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Results of Study Comparing Liquid Cooling Methods

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Topical HPC

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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 MICROELECTRO

F. HONNOR and N

Mechanical Engineering Laboratory, English Electri

PACKAGING AND COOLING WITH

6. DIRECT LIQUID COOLING

The idea of a liquid in direct contact with the active device is apt to frighten the electronics engineer because of the susceptibility of semi-conductor 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.,[4] and in the U.K.,[5] have shown that

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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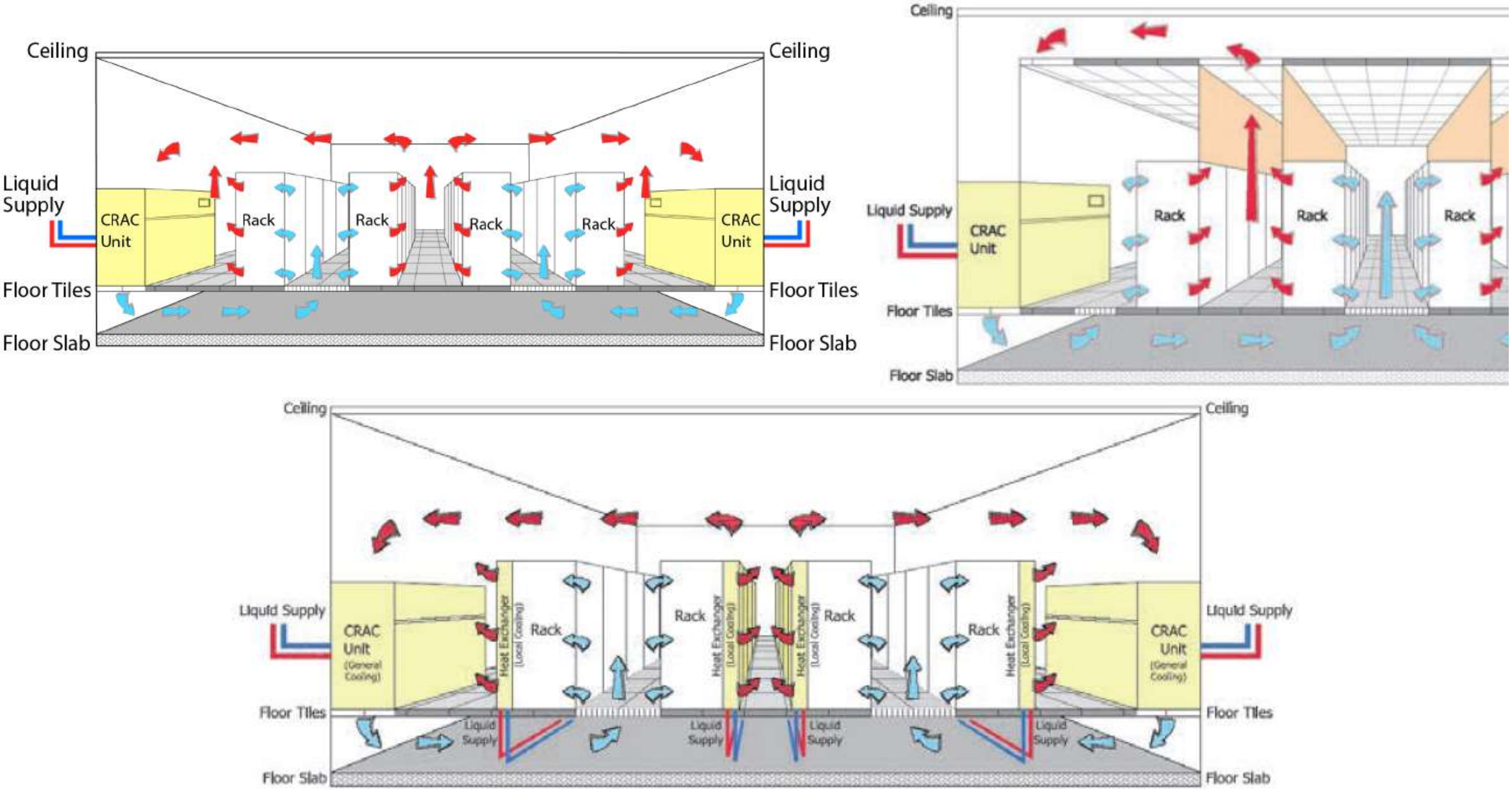

