Open Bath Evaporative Immersion Cooling

A novel approach to liquid cooling promises to virtually eliminate the cost of cooling datacenters while facilitating heat recovery and reducing cooling equipment cost, complexity and environmental footprint.

Conventional Air and Liquid Cooling

Modern air-cooled datacenter facilities tend to be inefficient and hardware and real-estate intensive. Even the most efficient of these, so called “free” air-cooled facilities, draw significant power for chassis fans and facility blowers, components that often end up as E-waste. Furthermore, facilities like these must be located in relatively cool climates. Like the servers they house, these facilities are large as required to contain and hardware and airflow paths. Heat leaves the facility as a high volume, low grade air stream that cannot be easily captured and utilized.

“All-liquid” cooling refers to cooling techniques by which all heat is removed from a server by a liquid without air as an intermediate. It offers increases in efficiency, power density and the utility of the heat removed while reducing facility size and construction cost. However, implementation of traditional all-liquid cooling schemes is complicated by the number and variety of heat generating devices on a server and the requirement that each server within a rack be “hot swappable.” This makes it challenging to efficiently capture all of the heat generated on a printed circuit board and move it to an external liquid stream. Consequently, all-liquid systems bear inherent costs for design and fabrication of cold plates, redundant pumps, plumbing, couplings, controls, connectors, clamshells and heat exchangers: more E-waste, more to go wrong.

The Merits of Open Bath Evaporative Immersion

In this simple concept, servers are immersed side-by-side in a nonflammable dielectric liquid that boils on the heat generating devices (Figure 1). This much is not new. What’s unconventional is that this is done in modular “semi-open” baths so called because they are closed when access is not needed much like a chest type food freezer. Like a freezer, these baths operate at atmospheric pressure and have no specialized hermetic connections for electrical inputs and outputs. Instead, each server plugs into a backplane in the bottom of its bath. Electrical connections from the backplane enter a conduit beneath the liquid level and exit the top of the tank.

The vapor the servers generate rises to condense on a coil integrated into the tank and fed by tower water or water used at some distance for comfort heating, greenhouses, etc. Alternatively, the vapor can flow passively to an outdoor natural draft cooling tower where it transfers its heat to outdoor air: true “free” air cooling. To swap a server, one simply opens the bath and pulls the server slowly upward. Fluid remaining on the server quickly flashes to vapor and is captured by the coil. The server leaves the bath dry. The same principle is used in vapor degreasers. These common machines are used for precision cleaning in various industries and they lose very little fluid despite the fact that they are often open to ambient processing hundreds of parts per day.

Chief among the advantages of this concept is that most of the aforementioned cooling components are eliminated as are considerations relating to their integration, reliability and power consumption. Power density and efficiency are high and fire protection is intrinsic to the technology. Of course, there are other considerations, such as fugitive fluid emissions. Since these occur at one vent point rather than at countless seals and junctions, they are easily quantified and mitigated.

2-Phase Immersion is Proven

If it sounds a little radical, know that passive 2-phase (evaporative) immersion cooling has been used for decades to cool high value electronics in tens of thousands of systems including transformers, traction inverters, supercomputers and klystrons (Figure 2). This technology is still in use today, being favored for its simplicity, reliability, power density and performance. Most often these systems use sealed pressure vessels with hermetic electrical connections and are evacuated and filled much like refrigeration systems. Because it can be costly to create such an enclosure for computational electronics with a lot of IO, Engineers often dismiss the idea of immersion in the context of commodity datacenter equipment. The open bath concept eliminates these complexities.

Benefits

The performance capabilities of the technology were published at the 26th IEEE Semitherm Symposium this February in a work awarded best paper. Figure 3 shows an experiment that demonstrated the ability to remove 4kW from 20 simulated CPUs on a 20X17cm PCB with only 200cc of fluid. Servers this dense could be packaged into modular baths like that shown in Figure 4. An 80-kW bath might require only 7 GPM of 30°C water and deliver it at a very useful 74°C. The paper includes the theoretical basis for predicting emissive losses and showed the possible reductions in initial hardware cost, operating cost and greenhouse gas emissions in metric tons CO_2 equivalent or MCTE (Figure 5).

