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A Nove Heat Recovery Strategy for Data Centers: A Case Study

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Abstract—The paper introduces a novel strategy for optimizing waste heat recovery in data centers (DHs). With this strategy, waste heat from a data center is first upgraded to 60-90 ºC in a water-to-water heat hump plant and then introduced to local district heating (DH) network to provide heating for nearly buildings. At the same time, the cooling product from the heat pump plant is utilized as a free by-product (energy company pays electricity for heat pumps) to cool the data center. Both energy company and data center involve in investing heat pumps. This strategy can significantly cut power cost and CO_2 emission for energy company and data center (cooling is free). The potential is large for this strategy because, event in summer, heating demand is far more than total IT capacity of data centers in Finland. Furthermore, this strategy is applicable for all kinds of existing data center cooling systems. The paper also describes a real green data center (over 1 MW IT load) implemented by this novel strategy.

Keywords— Data center, heat recovery, waste heat reuse, heat pump, district heating network, CO_2 emission

I. Introduction

This During the two past decades, the increasing demands for data processing, data storage and digital communications have led to a dramatic growth in data center industry. By 2017, it is estimated that there are over eight million data centers (DC). These data centers consume about 1.5 to 2% of total global electricity, corresponding to 400 TWh, or close to the total amount of electricity used in France [1]. The reuse of these waste heat will reduce the use of fuels for electricity production as well as the consequent air pollution and global warming. Despite these benefits, heat reuse is still rare for data center industry. The big challenge is that fully reusing waste heat locally is very difficult. For example, in June, monthly heating demand (space heating + domestic hot water) is only 3.1 kWh/m^2 for apartment blocks in Helsinki, Finland [2]. A 5 MW data center needs to maintain over 1,5000 apartments (each about 70 m^2) for totally reusing its waste heat production in June, which is not feasible. The only option to entirely reuse waste heat for a data center is to join local district heating networks. But energy companies often have restrictions on supply water temperature (e.g. 60+ ºC for supply water temperature in Finland). Normally the generated hot water from waste heat is lower than 30 ºC. Therefore, heat pumps are needed to upgrade waste heat, which in turn increases electricity cost. These hamper investment in heat recovery for data centers.

This paper introduces a novel heat recovery strategy to address the above issues for data centers.

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II. A NOVEL HEAT RECOVERY STRATEGY

Theoretically, in this novel strategy, only one heat pump is needed, and its heating and cooling productions both are utilized to benefit data center and energy company (Fig.1).

The waste heat from a data center (green line, Fig. 1) is entirely supplied to a water-to-water heat pump to increase its temperature to 70 to 90 ºC (red line, Figure 1). The upgraded waste heat flows to the local district heating (DH) network to heat nearby buildings. The associated cooling product from the heat pump (blue line, 20 ºC, Fig. 1) is utilized to cool the data center (cooling can be free for the data center). Dry cooler or dry hybrid cooler is used as emergency cooling. This greatly reduces investment for a chilled water system because no chiller is needed. In this way, this novel strategy will bring benefits to both the owner of the data center and energy company (Table 1).

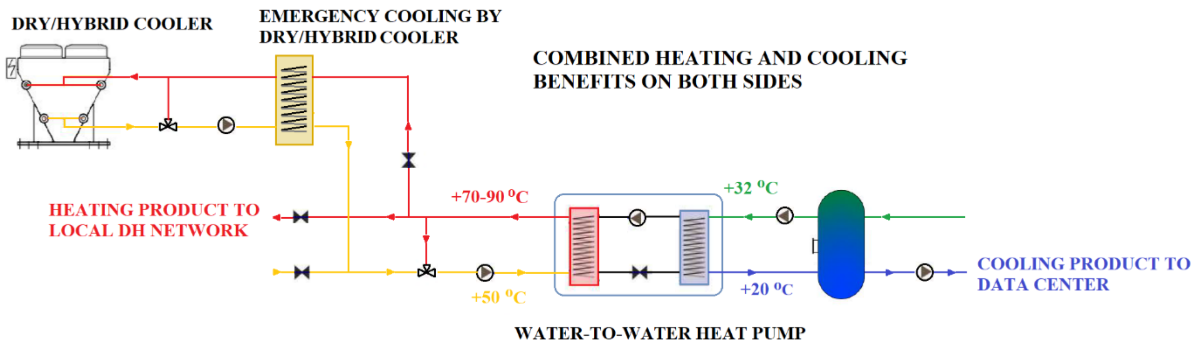

Fig.1. Schematic of the novel heat recovery strategy in data centers [3].