Source: ASHRAE Datacom volume 2

Liquid Cooling Solutions

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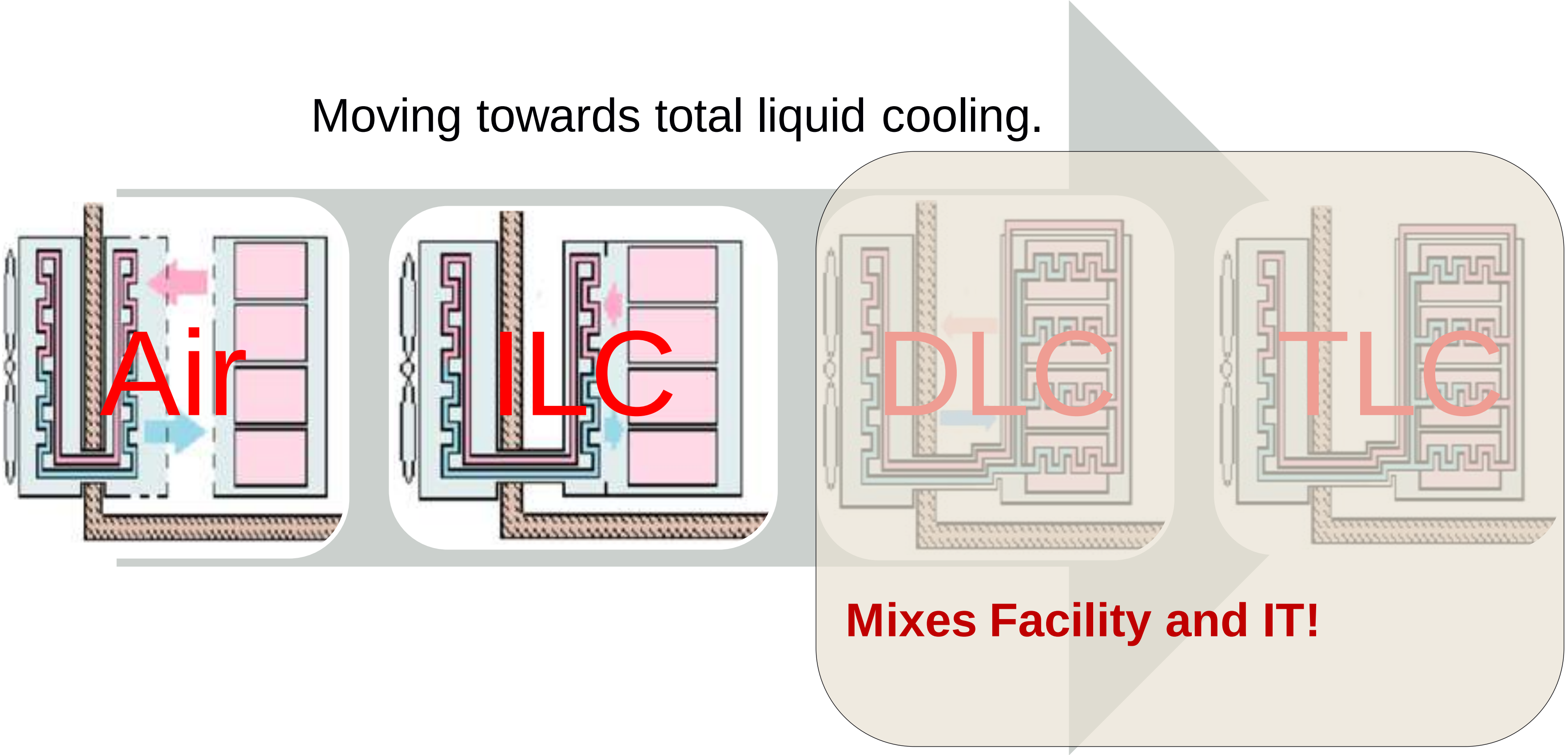
Moving towards total liquid cooling.



