



# Results of Study Comparing Liquid Cooling Methods

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- Leeds, **England**

- Tier 2 HPC for 8 northern English Universities.
- Tier 3 facilities for researchers in all faculties

- The Tier 1 HPC facilities (Archer) are in Edinburgh, **Scotland** – Tier 1 is a **national** facility

- Scottish Independence means Tier 1 facility should be repatriated!
- Government can influence!



# Liquid cooling is not new.



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*Microelectronics and Reliability*

Pergamon Press 1969,

PACKAGING AND COOLING WITH

## 6. DIRECT LIQUID COOLING

### PACKAGING AND COOLING WITH MICROELECTRO

The idea of a liquid in direct contact with the active device is apt to frighten the electronics engineer because of the susceptibility of semiconductor materials to diffusion of impurities. In addition, the motion of the cooling fluid in contact with the slice could result in damage to its flimsy structure. A small number of research workers in the U.S.A.,<sup>(4)</sup> and in the U.K.,<sup>(5)</sup> have shown that

**F. HONNOR and D**

Mechanical Engineering Laboratory, English Electri

*Microelectronics and Reliability*

Pergamon Press 1973. Vol. 12, pp. 163–173.

Printed in Great Britain

## LIQUID IMMERSION COOLING OF SMALL ELECTRONIC DEVICES

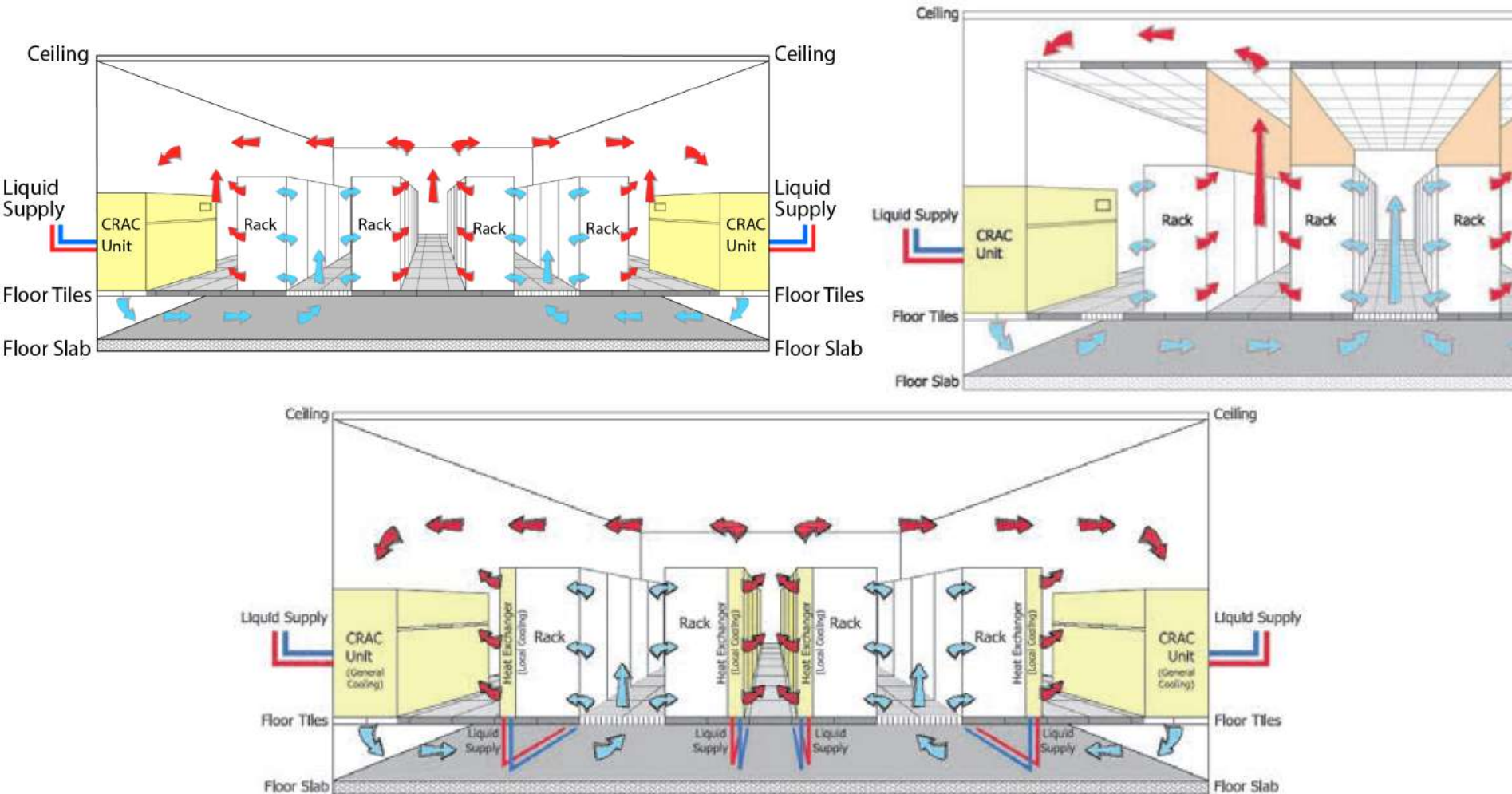
**E. BAKER**

Bell Telephone Laboratories, Whippany, New Jersey, U.S.A.

