recommended (applies to all A classes)								
A1 to A4	18 to 27	5.5 °C DP to 60% RH and 15 °C DP						
Allowable								
A1	15 to 32	20 % to 80 % RH	17	3050	5/20	5 to 45	8 to 80	27
A2	10 to 35	20 % to 80 % RH	21	3050	5/20	5 to 45	8 to 80	27
A3	5 to 40	-12 °C DP & 8% RH to 85% RH	24	3050	5/20	5 to 45	8 to 85	27
A4	5 to 45	-12 °C DP & 8% RH to 90% RH	24	3050	5/20	5 to 45	8 to 90	27

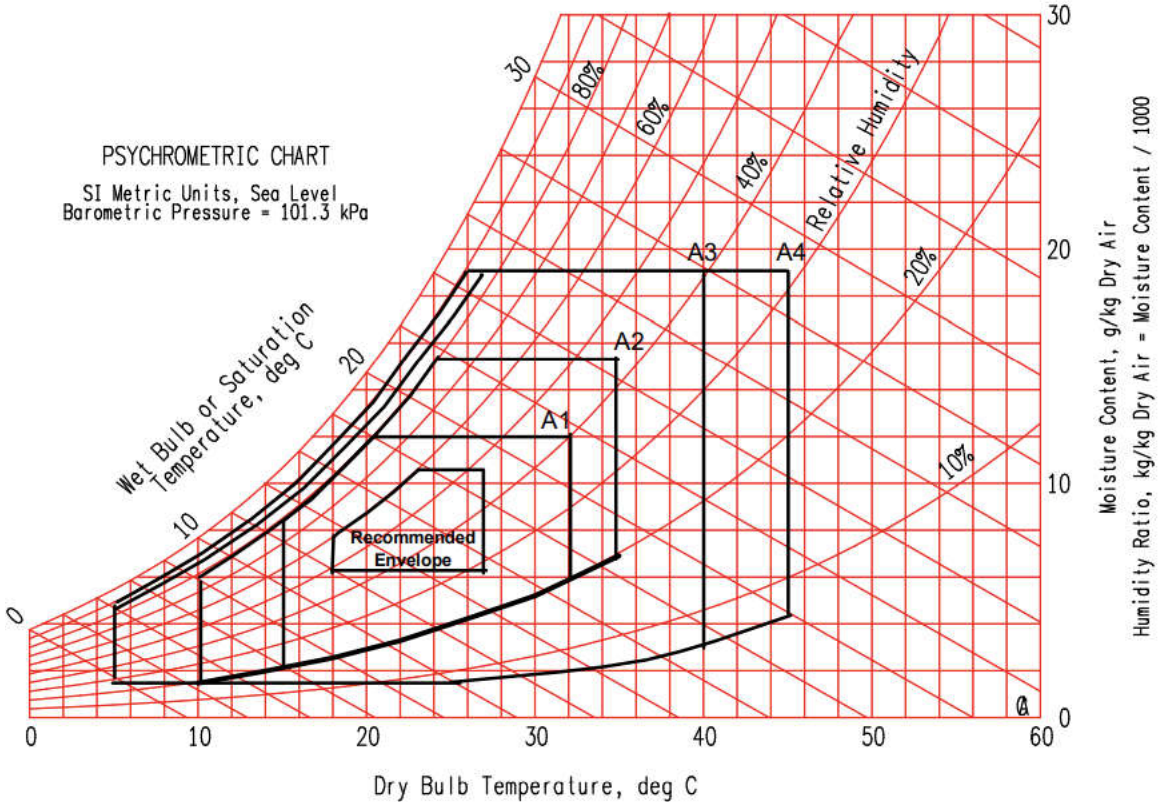

Figure 2.8: ASHRAE Environmental Classes for Data Centers [8]

Wahlroos et al. [27] show that the temperature of captured waste heat depends on the location where it is captured and cooling technology. In air-cooled technology, the temperature of captured waste heat is between 25-35 °C. And by liquid cooling technology waste heat can be captured at a higher temperature between 50-60 °C which is better for district heating. Also, they suggest that since the waste heat temperature typically was low in the data center, a heat pump could be used to increase the temperature.

Oltmann et al. [2] also show that the possibility of recovery waste heat technology depends on the temperature available and at low temperature (30-40 °C) for using local space or hot water heating and for district heating at (50-60 °C). Also, if the temperature of the waste heat data center is not as high as enough for district heating it can be increased by the heat pump. Moreover, they show that the high cooling inlet temperature can be up to 60 °C for the water-cooling data center and it means better waste heat utilization.

Patel [10] presents that due to having an energy-efficient air cooling (AC) data center, the cold inlet air to all the systems should be maintained at typically 25 °C and, output hot air is 40 °C and fluidic separation of cold and hot streams is necessary. He shows that due to reaching this condition a set point is defined at approximately 18 °C in the air-cooling data center. The setpoint is the temperature of the return air from the data center.

Ebrahimi et al. [5] represent a wide range of operating conditions and temperature limits in typical air-cooling data centers and water-cooling data centers. it is suggested that by them in air-cooling technology the inlet temperature range (cold aisle) is between 10-32 and in water cooling technology it can be between 20-60 ℃ for water supply to the server. Other conditions are shown in the tables 2.2 and 2.3.

Table 2.2: Summary of "typical" air-cooled data center heat sources and streams [5]

Parameter	Value
Cold aisle (CRAC supply) temperature	10-32 ℃
Hot aisle (CRAC return) temperature	50-60 ℃
Temperature rise over server	10-20 ℃
Airflow per rack	200-2500 CFM
Chiller water supply to CRAC	7-10 ℃
Chiller water return from CRAC	35 ℃

Table 2.3: Summary of "typical" water-cooled data center heat sources and streams [5]

Parameter	Value
Water supply to server	20-60 ℃ (std) 70-75 ℃ (max)
Water exit from server	2-5 ℃ temperature rise over server
Water flow rate per rack	5-10 GPM
ΔT from water to lid	5-18 ℃
Buffer heat exchanger flow rate	5-10 GPM
Buffer heat exchanger supply temp	3-5 ℃ above ambient

Brunschwiler et al. [28] introduce high-performance liquid cooling devices with minimal thermal resistance. The inlet temperature of the water can be 60 ℃ to keep junction temperature under 85℃. Therefore, chillers and electrical power consumption are eliminated, and direct reuse of heat is provided. They show that around 85% of board heat is collected. Due to providing this criterion, the maximum inlet temperature can be increased by 75 ℃.

