Direct Warm Water Cooled Linux Cluster Munich: CooLMUC - a PRACE-Prototype System at the Leibniz Supercomputing Centre (LRZ) to Explore the Re-use of HPC System Waste Heat for Heating and Cooling

In addition to the pure computational power, energy consumption of HPC systems has recently become an important measure for the comparison of supercomputers [1]. As the energy necessary to operate supercomputers is the sum of the energy consumed by the computer itself and the energy necessary to cool the system, many HPC vendors and technology providers are currently investigating measures to minimize the total data centre power consumption [2] [3]. Researchers from IBM Rüschlikon demonstrated recently with the Aquasar prototype that the concept of hot water direct chip cooling and re-use of the waste heat for building heating can be effectively used to lower the carbon footprint of data centres [4].

With the direct warm water cooled MEGWARE CooLMUC cluster jointly funded by the Bavarian State Ministry of Sciences, Research and the Arts (StMWFK), the German Federal Ministry for Education and Research (BMBF) and the European Commission (EC), we actively investigate to what extend the energy efficiency of supercomputing centres can be improved by using this novel cooling technique. In addition, we also explore the possibilities of re-using the waste heat of the prototype system for heating and cooling. For that reason, the waste heat outlet of the CooLMUC system shown in Figure 1 is connected to an adsorption chiller (blue box on the left hand side of the picture) as well as the LRZ building heating system.

Figure 1: The MEGWARE CooLMUC PRACE-1IP prototype at Leibniz Supercomputing Centre - proof of concept for the re-use of waste heat for heating and chilled water generation.

Advantages of Direct Warm Water Cooling

Table 1 compares the thermal attributes of air and water. Due to its better thermal conductivity and larger volumetric heat capacity, the thermal inertia or cooling efficiency of water is by a factor of more than 300 larger than the thermal inertia of air. The 300-fold better cooling efficiency of direct warm water cooling provides the following advantages:

- Lower power consumption and hence better energy efficiency

- Realization of ultra-high compute power and electrical power densities per rack
- Very low data centre PUE due to year-round free cooling of IT systems regardless of local clime
- More possibilities for effective re-use of system waste heat

	Air [20°C]	Water [20°C]
Thermal conductivity [J/(m*K*s)]	0,026	0,598
Volumetric heat capacity [J/(m3 * K)]	1213	4174472
Thermal inertia [J/(m^2 * K * s$^{1/2}$)]	5,09	1579,98

Table 1: Air versus water – a comparison of thermal attributes

CooLMUC System Design

CooLMUC is the first AMD processor based direct warm water cooled cluster worldwide. The system comprises of 178 dual socket compute nodes with 2.0 GHz AMD Magny Cours processors and 16 GByte of main memory. The main interconnect network is realized through Infiniband QDR using a fat tree topology. In addition, each node has two Gbit Ethernet ports for IPMI and a service network which is used to boot the diskless nodes and to provide the root file system over NFS. A network bridge component connects the Infiniband network to the upstream Ethernet services at LRZ.

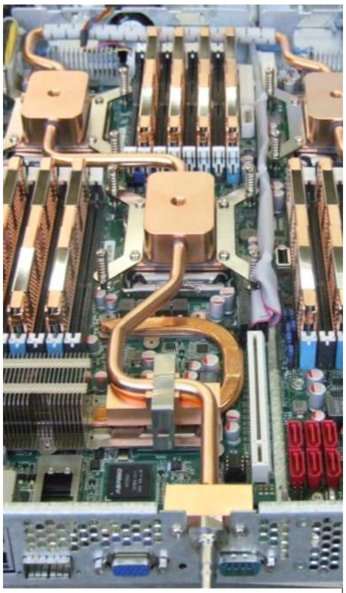

Figure 2: Top view of a CooLMUC compute node

As shown in Figure 2, the CPUs, the memory modules, chipset and the IB chips of the compute nodes are direct water cooled. The 3 compute node racks shown on the right hand side of Figure 1 are closed in order to separate the air flow in the racks from the air flow in the computer room. Each rack contains two evaporator modules from KKU [5] shown in Figure 3 for air cooling of not direct water cooled components. These novel modules use the direct evaporation of a refrigerant agent for the continuous cooling of the rack air. Hence the MEGWARE ColdCon system packaging and cooling concept [6] allows for operation of the CooLMUC cluster without any room air conditioning.

Figure 3: KKU RCL evaporator modules for rack air cooling

For the proof of concept for the re-use of waste heat for chilled water generation and heating as well as to measure the total energy needed to run scientific simulations (energy to solution), the prototype is equipped with fine-grained power monitoring and management tools. Parameters that can be controlled by this system range from automatic over-clocking/down-clocking of single compute nodes to the controlling of the entire cooling apparatus to meet the temperature requirements of the consumers of the dissipated waste heat.

