# Economic investigation of heat pumps for heat recovery from data center

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## Abstract

The rapid growth of technology and digitalization lead to an increase in the number of data centers around the world. Data centers produce a considerable amount of heat because of their servers and a large number of electric components. The heat generated by the data centers can be used as a potential source of heating, but the quality (temperature level) of the heat is normally low. In this work, the temperature of the excess (cooling) water from a data center is 45 °C. Generally, there is a possibility to use heat pumps to improve the quality of the heat. To obtain a district heating temperature of 60 °C, 70 °C and 80 °C, the coefficient of performance (COP) was calculated to 5.5, 4.3 and 3.5, respectively. This work is about utilization of the excess heat from a data center with three alternative heat pump solutions with a payback period and economic potential for 10 and 20 years. The simulation process was done by Aspen HYSYS. It was observed that the payback period as expected increases with decreasing COP. The payback period was calculated to values between 2.6 and 5.5 years, depending on the market situation and the delivery temperature. In this work, it is shown that Aspen HYSYS is a reasonable tool to calculate alternatives for heat recovery from data centers based on heat pumps.

*Key words: Data center, heat recovery, district heating, heat pump, Aspen HYSYS*

## 1. Introduction

### *1.1. Background*

With the development of information in technology these days, the need for using DCs[1] has steadily increased which has led to an increase in the electricity consumption. On a global scale, the DC 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 (Oltmanns *et al.*, 2020). 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. All heat generated by the DCs can be used as a potential source of heating. the cold climate in Nordic countries is extremely suitable for DCs, providing much-needed cooling energy while there is a high demand for heat in these countries. However, the waste heat temperature is generally lower than the required heating temperature, which is a crucial obstacle for using this waste heat.

The heat pump technology can raise the temperature of waste heat to the required heating temperature by using high-grade energy like electricity and make this approach economically, financially, and environmentally profitable. Also, there are many options for waste heat recovery location in DC, such as the waste heat of return air from CRAC[2], CRAH[3], the waste heat of the cooling water from IT room, and the waste heat of cooling water from chillers which will make different capacity and temperature for waste heat recovery. Moreover, required heating temperature and different cycle type of heat pumps can lead to different thermodynamic and financial evaluation (Li *et al.*, 2021). In summary, in this study, thermodynamic and economical evaluation is based on the required heating temperature and a basic cycle of heat pump and then economic consideration is investigated.

### *1.2. Literature review on energy recovery from DCs*

There are different techniques for recycling waste heat for low temperatures. A simple way to reuse

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[1] Data centers

[2] Computer room air conditioner

[3] Computer room air handler

low-quality energy is in HVAC[4] 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. By using liquid cooling in DCs it is possible to provide a slightly higher quality of waste heat up to 50-60°C and by two-phase cooling systems, the temperature is as high as 70-80 which is more than sufficient for any heating or hot water application which can be used in DH[5]. Also, this heat provides an income for the DC. District heating is used in Europe more than in the US, particularly in Nordic countries. Moreover, this waste heat can be used for preheating domestic hot water which can lead to energy savings and emission reduction by reducing the use of fossil fuels. And 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. The next heat recovery technique is the heating of water in the thermal Rankine cycle of a power plant. The waste heat from the DC is used to preheat boiler feed water which can reduce the consumption of fossil fuels and pollution. They show that it will be more beneficial if a two-phase DC cooling system is used because of the high temperature (Ebrahimi et al., 2014).

Electricity can also be generated by DC waste heat directly through ORC[6] which is investigated by. This technology work as the steam Rankine cycle, but use an organic fluid with a lower boiling point as working fluid. They depict ORC consisting of a turbine, condenser, pump evaporator, and superheater. The superheater is only necessary when the fluid is wet (Chen *et al.*, 2010).

Waste heat of a DC can be used for preheating the water in a coal-fired power plant. One investigation shows that by utilization of waste heat the efficiency of the power plant is increasing up to 2.2% under certain optimized conditions and this performance can lead to a high saving in fuel cost and decrease carbon emission (Marcinichen *et al.*, 2012).

Another investigation is the utilization of excess heat of a DC in the technical university of Darmstadt, Germany (Oltmanns *et al.*, 2020). They show that Direct hot-water cooling for the high-performance computers is provided in the new DC 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 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. Also, there is a 4% of $CO_2$ emission reduction on the campus Lichtwiese.

The utilization of DC waste heat for an indoor swimming pool in Barcelona is studied (Oró *et al.,* 2018). Results show that liquid-cooled DC can reduce energy consumption up to 30% in comparison to air-cooled DC.