Sherma et al. [29] investigate optimal operating conditions of water-cooled microprocessor chips according to heat recovery and chip thermal reliability. They show that for an optimal coolant flow rate of 1 (l/m) the maximum inlet temperature can be between 40-50 ℃ and also electronic chips can withstand a maximum temperature between 85-90 ℃.

3 Process description

This chapter gives detail about the heat pump and different parts of it, then the cooling system and waste heat of the Rjukan data center in Telemark Norway is described.

3.1 Description of the heat pump process

Heat pump technology provides an efficient and sustainable solution for heating and cooling conditions. A conventional heat pump is defined as a compression refrigeration cycle powered by either mechanical energy or electricity. Ammonia and chlorinate or fluorinate hydrocarbons are usually used in heat mumps as refrigerants. Since chlorofluorohydrocarbons (CFC's) are ozen depleting other refrigerants which are environmentally friendly such as pure hydrocarbons are useful [30, 31]. In most data center duo to use waste heat, it is necessary to use a heat pump for increasing output temperature and high quality of waste heat.

A heat pump is a mechanical system that allows heat transfer from one location at a lower temperature (heat source) to another location at an upper temperature (heat sink). Therefore, a heat pump is called a heater if it is used because of the warming heat sink, and it is called a cooler or refrigerator if it is used because of a cooling heat source. The operating principle for both items is similar [32]. The heat pump is made of a number of individual components, including a compressor, two exchangers (a condenser and an evaporator), an expansion valve, and a refrigerant circulating from high pressure (red line) to low pressure (blue line). Figure 3.1 depicts a mechanical compression of a conventional heat pump. The cooling effect is generated by the cold liquid refrigerant in the evaporator and the heating effect is generated by the hot refrigerant in the condenser [33].

The refrigerant circulates due to the temperature and pressure difference between the components so that closed-loop is divided into a high-pressure side where heat is given off (red line), and a low-pressure side where heat is absorbed from a heat source (blue line). A two-phased refrigerant goes into the evaporator where the vaporization of liquid provides the cooling effect and then the refrigerant leaves the evaporator and goes to the compressor by sucking. In the compressor, the refrigerant gains high pressure and becomes superheated. The output from the compressor enters to the condenser where the vapoured refrigerant is cooled and condensed to a saturated liquid. In the condenser, the heat of the refrigerant is released to the ambient. After that, the refrigerant enters the expansion valve where it is expanded to lower pressure and the liquid refrigerant is vaporized because of the expansion valve before entering the compressor [30].

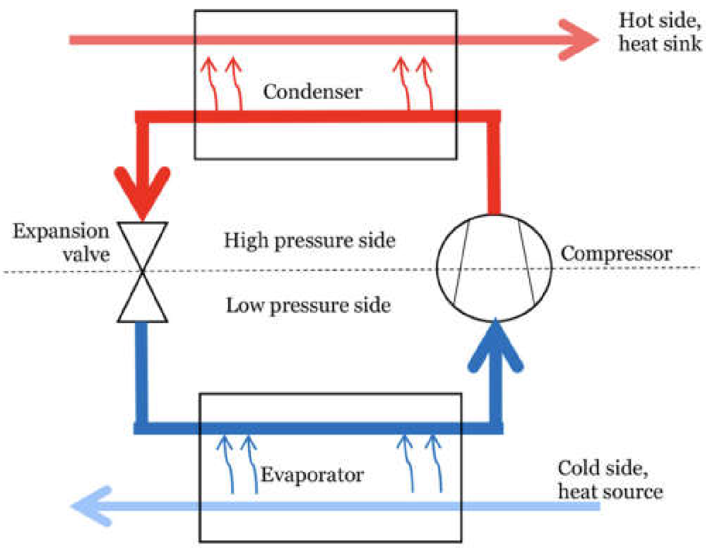

Figure 3.1: Main components and principle of heat pumps [33]

the merit of a refrigerator or heat pump is measured by a parameter called coefficient of performance (COP). It is the ratio of useful heat given off or taken up by the system to net work done on the system in the one cycle. The equation 3.1 represent COP of the heat pump [30].

$$COP = \frac{Q_{condenser}}{W} \tag{3.1}$$

$$W = Q_{condensor} - Q_{Evaporator} \tag{3.2}$$

In the equation, 3.1 $Q_{condenser}$ is the amount of released heat from the condenser. $Q_{Evaporator}$ is the amount of giving off heat to the evaporator, and W is the power required in the compressor. If there is no heat loss, the difference between input and output heat in the refrigeration cycle is equal to net work of the system [30].

3.2 Description of Telemark, Rjukan, data center

Rjukan data center is located in Telemark region of Norway. The site consists of 4 buildings and around 7 MW is the current total capacity. Due to having good hydroelectric power close to the data center the location for the data center is great. The size of server rooms with ready-built facilities is 865 m2. Telemark data center shows in figure 3.2.

In the data center Telemark, Rjukan, uses air for a natural cooling system with a medium temperature of 13 °C. And this means that for around 330 days of the year free cooling is available [34].

Figure 3.2: Data center of Telemark of Norway [35]

In the data center it is assumed that all the electrical power is transformed into heat, which must be extracted by a proper cooling system. It is very important to have high energy efficiency, minimal cost, and reliability according to design requirements and proper cooling systems. Although most data center does not utilize 100% capacity, the cooling system should be designed for the worst-case scenario in the data center. And how to control and predict the temperature in the data center is a vital item for the cooling system design.

One possible project is the utilization of waste heat from Rjukan data center. In this project, district heating for a fish farm from the waste heat of the data center will be planned. Since the quality of waste heat is low and the output water temperature is around 23 °C, using of heat pump for increasing the temperature of output water temperature is one possible solution. In this work the output water temperature in data center is assumed 45 °C and different alternative heat pumps due to increase water temperature is evaluated.

4 Material and energy balance calculation

In this chapter relevant material and energy balance of the system calculates by Aspen HYSYS.

4.1 Simulation setup in Aspen HYSYS

Due to calculation and simulation of the cooling system Aspen HYSYS version 12 is set up and used. Two pure components water which use in cooling process of data center and refrigerant which is refrig-22 (R-22) are selected in the component list. After that, Peng-Robinson is selected as a thermodynamic package for simulation in the Aspen HYSYS since it is relevant for these components. The default parameters for the package are used. Then the mechanical equipment of the heat pump which is evaporator, condenser, compressor, and expansion valve is defined with relevant streams.

4.2 The energy required calculation from Aspen HYSYS

4.2.1 Total energy requirement calculation

In the thesis, energy calculation is done by Aspen HYSYS. There alternatives were selected for simulation heat pumps in the Aspen HYSYS. The setup initial condition for these simulations is shown in the tables 4.1, 4.2 and 4.3.