# Traditional Air cooling



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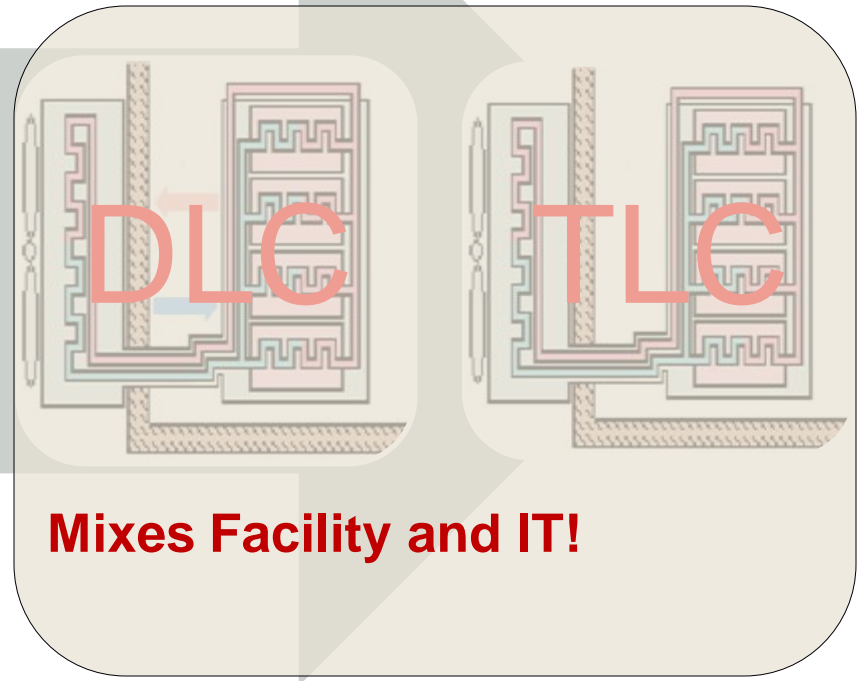
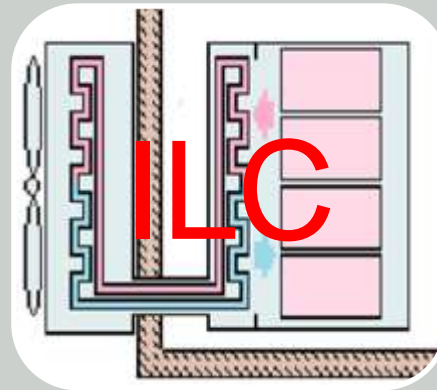
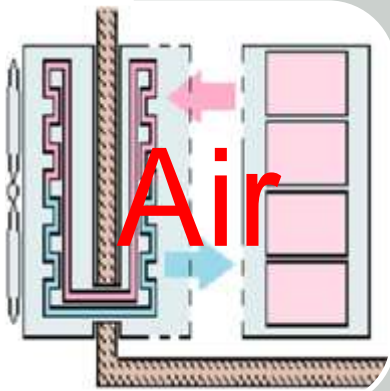
Source: ASHRAE Datacom volume 2

# Liquid Cooling Solutions



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Moving towards total liquid cooling.



ILC = Indirect Liquid Cooling – 100% Air with liquid to the rack.

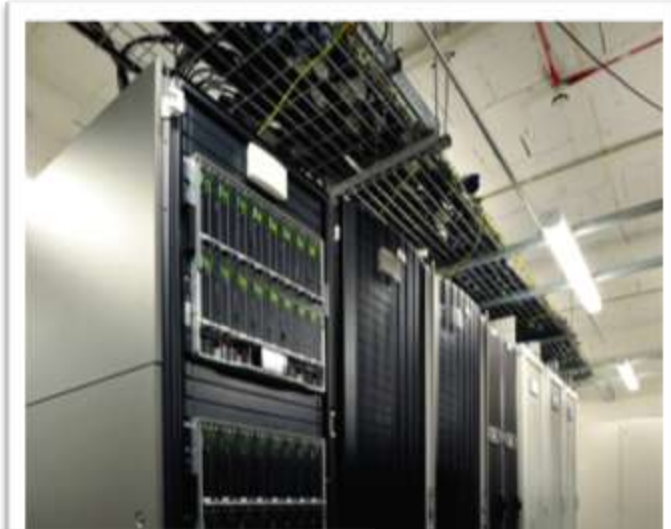
DLC = Direct Liquid Cooling –  $0% < \text{Air} < 100%$  with liquid to the rack.

TLC = Total Liquid Cooling – 0% Air with liquid to the rack.

