



PART 1: HISTORY

Liquid Cooling Cold Plates

By Dustin Demetriou, Ph.D., Member ASHRAE; David Quirk, P.E., Member ASHRAE

As the information technology equipment (ITE) industry begins to transition from air- to liquid-cooled servers, the term “cold plate” has begun to infiltrate the vernacular of the HVAC community. Far from being a tasty salad dish on ice, the “cold plate” is an integral component of a liquid-cooled server. As such, this and two succeeding columns take a break from our typical focus on the facility side of data centers to focus on the server processor’s cold plate: its definition, history, design, maintenance and future trends. A better understanding of cold plates will hopefully provide insight to aid in the design of more resilient and energy efficient liquid-cooling systems.

What is a Cold Plate?

As used in the IT industry, a “cold plate” is a heat exchanger. The cold plate is generally constructed of a metal plate with fins and channels to facilitate the removal of heat from a computer’s high heat density processors to a cooling liquid, typically pumped and forced through the channels where they absorb the heat. The cold plates in a liquid cooling technology cooling system (TCS) are roughly equivalent to the

Dustin Demetriou, Ph.D., is chair of the ASHRAE TC 9.9 IT subcommittee.
David Quirk, P.E., is president at DLB Associates.

terminal units of a distributed chilled water system, but with very specific temperature, flow, pressure drop, material compatibility and cleanliness requirements.

History of Cold Plate Technology

Cold plates have been used for thermal management since the 1960s, particularly in aerospace and military applications, where air-cooling was insufficient.

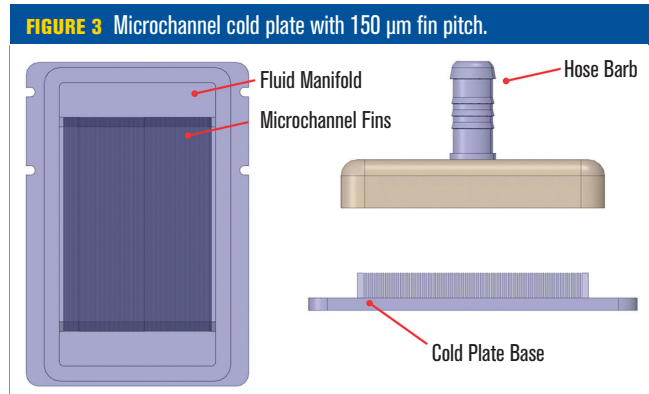
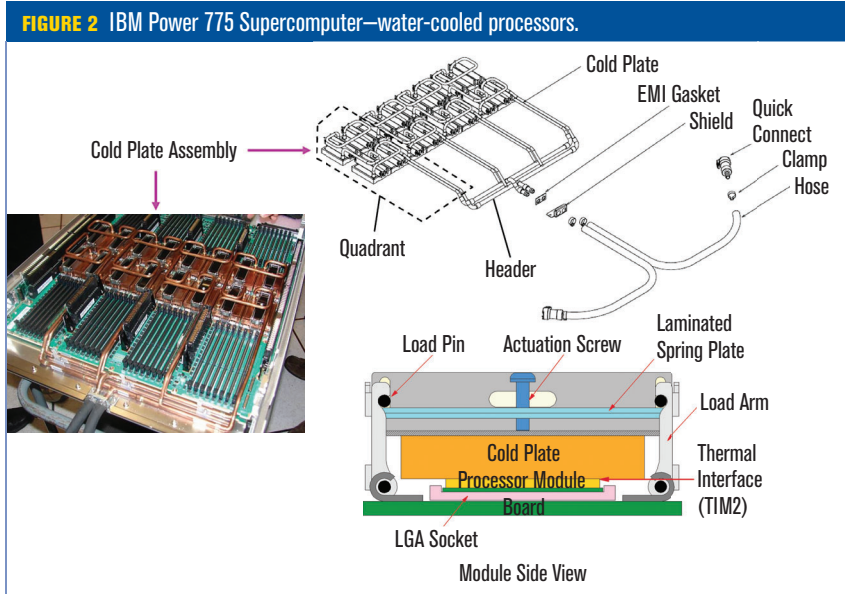
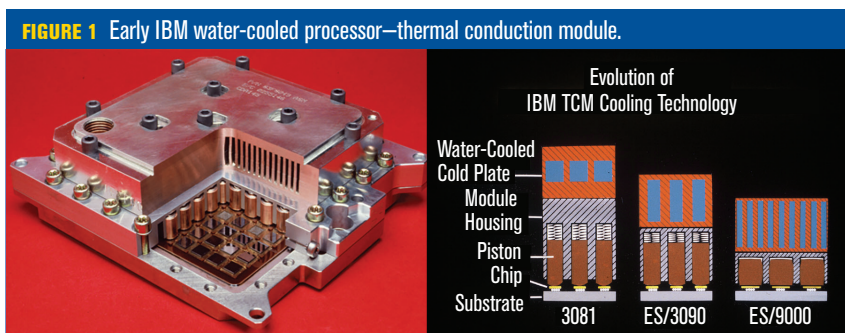
The trend toward higher circuit power density in the electronics industry necessitated a switch to liquid cooling.¹ IBM's thermal conduction module is an example of direct liquid-cooled bipolar CPUs back in the 1980s. Heat was conducted across a piston-and-hat structure to a module surface where it was then conducted into a liquid-carrying cold plate. The cold plate is analogous to an air-cooled heat sink in that it has extended surfaces, or fins, with fluid carrying channels.

