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Direct Excess Heat Utilization from a High Performance Computer in an Existing Unrenovated Building: A Case Study

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Summary

This study quantifies the savings potential of fossil district heat for the case study of the architecture building of the Technische Universität Darmstadt by directly using excess heat of a high performance computer (HPC). It is based on the already implemented demonstrators of a hot-water-cooling system for the new HPC and on the integration of low temperature ceiling heating systems in the otherwise unrenovated architecture building. As a result, with an excess heat utilization rate of 52 %, more than 60 % of the fossil building's district heating demand can be saved.

Keywords: excess heat utilization, low temperature heating, high performance computer, building renovation

1. Introduction

For the decarbonization of the building sector, there is no alternative to reducing the demand for fossil fuels. Currently, about 75 % of the German building stock is heated with natural gas or oil (dena, 2021). The current energy crisis has further increased the urgency of substituting fossil fuels. Accelerated and comprehensive implementation of alternative heat supply concepts through increased use of renewable energies and excess heat in buildings is a key to this. Whereas new buildings have very good energetic properties, existing buildings often have high specific heat demands and make up the majority of the current building stock. Additionally, old buildings also require high supply temperatures, thus it is difficult to supply them with renewable heat that can mainly only be used efficiently at lower temperatures.

The advancing digitalization leads to an increasing growth of data center capacities, resulting in an increasing demand for electric energy (Hintemann, 2020). The resulting excess heat is mainly dissipated to the environment. This increasing potential can be used as a valuable resource to cover the heat demand of adjacent buildings. To balance the differences between demand and supply and to increase the potential of excess heat utilization, low-temperature district heating networks are well suited. In existing district heating networks, the connected buildings have to be addressed first to reduce the temperature levels (Averfalk et al., 2021).

2. HPC excess heat utilization

Data center excess heat temperatures depend strongly on the implemented cooling technologies, which can be divided into four different approaches. The most common is server cooling via the data center room air, using computer room air handlers or computer room air conditioners. The second method cools the air locally at the server through rear door air-water heat exchangers. The third method is a combination of direct water-cooling of the hottest server components and air-cooling for the remaining parts. The last approach is to fully emerge the server in a dielectric fluid. While the most widespread

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heat transfer medium is air, water-cooling offers many advantages. It reduces the additional energy required for cooling, enables higher power densities, and allows higher excess heat temperatures (Davies et al, 2016).

According to Ebrahimi et al. there are several possibilities to utilize data center excess heat: space heating and hot water preparation, district heating, power plant co-location to preheat boiler water, absorption refrigeration, Organic Rankine Cycles, piezoelectrics, thermoelectrics, biomass co-location and desalination. When using the excess heat to supply buildings, heat pumps are often used to raise the temperature level to meet the building's requirements. In newer buildings, direct excess heat utilization without heat pumps is usually possible (Ebrahimi et al., 2014).

In this work, only excess heat utilization for the provision of space heating is investigated, since the HPC is located in close vicinity to larger university buildings. In addition, direct excess heat utilization without the use of heat pumps is particularly energy efficient.

3. Temperature reduction in buildings

Decarbonization of the heat demand in existing buildings can be achieved by saving heat through measures to improve the energetic quality of the building envelope. This has been sufficiently researched and is state of the art. However, if an increased substitution of heat demand with renewable heat is aspired, the level of system temperatures is the key target. Renewable excess heat potentials, which are often at a low temperature level, can only be used efficiently by reducing the temperature in the building heating system.

In order for renewable heat to be efficiently integrated into building energy systems, it is important that the return temperature is as low as possible in addition to the level of the supply temperature. Various structural and operational measures can be used to reduce system temperatures in building heating systems to different degrees. A low-investment measure is the installation of string-balanced valves and pre-set radiator valves including a hydronic balancing of the heating system (Schmidt et al., 2017). Based on this, the heating curve can be lowered step by step. By replacing critical or undersized radiators, the supply and return temperature for the entire building can be reduced (Østergaard et al., 2016). A great temperature reduction can be achieved once by refurbishing the building envelope and thus reducing the heating load. Another strategy is to increase the heating surfaces by installing surface heating systems, which allows the same heating load to be delivered at a lower temperature (Lund et al., 2014; Sauerwein et al., 2023). The implementation of surface heating systems in new buildings is state of the art. Particularly for the use of ceiling heating systems in the unrenovated non-residential building stock, there are often concerns regarding negative effects on thermal comfort.