Waste heat utilization from both the DC and district heating networks in the city Espoo, Finland was investigated. The results showed that the operation cost saving in the system was 0.6 – 7.3%. Also, it was observed that the price of obtained waste heat affects the utilization level of waste heat (Wahlroos *et al.,* 2017).

DC energy efficiency and potential of waste heat capturing analyses showed that waste heat could be captured from 97 % of the total power consumed. Also, it was observed that waste heat from a 1 MW DC could provide the heat demand for over 30,000 $m^2$ non-domestic building annually (Lu *et al.* 2011).

### *1.3. Possible temperatures in cooling principle in DCs*

Due to proper and efficient utilization of DC 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 important references to determine the favorable environment and temperature and also standard range for DC is provided by the American Society of Heating, Refrigerating, and Air Conditioning Engineers (ASHRAE, 2015). The technical committee recommends that DC equipment should be in the temperature range 18-27°C to fit the manufacturer's provided criteria and also give some information about the allowable range of equipment environmental specifications which shows in Fig. 1. In addition to this, the guideline classify DC 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 and Class A2/A3/A4 are an information technology space with some controlled environmental parameters.

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[4] Heating ventilation air condition.

[5] District heating.

[6] Organic Rankine cycle

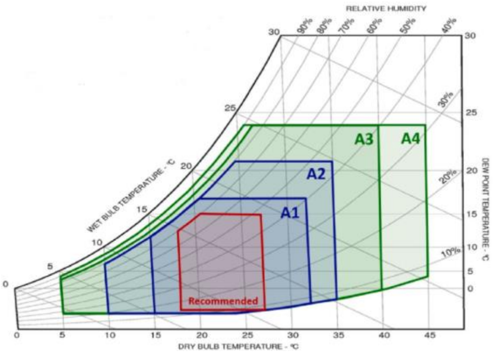

Figure 1: Ambient temperature classification of IT equipment by ASHRAE (Zhang *et al.* 2023)

The temperature of captured waste heat depends on the location where it is captured and on 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 (Wahlroos *et al.* 2017).

It was observed that the high cooling inlet temperature can be up to 60 °C for the water-cooling DC and it means better waste heat utilization (Oltmanns *et al.* 2020).

Based on investigation for having an energy-efficient air cooling (AC) DC, 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 (Patel, 2003).

The optimum temperature range to utilize the waste heat in air cooled DC was shown to be 35-45°C, in water-cooled DC systems and the output temperature could be higher in the range of 60-70 °C. Also, by two-phase cooling systems, the temperature was as high as 70-80 °C (Ebrahimi *et al.* 2014).

Another investigation showed that the inlet temperature of the water could be 60 °C to keep junction temperature under 85°C. it showed that around 85% of board heat is collected. Due to providing this criterion, the maximum inlet temperature can be increased to 75 °C (Brunschwiler *et al.*, 2009).

## 2. Methodology

### *2.1. Process description*

Heat pump technology provides an efficient and sustainable solution for utilizing low temperature heating sources. A conventional heat pump is defined as a compression refrigeration cycle powered by either mechanical energy or electricity. In most DC which use waste heat, it is necessary to use a heat pump for increasing output temperature and high quality of waste heat. Ammonia and chlorinated or fluorinated hydrocarbons are usually used in heat pumps as refrigerants. Since chlorofluorohydrocarbons are ozone depleting other refrigerants which are environmentally friendly such as pure hydrocarbons are useful.

The heat pump is made of a number of individual components, including a compressor, a condenser an evaporator, an expansion valve, and a refrigerant circulating from high pressure (red line) to low pressure (blue line). Fig. 2 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.

The refrigerant circulates due to the temperature and pressure difference between the components so that the closed-loop is divided into a high-pressure side and a low-pressure side. 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. 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 (Johansson, 2021).

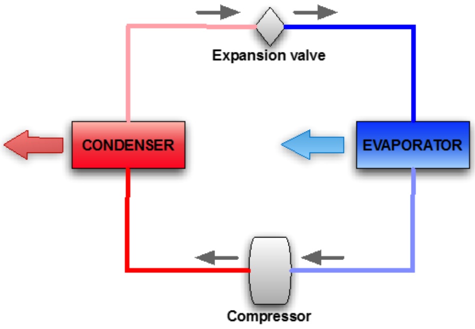

Figure 2: Main components of heat pumps (Øi and Tirados, 2015)

The merit of a refrigerator or heat pump is measured by a parameter called 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 1 and 2 represent how to calculate COP of the heat pump (Øi and Tirados, 2015).

$$COP = \frac{Q_{Condenser}}{W} \tag{1}$$

$$W = Q_{condensor} - Q_{Evaporator} \tag{2}$$

In equation 2, $Q_{Condenser}$ 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.

