Application of Thermoelectric Coolers in Thermal Management

With the increase in power dissipation and the shrinkage of package sizes, air cooling is getting to its limit or soon will reach a point at which liquid cooling becomes inevitable. In order to comply with Moor's law, higher heat transfer mechanisms are needed to achieve the goal. In some applications with limited space or lack of refrigerated liquid, liquid cooling by itself might not even be enough. In these circumstances TEC can play a vital role. In this article we will look at some work done by researchers using TEC in the liquid cooling arena.

Davis et al [1] used a TEC module bonded to a copper plate to spread the heat due to the size of a small component. The hot side of the TEC is soldered to a micro channel water block. The function of the water block is to remove the heat from the TEC and transfer it to the radiator, which is cooled by a fan. Figure 1 shows the configuration of this test.

The commercialized product of this concept is shown in Figure 2.

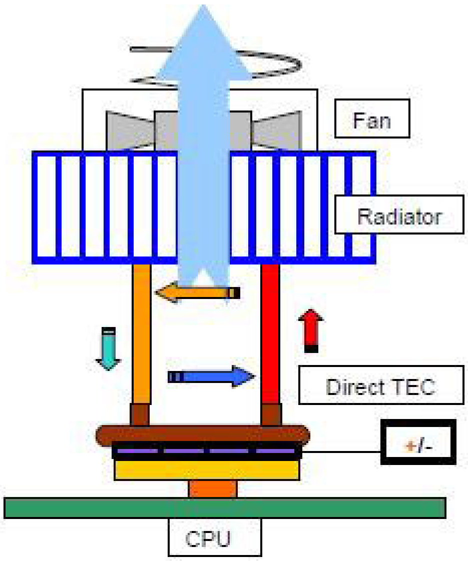

Figure 1. Direct Liquid Cooling Using a TEC [1]

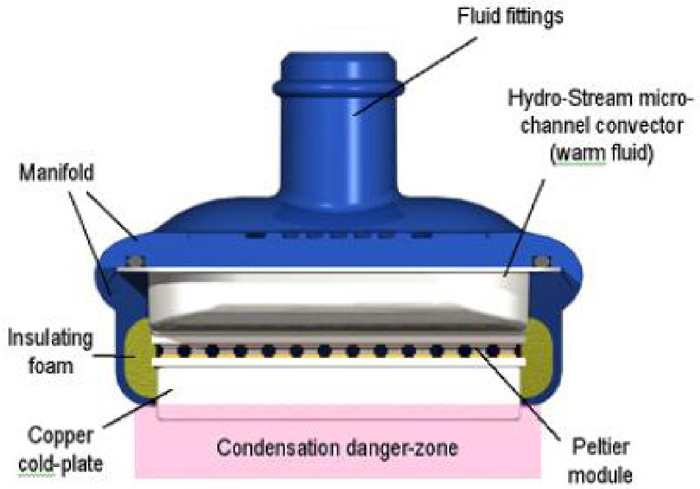

Figure 2. HydroTECH CPU Cooler [1]

Figure 3 shows the results of the experiment with this device.

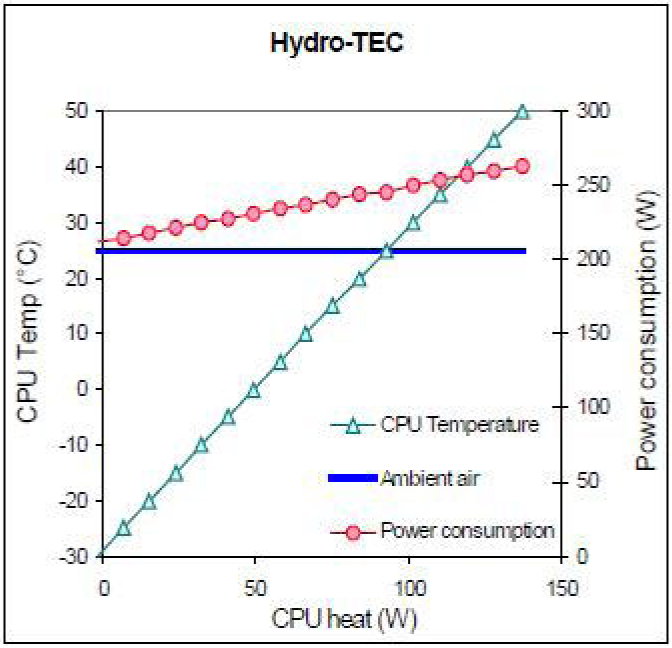

Figure 3. CPU Temperature as a Function of Power Dissipation for HydroTECH CPU Cooler [1]