4. Implementations at Technische Universität Darmstadt

As part of the "EnEff:Stadt Campus Lichtwiese" research project, a concept for the excess heat utilization of the HPC located on the campus “Lichtwiese” of Technische Universität Darmstadt was developed (Oltmanns et al., 2020) and subsequently implemented. To ensure high excess heat temperatures, the HPC is cooled via hot-water-cooling (Fig. 1 left). The excess heat is further upgraded via a heat pump and eventually fed into the return line of the university’s district heating network. This setup needs additional electric energy to use the excess heat, but because of the high excess heat temperatures, the operation of the heat pump is very efficient. Since the excess heat utilization went into operation in the beginning of 2021, an average COP higher than 5 could be achieved (Feike et al., 2021).

To analyze and optimize this concept, an additional monitoring system was implemented. Among other parameters, the available excess heat of the HPC as well as the corresponding temperatures are measured, which fluctuate depending on the computational load of the HPC (Fig. 2 left). The excess heat varies quite strongly between 160 kW and 410 kW with an average output of 351 kW. The fluctuation of the excess heat temperature is relatively small in a range between 45 °C and 52 °C with an average value of 47.2 °C.

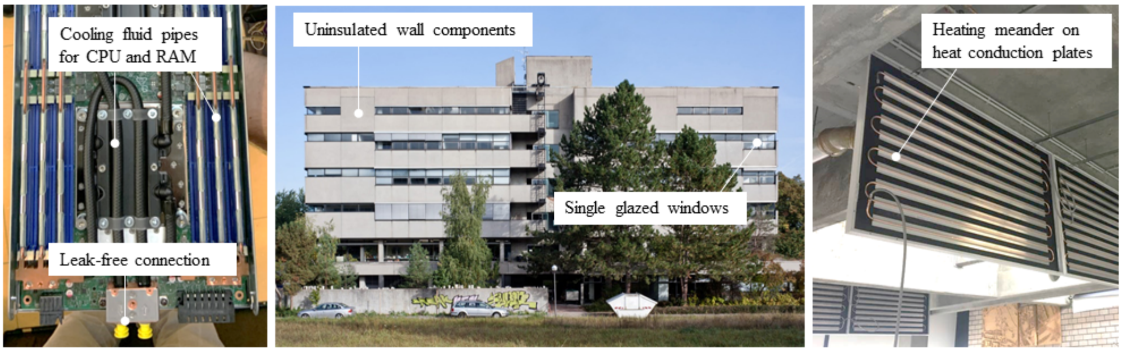

Fig. 1: Hot-water-cooling on a server blade (left), listed architecture building (source: Jakob Philipp Weise) (middle), integration of ceiling heating panels (right)

In another part of the research project, the potential for temperature reduction in unrenovated existing buildings by installing a low-temperature heating system inside the listed architecture faculty building (Fig. 1 middle) is investigated. Space heating is covered by ceiling heating panels (Fig. 1 right) together with the existing radiators at the same temperature level. This makes it possible to achieve a high level of thermal comfort even for workplaces close to the facade: In addition to a reduced cold air drop in the window area, the radiation temperature asymmetry between the cold facade and the warm ceiling is effectively limited. In operation, it was possible to reduce the supply temperature by more than 30 K to 45 °C at very low outside temperatures (Fig. 2 right), while complying with normative thermal comfort requirements (ISO 7730).