### *2.2. Simulation by Aspen HYSYS*

Due to calculation and simulation of the cooling system Aspen HYSYS is used. Two pure components, water which is used in the cooling process of DC and refrigerant which is refrig-22 (R-22) are selected in the component list. R-22 is selected as a typical refrigerant, but it is however gradually phased out in the industry due to the ozone depleting effect. After that, Peng-Robinson is selected as a thermodynamic package for simulation in the Aspen HYSYS since it is relevant for these components and applicable for large range of temperature and pressure and two phases, also has a large binary interaction parameter database. 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.

Three alternative heat pumps are simulated in the Aspen HYSYS. Initial conditions are provided in Tab. 1, 2, and 3.

Table 1: input condition for alternative 1 in Aspen HYSYS

| Name | Water 1 | Water 6 | Fluid 2 | Fluid 3 |
|---|---|---|---|---|
| **Temperature (°C)** | 45 | 60 | UN | UN |
| **Pressure (kPa)** | 101 | 101 | 1300 | 3000 |

Table 2: input condition for alternative 2 in Aspen HYSYS

| Name | Water 1 | Water 6 | Fluid 2 | Fluid 3 |
|---|---|---|---|---|
| **Temperature (°C)** | 45 | 70 | UN | UN |
| **Pressure (kPa)** | 101 | 101 | 1300 | 3500 |

Table 3: input condition for alternative 3 in Aspen HYSYS

| Name | Water 1 | Water 6 | Fluid 2 | Fluid 3 |
|---|---|---|---|---|
| **Temperature (°C)** | 45 | 80 | UN | UN |
| **Pressure (kPa)** | 101 | 101 | 1300 | 4000 |

Modelling of heat pump by Aspen Hysys is presented in Fig. 3.

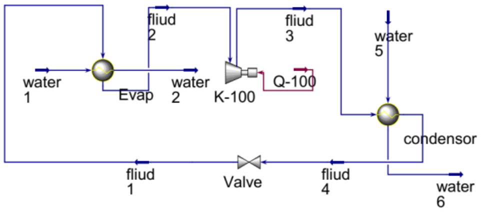

Figure 3: Simulation model of heat pump in Aspen HYSYS

Water 1 is output cooling water from the DC and water 6 is water supplied to the district heating network after using a heat pump.

## 3. Results

### *3.1. Simulation results of Aspen HYSYS*

The simulation results for three alternatives are shown in Tab. 4, 5 and 6 respectively. As it can be seen, thermodynamic properties of components are calculated by Aspen Hysys software and the heat flow of water and fluid are shown which can be easily calculated the compressor work and condenser heat transfer to calculate COP of heat pumps for three delivery temperatures.

Table 4: Results of material and energy balance achieved from Aspen HYSYS for alternative 1.

| | Wat 1 | Fluid 1 | Wat 2 | Fluid 2 | Fluid 3 | Wat 5 | Wat 6 | Fluid 4 |
|---|---|---|---|---|---|---|---|---|
| **V, frac** | 0 | 0.32 | 0 | 1 | 1 | 0 | 0 | 0 |
| **Temp (°C)** | 45 | 33.3 | 35 | 33.3 | 93.1 | 45 | 60 | 69.8 |
| **Press (kPa)** | 101 | 1300 | 101 | 1300 | 3000 | 101 | 101 | 3000 |
| **Mass flow (kg/h)** | 1000 | 362.3 | 1000 | 362.3 | 362.3 | 814.9 | 814.9 | 362.3 |
| **Heat flow (kJ/h)** | -1.580 e7 | -2.151 e6 | -1.584 e7 | -2.108 e6 | -2.098 e6 | -1.288 e7 | -1.282 e7 | -2.151 e6 |

Table 5: Results of material and energy balance achieved from Aspen HYSYS for alternative 2.

| | Wat 1 | Fluid 1 | Wat 2 | Fluid 2 | Fluid 3 | Wat 5 | Wat 6 | Fluid 4 |
|---|---|---|---|---|---|---|---|---|
| **V. frac** | 0 | 0.40 | 0 | 1 | 1 | 0 | 0 | 0 |
| **Temp (°C)** | 45 | 33.26 | 35 | 33.26 | 104.9 | 45 | 70 | 77.45 |
| **Press (kPa)** | 101 | 1300 | 101 | 1300 | 3500 | 101 | 101 | 3500 |
| **Mass flow (kg/h)** | 1000 | 414.5 | 1000 | 414.5 | 414.5 | 520.4 | 520.4 | 414.5 |
| **Heat flow (kJ/h)** | -1.580 e7 | -2.454 e6 | -1.584 e7 | -2.411 e6 | -2.398 e6 | -8.223 e6 | -8.166 e6 | -2.454 e6 |