# Indirect Liquid Cooling to the racks. Photographs



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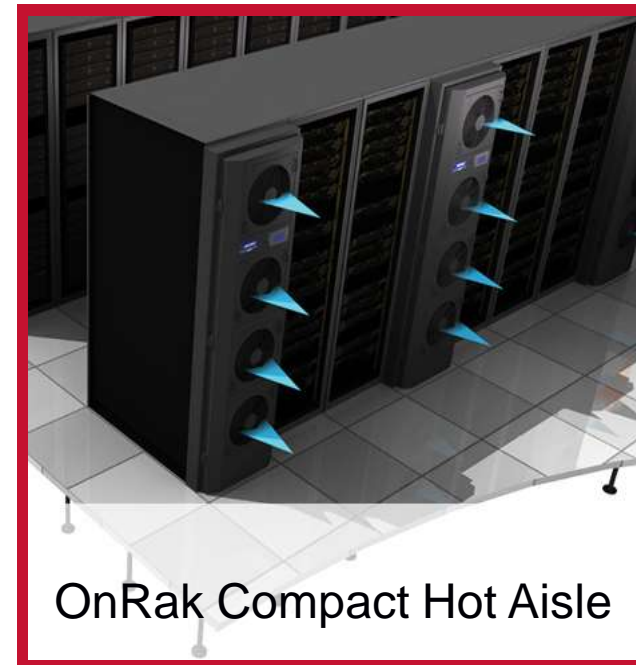
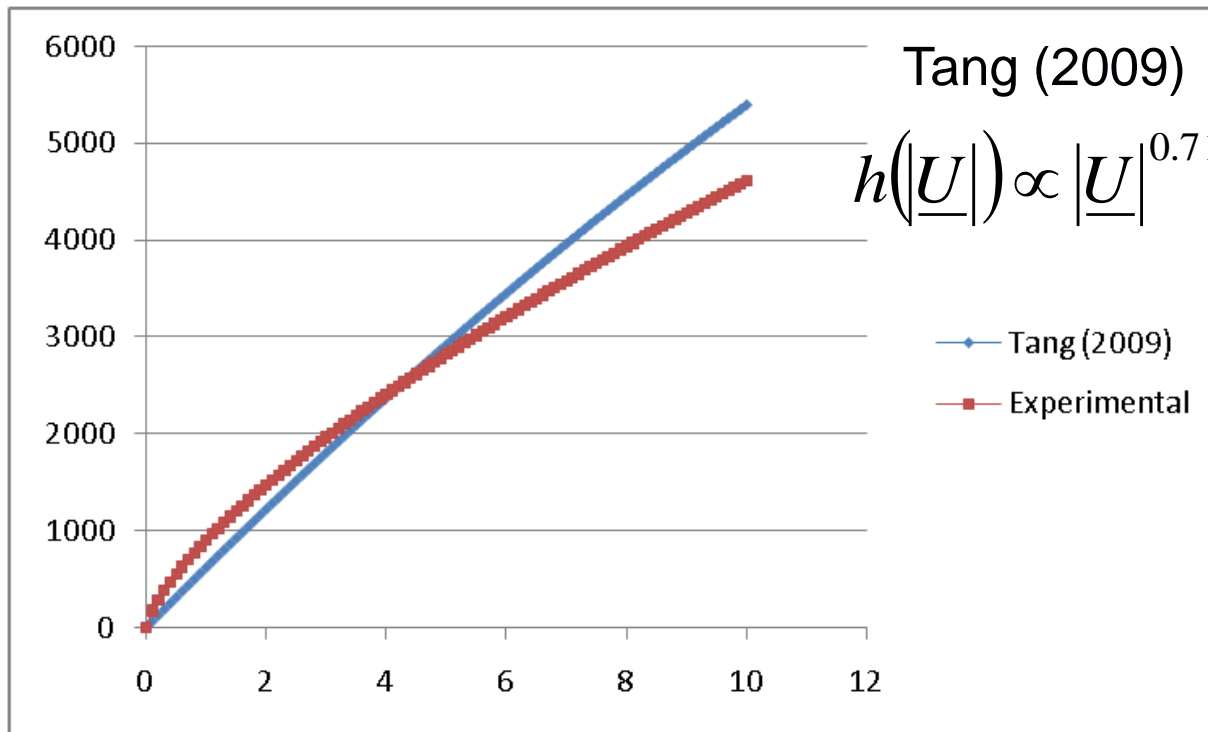
**Airedale**  
APPLIED THERMAL INNOVATION

# Indirect Liquid Cooling to the rack Performance



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$$\dot{Q}_{bdc} = \dot{m} h(|\underline{U}|) A (T_{ref} - T_{air})$$

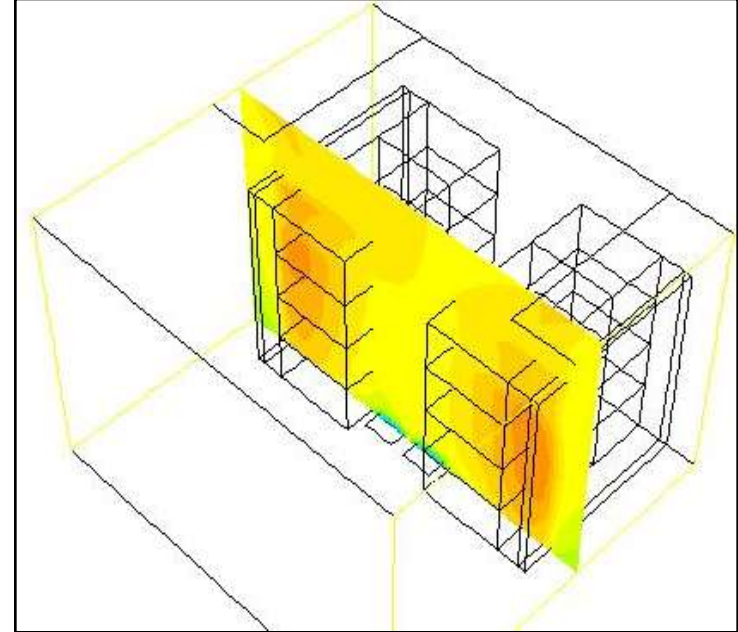
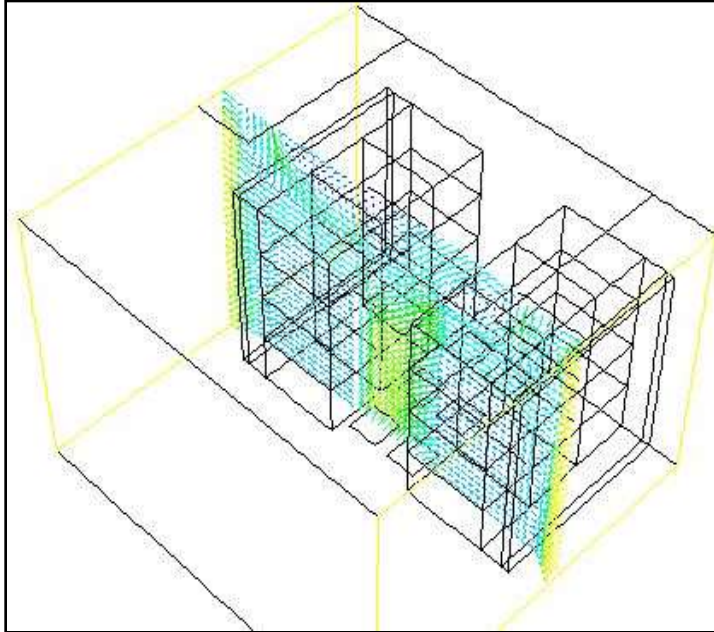