Table 4.1: input condition for alternative 1 in Aspen HYSYS

Name	Water 1	Water 6	Fluid 2	Fluid 3
Temperature (°C)	45	60	unknown	unknown
Pressure (kPa)	101	101	1300	3000
Fluid package	Peng-Robinson			

Table 4.2: input condition for alternative 2 in Aspen HYSYS

Name	Water 1	Water 6	Fluid 2	Fluid 3
Temperature (°C)	45	70	unknown	unknown
Pressure (kPa)	101	101	1300	3500
Fluid package	Peng-Robinson			

Table 4.3: input condition for alternative 3 in Aspen HYSYS

Name	Water 1	Water 6	Fluid 2	Fluid 3
Temperature (°C)	45	80	unknown	unknown
Pressure (kPa)	101	101	1300	4000
Fluid package	Peng-Robinson			

In figure 4.1 the model simulation for heat pump is represented in Aspen HYSYS. Water 1 is output cooling water from the Data centre and water 6 is water supplied to the district heating network after using a heat pump. The simulation results for three alternatives are shown in tables 4.4. 4.5 and 4.6.

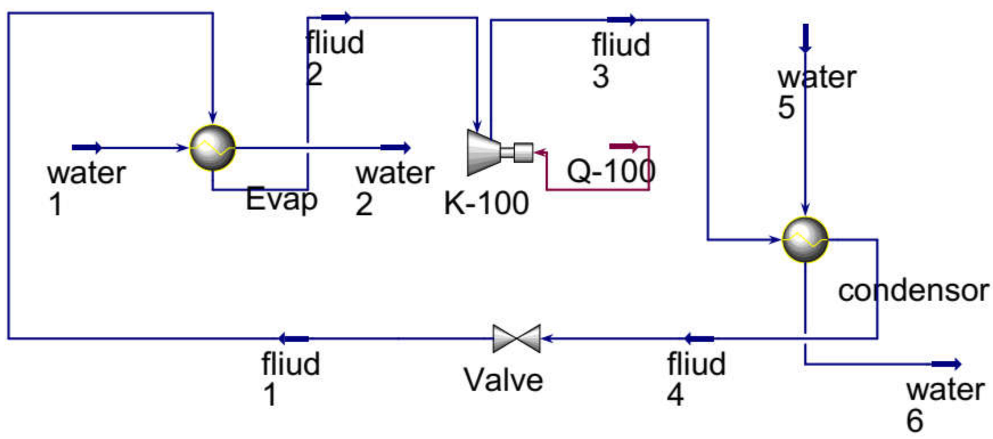

Figure 4.1: Simulation model of heat pump in Aspen HYSYS

Table 4.4: Results of material and energy balance achieved from Aspen HYSYS for alternative 1

Name	Water 1	Fluid 1	Water 2	Fluid 2	Fluid 3	Water 5	Water 6	Fluid 4
Vapour fraction	0	0.3223	0	1	1	0	0	0
Temperature (°C)	45	33.26	35	33.26	93.06	45	60	69.82
Pressure (kPa)	101	1300	101	1300	3000	101	101	3000
Molar flow (kgmole/h)	55.51	4.19	55.51	4.19	4.19	45.23	45.23	4.19
Mass flow (kg/h)	1000	362.3	1000	362.3	362.3	814.9	814.9	362.3
Liquid Vol flow (m^3/h)	1.002	0.2951	1.002	0.2951	0.2951	0.8165	0.2951	0.8165
Heat flow (kj/h)	-1.580e7	-2.151e6	-1.584e7	-2.108e6	-2.098e6	-1.288e7	-1.282e7	-2.151e6

Table 4.5: Results of material and energy balance achieved from Aspen HYSYS for alternative 2

Name	Water 1	Fluid 1	Water 2	Fluid 2	Fluid 3	Water 5	Water 6	Fluid 4
Vapour fraction	0	0.40	0	1	1	0	0	0
Temperature (°C)	45	33.26	35	33.26	104.9	45	70	77.45
Pressure (kPa)	101	1300	101	1300	3500	101	101	3500

Molar flow (kgmole/h)	55.51	4.793	55.51	4.793	4.793	28.89	28.89	4.793
Mass flow (kg/h)	1000	414.5	1000	414.5	414.5	520.4	520.4	414.5
Liquid Vol flow (m3/h)	1.002	0.3375	1.002	0.3375	0.3375	0.5214	0.5214	0.3375
Heat flow (kj/h)	-1.580e7	-2.454e6	-1.584e7	-2.411e6	-2.398e6	-2.454e6	-8.223e6	-8.223e6

Table 4.5: Results of material and energy balance achieved from Aspen HYSYS for alternative 3

Name	Water 1	Fluid 1	Water 2	Fluid 2	Fluid 3	Water 5	Water 6	Fluid 4
Vapour fraction	0	0.4965	0	1	1	0	0	0
Temperature (°C)	45	33.26	35	33.26	115.4	45	80	84.32
Pressure (kPa)	101	1300	101	1300	4000	101	101	4000
Molar flow (kgmole/h)	55.51	5.639	55.51	5.639	5.639	22.23	22.23	5.639
Mass flow (kg/h)	1000	487.6	1000	487.6	487.6	400.4	400.4	487.6
Liquid Vol flow (m3/h)	1.002	0.3971	1.002	0.3971	0.3971	0.4012	0.4012	0.3971
Heat flow (kJ/h)	-1.58e7	-2.88e6	-1.584e7	-2.836e6	-2.819e6	-6.327e+6	-6.266e+6	-2.88e6

4.2.2 Calculation of COP for heat pump

For alternative 1:

The evaporation temperature from the simulation is found 33.26ºC
The condensation temperature from the simulation is found 69.82ºC
From the simulation the amount of heat output from the condenser, QC = 52800 kJ/h
From the simulation power required in the compressor, W = 9687kJ/h

$$COP = \frac{Q_{condenser}}{W} = \frac{52800}{9687} = 5.45$$

For alternative 2:

The evaporation temperature from the simulation is found 33.26ºC
The condensation temperature from the simulation is found 77.45ºC
From the simulation the amount of heat output from the condenser, QC = 56310 kJ/h
From the simulation power required in the compressor, W = 13150kJ/h

$$COP = \frac{Q_{condenser}}{W} = \frac{56310}{13150} = 4.282$$

For alternative 3:

The evaporation temperature from the simulation is found 33.26ºC
The condensation temperature from the simulation is found 84.32ºC
From the simulation the amount of heat output from the condenser, QC = 60740 kJ/h
From the simulation power required in the compressor, W = 17580kJ/h

$$COP = \frac{Q_{condenser}}{W} = \frac{60740}{17580} = 3.455$$

5 Cost calculation

In this chapter represents the cost calculation related to the heat recovery process.