Table 6: Results of material and energy balance achieved from Aspen HYSYS for alternative 3.

| | **Wat 1** | **Fluid 1** | **Wat 2** | **Fluid 2** | **Fluid 3** | **Wat 5** | **Wat 6** | **Fluid 4** |
|---|---|---|---|---|---|---|---|---|
| **V. frac** | 0 | 0.4965 | 0 | 1 | 1 | 0 | 0 | 0 |
| **Temp (°C)** | 45 | 33.26 | 35 | 33.26 | 115.4 | 45 | 80 | 84.32 |
| **Press (kPa)** | 101 | 1300 | 101 | 1300 | 4000 | 101 | 101 | 4000 |
| **Mass flow (kg/h)** | 1000 | 487.6 | 1000 | 487.6 | 487.6 | 400.4 | 400.4 | 487.6 |
| **Heat flow (kJ/h)** | -1.58 e7 | -2.88 e6 | -1.584 e7 | -2.836 e6 | -2.819 e6 | -6.327 e6 | -6.266 e6 | -2.88 e6 |

### *3.2. Calculation of COP for heat pump*

After simulation by Aspen Hysys, the COP of three alternative Heat Pumps is calculated.
For alternative 1:

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

For alternative 2:

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

For alternative 3:

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

So, when the supplies water to district heating are 60, 70 and 80 the COP are 5.45, 4.282 and 3.455 respectively.

### *3.3. Economic calculation*

To calculate the energy cost, it is used simple assumptions. Economic calculation is done for two market situations. In the first market situation, electricity price is assumed 0.107 EUR/kWh in winter and 0.05 EUR/kWh in summer and in the second one the electricity price is equivalent 0.107 EUR/kWh or 1.07 NOK/kWh during the year, and the district heating price is obtained from DH company which is 0.05 EUR/kWh (Li *et al.*, 2021). Calculation of economic potential is presented by equation 3.

$$Economic\ potential = Price\ \times Recovered\ heat - \left(\frac{El\ Price\ \times Recovered\ Heat}{COP}\right) \qquad (3)$$

One 7 MW DC is investigated, and 100% heat recovery is assumed, so the recovered heat is calculated to 60 GWh/yr in the DC. The economic potential for no heat pump and three alternative heat pumps by the first economic market situation are calculated below.

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

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

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

$$\begin{aligned} &Economic\ potential\ with\ heat\ pump\ 3 \\ &= \ 0.05\frac{\mathrm{EUR}}{\mathrm{kWh}} \times 60\ \frac{\mathrm{GWh}}{\mathrm{yr}} \\ &- \left(\frac{(\frac{0.107+0.05}{2})\,\frac{\mathrm{EUR}}{\mathrm{kWh}} \times 60\ \frac{\mathrm{GWh}}{\mathrm{yr}}}{3.455}\right) \\ &= 1.637\ \frac{\mathrm{MEUR}}{\mathrm{yr}} \end{aligned}$$

For the case of no heat pump, all energy of the DC is utilized which is worth 3 MEUR while for three alternative heat pumps the economic potential decreased.
Economic potential for heat pumps also are calculated by the second market situation and the results are 1.82 MEUR/yr, 1.5 MEUR/yr and 1.14 MEUR/yr, respectively. However, If there is cheap surplus renewable energy available in special circumstances, it may improve the economy compared to the calculation.

### *3.4. Investment cost*

The total investment cost for heat pumps based on excess heat as heat source according to all categories are shown Tab. 7 (Li *et al.*, 2021).

Table 7: total investment cost for HP project (Li *et al.*, 2021)

| **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 the 7 MW DC is in the third category, it is between the amount of 0.72 to 0.67 M€/MW, and for simplicity 0.7 M€/Mw is assumed in the investigation. Since the DC is assumed 7 MW the total investment cost is 4.9 M€.

### *3.5. Calculation of the payback period*

The payback period is the time that the initial investment is fully recovered. The payback period PB is calculated in equation 4 (Li *et al.*, 2021).

$$B_{sav}\left(\frac{(1+i)^{PB}-1}{i(1+i)^{PB}}\right)-Invt = B_{sav}\left(\frac{1-(1+i)^{-PB}}{i}\right)-Invt = 0 \qquad (4)$$

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.