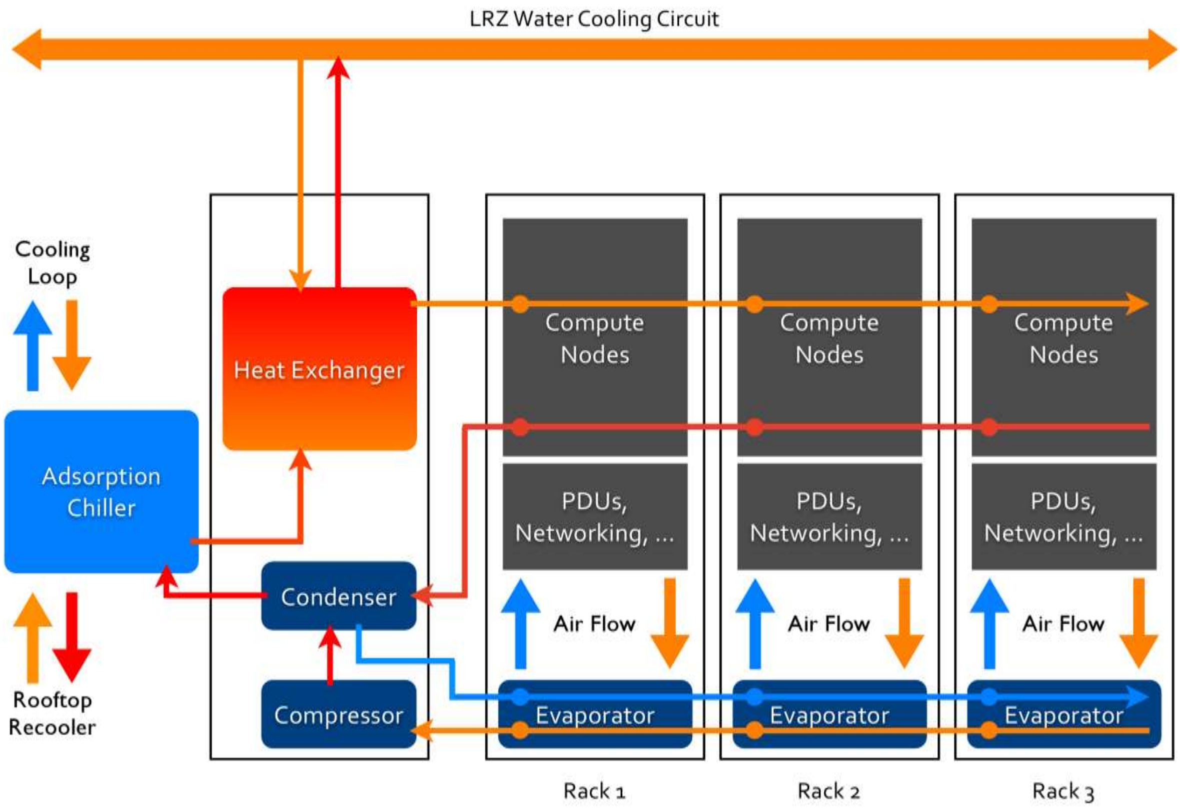

Figure 4 CooLMUC cooling scheme. The completely closed system is connected to the LRZ warm water cooling loop by means of a water-water heat exchanger. An additional water loop leads to the roof for recooling the adsorption chiller.

Figure 4 shows the CooLMUC cooling scheme. The completely closed system is connected to the LRZ warm water cooling loop by means of water-water heat exchangers. One loop provides water at 40°C directly to the nodes where the flow runs through copper pipes connecting special heat sinks on top of CPUs, memory modules, chipset and Infiniband HCAs. A second cooling loop based on standard compressor based cooling technology serves the in-rack evaporators that generate an airflow from the rear part of the racks to the front while at the same time re-cooling the air to the set temperature of 30°C. This is used to cool the remaining air cooled components of the prototype system. In order to use the heat collected from both cooling circuits to drive the adsorption chiller, the condenser of the second cooling circuit is cooled with water originating from the first cooling loop's outlet. This way, water inlet temperatures to the server of 40°C allow supply temperatures of 60°C to the adsorption chiller. Adsorption chillers work in a three phase cycle: In the first cycle, a refrigerant is evaporated to provide the cooling. The refrigerant is then adsorbed onto a silicate surface. Using the hot water from our cluster, the chamber is being re-activated (desorption). In the last step, the chamber is freed from desorption heat through a rooftop recooling loop before the refrigerant can evaporate again.