Experiments by Adam Thompson, PhD student at the Airedale test facilities in 2011.

# Indirect Liquid Cooling to the rack Performance



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Effect of using back door coolers on the cooling load of CRAC units with six 30kW racks, where  $\dot{m}_{CRAC}$  and  $\dot{m}_{BD}$  are the mass flow rate through the CRAC and back door respectively.

Configuration	Heat load on CRAC	Heat load on back door
CRAC	180 kW	0 kW
CRAC + passive	$\dot{m}_{CRAC} C_p (T_{OUT} - T_{IN}) = 14.5 kW$	$\dot{m}_{BD} C_p (T_{B4} - T_{AFTER}) = 164.8 kW$
CRAC + active	$\dot{m}_{CRAC} C_p (T_{OUT} - T_{IN}) = 11.5 kW$	$\dot{m}_{BD} C_p (T_{B4} - T_{AFTER}) = 170.8 kW$



# Indirect Liquid Cooling to the rack Performance



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- High Performance Computing (HPC) installation using ILC:
  - Installed in 2010 and 2011
  - System delivers 45Tflops in 6 racks, 3 with passive ILC rear doors and 3 with active ILC rear doors
  - One power measurement showed a consumption of 137kW (104kW compute, 33kW cooling) **giving a pPUE of 1.32** (137/104)
  - $45\text{TFlops}/137\text{kW} = \mathbf{0.33\text{Gflops/Watt}}$
  - HPC team reported an annual running cost saving of £50k per annum over traditional air cooling

# Direct Liquid Cooling into the server.



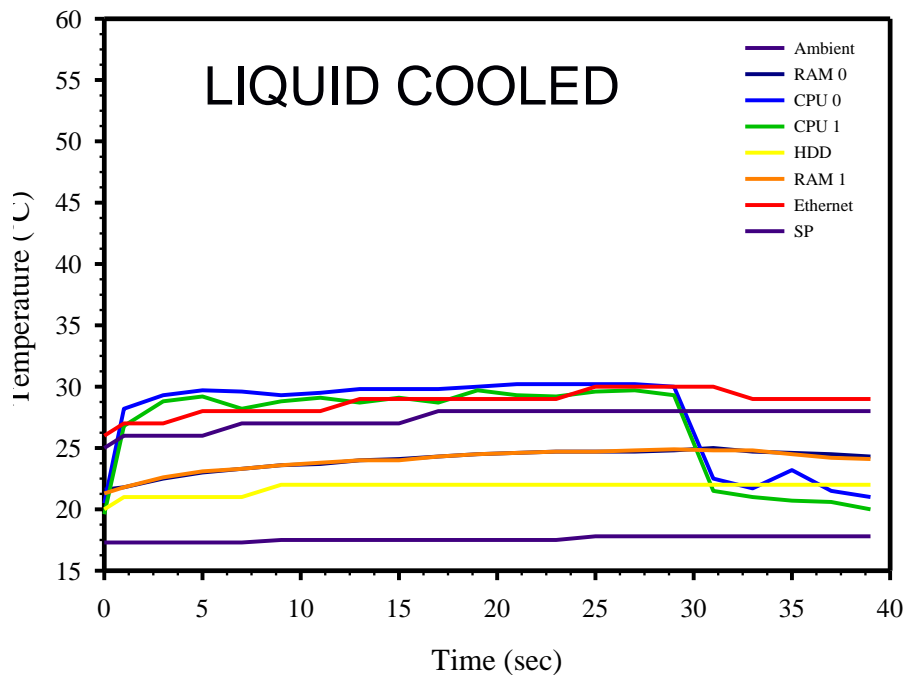
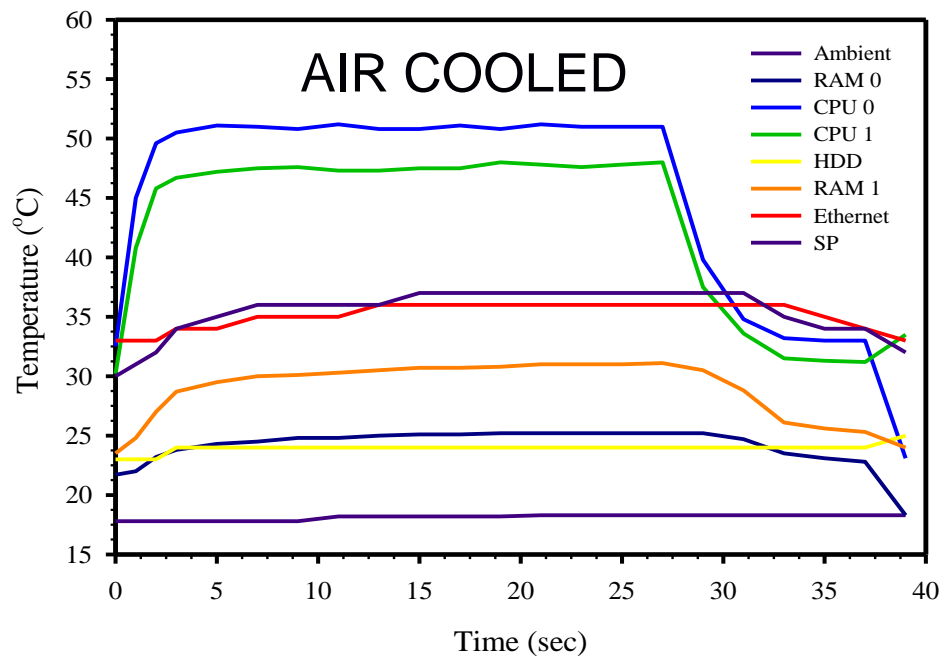
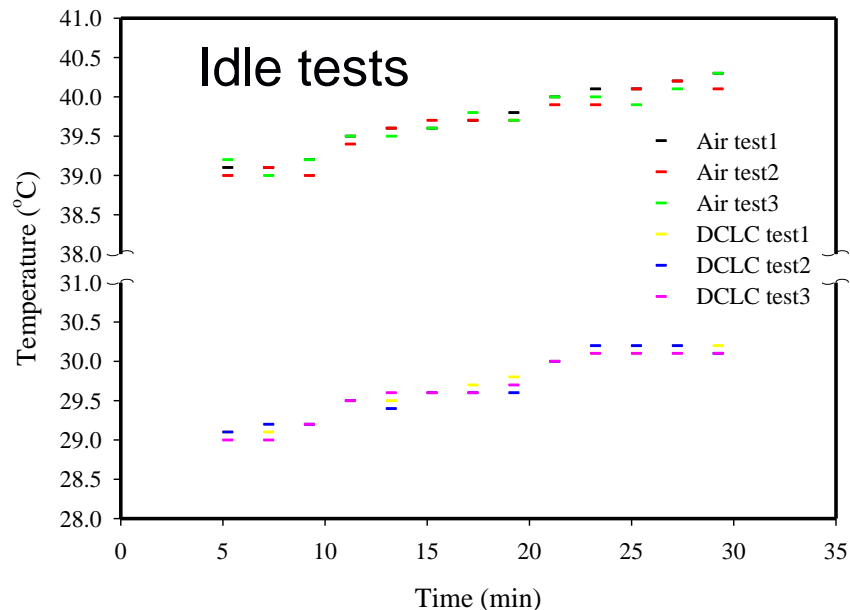
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- Retrofit into decommissioned (2007) HPC nodes
- Setup is in a laboratory.
- Primary research goal is to look at cooling on demand.