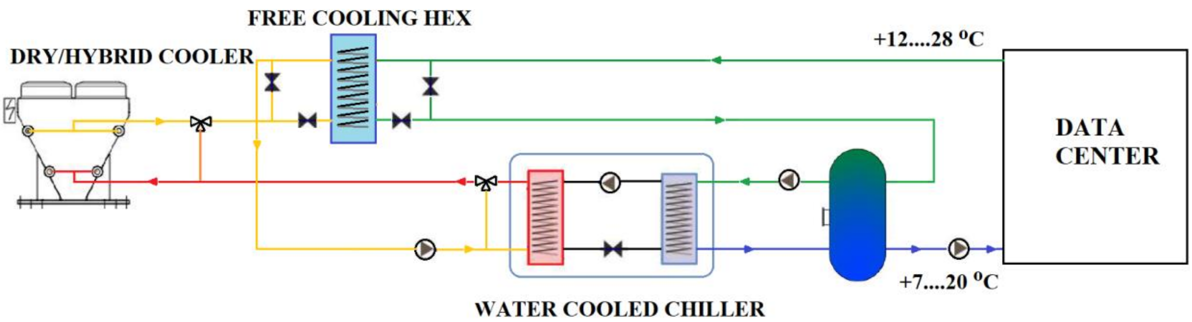

Fig. 2. A chilled water system [3].

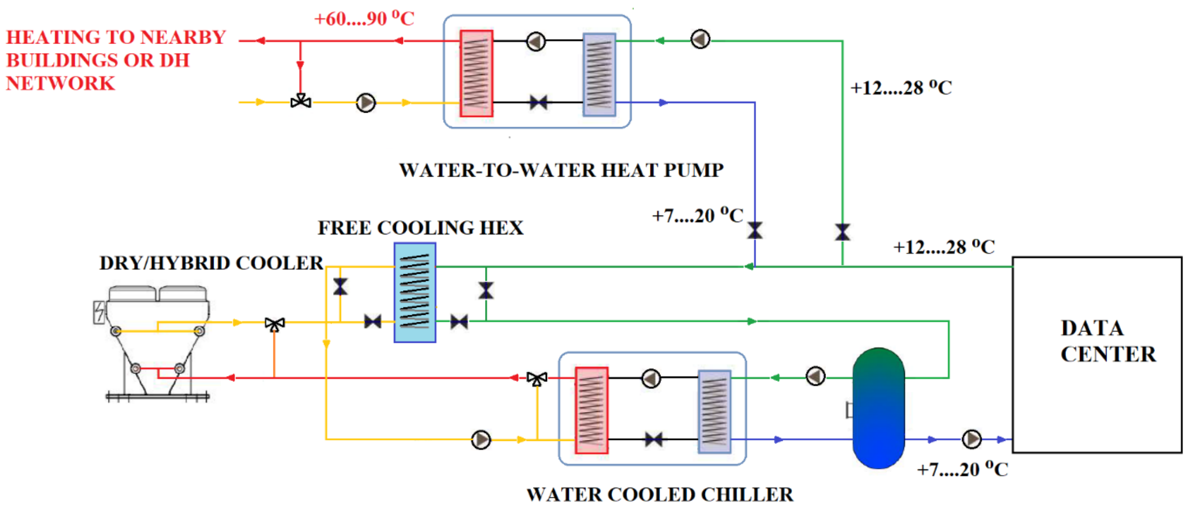

Fig. 3. The chilled water system with heat recovery unit [3].

TABLE I. BENEFITS FRO THE STRATEGY

The owner of data center
▲ Shared/reduced investment cost for additional cooling capacity (energy company invests in heat pump). ▲Reduced operational expenses (electricity cost of cooling generation) (e.g. energy company pays electricity for heat pump). ▲ Full scale heat recovery. Ecological solution where no heat is wasted. ▲ Good profit. ▲ Very short payback time for the investment.
Energy company
▲Heat pump plant with high heating output compared to the required investment cost. ▲Sustainable and economical source of heat energy (low-carbon district heating). ▲Heat pump plant with constant year-round heat production capability. ▲Good profit (e.g. reducing cost in boilers). ▲Payback time

The waste heat from a data center (green line, Fig. 1) is entirely supplied to a water-to-water heat pump to increase its temperature to 70 to 90 ^{o}C (red line, Fig. 1). The upgraded waste heat flows to the local district heating (DH) network to heat nearby buildings. The associated cooling product from the heat pump (blue line, 20^{o}C, Fig. 1) is utilized to cool the data center (cooling can be free for the data center). Dry cooler or dry hybrid cooler is used as emergency cooling. This greatly reduces investment for a chilled water system because no chiller is needed. In this way, this novel strategy will bring benefits to both the owner of the data center and energy company (Table 1).

Payback time is often less than four years for a chilled water cooled data center [3].