First Results on the CooLMUC Platform

In a first set of experiments, we intended to show the advantages of direct liquid cooling over traditional air cooled systems. For this, we compared the CPU temperatures and power consumption of a water cooled node of CooLMUC to an air cooled node with similar hardware when running under full load (mprime stress test). Figure 5 shows the results obtained for air cooling at 23°C, a quite typical temperature for computer rooms today, in comparison to direct water cooling with water inlet temperatures of 30°C, 40°C and 50°C. The experiment shows that water inlet temperatures of even 40°C are sufficiently low to keep the CPU temperatures in the same range than air-cooled systems using 23°C cold air. Thus, direct water cooled systems can be operated year-round with free cooling only. Also, the power consumption of the air cooled node is higher due to the requirement of additional chassis fans. The slight increase of power consumption at higher water inlet temperatures can be explained with the occurrence of leakage currents in the CPUs which increase with the operating temperature.

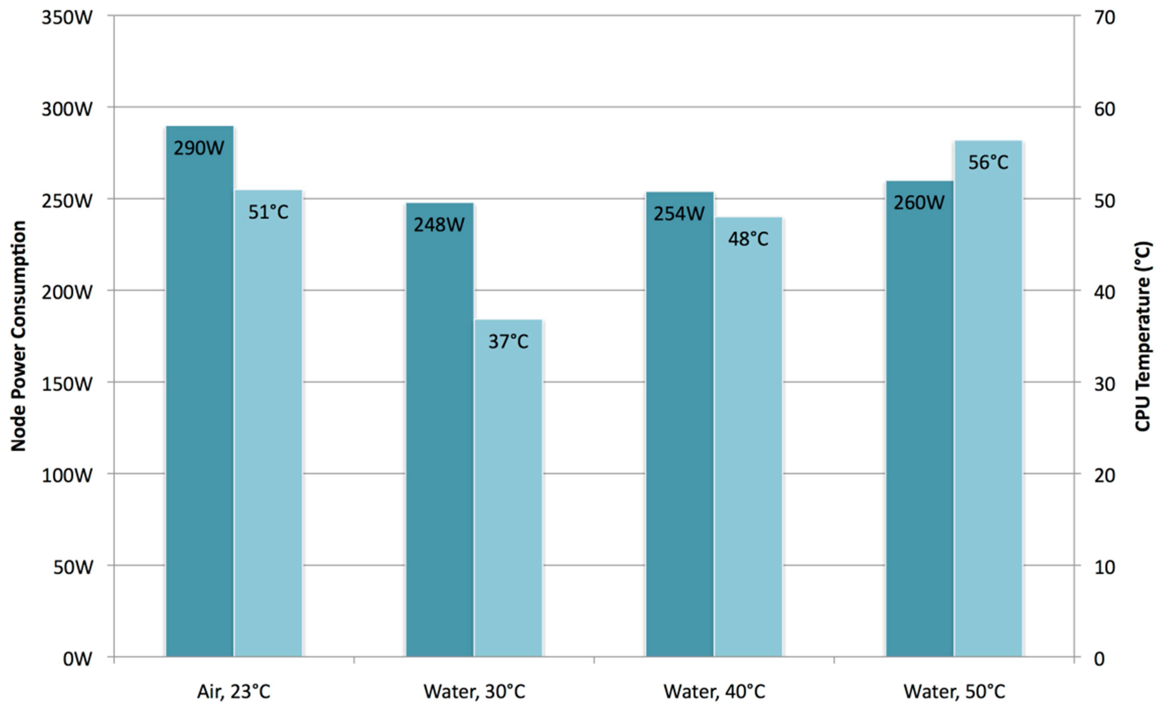

Figure 5: Comparison of an air cooled cluster node to a direct water cooled at different inlet temperatures

References

[1] D. W.-c. Feng, “Green500,” [Online]. Available: http://www.green500.org/.

[2] “ASHRAE,” [Online]. Available: http://www.ashrae.org/.

[3] “Green Grid,” [Online]. Available: http://www.thegreengrid.org/.

[4] “Zero-emission datacrenter,” IBM, [Online]. Available: http://www.zurich.ibm.com/st/energy/zeroemission.html.

[5] “KKU,” Kälte Klima Umwelt, [Online]. Available: http://www.kku-lukas.de/.

[6] “MEGWARE ColdCon,” MEGWARE, [Online]. Available: http://www.megware.com/config/media/files/233_ColdCon_Datasheet.pdf.