Principles of Hot-Water Cooling

Green Supercomputers

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Abstract

As the need for efficient cooling solutions for use in datacenters and HPCs always increases, hot water cooling provides a solution that is both energy efficient and not very expensive to implement compared to other solutions. Hot water cooling uses water at temperatures between 40 and 65 °C to cool processing components in datacenters and HPCs. This way, a portion of the heat energy generated by the processor can be reused as an energy source in different approaches. This increases the energy efficiency significantly while lowering the carbon footprint at the same time. Some ways to reuse the energy will be discussed alongside general benefits and difficulties/challenges.

Contents

1 Introduction

As computer systems become more and more dense, the heat production per area increases dramatically and currently, 30 kW of generated heat per rack isn't unusual. A survey by PRACE revealed, that the average heat density per rack equals 10 kW/rack while most systems had more than 20 kW/rack installed. Plans for the future include heat densities up to 45 kW/rack. Thus, the need for appropriate cooling solutions gets greater than ever before. 70 % of the surveyed centers have less than 2 MW of cooling power installed while plans for the future are that 30 % wil have more than 10 MW [1]. In today's datacenters and high performance computers, cooling the processing units and other heat producing components actually takes up up to 40 % of the total energy consumption [1]. In (year) a total of $25,000,000,000 was spent on the power and cooling of datacenters and HPCs [4] and the trend goes towards even higher costs. Unfortunately, although the amount of heat energy generated by datacenters and HPCs is immense, most of the energy goes into the air and isn't put to use again. Not only does this make a bad impact on the carbon footprint but it is also a huge waste of money and power. First improvements about cooling efficiency were made when water cooling was applied. As it gets harder to manage the airflow appropriately the denser a system gets packed, water cooling gets favorable over a comparable air cooled solution. Also, water has a much higher heat conductivity than air at $0.65\ \mathrm{W\,m^{-1}\,K^{-1}}$ compared to $0.0262\ \mathrm{W\,m^{-1}\,K^{-1}}$. As the heat sinks used for water cooling are smaller than their air cooled counterparts, water cooling solutions allow for even more densely packed systems. Hot water cooling is a new solution that makes enormous energy savings possible. A hot water cooling setup utilizes the fact that most processor used in datacenters and HPCs run stable at temperatures up to 80 °C while the power consumption doesn't increase very much when going to higher running temperatures. Thus, hot water cooling has many advantages regarding energy reuse and improving the carbon footprint.

2 Setup

A hot water cooling setup is very similar to a normal water cooling setup in general, but some details are quite different. The water runs through a heat sink that is applied on top of the processor, gets heated up, leaves the computer, is cooled down again to the inflow temperature and the cycle repeats. In a hot water cooling setup, some of these steps are executed differently than in a normal water cooled solution. The main difference is the way the water gets cooled. In a normal water cooling setup, the water gets cooled actively and doesn't do any useful work. When using hot water, the outflow temperature is high enough to allow for reusing the heat energy while the water gets cooled down at the same time [3].

Another great difference lies within the heat sink. Hot water cooling heat sinks use a network of fine micro channels that are engineered to mimic the human blood system to dissipate the heat. This helps maximizing the heat flow and thus the heat dissipation efficiency (Fig. 1). The heat exchanger that cools the water down to the inflow temperature is mostly not a real discrete heat exchanger when it comes to hot water cooling. Instead, the water serves as a heating agent for an under-floor heating in a building for example or powers an adsorption chiller/trigeneration plant while cooling down. In general, a hot water cooling setup can be applied as a replacement of an existing air-cooled solution by removing the heat sinks and exchanging them to the hot water cooling ones. This method was used in the iDataCool experiment for example [4].

Otherwise, this type of setup can also be implemented directly when building a datacenter/HPC as it was done at the SuperMUC Supercomputer at LRZ. [3]