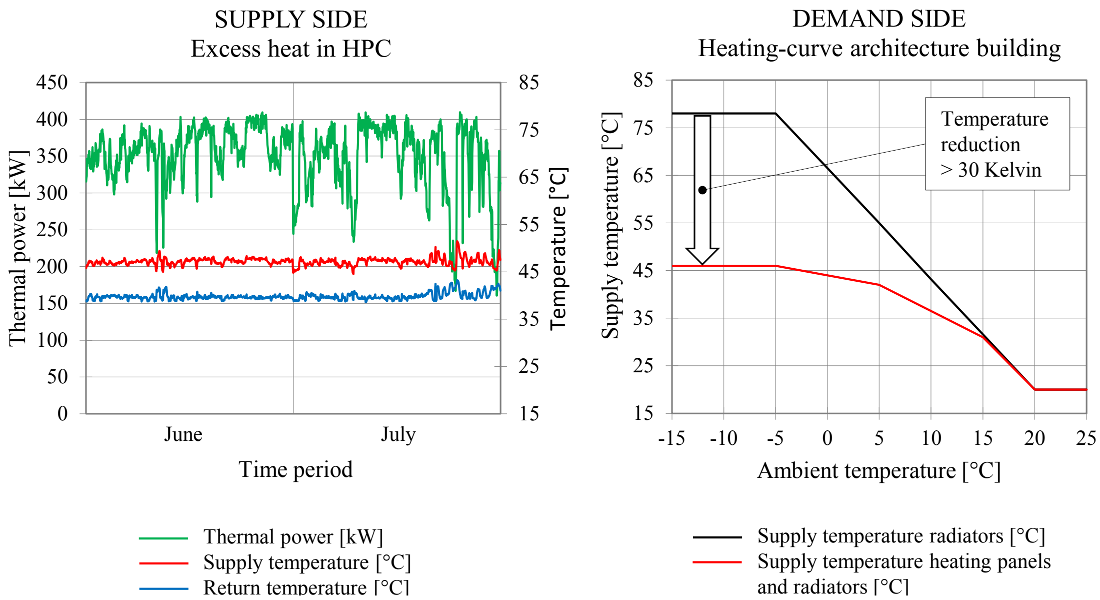

Fig. 2: Supply side: Excess heat HPC (left), Demand side: Heating-curve architectural building (right)

5. Direct utilization of excess heat

Based on measured data during the operating phase regarding the excess heat potential of the HPC and the low-temperature compatibility of the architecture building, the interconnection of supply and demand by a direct excess heat utilization shall now be investigated (Fig. 3).

For this purpose, the share S_u of usable excess heat Q_u in the available excess heat Q_a and the share S_d of usable excess heat Q_u in the total heat demand of the building Q_d is quantified in the following according to (eq. 1) and (eq. 2).

$$S_u = \frac{Q_u}{Q_a} \qquad \text{(eq. 1)}$$

$$S_d = \frac{Q_u}{Q_d} \qquad \text{(eq. 2)}$$

On the supply side, a temperature loss of 2 K per heat exchanger and distribution losses in the pipes of 5 % are assumed. This reduces the average heat output on the building side to 334 kW at 43 °C. For the demand side, an annual load curve, mass flows and system temperatures are thermally simulated in hourly resolution using a validated building model in the software IDA-ICE 4.8. The heating loads are primarily covered by excess heat. If the temperature level of 43 °C is not sufficient, or the heating load exceeds the available excess heat capacity, the remaining heat demand is covered by district heating (Fig. 3). The calculations were first carried out with the average values of the excess heat power and temperature and in the next step with the dynamic, fluctuating measured values. For this purpose, an annual profile was extrapolated from the measured data for June and July 2022, because the HPC was operated as intended during this time period.

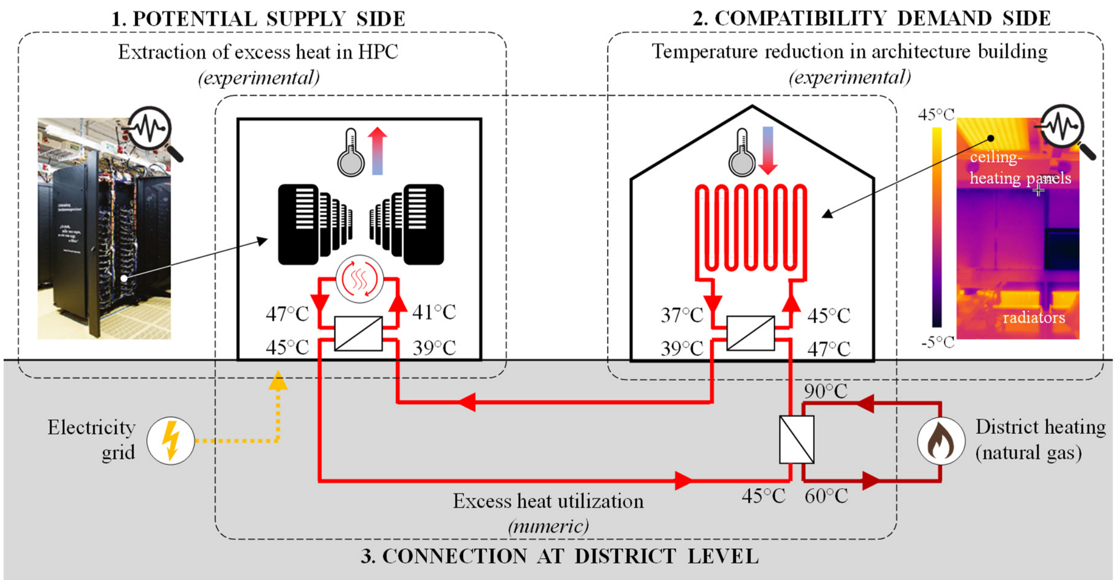

Fig. 3: Energy concept and research design of direct excess heat utilization in the architecture building

6. Evaluation and conclusion

The results show that approximately 63 % (S_d) of the total annual heat demand can be substituted directly by usable excess heat of 1,527 MWh/a. The remaining demand of 910 MWh/a (37 %) must be covered by fossil district heating. Due to the seasonal discontinuity of the heat demand approximately 52 % (S_u) of the available excess heat of the HPC can be used (Fig. 4 left). In winter, S_u reaches 98 %, but in summer S_u drops to 0 % because of non-existent heat demand. In this case, the available excess heat has to be dissipated to the environment via free cooling. In the comparison between the calculation approach with average or fluctuating values for the excess heat power and temperature, only marginal differences of less than 0.5 % are found.