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

DLC = Direct Liquid Cooling – 0%<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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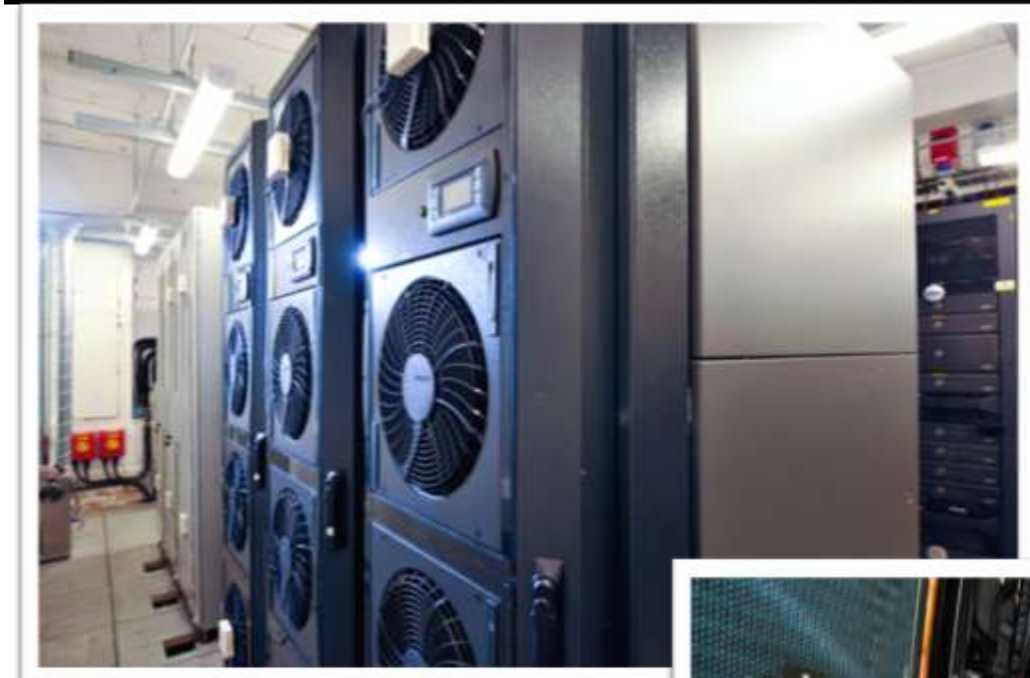

Airedale
APPLIED THERMAL INNOVATION

Indirect Liquid Cooling to the rack Performance

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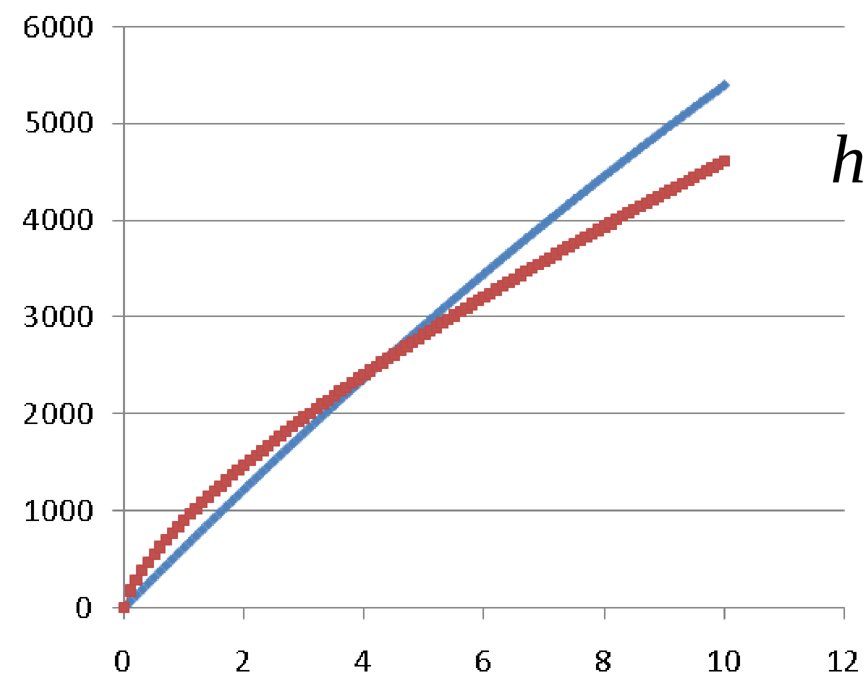
$$\dot{Q}_{bdc} = \dot{m}\, h(|\underline{U}|)\, A(T_{ref} - T_{air})$$