5.1 Energy cost calculation

Due to calculating energy cost, it is necessary to use simple assumptions.

The price of electricity is equivalent 1.07 NOK/kWh or 0.107 EUR/kWh which means total electricity cost divided by electricity use and the district heating price is obtained from DH company which is 0.05 EUR/kWh [19].

So, duo to know energy bills it is necessary to calculate heating and electricity bills the equation 5.1 represent heating bill which contains two parts, fixed and variable.

$$B_{heat(tot)} = B_{heat(fix)} - B_{heat(var)} \tag{5.1}$$

where $B_{heat(tot)}$ is the total heating cost, $B_{heat(fix)}$ is the fixed part, and $B_{heat(var)}$ is the variable part [19].

Also, the fixed part is devided to two parts and calculated in equation 5.2 as follow:

$$B_{heat(fix)} = \dot{Q}_{peak,sum} . P_{heat(fix,sum)} - \dot{Q}_{peak,win} . P_{heat(fix,win)} \tag{5.2}$$

In the equation, 5.2 $Q_{peak,sum}$ and $Q_{peak,\ win}$ are the peak load for the summer and winter seasons, and $P_{heat(fix,sum)}$ and $P_{heat(fix,\ win)}$ are the fixed heating prices for the summer and winter seasons, respectively. In this investigation peak load for summer and winter are assumed the same, half of total load, and the electricity price is assumed 0.107 EUR/kWh in winter and 0.05 EUR/kWh in summer. Also, the price of district heating is fix during the time and is 0.05 EUR/kWh.

The variable part is calculated in equation 5.3 which in this investigation is neglected [19].

$$B_{heat(var)} = Q_{heat} . P_{heat(var)} \tag{5.3}$$

Were Q_{heat} is the total heat use and the variable heating price is $P_{heat(var)}$. These prices are obtained from local DH Company.

The electricity bill is also divided into two parts, fixed and variable. The fixed part is determined by electricity use in Norway and for the variable part which used in this investigation, equation 5.4 is represented.

$$B_{elec} = E_{elec} \,.\, P_{elec} \tag{5.4}$$

Where B_{elec}, E_{elec} and P_{elec} are electricity cost, electricity use, and equivalent electricity price [19].

Calculation of economic potential is presented by equation 5.5 [36]

$$\begin{aligned} &Economic\ potential \\ &= Price\ \times Recovered\ heat - \left(\frac{Elc \times Price\ Recovered\ Heat}{COP}\right) \end{aligned} \tag{5.5}$$

$$\begin{aligned} &Economic\ potential\ without\ heat\ pump = Price\ \times Recovered\ heat \\ &= 0.05 \frac{EUR}{kWh} \times 60\ \frac{GWh}{yr} = 3.00\ \frac{MEUR}{yr} \end{aligned}$$

$$\begin{aligned} &Economic\ potential\ with\ heat\ pump\ 1 \\ &= 0.05 \frac{EUR}{kWh} \times 60\ \frac{GWh}{yr} \\ &- \left(\frac{\left(\frac{0.107 + 0.05}{2}\right) \frac{EUR}{kWh} \times 60\ \frac{GWh}{yr}}{5.45}\right) = 2.136\ \frac{MEUR}{yr} \end{aligned}$$

$$\begin{aligned} &Economic\ potential\ with\ heat\ pump\ 1 \\ &= 0.05 \frac{EUR}{kWh} \times 60\ \frac{GWh}{yr} \\ &- \left(\frac{\left(\frac{0.107 + 0.05}{2}\right) \frac{EUR}{kWh} \times 60\ \frac{GWh}{yr}}{4.282}\right) = 1.9\ \frac{MEUR}{yr} \end{aligned}$$

$$\begin{aligned}&\mathit{Economic\ potential\ with\ heat\ pump}\ 1\\&= 0.05\frac{EUR}{kWh}\times 60\ \frac{GWh}{yr}\\&-\left(\frac{\left(\frac{0.107+0.05}{2}\right)\frac{EUR}{kWh}\times 60\ \frac{GWh}{yr}}{3.455}\right)=1.637\ \frac{MEUR}{yr}\end{aligned}$$

Another alternative simple method to calculate energy cost calculation is assume that the same price is investigated for electricity price during the winter and summer seasons which is investigated below.

In Rjukan data center there is no Heat pumps for the increasing temperature of output water in the data center. In this investigation economic potential for the data center is calculated by and without heat pumps and compare the results.

$$\begin{aligned}\mathit{Economic\ potential\ without\ heat\ pump} &= \mathit{Price}\ \times \mathit{Recovered\ heat}\\&=0.05\frac{EUR}{kWh}\times 60\ \frac{GWh}{yr}=3.00\ \frac{MEUR}{yr}\end{aligned}$$

$$\begin{aligned}&\mathit{Economic\ potential\ with\ heat\ pump}\ 1\\&= 0.05\frac{EUR}{kWh}\times 60\ \frac{GWh}{yr}\\&-\left(\frac{0.107\frac{EUR}{kWh}\times 60\ \frac{GWh}{yr}}{5.45}\right)=1.82\ \frac{MEUR}{yr}\end{aligned}$$

$$\begin{aligned}&\mathit{Economic\ potential\ with\ heat\ pump}\ 2\\&= 0.05\frac{EUR}{kWh}\times 60\ \frac{GWh}{yr}\\&-\left(\frac{0.107\frac{EUR}{kWh}\times 60\ \frac{GWh}{yr}}{4.282}\right)=1.5\ \frac{MEUR}{yr}\end{aligned}$$

$$\begin{aligned} &\textit{Economic potential with heat pump } 3 \\ &= 0.05\frac{EUR}{kWh} \times 60\ \frac{GWh}{yr} \\ &- \left(\frac{0.107\frac{EUR}{kWh} \times 60\ \frac{GWh}{yr}}{3.455}\right) = 1.14\ \frac{MEUR}{yr} \end{aligned}$$

For the case of omitting heat pumps, all 60 GW energy of data center can be utilized to district heating network and based on 0.05 €/kW price of district heating the economic potential is 3 MEUR per year.

5.2 Investment cost calculation

Investment costs of large-scale HP projects are consisting of categories as shown in table 5.1 [36].

Table 5.1: Collection of investment costs for the following cost fraction categories [36]

Total	HP	Heat source	Construction	Electricity	Consulting	Others

Based on Peiper's calculation the total investment cost for heat pumps based on excess heat as heat source according to all categories is shown table 5.2.