The characteristic liquid flow channel width was typically in the milli-scale range. Channels evolved down to 1.6 mm (0.06 in.) in the IBM ES9000 (1982) cold plate, which was used in the bipolar generation of liquid-cooled products (*Figure 1*).

After the transition from bipolar to complementary metal oxide semiconductor (CMOS) technology in the early-1990s, liquid cooling was replaced with air-cooling as device power density decreased. Around 2005, prior to the industry's move to multi-core processors, power density reached a level that necessitated a transition back to liquid cooling using cold plate technology.

An example of direct liquid-cooled processors of that vintage can be found in IBM's Power 775 Supercomputer² (*Figure 2*). A cold plate assembly consisting of 16 individual copper cold plates cools 16 processor modules.

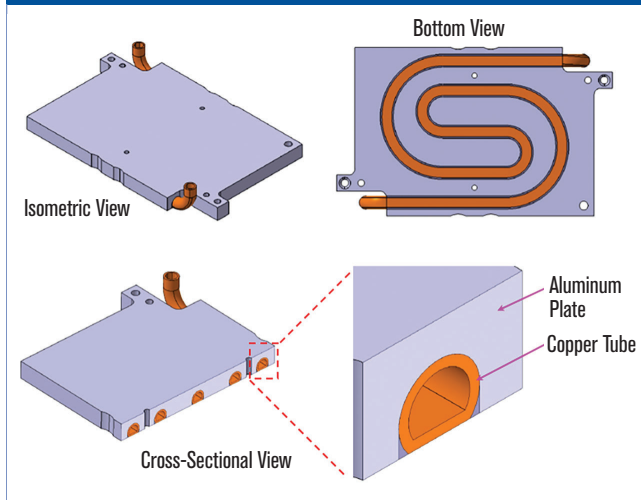
Four groupings (quadrants) of four cold plates, with each of the four cold plates being fluidically connected in series, are connected in parallel via a copper manifold wherein liquid is fed and returned through single inlet and outlet connections.



Each cold plate consisted of 42 flow channels 0.5 mm (0.02 in.) wide $\times$ 8 mm (0.3 in.) deep. Flow is managed within the cold plate so that the water flows serially through three groupings of 13 channels (i.e., a three-pass design).

Similarly, the Fujitsu K Supercomputer³ was cooled by an eight-cold-plate modular liquid cooling unit (LCU). Each cold plate is mounted to a lidded module. Power conversion modules are cooled by liquid in addition to the processor modules. The cold plates are connected

FIGURE 4 Aluminum plate with embedded copper tube cold plate.



in a series/parallel network with a single inlet and outlet per LCU.