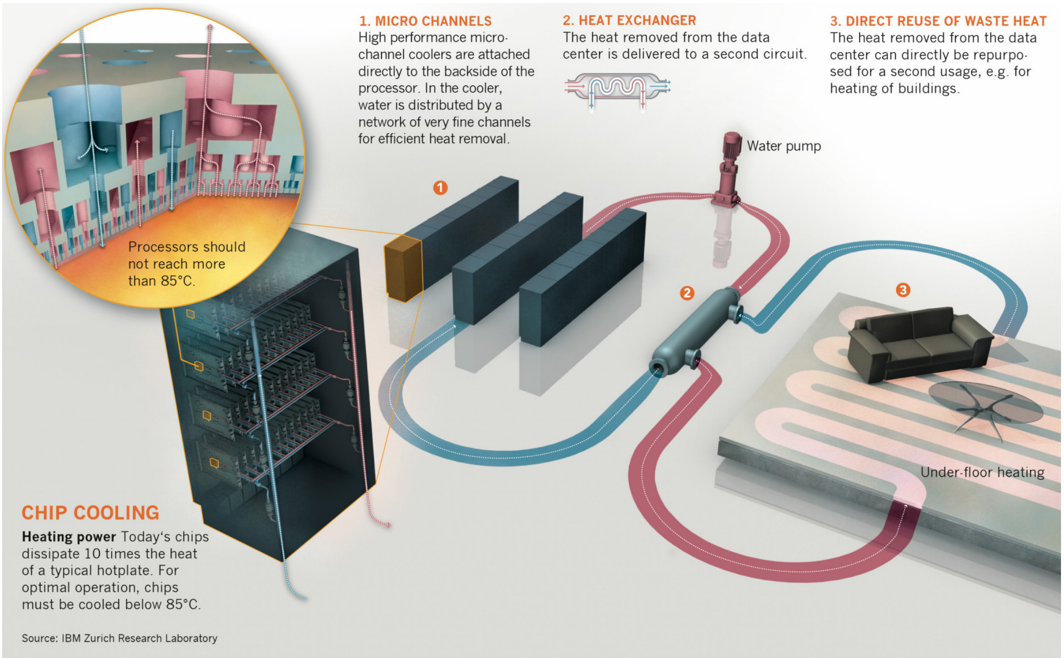

Figure 1: Water circuit at LRZ [5]

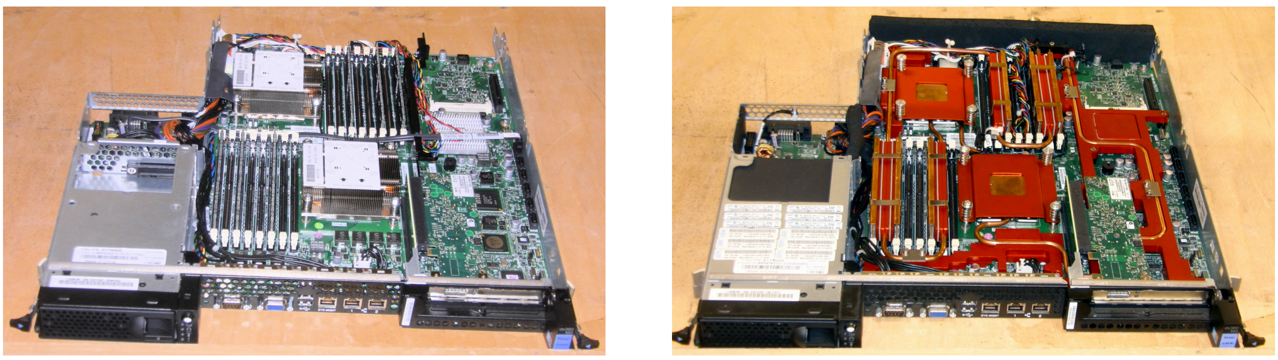

Figure 2: Left: Original air-cooled iDataPlex dx360 M3 compute node. Right: iDataCool compute node with new water-cooling solution, consisting of a copper pipeline, copper heat sinks for processors and memory, and aluminium heat bridges. [4]

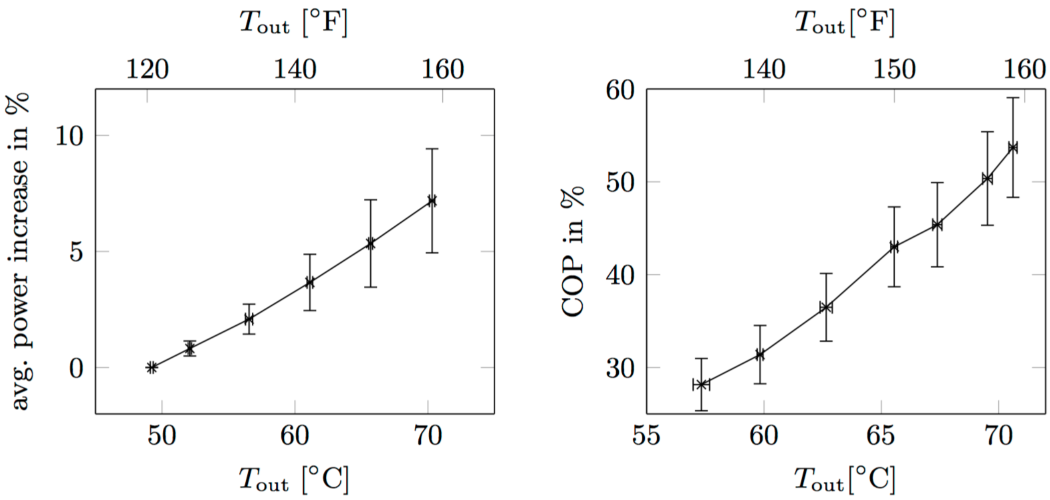

Figure 3: Relative node power increase for 13 nodes with six-core E5645 processors and COP (coefficient of performance) of adsorption chiller [4]