The payback period is calculated for three delivery temperatures by two market situations and the results are shown in Fig. 4 so that when the delivery temperature goes down or the COP of heat pumps goes up, the payback period reduces.

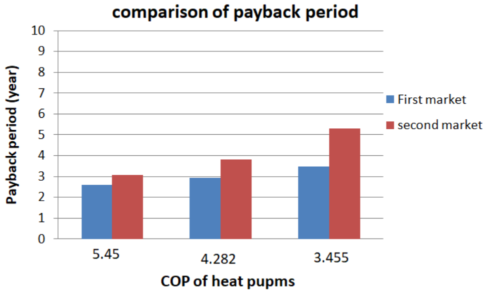

Figure 4: Comparison of payback period for three delivery temperatures by two market situations

### *3.6. Economic result*

The economic result for all four alternatives is calculated when the project are run for 10 and 20 years. The factor for constant income is given by equation 5.

$$Factor = \left(\frac{1-(1+i)^{-n}}{i}\right) \qquad (5)$$

For n=10 years and i=7% the factor is 7.02, and for n=20 years and i=7% the factor is 10.59. Therefore, the economic result for the four alternatives is calculated by equation 6 (Sharfuddin and Øi, 2020).

$$Economic\ result = (Economic\ potential \times factor) - Investment\ cost \qquad (6)$$

It is noticeable that for the case without heat pump, there is no investment cost for installing heat pump. Therefore, the economic result for 10 years is 21.06 MEUR and for 20 years is 31.77 MEUR. Also, economic result is calculated for three delivery temperatures based equation 6. The results of 20 years investigation are shown in Fig. 5, 6 for all alternatives and by the first and second market situations respectively, so that there is an increased trend of economic potential by increasing COP of heat pump or decreasing delivery temperature. Also, the same pattern is for 10 years calculation.

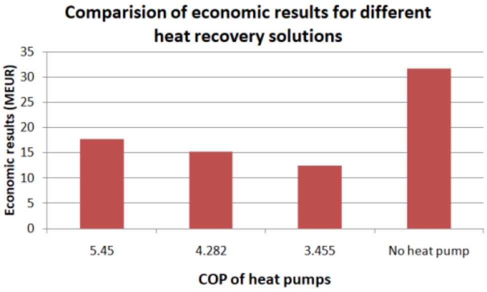

Figure 5: Comparison of economic result of investigation in 20 years by first market situation

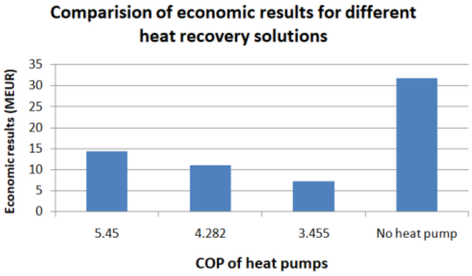

Figure 6: Comparison of economic result of investigation in 20 years by second market situation

## 4. Summary and Discussion

The excess heat of DCs can be utilized as a renewable source of energy. Due to having efficient utilization of excess heat DC, the excess heat should be connected to a district heating network. However, the quality of heat from the DC is low and needs to be improved. A heat pump can be used for the purpose of improving heat quality. Aspen HYSYS software is used for simulation and economic optimization under different conditions. In all cases, water will leave the DC at 45℃, and in one case without a heat pump and three alternatives with heat pumps entering the district heating network at 60℃, 70℃ and 80℃ are simulated. After simulation by Aspen Hysys, it is observed that the COP of three alternative heat pumps decreases by increasing water supply temperature (5.5, 4.3, and 3.5 respectively).

Economic considerations including investment cost, payback period, and the economic result for 10 and 20 years have been done by two market situations with specified prices for electricity and district heating costs.

It is observed that the payback period as expected increases by decreasing COP and higher supply water temperature so that it changes from 2.6, 2.9, and 3.5 years to 3.1, 3.8, and 5.3 years for the three delivery temperatures with the first and second market situations of calculation respectively.

Moreover, the economic potential for three delivery temperatures show that a higher COP will produce a higher economic potential and a lower COP will give lower economic values. Also, it is shown that the first market situation provides higher economic potential when the price of electricity cost has been calculated in two parts.

However, it is noticeable that the same price for district heating cost is assumed for all alternatives while the water supply temperature using a heat pump is higher than without a heat pump. That is why without heat pump scenario is the most economical alternative for two market situations. Also, the price of electricity and district heating may vary from one place to another which can affect the results. Another item that can affect the results is pipeline cost for the district heating network which has a dependency on climate, length of connection, and environmental situation. All in all, the calculation and investigation depict that a high potential for utilization of waste heat is available from DC.

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