Table 5.2: Specific total investment cost for HP project depending on excess heat and HP capacity [36]

HP capacity	Specific cost , million €/MW
0.5 MW< $HP_{capacity}$<1 MW	1.3 to 0.97
1 MW< $HP_{capacity}$<4 MW	0.97 to 0.72
4 MW< $HP_{capacity}$<10 MW	0.72 to 0.67

Therefore, the investment cost of a heat pump in Rjukan data center (7 MW) is in the third category and between the amount of 0.72 to 0.67 M€/MW is used and for simplicity 0.7 M€/Mw is assumed in the investigation. Since the Rjukan Data center is assumed 7 MW the total investment cost is 4.9 M€. Moreover, in figure 5.1, the total investment cost is broken down into different categories [36].

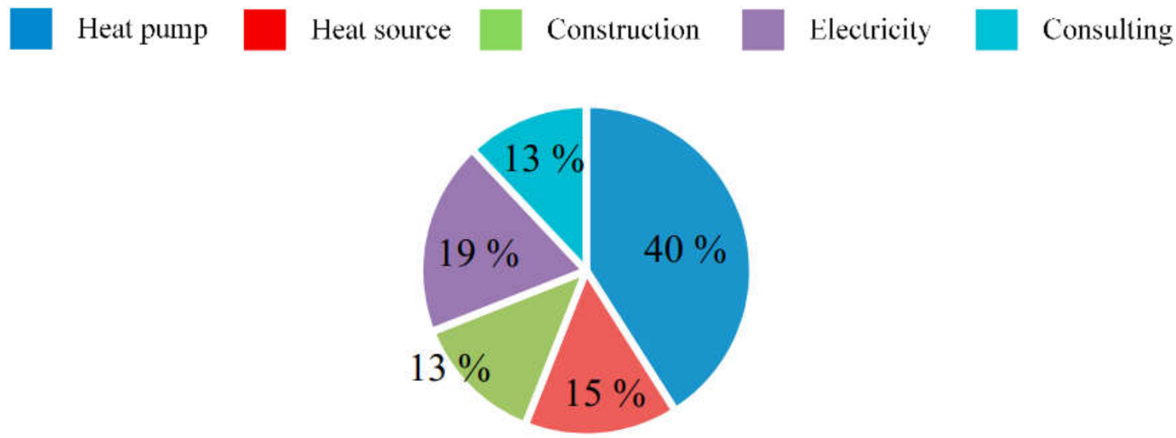

Figure 5.1: Breakdown of investment cost for HP based on excess heat source [36]

The cost of heat pumps facilities is the most important item in the cost investigation of heat recovery. The heat pumps are very critical to determine. Therefore, according to the data center load, and the target of the waste heat data centre the heat pumps can be estimated.

5.3 Evaluation of pipeline cost

Pipeline cost is very much dependent on the distance between the data center heat recovery facility to the district heating network. In addition to this, the environment and climate will play an important role in determining the materials of the pipeline. Therefore, the cost of the pipeline is variable depending on the condition. However, it can be optimized that the heat pump cost will be relatively larger than the pipeline cost.

5.4 Calculation of the payback period

The payback period is the time that the initial investment is fully recovered. This item is one of the most used methods to evaluate initial investments. The payback period *PB* is calculated in equation 5.5 [19].

$$B_{sav}\left(\frac{(1+i)^{PB}-1}{i(1+i)^{PB}}\right) - Invt = B_{sav}\left(\frac{1-(1+i)^{-PB}}{i}\right) - Invt = 0 \tag{5.5}$$

In the equation B_{sav} is the annual energy bill saving, *Invt* is the initial investment. The interest rate is i which in this study is 7 %. The payback period, *PB*, indicates the number of years for the recovery of the investment [19].

For alternative 1:

First method:

$$2.136\ M€\left(\frac{1-(1.07)^{-PB}}{0.07}\right)-\left(0.7\frac{M€}{MW}\times 7MW\right)=0 \quad \rightarrow \quad PB=2.587\ year$$

Second method:

$$1.82\ M€\left(\frac{1-(1.07)^{-PB}}{0.07}\right)-\left(0.7\frac{M€}{MW}\times 7MW\right)=0 \quad \rightarrow \quad PB=3.08\ year$$

For alternative 2

First method:

$$1.9\ M€\left(\frac{1-(1.07)^{-PB}}{0.07}\right)-\left(0.7\frac{M€}{MW}\times 7MW\right)=0 \quad \rightarrow \quad PB=2.94\ year$$

Second method:

$$1.5\ M€\left(\frac{1-(1.07)^{-PB}}{0.07}\right)-\left(0.7\frac{M€}{MW}\times 7MW\right)=0 \quad \rightarrow \quad PB=3.8\ year$$

For alternative 3

First method:

$$1.637\ M€\left(\frac{1-(1.07)^{-PB}}{0.07}\right)-\left(0.7\frac{M€}{MW}\times 7MW\right)=0 \quad \rightarrow \quad PB=3.475\ year$$

Second method:

$$1.14\ M€\left(\frac{1-(1.07)^{-PB}}{0.07}\right)-\left(0.7\frac{M€}{MW}\times 7MW\right)=0 \quad \rightarrow \quad PB=5.3\ year$$

It is observed the payback periods are 2.587, 2.94 and 3.475 years for the first method of calculation and 3.08, 3.8 and 5.3 years for the second method of calculation for three alternatives using of heat pumps for the data center.

Moreover, if the economic potential for these three items is investigated for 10 and 20 years. The calculated results are presented below.

For 10 years period investigation and i=7% the factor is calculated 7.02 and for 20 years period investigation with i=7% the factor is calculated 10.59. Therefore, the economic result for the tree alternatives heat pumps is calculated by equation 5.6 [35].

$$Economic\ result\ =(Economic\ potential\times factor)-Investment\ cost \tag{5.6}$$

For alternative 1:

First method:

$$Economic\ result\ 1 = (2.136\ M€ \times 7.02) - \left(0.7\frac{M€}{MW} \times 7MW\right) = 10.1\ M€$$

$$Economic\ result\ 1 = (2.136\ M€ \times 10.59) - \left(0.7\frac{M€}{MW} \times 7MW\right) = 17.72\ M€$$

Second method:

$$Economic\ result\ 1 = (1.82\ M€ \times 7.02) - \left(0.7\frac{M€}{MW} \times 7MW\right) = 7.876\ M€$$

$$Economic\ result\ 1 = (1.82\ M€ \times 10.59) - \left(0.7\frac{M€}{MW} \times 7MW\right) = 14.37\ M€$$

For alternative 2:

First method:

$$Economic\ result\ 2 = (1.9\ M€ \times 7.02) - \left(0.7\frac{M€}{MW} \times 7MW\right) = 8.438\ M€$$

$$Economic\ result\ 2 = (1.9\ M€ \times 10.59) - \left(0.7\frac{M€}{MW} \times 7MW\right) = 15.22M€$$

Second method:

$$Economic\ result\ 2 = (1.5\ M€ \times 7.02) - \left(0.7\frac{M€}{MW} \times 7MW\right) = 5.630\ M€$$

$$Economic\ result\ 2 = (1.5\ M€ \times 10.59) - \left(0.7\frac{M€}{MW} \times 7MW\right) = 10.985\ M€$$

For alternative 3:

First method:

$$Economic\ result\ 3 = (1.637\ M€ \times 7.02) - \left(0.7\frac{M€}{MW} \times 7MW\right) = 6.59\ M€$$

$$Economic\ result\ 3 = (1.637\ M€ \times 10.59) - \left(0.7\frac{M€}{MW} \times 7MW\right) = 12.44\ M€$$

Second method:

$$Economic\ result\ 3 = (1.14\ M€ \times 7.02) - \left(0.7\frac{M€}{MW} \times 7MW\right) = 3.103\ M€$$

$$Economic\ result\ 3 = (1.14\ M€ \times 10.59) - \left(0.7\frac{M€}{MW} \times 7MW\right) = 7.172\ M€$$

For the case without heat pump, there is no investment cost for installing heat pumps. Therefore, the economic result for 10 years is 21.06 MEUR and for 20 years is 31.77 MEUR.

5.5 Briefly of price assumption and condition for cost calculation

As a briefly, the price condition all items for cost calculation is presented in the table 5.3.

Table 5.3: Price assumptions for cost calculation

<table>
<tr><th>Items</th><th colspan="2">Price of electricity (EUR/kWh)</th><th>District heating price (EUR/kWh)</th><th>Investment cost (M€/MW)</th><th>Interest rate (%)</th><th>Factor for 10 years</th><th>Factor for 20 years</th></tr>
<tr><td rowspan="2">First method</td><td>Winter season</td><td>0.107</td><td rowspan="2">0.05</td><td rowspan="3">0.7</td><td rowspan="3">7</td><td rowspan="3">7.02</td><td rowspan="3">10.59</td></tr>
<tr><td>Summer season</td><td>0.05</td></tr>
<tr><td>Second method</td><td colspan="2">0.107</td><td>0.05</td></tr>
</table>

6 Discussion

6.1 Based on Aspen HYSYS calculation

Data center waste heat should be connected to the district heating network. A heat pump can be very useful due to increasing the quality of heat if the quality of heat is low. Heat pump increases the temperature of the heat of the data centre according to the target of DH. The cooling effect of refrigerants will increase the temperature of heat. In this investigation, for three alternative heat pumps the evaporation temperature is the same 33.26℃ while the condenser temperature is changed and there are 69.82℃ with COP 5.45 in alternative 1, 77.45℃ with COP 4.282 in alternative 2 and 84.32℃ with COP 3.455 in alternative 3. It means that the heat pump will supply high-temperature water to the district heating network it will generate a low COP and vice versa.

6.2 Economic potential analysis

In the case of economic optimization three alternatives heat pumps by two methods of calculation and without heat pump are evaluated. In the case without heat pump all the recovered 60 GW can be utilized which will be worth 3 MEUR. Payback period is investigated for all alternatives, payback period increases by the decreasing COP and the higher supply water temperature so that it changes from 2.587, 2.94 and 3.475 years for the three alternatives with first method of calculation respectively. Also, for the second method it varies from 3.08, 3.8, and 5.3 years respectively. In figure 6.2 the comparison of payback period for two methods in different COP is shown.

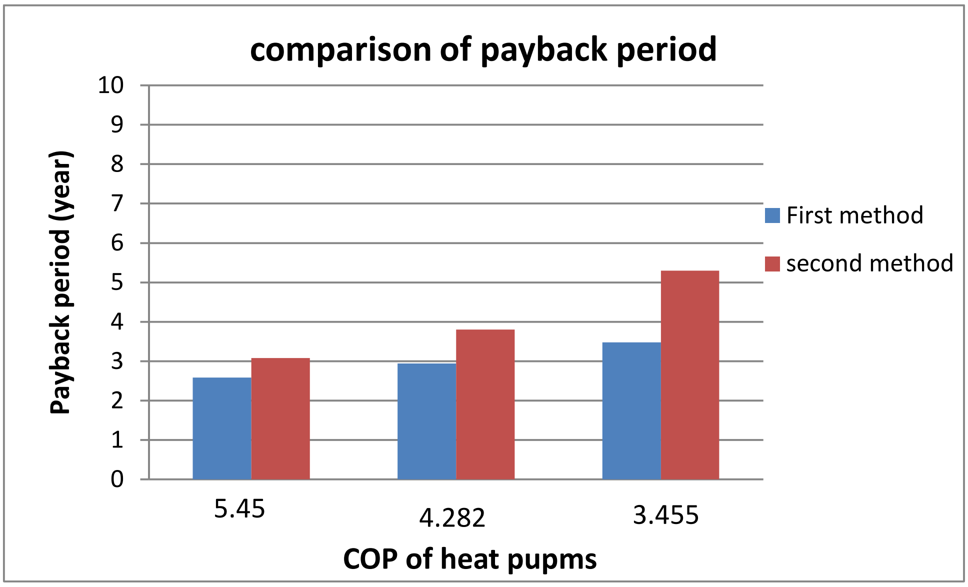

Figure 6.2: Comparison of payback period for three alternative heat pumps by two methods

Moreover, if the heat recovery process can be run from waste heat of the data center for 10 and 20 years, all the three alternatives will be economical. The heat pump investment cost estimated 4.9 MEUR. Therefore, all alternatives will give a positive net present value. The value will be for no heat pumps 20.06 MEUR and 31.57 MEUR for 10 and 20 years respectively. Heat pump with COP 5.45, heat pump with COP 4.282 and heat pump with COP 3.455 by first method of calculation are 10.1 MEUR, 8.438 MEUR and 6.59 MEUR for 10 years and 17.72 MEUR, 15.22 MEUR and 12.44 MEUR for 20 years respectively. Also, by the second method of calculation there are 7.878 MEUR, 5.63 MEUR and 3.103 MEUR for 10 years, and 14.37 MEUR, 10.985 MEUR and 7.172 MEUR for 20 years investigation, as well. Also, it is noticeable that the same price for district heating is assumed with or without heat pumps while the water supply temperature with using heat pump is higher than without heat pumps. That's why no heat pump scenario provides better economic potential for both time periods.