Fig. 1 presents an ideal situation for the novel strategy. This can only happen when energy company involved in the system planning of a data center. However, the novel heat recovery strategy introduced here can be used for all kinds of existing data center cooling systems, e.g. direct air cooling, indirect air cooling, chilled water systems, district cooling and liquid cooled servers. For an existing cooling system, the investment on heat pump can be shared by the owner of data center and energy company.

A. *Chilled water systems*

Fig. 2 shows a typical chilled water system. Fig. 3 illustrates the implementation of the novel heat recovery strategy for the above chilled water system (Fig. 2).

B. *Direct air cooling systems*

A direct air cooling system is displayed in Fig. 4. Fig. 5 shows the implementation of the novel heat recovery system in the above system.

III. CASE STUDY

A data center was built on a campus in a town near Helsinki in Finland. The IT capacity was a bit over 1 MW, and the novel strategy shown in Fig. 1 was adopted for the data center. At the beginning, the waste heat was considered to be supplied to local campus buildings in order to reduce the need for district heating energy. But, the IT load of the data center was estimated to be going to increase significantly in the next few years. In addition to campus buildings, waste heat could also benefit the whole region in cold winter because there are large existing DH pipes (supply/return, DN150-DN200) near the site. Therefore, a local energy company was introduced to the project, and the energy company decided to invest in the heat pump. Return-return connection was chosen for connecting the heat pump to the local DH network. The whole system started to run in early January of 2017. Fig. 6 shows the system at a time instant.

The heat pump plant (Fig. 6) includes two heat pumps (COP=3.6) with HFO-1234ze (1,3,3,3-Tetrafluoropropene) as a refrigerant, which was developed as a "fourth generation" refrigerant to replace R-134a and has very low global-warming potential (GWP < 1). The heat pumps cool the water temperature from the data center from 15 ^{o}C to 10 ^{o}C (Fig. 6). The extracted heat is supplied to the return line of the local DH network at 60-70 ^{o}C hot water to mix with the return water. This reduces the temperature difference between the supply and return lines of the local DH network, and thus boosts the energy efficiency of the whole system.

From January to October in 2017, the heat pumps provided around 11 000 MWh of heat energy with temperatures ranging from +55 to 70 ^{o}C to the local DH network. Then, the average heat power produced by the two heat pumps would be 1.53 MW (=11000/(24*30*10)). Compared with the heat power produced at one time instant (i.e. 1.59 MW, Fig. 6), almost all waste heat generated by the data center was recovered and supplied to the local DH network.

Because the agreement between the DC owner and the DH operator is confidential, it is unable to know how exactly running cost of the heat pump plant (mainly electricity input for heat pumps) is paid. But more likely the DH operator pays electricity bill for the two heat pumps to get the recovered waste heat from the data center (cooling is then entirely free for the DC owner). In Finland, CO_2 emissions are 181 g/kWh for electricity production and 176 g/kWh for district heating production in Finland [5]. Assuming that annually 1.59 MW waste heat is recovered at 65 ^{o}C hot water (COP=3.6 for two heat pumps) and supplied to local DH (average supply water temperature is about 87 ^{o}C [6]), annual CO_2 emission reduction is 1131.2 tCO_2 (= (1.59*24*365*176/1000)*65/87-(1.59*365*24*181/3.6)/1000) for local DH network. A graph within a graph is an “inset”, not an “insert”. The

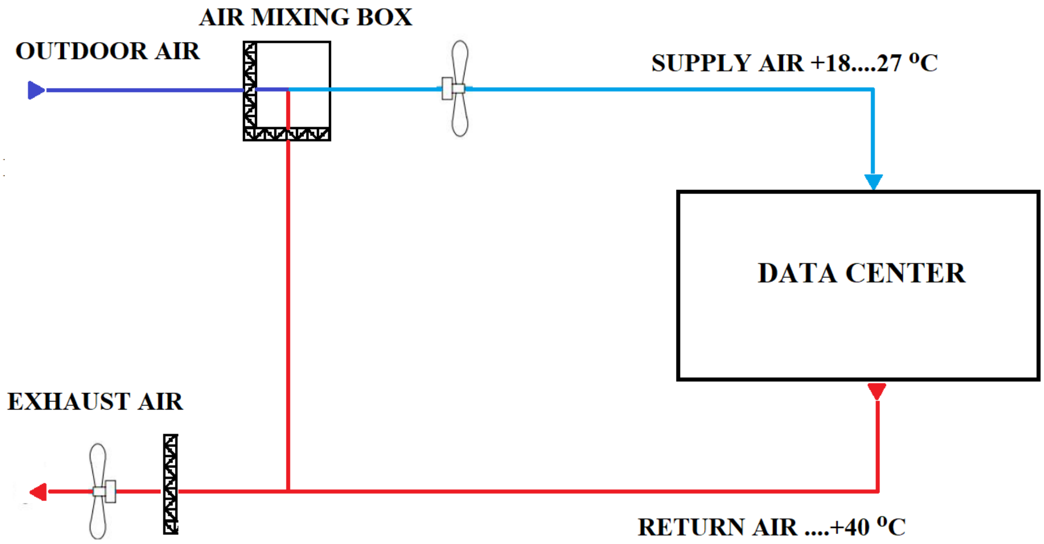

Fig. 4. Direct air cooling system [3].