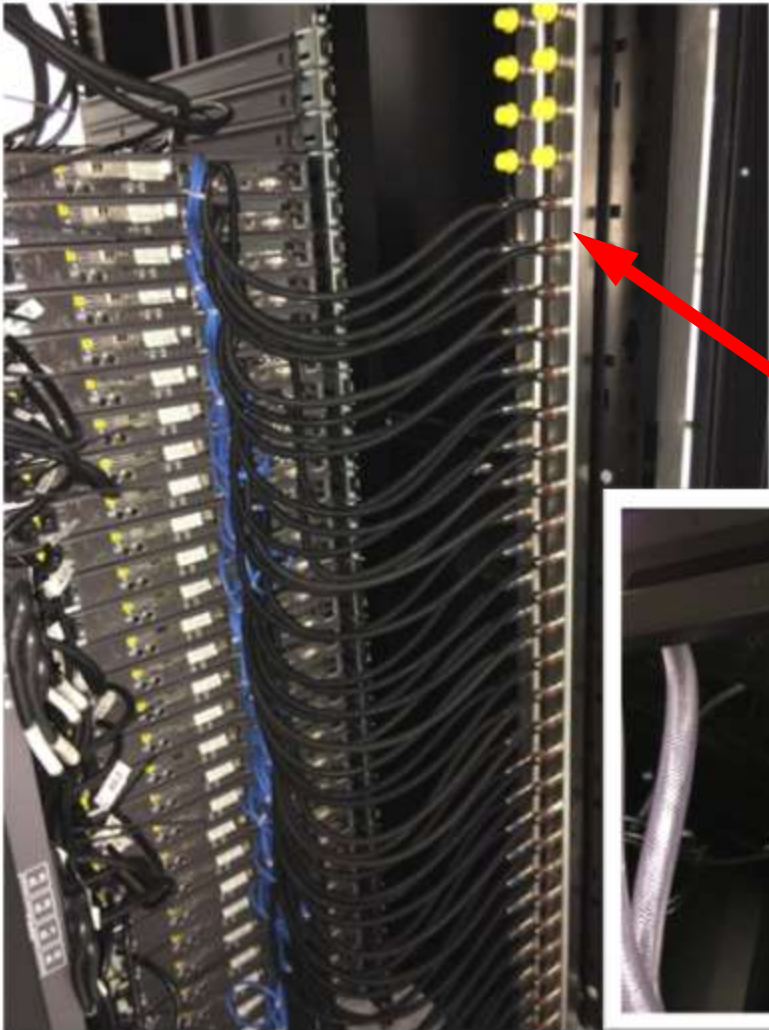


# Direct Liquid Cooling into the server

Using StressLinux - a load profile is run for 6 minutes each time.