This figure shows that, for a power consumption of 245 W, a CPU with power dissipation of 100 W can be maintained at a temperature of 37 °C with ambient air temperature of 25 °C. To obtain a better performance, especially for small foot print components such as 15x15 mm, the spreading resistance has to be minimized. Spreader plates or vapor chambers have finite conduction resistance which will degrade the performance of the system.

To alleviate this problem, instead of using the spreader plate, they used a water block to circulate the cold liquid and remove the CPU heat. The fluid then returns to the micro channel heat exchanger which is bonded to the cold side of the TEC. There is also a micro channel heat exchanger on the hot side of the TEC which sends the fluid to the radiator to remove the heat. Figure 4 shows this concept. Figure 5 shows the CPU temperature calculated as a function of power dissipation and the power input to the TEC. It shows that at 180W power dissipation, the CPU temperature is maintained at 30 °C, at an ambient temperature of 25 °C. The power input to the TEC was 220 W. As mentioned before, the last data is based on a theoretical prediction and not the actual experiment.

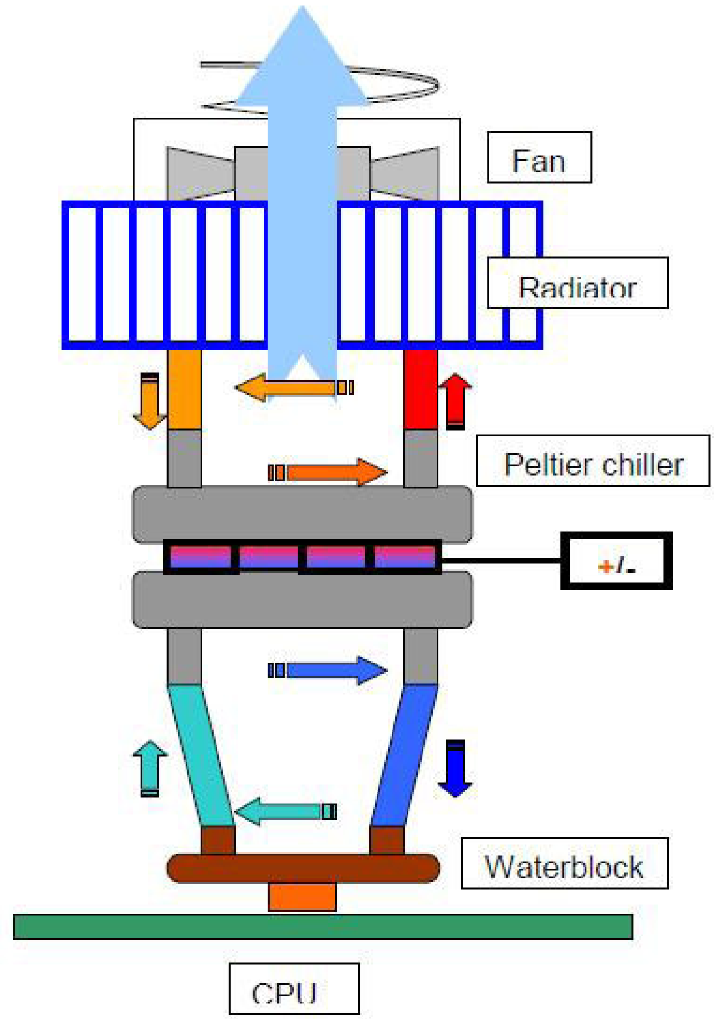

Figure 4. CPU Liquid Cooling Using a TEC and Water Block [1]

Bilski et al [2] conducted similar experiments using TEC and heat exchangers to cool a heat generating device. It can be easily shown that if one uses a TEC in a cooling loop, the overall thermal resistance can be calculated as:

$$R = \sum R_u - \frac{\Delta T_{TEC}}{Q} + \left(1+\frac{1}{COP}\right) \cdot \sum R_D$$

