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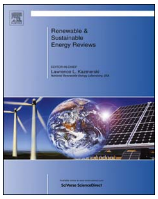

Future views on waste heat utilization – Case of data centers in Northern Europe

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ABSTRACT

In this study the potential for data center waste heat utilization was analyzed in the Nordic countries. An overview of upcoming data center projects where waste heat is utilized is presented. Especially in Finland data center operators are planning to reuse waste heat in district heating. However, business models between the district heating network operator and data center operator are often not transparent. The implications of economics and emissions on waste heat utilization in district heating were analyzed through life cycle assessment. Currently the biggest barriers for utilizing waste heat are the low quality of waste heat (e.g. low temperature or unstable source of heat) and high investment costs. A systematic 8-step change process was suggested to ensure success in changing the priority of waste heat utilization in the data center and district heating market. Relevant energy efficiency metrics were introduced to support rational decision-making in the reuse of waste heat. Economic calculations showed that the investment payback time is under the estimated lifetime of the heat pump equipment, when waste heat was utilized in district heating. However, the environmental impact of waste heat utilization depends on the fuel, which waste heat replaces.

1. Introduction

The issue of energy efficiency in data centers (DC) is an emerging concern, as more and more data is saved, processed and transferred to offer a multitude of digital services. It has been suggested that centralized DCs are more energy efficient than individual and distributed information technology (IT) [1]. It is estimated that DCs already accounted for 1.1–1.5% of the world's total electricity consumption in 2010 [2]; and in 2013, the IT sector represented 10% of the world's electricity consumption [3]. In addition to direct electricity consumed by the information and communication technology (ICT) hardware and basic infrastructure, DCs require vast amounts of cooling energy, typically produced with air conditioning units. The electricity consumed in a DC almost completely converts to heat. However, the heat is mostly not utilized, even though various solutions already exist.

Modern DCs can contain thousands of server racks, and the nominal power of DCs can be over 400 MW. This also means that the floor area of DCs is increasing, and the computing power of DCs continues to grow, resulting in increased energy consumption in DCs. The United States has had the highest electricity consumption worldwide (with a share of 25–35% of the total power consumption [2]) in the DC industry, but as the demand for data and energy efficiency in DCs keeps growing, more suitable locations for DCs are searched for.

There are several prerequisites for DC location. DCs require both cheap and reliable energy, a stable political environment, and a location near where the data is consumed in order to keep data transfer delays low. For remote areas (e.g., the Nordic countries), it is essential that telecommunication links are adequate for allowing efficient data transfer to other parts of the world.

The cold climate in the Nordic countries is extremely suitable for

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Abbreviations: ALCA, attributional life cycle assessment; CAPEX, capital expenditure; CFD, computational fluid dynamics; CHP, combined heat and power; CLCA, consequential life cycle assessment; COP, coefficient of performance; CPU, central processing unit; CRAC, computer room air conditioner; CRAH, computer room air handler; CSF, critical success factor; DC, data center; DCeP, data center energy productivity; DH, district heating; DSC, dynamic smart cooling; DWPE, data center workload power efficiency; ERE, energy reuse effectiveness; ERF, energy reuse factor; FVER, fixed-to-variable energy ratio; GRI, global reporting initiative; HOB, heat-only boiler; HP, heat pump; HPC, high-performing computing; ICT, information and communication technology; IT, information technology; NPUE, network power usage effectiveness; NZEB, net-zero energy building; OPEX, operating cost; PDE, power density efficiency; PPW, performance per watt; PUE, power usage effectiveness; RHI, return heat index; RTI, return temperature index; SHI, supply heat index; SLA, service level agreement; sPUE, system power usage effectiveness; TCO, total cost of ownership; WPE, workload power efficiency

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DCs by providing natural and cheap cooling energy. Furthermore, there is a high demand for heat in these countries and industrial waste heat is already utilized in different processes and district heating (DH) on a large scale, especially in Finland and Sweden. Waste heat in DH was 3.3% in 2015 [4] in Finland and 8% in 2014 in Sweden [5]. DH with highly efficient combined heat and power (CHP) is exceptionally common in Finland and Sweden. As the housing stock is becoming better insulated, DH networks are striving towards lower temperatures, which would enable feeding lower quality heat to the DH network. Therefore, there may be even more potential to utilize the waste heat from DCs in the future.

In this study, the current solutions and technologies in existing Nordic DCs and potential in the future were analyzed. The target was to give an example of an adequate solution for waste heat recovery and utilization both economically and technically, in the Nordic countries. In Finland, many DCs are built close to an existing DH network. Thus it is proposed that utilizing waste heat in DH networks would be economically the most viable solution. In Finland, the DH networks and DCs are owned by separate utilities. Therefore the benefits for both parties were evaluated and how the investments should be concluded between the parties were discussed. An 8-step systematic change process to overcome barriers is suggested. Available energy efficiency metrics were reviewed, and a subset of relevant metrics that provide data to support investment decision-making for both, DC operators and DH operators were suggested.