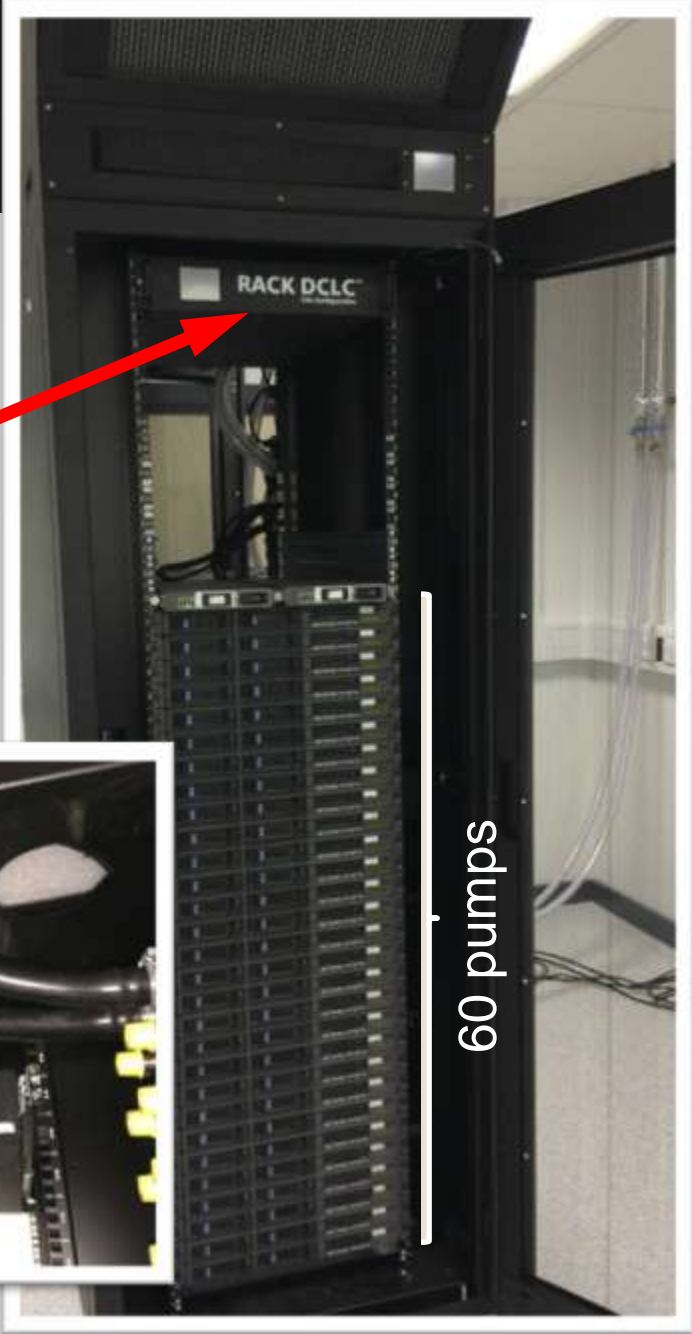
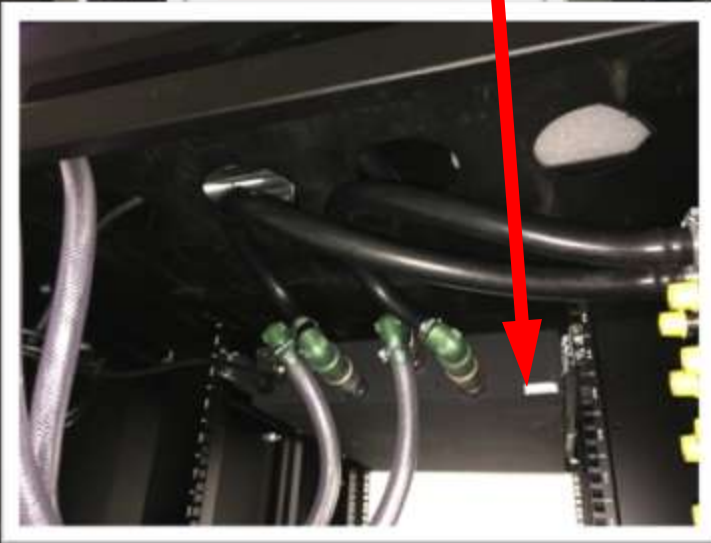


# Direct Liquid Cooling into the server



CHx – liquid to liquid

Cooling manifold



60 pumps

# Direct Liquid Cooling into the server



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- Each *air cooled* server is 230W power consumption.
- At *air cooled* server max load the temperature difference is around 18°C giving a flow rate of 9 litres per second.
- The *direct liquid cooled (DLC)* server loses 4 of the 8 fans.
- With half the flow rate and a measured temperature difference of 8°C the rate of heat taken up by the air for each server is 44W.
- For 30 servers in a rack – the liquid cooled retrofitting harvests 78% of the heat into the water and the heat load in the laboratory is estimated to be 1.4kW.
- The **pPUE** is difficult to calculate as building water supplies many laboratories.