It is observed that the alternatives with higher COP will produce a higher economic potential and lower COP will produce lower economic values. Also, it is shown that first method of calculation provides higher economic potential since the price of electricity has calculated in two parts for heat pumps. All the economic results of three alternatives heat pumps and without heat pump for the two methods are shown in the figure 6.3 and 6.4 for 10 years period and in the figure 6.5 and 6.6 for the 20 years period.

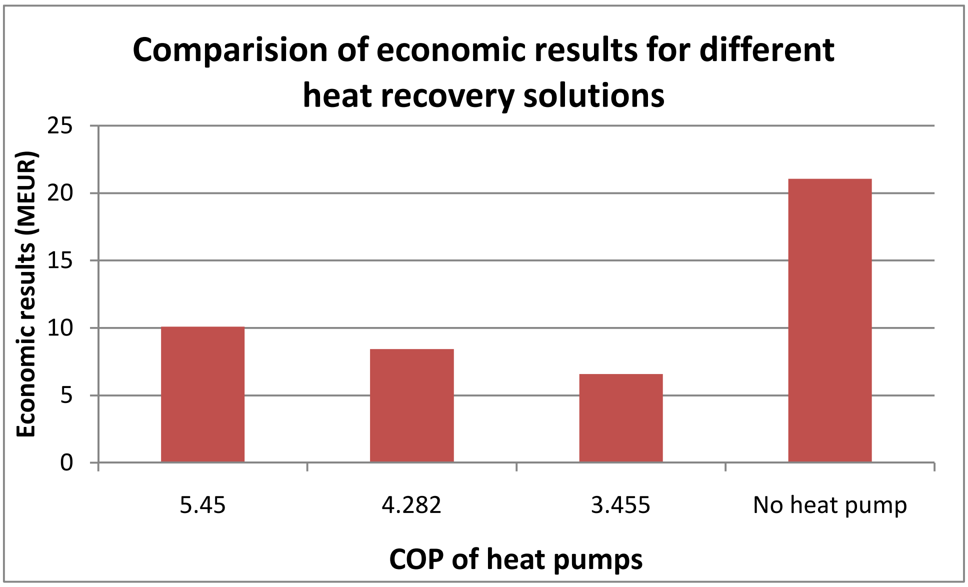

Figure 6.3: Comparison of economic result of investigation in 10 years by first method

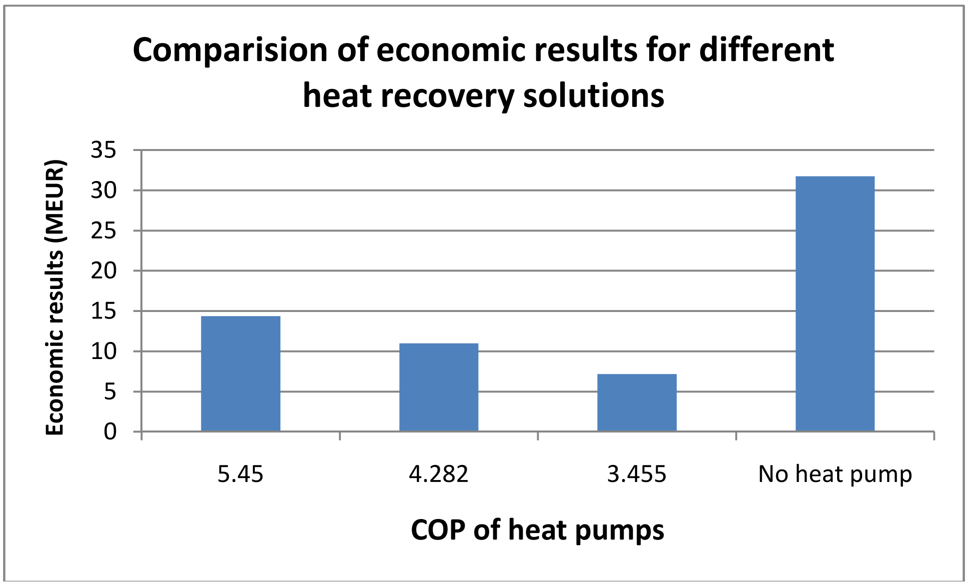

Figure 6.4: Comparison of economic result of investigation in 10 years by second method

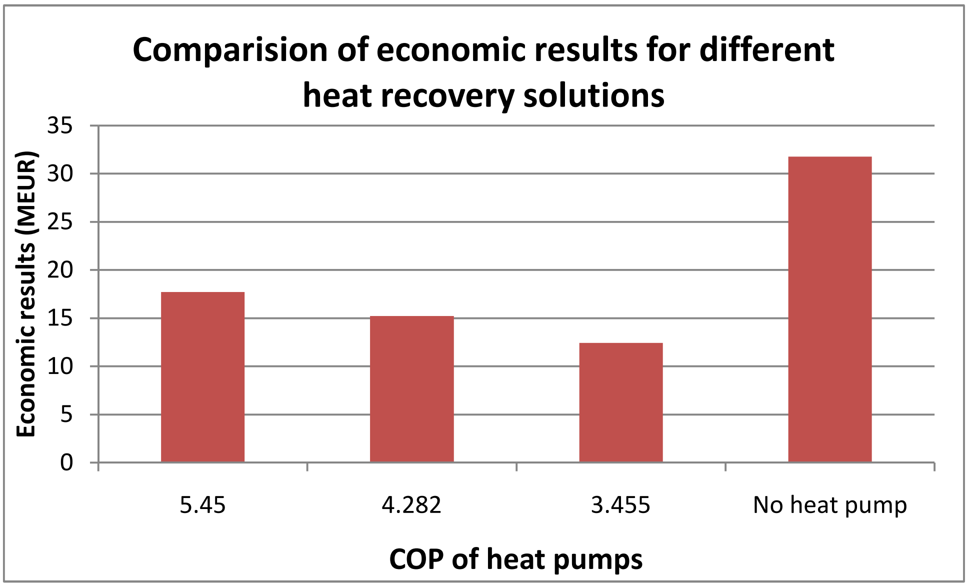

Figure 6.5: Comparison of economic result of investigation in 20 years by first method