2. Literature review

Many studies concerning facility energy efficiency in DCs have been conducted recently. Most of the studies on the energy efficiency of facilities are related to efficient cooling systems, electricity consumption and integrating renewable electricity with DCs. Instead, reusing waste heat from DCs is studied less. But in recent years, research has become more topical and some case studies have been conducted.

To have a green and sustainable image, DC operators have different strategies for procuring renewable electricity. DC operators can produce their own electricity on-site or off-site, for example by solar or wind power, or they can purchase the electricity certified as green energy (green certificates, guarantee of origin, power purchase agreements, etc.). Goiri et al. [6] studied the scheduling of power demand with variable renewable generation to minimize the use of an electrical grid to supply power by implementing solar panels with DCs. Oro et al. [7] studied strategies for integrating renewable energy in DCs and suggested that electricity consumption in DCs should be dynamically modeled to truly understand the potential for increased energy efficiency.

One key question considering new DCs is the effect of location on DC energy efficiency. Depoorter et al. [8] studied the electricity generation portfolio, on-site generation, and cost of electricity in different locations. The results showed that implementing direct free air cooling could save from 5.4% to 7.9% of the consumed electricity depending on the location. In Sweden the electricity is considerably cheaper than in Germany, and a DC could save up to 42.5% in energy costs. The study also demonstrated that due to the high share of hydro power and nuclear power in Sweden, a DC in Stockholm would emit more than 30 times less CO_2 than a DC located in London, according to the calculations. However, due to international electricity transmission connections, comparing emissions of national electricity production mixes is questionable.

There is not a single method for reusing waste heat, and different applications and scales of utilization have been investigated. Marcinichen et al. [9] showed that low temperature waste heat from a DC could be used in preheating feed water of a power plant. Utilization would lead to fuel savings in the power plant and increase the efficiency of the power plant by up to 2.2%. Ebrahimi [10] studied waste heat utilization through absorption cooling machines. The study showed that the payback time for retrofitting an absorption system can be as low as 4–5 months in a 10 MW DC.

Lu et al. [11] evaluated energy efficiency in real DCs in Finland and the potential for capturing waste heat. The study showed that 97% of the power consumption could be captured as waste heat. The study concluded that waste heat at a 1 MW DC, operating at half of its nominal load, could fulfill the heat demand for over 30,000 m^2 of non-domestic buildings annually. Sorvari [12] studied waste heat reuse in heating a spa and rental cottages in Northern Finland. The results suggested that the DC waste heat would satisfy the heat demand almost completely for over 60,000 m^2. Kupiainen [13] compared two different cooling options for a DC in the Futura building in Jyväskylä in Central Finland. The combination of free cooling with heat pumps (HPs) resulted in €280,000 lifetime savings in 20 years compared to a free cooling and refrigeration machine.

Stenberg [14] simulated a 3 MW DC in Helsinki, Finland. An optimal set-up for temperatures for utilizing the waste heat in a computer room air handler (CRAH) cooled DC was studied. The results of the study showed that utilizing the waste heat could result in lifetime savings of millions of euros with a lifetime of 20 years. The most cost-efficient system would be a HP priming the waste heat to 75 °C and selling heat to either the supply or return side of a DH network depending on the outside temperature. Investment costs for HPs which increase the temperature up to 75 °C (coefficient of performance (COP) 3.5) are €420,000 higher than in the reference case where the cooling of the server room is conducted by free cooling and waste heat is not utilized. As the HPs were used for cooling the server room, it increases the annual electricity consumption by over 4 GWh compared to the reference case, which increases the costs. Nonetheless, the annual revenue from selling the waste heat to a DH network would be close to €600,000 in this case. All in all, the study suggests that the payback time of the cooling equipment investment would be less than 2 years, as the revenues from selling the heat are larger than the additional electricity costs, investment costs, and operational and maintenance costs.

Davies et al. [15] studied the possibilities of DH networks in London and the potential for waste heat utilization. The possible savings of waste heat reuse in a DH were calculated assuming that the waste heat would replace natural gas based heat production. The study showed that using liquid cooling in DCs would generate the most savings in energy as well as in carbon savings. The cost savings in this case could be over £875,000 in the case of a 3.5 MW DC. In the UK, the DC heat could be categorized as waste heat and could in that case be eligible for the Renewable Heat Incentive, thus further encouraging the use of DC waste heat.

Based on the literature review, both technical solutions for waste heat utilization and case studies have been conducted. But commercialization of waste heat has hardly been done, even though the studies that have been made show that waste heat reuse results in significant savings in energy costs with considerably low payback periods. Real-life pilots and the amount of waste heat based on real data have hardly been discussed in the media, making it especially difficult to analyze the true utilization rate of the waste heat. Finnish DCs are beginning to increase transparency by bringing out the volumes of heat captured in an actual DC. Thus in this study, some of the most interesting new projects in the Nordic countries and their plans for utilizing waste heat were presented.

3. Methodology

The potential for waste heat utilization from DCs was analyzed by conducting a literature review on cooling technologies and solutions for waste heat utilization. In addition, some of the most interesting projects currently related to DC waste heat utilization in the Nordic countries are analyzed through available online sources and literature. Furthermore, the methodology behind analyzing energy efficiency