# Total Liquid Cooling by full immersion.



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Facility Deployment  
University of Leeds.  
Iceotope and 3M

UptimeInstitute®  
**GREEN ENTERPRISE  
IT AWARD 2013**



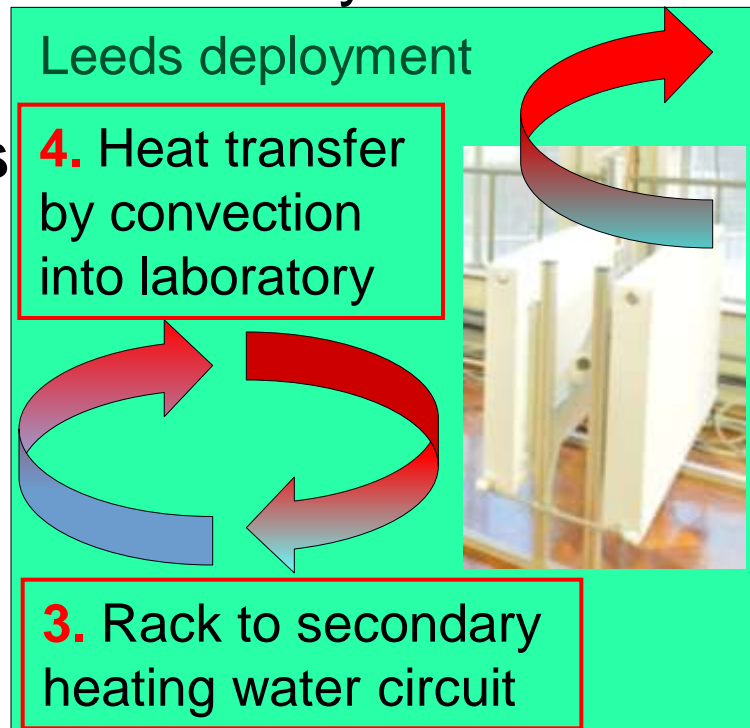
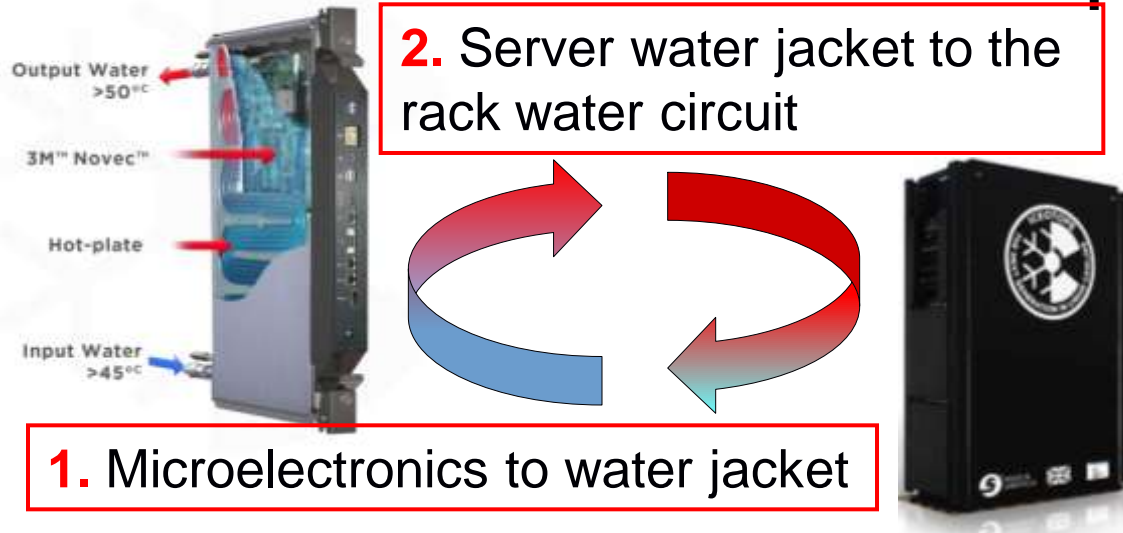
# Total Liquid Cooling by full immersion



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- The Iceotope solution does not use air, and therefore no fans. No need to consider server approach temperatures and humidity. Only need to consider CPU and system temperatures.

- **There are four heat transfer steps**



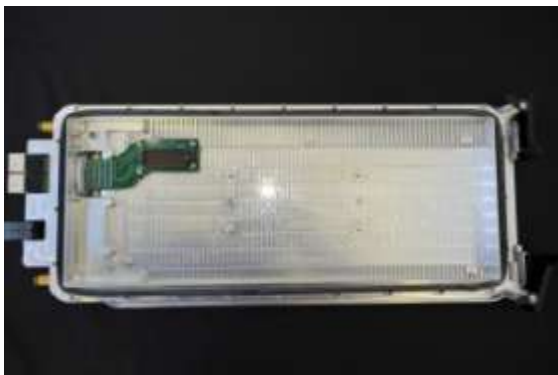
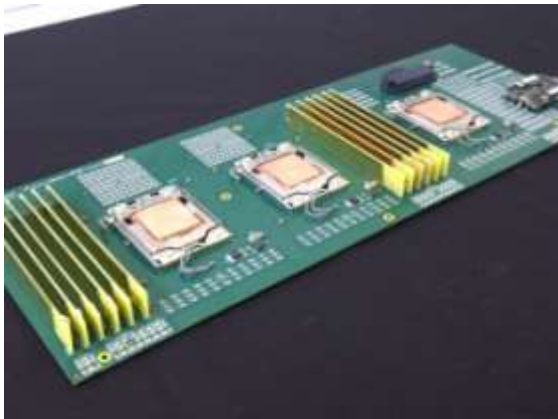
Heat transfer is in liquids – no fans are required at all.

# Total Liquid Cooling by full immersion: microelectronics level heat transfer



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- Heat transfer capabilities investigated using controlled proxy mainboard.