Tang (2009)

$$h(|\underline{U}|) \propto |\underline{U}|^{0.71}$$



OnRak Compact Hot Aisle

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

Indirect Liquid Cooling to the rack
Performance

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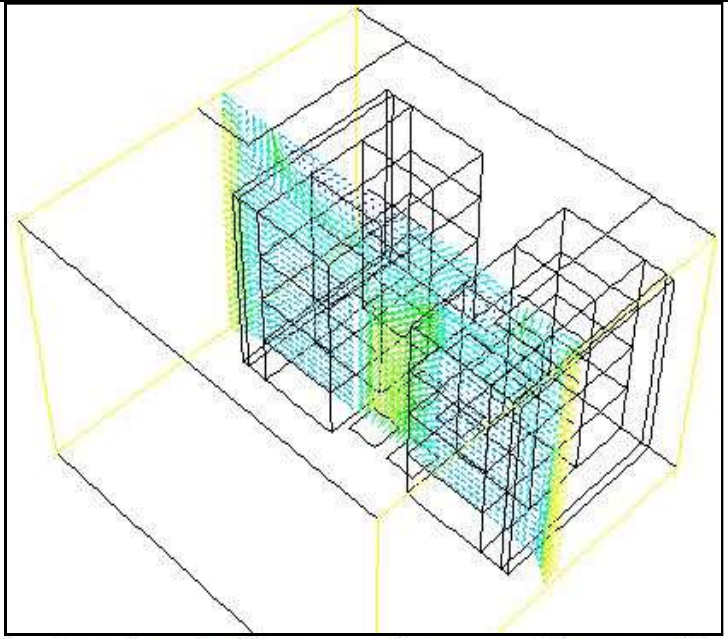

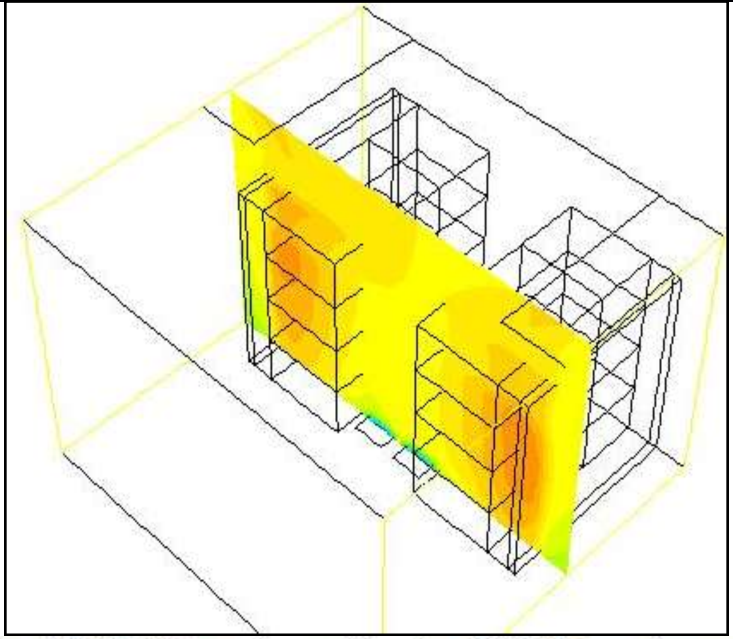

Effect of using back door coolers on the cooling load of CRAC units with six 30kW racks, where $\dot{m}_{CRAC}$ and $\dot{m}_{BD}$ are the mass flow rate through the CRAC and back door respectively.

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

Almoli, Ali, et al. "Computational fluid dynamic investigation of liquid rack cooling in data centres." *Applied energy* 89.1 (2012): 150-155.