In short, this simple modular technology offers unprecedented power density. It eliminates all server and most rack and facility level cooling hardware. It has no moving parts (aside from facility pumps) and only the simplest of active controls. Its operating cost and total environmental footprint are less than competitive technologies.

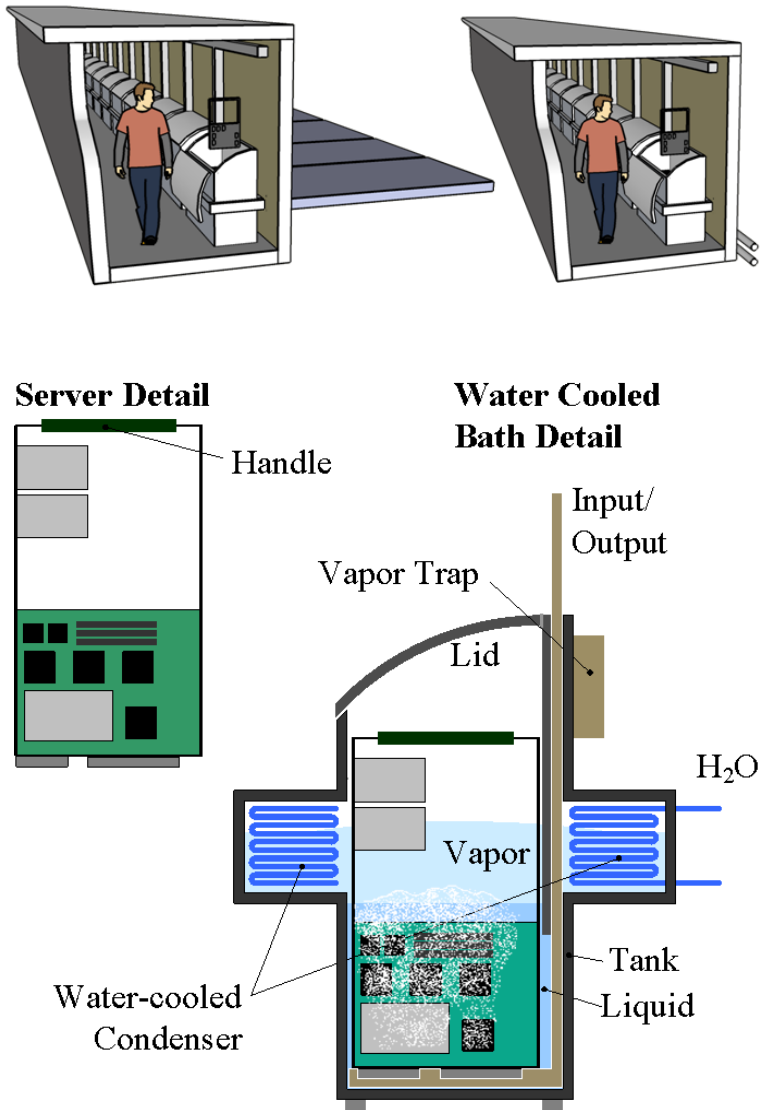


Figure 1 – Air- and water-cooled open bath immersion concepts (top). Detail of water-cooled open bath immersion concept (bottom)