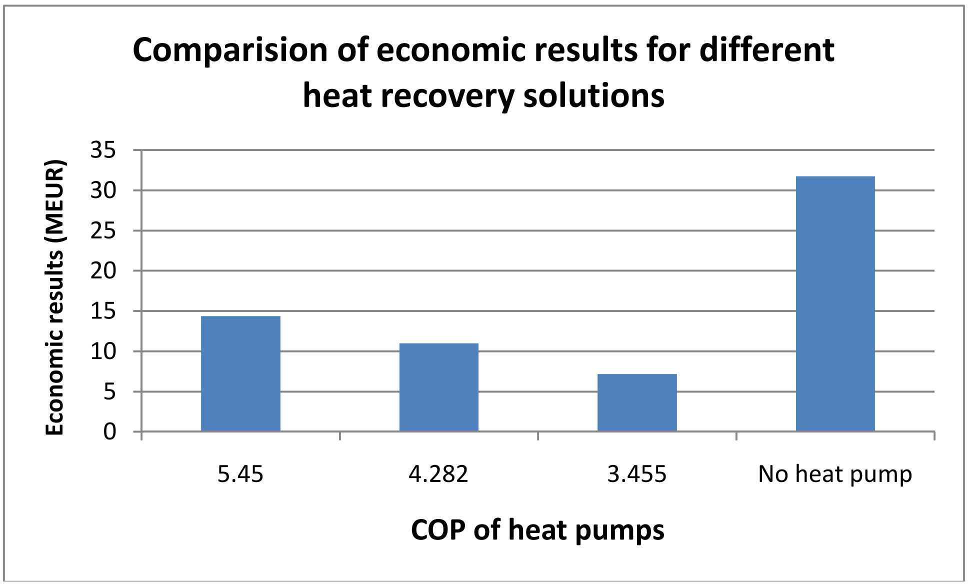

Figure 6.6: Comparison of economic result of investigation in 20 years by second method

7 Recommendations for future work

The thesis work was carried on based on literature study, output water temperature and pressure of the data center, simple assumptions about heat pumps and the target temperature for district heating also some assumption about economic calculation. For the exact analysis, there need some accurate mass flow rate of water and air also the exact price of electricity bill and the price of DH during the seasons. Also, in the simulation of heat pump by ASPEN HYSYS some simple assumption is done which can be modifying them in the future for example by investigation pressure drop, efficiency and type of mechanical equipments. Due to make the thesis or project more accurate in the future, these numbers should be collected. Also, the pipe line, constructer of district heating and the variation in different simulation can be investigated as a part of future work.

8 Conclusion

The depletion of fossil fuel resources, the harmful effect of using fossil fuel in the environment, global warming issues, and increasing demand for energy consumption around the world has pushed scientists and engineer to expand renewable energy resources. Data centers play an important role as a source of renewable energy. The excess heat of the data center can be utilized as a renewable source of energy. Also, by improving technology and necessitating installing new data center around the world, the role of this resource of excess heat becomes more efficient and can be used continuously around the world. The thesis deals with the heat recovery technology study in data center. The thesis starts with some basic information about different parts of data center and then some literatures study for different heat recovery technology. Cooling principle of data center such as free cooling, air-cooled, water-cooled and two phased cooled systems are also investigated.

Due to have efficient utilization of excess heat data center, the excess heat should be connected to district heating network. However, the quality of heat from the data canter is low and need to be improved. A heat pump can use the purpose of improving heat quality. Aspen HYSYS software is used for simulation and economical optimization at different conditions. In all cases water will leave the DC at 45℃, and one case without heat pump and three alternatives heat pumps with entering district heating network at 60℃, 70℃ and 80℃ are simulated. Payback period and two methods of economic calculation are used to calculate and compare economic potential of simulation. Refrigerant in Aspen HYSYS is set R-22 with Peng-Robinson fluid package. Pressure drop is neglected during simulation and properties are set in Aspen HYSYS. The COP for three heat pump alternative was calculated 5.45, 4.282 and 3.455 according to DH supply temperature 60℃, 70℃ and 80℃ respectively.

Payback period in two economical methods was calculated 2.6, 2.9, 3.5 years by the first method and 3.1, 3.8, 5.3 years by the second method according to COP 5.45, 4.282 and 3.455 respectively.

In case of calculating economic potential of the 60 GWh/a recovered heat data center during 10 and 20 years, the value without heat pumps is worth 20.06 and 31.77 MEUR respectively. This item is 10.1 MEUR, 8.438 MEUR, 6.59MEUR and 7.876 MEUR, 5.63 MEUR, 3.103 MEUR according to COP 5.45, 4.282 and 3.455 of heat pumps for 10 years period. Also, for 20 years period the results are 17.72 MEUR, 15.22 MEUR and 12.44 MEUR by the first method and 14.37 MEUR, 10.985 MEUR and 7.172 MEUR for the second method according to COP 5.45, 4.282 and 3.455 of heat pumps. Therefore, the most economical alternative is without heat pump and the heat pump with higher COP gives better economic potential in the simulation as well as the first method of calculating provides higher economical potential. By the way it is noticeable that the same prices are assumed for district heating regardless of the output temperature. Also, in the case without heat pump the output water is utilized for district heating directly.

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Appendices

Appendix A Master thesis task description

University of South-Eastern Norway

Faculty of Technology, Natural Sciences and Maritime Sciences, Campus Porsgrunn

FMH606 Master's Thesis

Title: Utilization of excess heat from data centres

USN supervisor: Lars Erik Øi

Cosupervisor: Mohammad Sharfuddin

External partner: Torkild Follaug, Green Mountain

Task background:

Data centers are delivering facilities to locate large computers for storing data including data access. The large computers are cooled by air (or possibly cooling water). The excess heat is normally regarded as lost energy. One way to increase the potential for utilization is to increase the temperature on the cooling air or cooling water outlet. One possibility for utilization of excess heat is district heating.

Task description:

1. Literature search on cooling principles in computers. Of special interest is to find maximum or optimum outlet temperature on cooling air or cooling water.
2. Process description of cooling processes for a large data centre. Both traditional processes and cases aiming at excess heat utilization should be evaluated.
3. Calculation of material and energy balances for a cooling process for a large data center. Also, calculation of payback period and economic potential for a specific energy recovery solution.
4. Evaluations of possible ways to utilize waste heat from a data center. The possibility of district heating including heat pumps should be evaluated.
5. Simulation and economical optimization at different condition of heat pumps in ASPEN HYSYS.

Student category: PT or EET students

Is the task suitable for online students (not present at the campus)? Yes

Practical arrangements:
The work will be carried out mainly at the University of South-Eastern Norway.

Supervision:
As a general rule, the student is entitled to 15-20 hours of supervision. This includes necessary time for the supervisor to prepare for supervision meetings (reading material to be discussed, etc).

Signatures:

Supervisor (date and signature): 26/4-22

Student (write clearly in all capitalized letters): VAHID ZANGENEH

Student (date and signature): 26/4/2022