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 read doors
  - One power measurement showed a consumption of 137kW (104kW compute, 33kW cooling) **giving a pPUE of 1.32** (137/104)
  - 45TFlops/137kw = **0.33Gflops/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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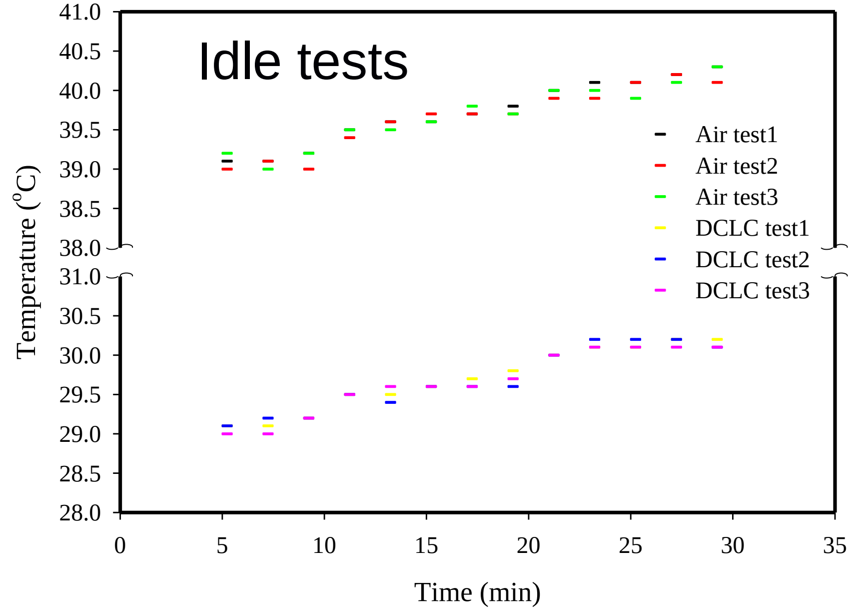
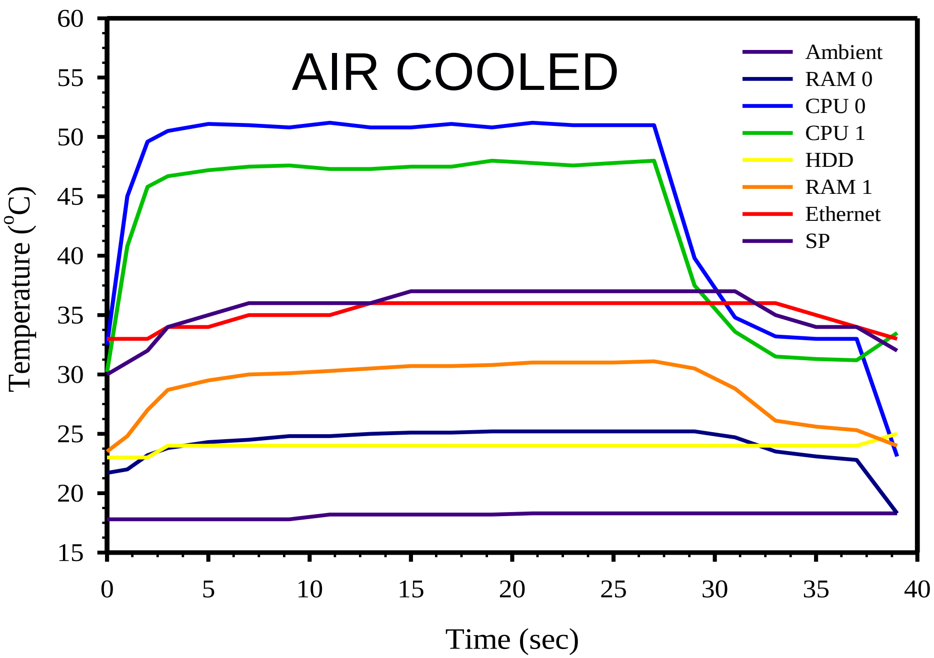
- Retrofit into decommissioned (2007) HPC nodes
- Setup is in a laboratory.
- Primary research goal is to look at cooling on demand.