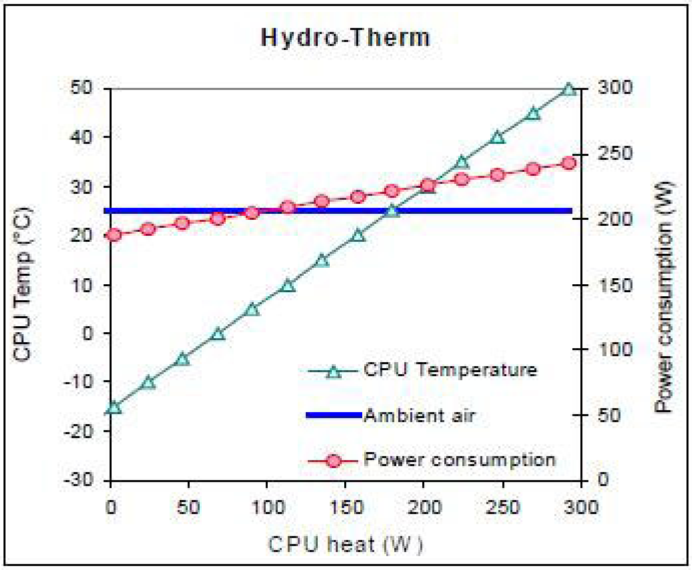

Figure 5. CPU Temperature as a Function of Power Dissipation for HydroTherm CPU Cooler [1]

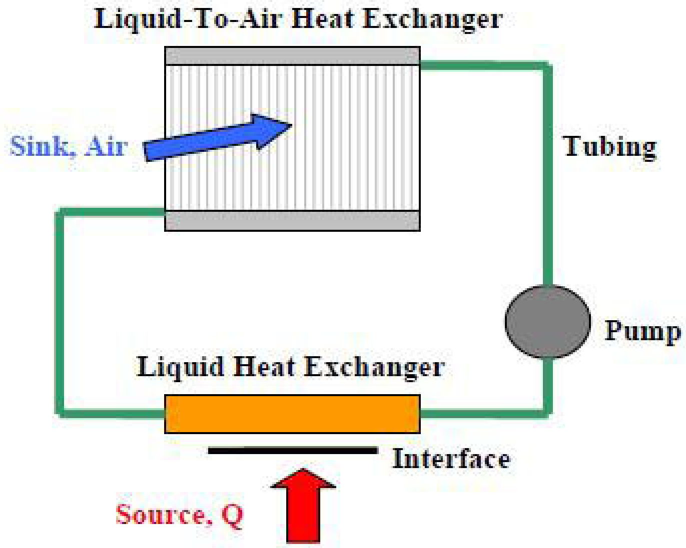

Figure 6. Base Line Liquid Cooling System [2]

Where,

R = overall thermal resistance

R_u = thermal resistances at the upstream of the TEC

ΔT_{TEC} = temperature difference across the TEC

COP = coefficient of performance of the TEC

R_D = thermal resistances at the downstream of the TEC

Q = power dissipation of the device

This equation shows that in order to minimize the thermal resistance, the upstream and downstream resistances have to be minimized. Equally important is to maximize the COP of the TEC. The higher the COP, the smaller the R value. This equation also shows that to achieve a low thermal resistance requires increasing the temperature difference across the TEC.

Bilski et al [2] used a baseline reference liquid system shown in Figure 6. This base line liquid cooling system uses a heat exchanger attached to the heat source. The heated liquid is then pumped to a liquid-to-air heat exchanger which is then cooled by a fan. The thermal resistance of this system was indicated as 0.11 °C/W.