Since then, copper fin/channel cold plates have evolved dimensionally toward the micro-scale. Manufacturers have produced cold plates with fin thicknesses and channel spacing below 0.05 mm (0.002 in.). These microchannel cold plates are generally desirable when thermal performance is at a premium. However, they come with increased hydraulic resistance and increased need for system level filtration to ensure fluid quality.

A recent example of a skived microchannel cold plate is shown in Figure 3. The gap and fin width dimensions are both 150 μm . This common design has evolved over the generations to continually reduce the fin spacing for improved thermal performance.

The shrinking fin dimensions as well as the increased flow rate through each cold plate resulting from fewer parallel paths allowed recent generations to have improved thermal performance over previous generations.⁴

Alternative designs composed of aluminum plates with embedded copper tubes have also been used in lieu of the higher-performing copper cold plates.⁵ They provide adequate thermal performance at a lower system pressure drop, are less expensive and weigh less.

The entire system design must be taken into account when designing/specifying a cold plate. Choices at the system level can elevate design requirements on the cold plate (i.e., allow for a lower performance/lower cost design).⁶

Specifically, given a thermal resistance target that can

be met with a low flow, expensive, high pressure drop cold plate or a high flow, inexpensive, low pressure drop alternative, the coolant routing within the system (parallel versus serial paths, for example) and the available pump performance are key to the cold plate selection. Cold plate thermal resistance performance does not always translate to a better design (i.e., one that most closely satisfies all of the design constraints of pressure drop, cost and thermal performance). Conversely, a more costly cold plate also does not guarantee a better design.

Summary

The invention of the liquid-cooling cold plate goes back about 60 years. Initially used in aerospace and military applications, they were adopted for use in mainframe processors and early supercomputers. The scale of the fins on cold plates has trended toward both thinner fins and thinner spacing between fins, which increases heat transfer performance, but at the cost of increased pressure drop and liquid filtration requirements.

For more information see *ASHRAE Datacom Book 13, IT Equipment Design Impact on Data Center Solutions*.⁷

Part 2 of this column will delve into the detailed design of cold plates, including designs intended to serve processors with heat dissipation approaching 1 kW.

References

1. Chu, R.C., R. Simons, M. Ellsworth, R. Schmidt, et al. 2004. "Review of cooling technologies for computer products." *IEEE Trans. of Devices and Materials Reliability*, 4(4): 568–585.
2. Campbell, L.A., M.J. Ellsworth, A. Sinha. 2009. "Analysis and design of the IBM Power 575 supercomputing node cold plate assembly." *Proceedings of the ASME 2009 Pacific Rim Technical Conference and Exposition on Packaging and Integration of Electronic and Photonic Systems (InterPACK2009)* 897–905.
3. Wei, J. 2011. "Hybrid cooling technology for large-scale computing systems—from back to the future." *Proceedings of the ASME 2011 Pacific Rim Technical Conference and Exposition on Packaging and Integration of Electronic and Photonic Systems (InterPACK2011)* 107–12.
4. Demetriou, D.W., M.P. David, C. VanDeventer, R. Zoodsma, et al. 2021. "Advanced in IBM z water cooling: z13, z14, z15." *Proceedings of IEEE ITherm 2021*.
5. Ellsworth, M.J., G.F. Goth, R.J. Zoodsma, A. Arvelo, et al. 2012. "An overview of the IBM Power 775 Supercomputer water cooling system." *Journal of Electronics Packaging* 143(2).
6. Ellsworth, M.J., L.A. Campbell. 2011. "Design considerations for high performance processor liquid cooled cold plates." *Electronics Cooling Magazine* 4(12):6–11.
7. ASHRAE. 2016. *Datacom Book 13: IT Equipment Design Impact on Data Center Solutions*. (PDF available by annual subscription through ASHRAE's On-line Datacom Encyclopedia) <https://tinyurl.com/bdzd5rke> ■