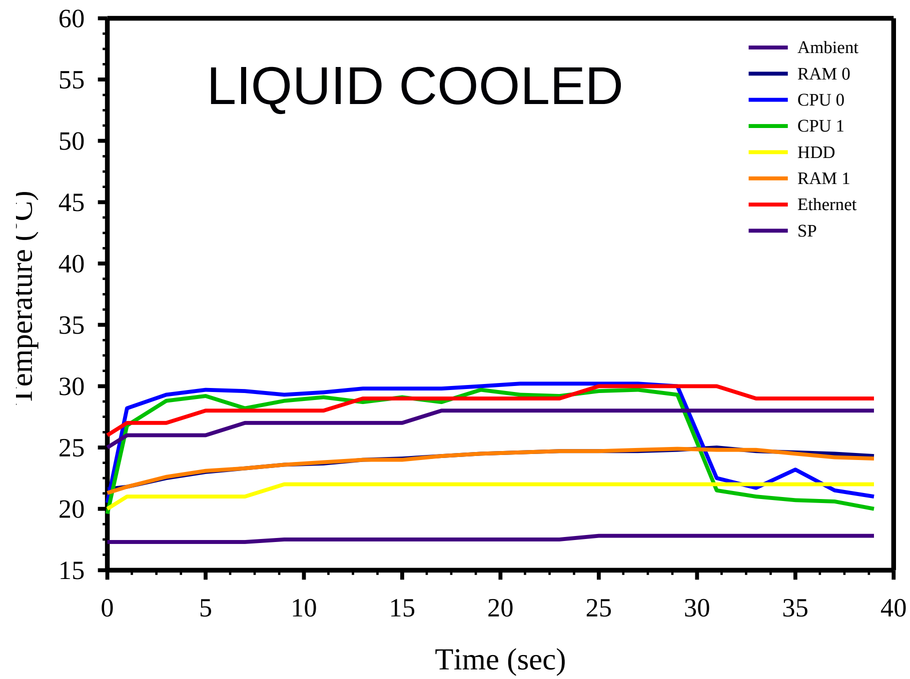
CoolIT SYSTEMS

Direct Liquid Cooling into the server

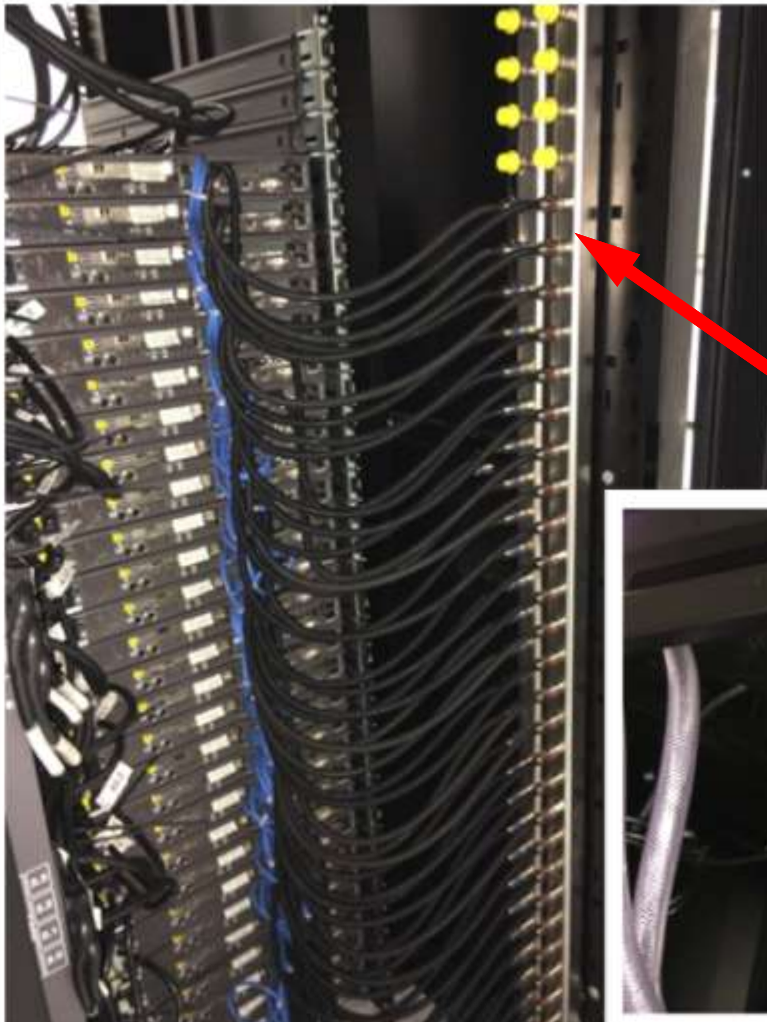


Using StressLinux - a load profile is run for 6 minutes each time.