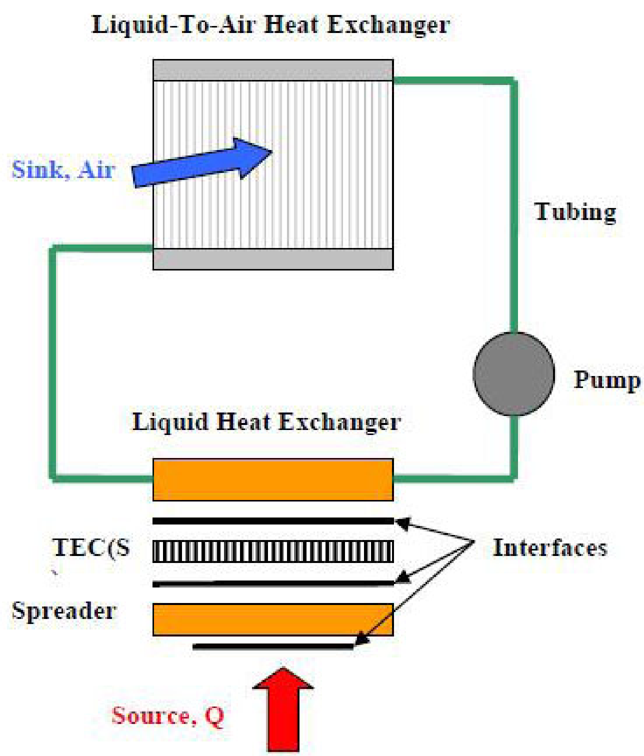

Figure 7. TEC Based Liquid Cooling System [2]

They conducted their experiment based on a TEC-enabled liquid cooling system shown in Figure 7. In this experiment, a spreader plate such as a copper plate or vapor chamber was use to spread the heat from a small source. A TEC was bonded to the spreader plate on the cold side. The hot side is bonded to a liquid heat exchanger. The heated fluid is then pumped to a liquid-to-air heat exchanger. They argued that if, instead of the spreader plate they had used a liquid heat exchanger system, a better performance would have been achieved, but due to complexity of such a system, it was not pursued.

The experimental data for this system is shown in Table 1. The data is shown for different power loadings, different spreader plates and TEC power. The temperature difference across the sink is the temperature difference between the component case and the ambient temperature. The R_{sink} is calculated as:

$$R_{sink} = \frac{T_{case} - T_{ambient}}{Q}$$

Where;

T_{case} = maximum temperature of the heat spreader

It is evident from the data that, for low power dissipation of 100W and 125W, a 4 mm solid copper performed better than a vapor chamber. Only at high powers of 175 and 200W did the vapor chamber perform better. In all cases, except the very high power dissipation of 200W, the overall thermal resistance of the TEC system outperformed the base line liquid cooling system which is at 0.11 °C/W. The authors indicate that the performance of the TEC system for high power can be improved if they had used a higher power TEC for that application.

It is also interesting to see that, for low powers, the temperature of the sink went below ambient which, in a real application might need a feedback control to prevent from condensation. The data is quite promising and shows that very low component temperatures can be achieved by properly designing and incorporating a TEC in a cooling loop.

Load	TEC Voltage = 12VDC			
	ΔT_{sink} (°C)	R_{sink} (°C/W)	TEC Power (W)	Spreader
100W	-1.0	-0.010	63.6	V.C.
125W	5.0	0.040	65.2	V.C.
150W	10.4	0.069	66.7	V.C.
175W	16.5	0.094	68.2	V.C.
200W	23.1	0.116	69.6	V.C.
100W	-1.4	-0.014	63.4	Cu Plate
125W	4.8	0.038	64.8	Cu Plate
150W	10.4	0.069	66.7	Cu Plate
175W	17.8	0.102	68.3	Cu Plate
200W	25.0	0.125	69.6	Cu Plate

Table 1. Experimental Data for the System Shown in Figure 7 [2]

The application of TEC in processor cooling shows that it can be a viable technique for the next generation of components with very high power consumption, particularly in some applications where even liquid cooling by itself is not enough. In doing so, there are many challenges that have to be considered, such as condensation issues, reliability, cost, energy consumption and complexity of the system. The TEC technology has its limitation due to low COP when compared to traditional vapor compression refrigeration. However their simplicity and lack of mechanical parts make them more attractive. From the energy point of view, there needs to be a breakthrough in material science to make the TECs more efficient to be able to compete with vapor compression cycles.

References:

1. **Davis, M., Weymouth, R., Clarke, P., "Thermoelectric CPU cooling using high efficiency liquid flow heat exchangers", hydrocool.com**

2. **Bilski, J., Baldassare, G., Connors, M., Toth, J., Wert, K., "electronics cooling using a self-contained, sub-cooled pumped liquid system", 24th IEEE SEMI-THERM Symposium, 2008**