Considering the unrenovated building envelope and the unchanged high heating loads, the result of this study is encouraging: By integrating low-temperature ceiling heating systems, excess heat can be efficiently integrated into the heat supply at a low temperature level and more than half (63 %) of the demand for fossil district heating can be replaced.

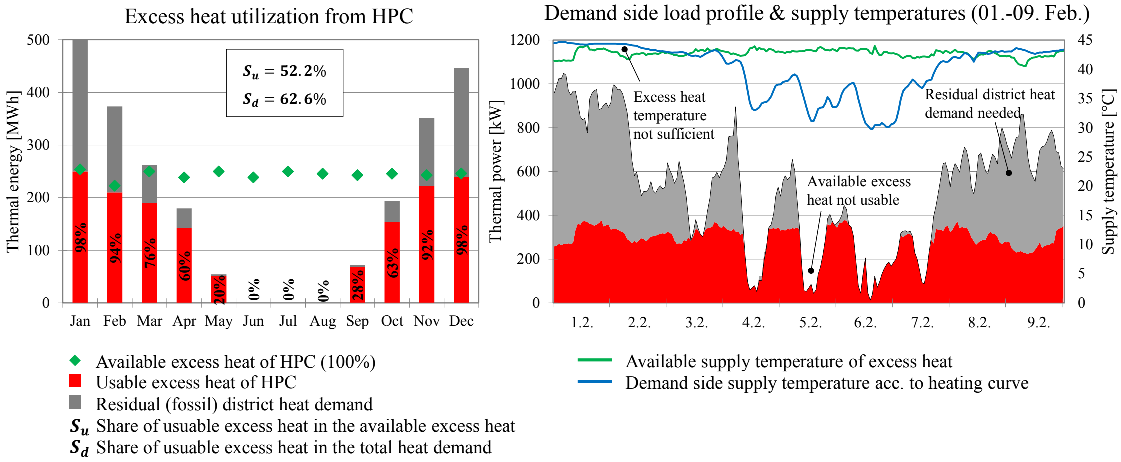

Fig. 4: Excess heat utilization from HPC (left), demand side load profile & supply temperatures (right)

The results also show, that for the decarbonization of heating networks through increased integration of renewable (excess) heat, the temperature reduction potential on the building side should also be considered. A holistic planning of district energy systems should integrate actors from the energy supplier side as well as from the building side into the planning process at an early stage.

In this case, a static calculation based on mean values is legitimate for quantifying the share of excess heat utilization and the share of heat demand covered by excess heat. The calculation considering a dynamic profile has less impact on the characteristic values than initially expected. In times of high heat demand, which have a particularly dominant effect on the characteristic values, the complete excess heat can be used regardless of whether it has a constant or fluctuating character.

Compared to solar thermal potentials, the results show a comparatively high excess heat utilization potential, since the supply profile does not show any seasonal characteristics.

7. Outlook

The knowledge gained from this study will be used to implement direct excess heat utilization of the HPC in the nearby test halls in the next phase of the research project and to determine the actually usable excess heat potential. Furthermore, it is of interest to what extent the district heating demand can be additionally reduced by increasing the degree of excess heat utilization through load shifting measures during the transitional seasons.

In the context of the rapid expansion of data center capacities, their excess heat should also be increasingly used to heat buildings. The implementation of hot-water-cooling significantly improves the possibility to do so.

More surface heating systems should be installed, especially in existing buildings, in order to be able to integrate more local renewable (excess) heat. This should also be done if a facade renovation is not (yet) possible. In the sense of a strategy of "small steps" this can be a cost-effective option on the way to complete renovation.

As an alternative to the concept described here, buildings that still require very high supply temperatures can be supplied by decentralized heat pumps that use excess heat as a heat source. This could lead to a complete substitution of fossil fuels.

Considering the excess heat availability outside the heating season, the use of a seasonal low-temperature heat storage could also increase the coverage rate of the heat demand.

8. Acknowledgements

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