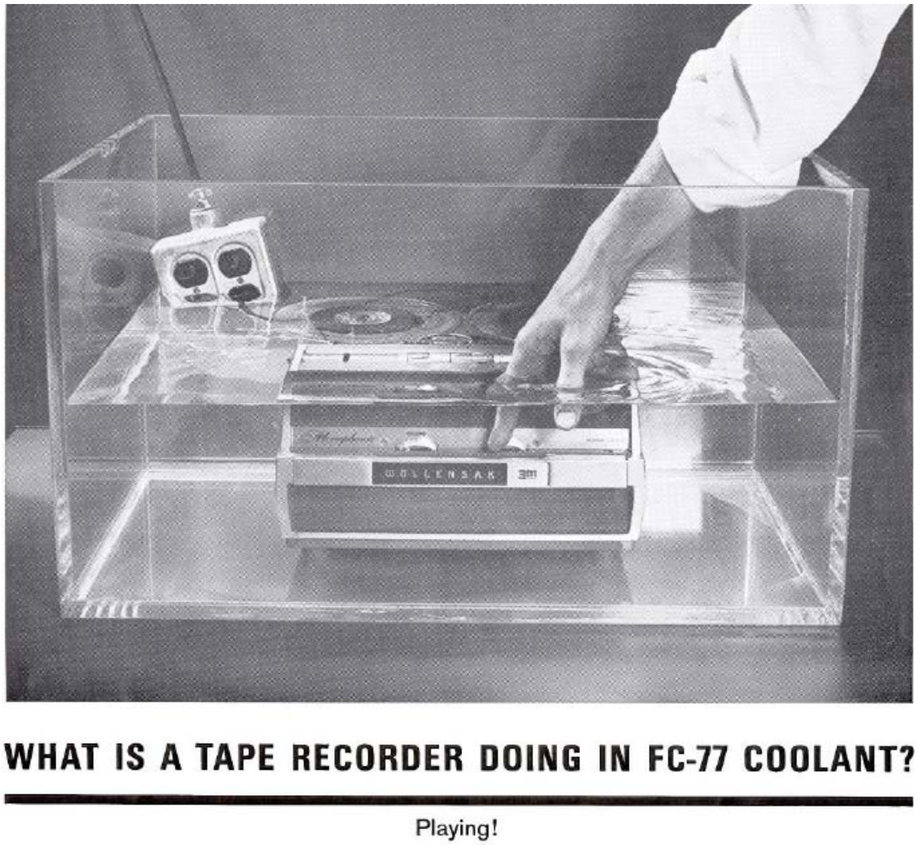


Figure 2 – 1965 ad showing the inertness and dielectric properties of immersion cooling.