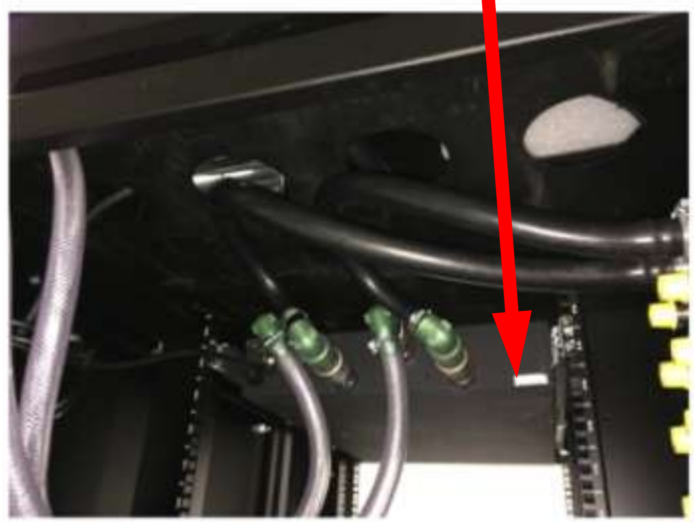


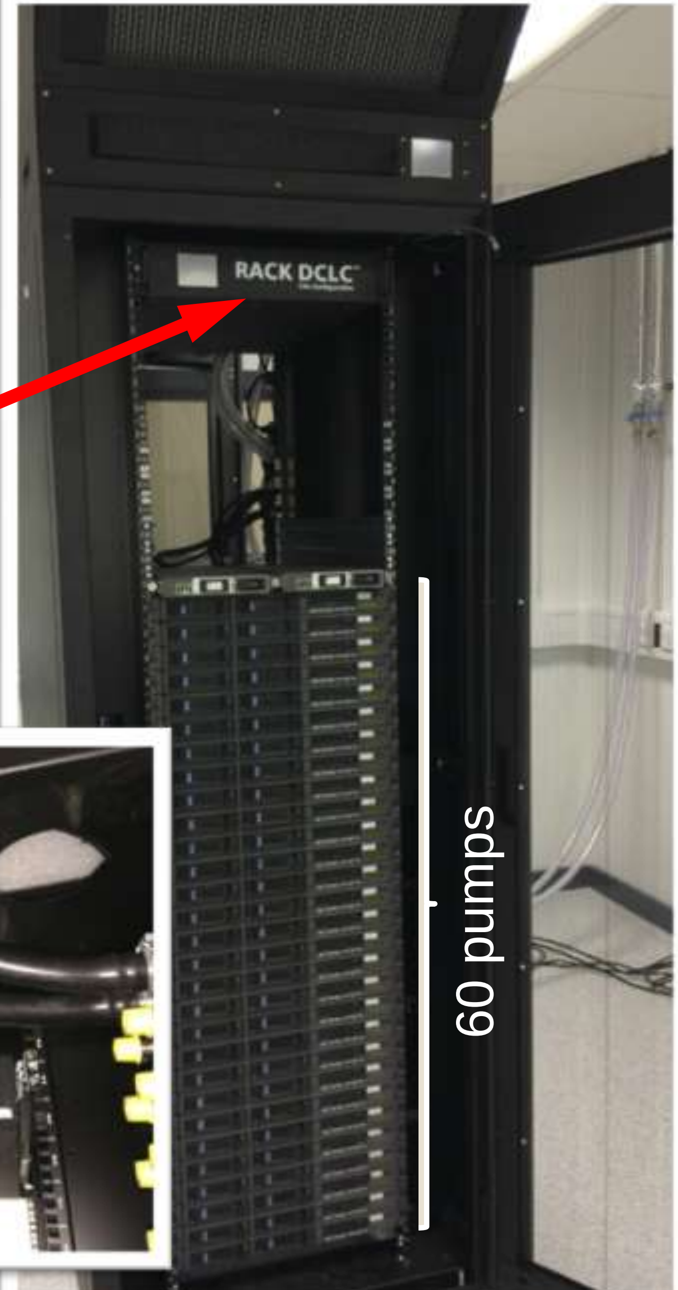
Direct Liquid Cooling into the server



CHx – liquid to liquid

Cooling manifold





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^{o}C giving a flow rate of 9 litres per second.
- The *direct liquid cooled (DLC)* server looses 4 of the 8 fans.
- With half the flow rate and a measured temperature difference of 8^{o}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