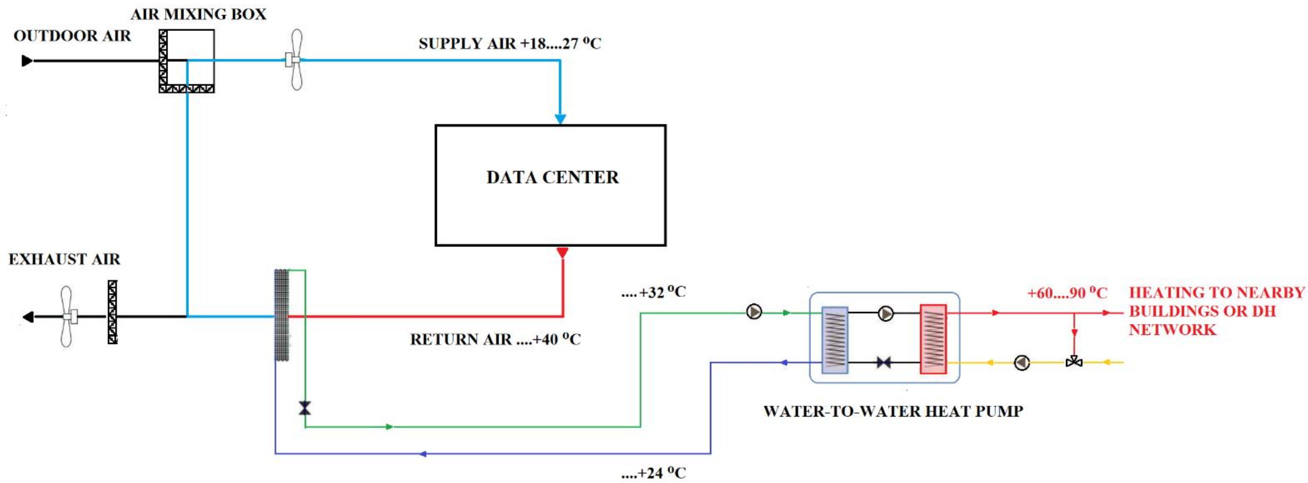

Fig. 5. The direct air cooling system with heat recovery unit [8].

IV. CONCLUSIONS

A novel heat recovery strategy is described in this paper for data centers. The strategy applies heat pumps to upgrade waste heat so the waste heat can be supplied to local district heating networks. The generated cooling energy from heat pumps can be directly used for cooling data centers. This novel strategy can be potentially implemented in any existing data center cooling system. The benefits the strategy could bring to the owners of data centers and energy companies are also introduced. The paper also describes a case study where the novel heat recovery strategy described in this paper (Fig. 1) was implemented in a real data center with over 1 MW IT load in Finland and the DH operator was assumed to pay electricity bill for heat pumps. From January to October of 2017, totally 11000 MWh waste heat was supplied to the local DH network from this data center. The simulation shows that annually 1131.2 tCO_2 can be reduced for the local DH network. Cooling could also be totally free for the DC. The novel heat recovery strategy can bring benefits to both DH operator and DC owner.

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REFERENCES

[1] A. Shehabi, S. Smith, D. Sartor, R. Brown, M. Herrlin, J. Koomey and W. Lintner, . “United States Data Center Energy Usage Report”, Ernest Orlando Lawrence Berkeley National Laboratory, 2016.

[2] P. Zangheri, R. Armani, M. Pietrobon, L. Pagliano, P.D. Milano, M.F. Boneta, and A. Müller, “Heating and cooling energy demand and loads for building types in different countries of the EU”, ENTRANZE Project, 2014.

[3] Granlund Oy, http://www.granlund.fi/en/sectors/data-center-mission-critical/, Finland, 2017.

[4] T. Mattila, The Finnish Datacenter Sector from the Invest-In Perspective. INVEST IN FINLAND", Finland, 2016.

[5] http://www.ilmastolaskuri.fi/en/electricity-consumption

[6] M. Wahlroos, M. Pärssinen, S. Rinnea, S. Syria and J. Manner, "Future views on waste heat utilization – Case of data centers in Northern Europe", Renewable and Sustainable Energy Reviews, vol 82, pp. 1749–1764.