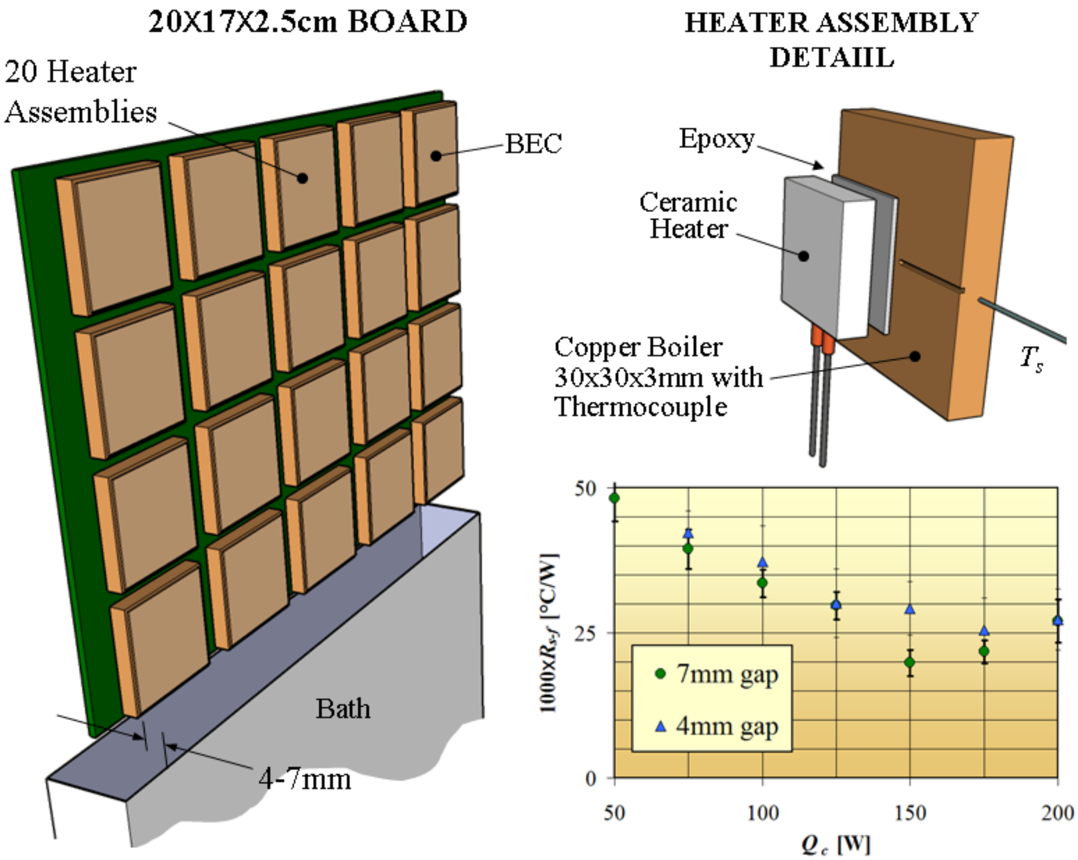
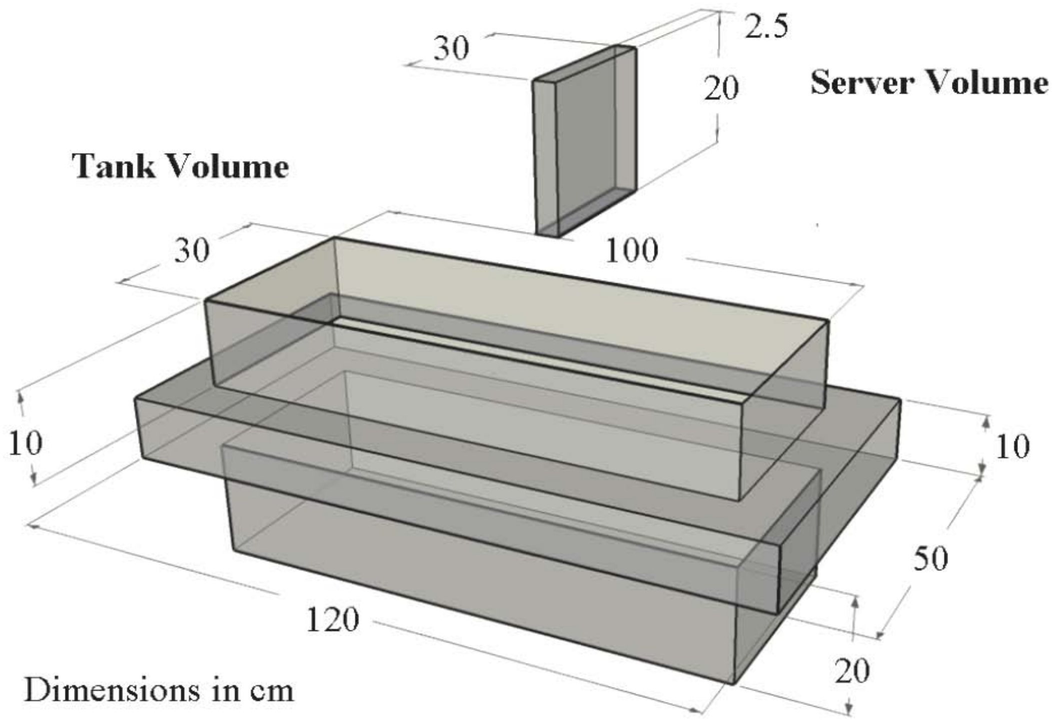


Figure 3 – Experiment (left) demonstrating the power density capabilities of immersion for a vertical PCB. Achieved 4kW per liter with only 200cc of dielectric fluid.