Water in	Water out	Water flowrate	Electrical Power in	Water power out
27°C	36°C	$1.15 \times 10^{-5} \text{ m}^3 \text{ s}^{-1}$	500W	432W
29°C	38°C	$1.13 \times 10^{-5} \text{ m}^3 \text{ s}^{-1}$	500W	441W
30°C	39°C	$1.13 \times 10^{-5} \text{ m}^3 \text{ s}^{-1}$	500W	448W
32°C	42°C	$1.10 \times 10^{-5} \text{ m}^3 \text{ s}^{-1}$	500W	464W
35°C	45°C	$1.105 \times 10^{-5} \text{ m}^3 \text{ s}^{-1}$	500W	461W

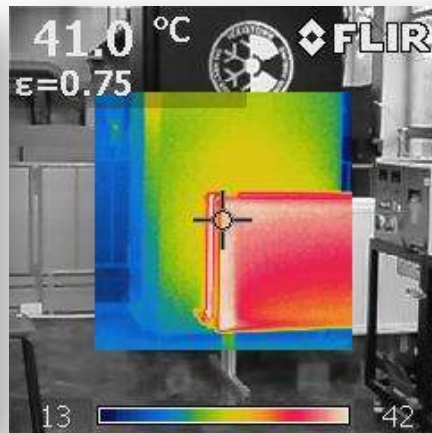


# Total Liquid Cooling by full immersion: rack to the lab heat transfer



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- Using 20W central heating pump.
- Two 2.5kW domestic hot water radiators.
- Thermal images show surface temperatures of the rack and the radiators.



- With 2.2kW IT and 95W of pumps gives pPUE = 1.05

# Liquid cooling summary



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**ILC**  
pPUE=1.32  
0.33GFlops/W

80 to 91%  
heat capture  
in liquid at  
18C



**DLC**  
pPUE TBC

Up to 78%  
heat capture  
in liquid at  
approx 25C



**TLC**  
pPUE=1.05  
1.07GFlops/W

89% heat  
capture in  
liquid at 45C

# Liquid Cooling Performance Comparison (System Model)



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	Type	Load	Number	ILC (RDHx)	TLC (Immersion)
Server / IT level	MotherBoard	305W	672	<b>204.96kW</b>	<b>204.96kW</b>
	Cooling Fans	23.4W	672	15.72kW	N/A
	Storage	0.85W	672	0.571kW	0.571kW
	PSU Fan	15.8W	168	2.65kW	N/A
	PSU loss	7% loss	168	15.67kW	14.43kW
			Performance	223.1TFLOPS	223.1TFLOPS
			<b>Total load</b>	<b>223.91kW</b>	<b>206.27kW</b>
Cabinet level	Cabinet fan	161W	14	2.254kW	N/A
	Pump	45W	14	N/A	0.63kW
	Telco	33.4W	28	0.935kW	0.935kW
	PDU	3.5% loss	28	7.84kW	7.84kW
			component	11.03kW	8.78kW
			<b>Total load</b>	<b>234.94kW</b>	<b>215.05kW</b>
Total Facility Power	UPS	4% loss	2	9.40kW	8.60kW
	Chiller	EER=3.03 Chiller on	2	77.54kW	N/A
		EER=19.3 Chiller off	2	N/A	11.14kW
	Ventilation	880W	10	8.8kW	N/A
			component	95.73kW	19.74kW
			<b>Total load</b>	<b>330.67kW</b>	<b>234.80kW</b>
			Total PUE	1.477	1.138
			MFLOPS/W	<b>674.7</b>	<b>950.2</b>
			Total cooling	<b>98.17kW</b>	<b>11.77kW</b>
			Power saving		<b>95.88kW</b>

MFLOPS/W is based on the full facility.

Systems: Supermicro X9D with dual Xeon (Sandy Bridge) E5-2670.



# Advantages of liquid cooling

- Data centre using xLC offers better space utilisation. Good for HPC facilities.
- Thermal inertia of DLC/TLC – failure in cooling system gives > 60 min before IT overheats. For air cooled this is around 120 seconds.
- Increased IT reliability – less thermal stress and/or corrosion of components with TLC.
- Reduced power consumption – server requires no fans (TLC) or a reduced number of fans for ILC.
- xLC increases the limits of rack density (good for HPC).
- TLC with good insulation offers a reduction in extra data centre infrastructure.
- xLC offers a greater potential for waste heat re-use – potential for carbon offsetting.
- TLC does not need any due point control – no risks/run hotter.

# Disadvantages of liquid cooling



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- Requirement for extensive leak detection. RDHx (ILC) well established and used in HPC. In-line Hx (e.g. APC) are now used.
- Extra complexity for cooling infrastructure at the rack level and perhaps not worth the associated risks for situations with  $< 5\text{kW}$  in the cabinet (Not usually HPC).
- Requires a raised floor or void for facility water circuits – not overhead.
- Liquid cooling to the rack or the row would need numerous valves or two facility water feeds to be concurrently maintainable.

# Summary



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- xLC can get a pPUE of around 1.05 (The 1 is really less than 0.93 as fans in servers can consume between 7 and 25% of server power). Yields more power for compute.
- Lower CapEX if most of the heat is harvested in liquid. OpEx is lower than best of air cooling.
- Liquid cooling has many environmental advantages – lower server power consumption, greater rack density, less constrained environment.
- Having the heat in the liquid offers greater potential for its reuse, which could be incentivised by carbon offsetting.

# Any Questions Please?



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- Email address: J.L.Summers@Leeds.Ac.UK
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Technology Road mapping  
EU funded PEDCA  
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