3 Benefits

Hot water cooling has many different advantages to it, as for example the opportunitiy to reuse the heat energy as the main benefit, and both the efficiency improvement of the overall setup and lowering the carbon footprint as well. The extent, to which the energy from the hot water can be reused, depends highly on the outlet temperature. Temperatures above 45 °C allow for using the water as a heat source for buildings which saves money on heating costs. Above 55 °C the water can be used to power adsorption chillers, that basically use the heat energy to cool another medium, similar to a fridge, but with the difference that a fridge uses electricity while adsorption chillers actually use heat energy. Trigeneration plants take this concept one step further. They use the heat energy to produce electricity, heat up and cool down other mediums at the same time. Trigeneration plants require even higher outlet temperatures to work. But one thing that is always to be kept in mind is that the processors limit the maximum outlet temperatures as they work only at temperatures up to 85 °C. But in general, the higher the outlet temperature is, the more heat energy can be reused and the higher are the energy savings and efficiency improvements.

Even when no system is implemented to reuse the heat, hot water cooling still saves energy. This is due to the fact that cold water cooling requires active compressor based cooling solutions to cool the water down to the inlet temperature. From 40 °C upwards, hot water cooling allows for free re-cooling using outside air all year in most geographic regions. Thus the need for energy hungry compressor based re-cooling solutions is eliminated. A more trivial advantage is the fact, that using cold water may let water vapor from the air condensate on the tubes, and condensation is always to be avoided in computer systems for obvious reasons [1].

The achievable efficiency improvement is enormous. For example, measurements at the SuperMUC supercomputer with its Aquasar hot water cooling system sshow energy savings up to 40 %. Here, the water is used to heat the LRZ buildings. In addition, LRZ expects savings of several millions of Euros in cooling costs [3].

The iDataCool experiment used an adsorption chiller to reuse the heat energy from the system and measured its efficiency increase relative to the power consumption increase of the processors when increasing the water temperature. The results are displayed in Fig. 3 and they clearly show that the adsorption chiller's coefficient of performance increases by 90 % while the power consumption only increases by 5 %. This is a perfect example how energy reuse improves when running at higher water temperatures.

The carbon footprint is a way to measure the environmental impact of a system and is mainly influenced by the overall energy consumption. Therefore, implementing a hot water cooling solution helps bringing the environmental impact way down, for example SuperMUC's Aquasar cooling system was able to reduce the carbon footprint of the LRZ by up to 85 %. While the input power of the supercomputer remains the same, less energy is required to re-cool the outflowing water and surrounding buildings are heated with the hot water from the system which also reduces the overall energy consumption [3].

4 Users and experiments

Hot water cooling is actually very rare to find yet, but there are some experimental setups and some real implementations in HPCs. Some of them will be listed below.

iDataCool is an HPC architecture that was developed at the University of Regensburg in co-operation with the IBM Research and Development Lab Böblingen. It is based on an iDataPlex platform from IBM, whose air-cooling solution was replaced. The custom hot water cooling solution that was installed allows for water temperature of up to 70 °C. The heat energy is reused through an adsorption chiller which provides cool water for other components of the computing center [4].

QPACE 2 is a custom-designed supercomputer that was developed in a collaboration of the University of Regensburg and Eurotech. It is based on Intel Xeon Phi processors and is used for large-scale lattice QCD simulations. QPACE 2 uses hot water at at least 50 °C for cooling which makes free cooling possible all year. This way, no additional energy has to be used for re-cooling purposes [2].

The last example is the SuperMUC[1] supercomputer that was alreasy mentioned a few times and which was the fastest supercomputer in Europe the time it was built. Its Aquasar cooling system was developed by IBM and operates at up to 60 °C inflow temperaure. The energy efficiency is 40 % higher and the carbon footprint 85 % better than it would be the case with a comparable air cooled solution [1].

5 Challenges

No technology is flawless and although hot water cooling has many strong advantages, some of its downsides have to be taken into account, too. If hot water cooling is implemented as a replacement of an existing air cooled solution, the thermal insulation is rather imperfect and there are little or even no options to improve it. This leads to a loss of heat energy to the environment which limits the heat energy that is available to be reused. Thus, the overall efficiency improvement is not as high as it could be [4]. As great as the benefits from the special heat sink design are, at first it has to be designed and the system has to be prepared to provide compatible cooling loops [1]. Like it is the case for ordinary water cooling systems, the water circuit must not show any leakage due to obvious reasons. The long-term reliability of the system may be harmed due to corrosion so further testing is needed. One advantage of hot water cooling also has a downside to it: As the system can be more densely packed, maintenance becomes very complicated. If something needs to be replaced or if upgrades are to be installed, everything has to be disassembled which takes much time.

[1] You can get additional information about SuperMUC on its own website [3]

6 Conclusion

All in all, it should be clear, that hot water cooling provides a greener and more efficient alternative to regular cold water cooling as long as datacenters and HPCs are concerned. Of course it won't be a practicable cooling method for ordinary home-based PCs and smaller servers, but on larger scales it makes enormous energy and money savings possible. Although there are some challenges related to hot water cooling, the technology still is a promising choice for future investments. More experiments and tests will definitely contribute to the technology.

References

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