Processor Power [W]	200			
Power per node [kW]	2			
Number Nodes per Tank	40			
Total Tank Power [kW]	80			
Working Fluid	1		2	
Fluid Boiling Point [°C]	49		74	
CPU Junction T [°C]	58.0		83.0	
Water Flow [gpm]	10	30	7	10
Water Inlet T [°C]	18.7	37.0	30.9	43.7
Water Outlet T [°C]	48.9	47.1	74.0	73.9

Figure 4 – Dimensions and energy balance for a modular 80kW bath

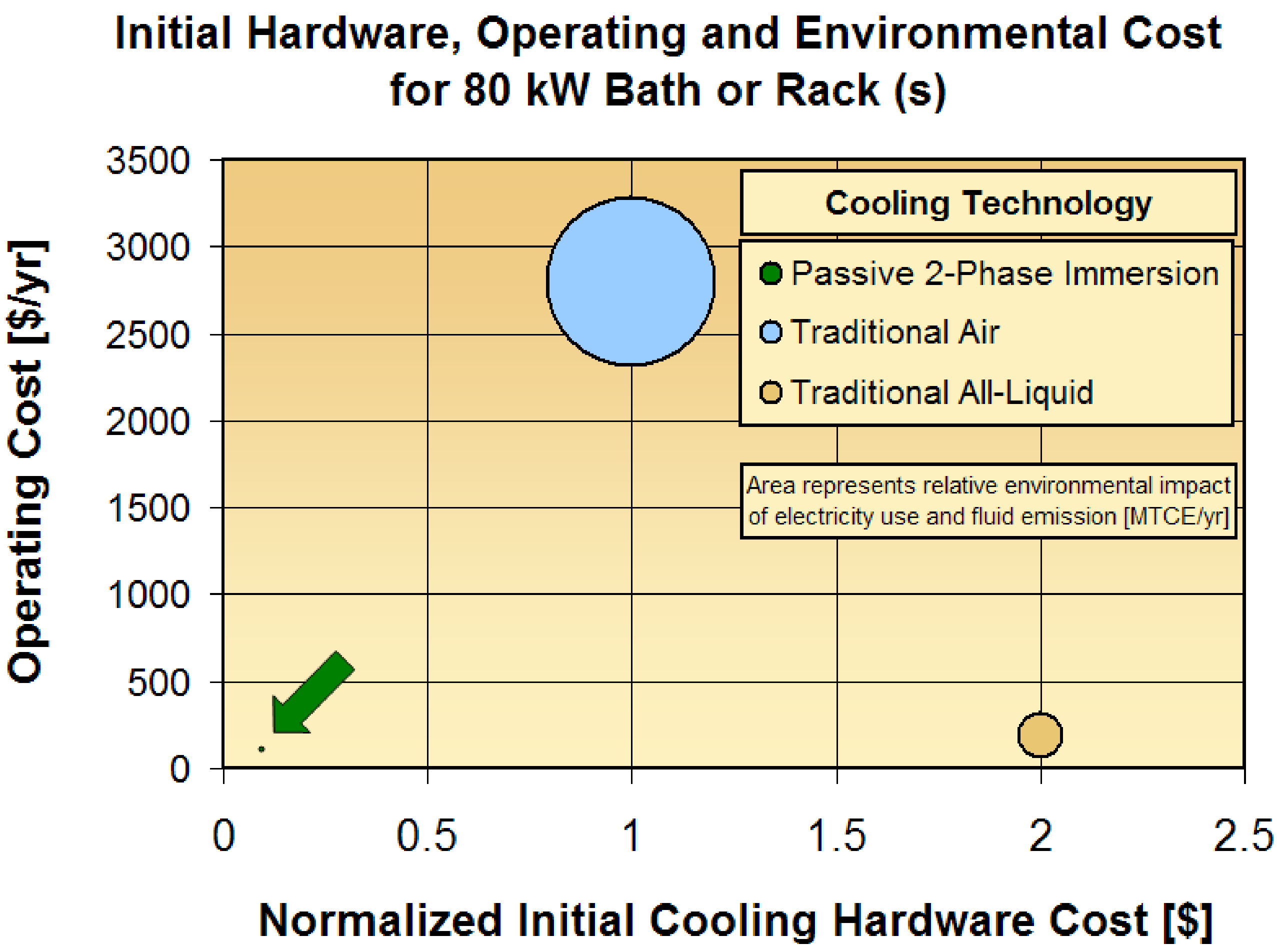


Figure 5 – Rack level initial hardware, operating and environmental, cost for modular 80kW bath versus conventional air and all-liquid solutions.