Uptime Institute
GREEN ENTERPRISE IT AWARD 2013

ICEOTOPE™

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**

1. Microelectronics to water jacket

2. Server water jacket to the rack water circuit

Leeds deployment

3. Rack to secondary heating water circuit

4. Heat transfer by convection into laboratory

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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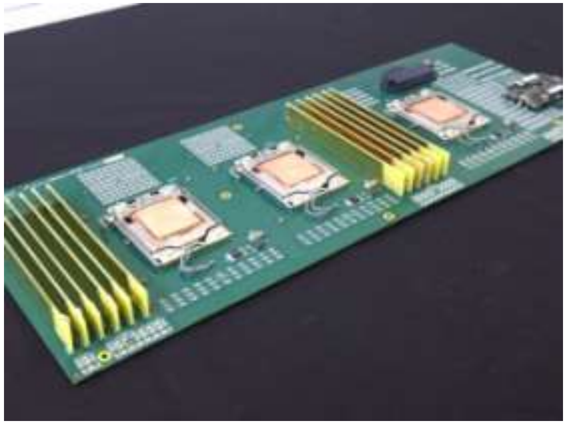
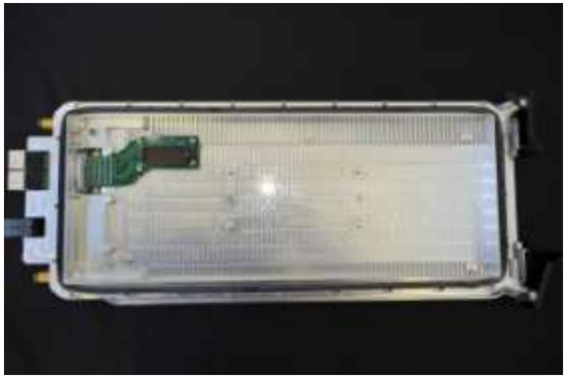
- Heat transfer capabilities investigated using controlled proxy mainboard.





Water in	**Water out**	**Water flowrate**	**Electrical Power in**	**Water power out**
27^{o}C	36^{o}C	1.15x10^{-5} m^{3}s^{-1}	500W	432W
29^{o}C	38^{o}C	1.13x10^{-5} m^{3}s^{-1}	500W	441W
30^{o}C	39^{o}C	1.13x10^{-5} m^{3}s^{-1}	500W	448W
32^{o}C	42^{o}C	1.10x10^{-5} m^{3}s^{-1}	500W	464W
35^{o}C	45^{o}C	1.105x10^{-5} m^{3}s^{-1}	500W	461W

Hopton, P., & Summers, J. (2013, March). Enclosed liquid natural convection as a means of transferring heat from microelectronics to cold plates. In *Semiconductor Thermal Measurement and Management Symposium (SEMI-THERM), 2013 29th Annual IEEE* (pp. 60-64). IEEE.

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

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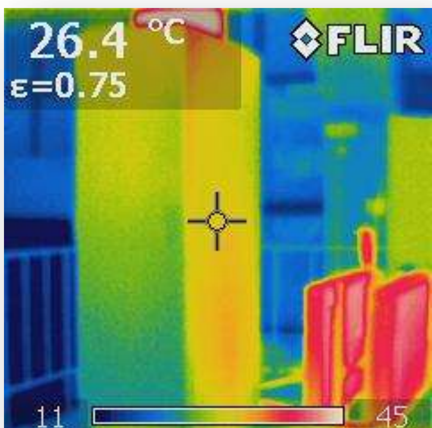
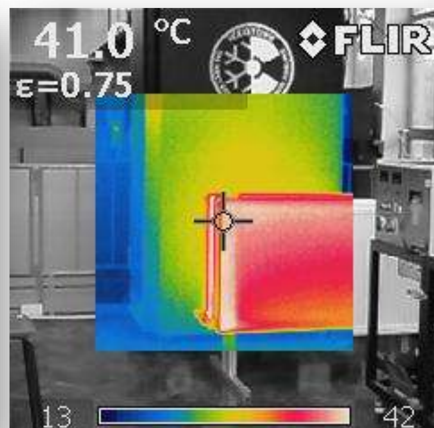
- Using 20W central heating pump.
- Two 2.5kW domestic hot water radiators.
- Thermal images show surface temperatures of the rack and the radiators.





- 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	**204.96kW**	**204.96kW**
	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
			Total load	**223.91kW**	**206.27kW**
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
			Total load	**234.94kW**	**215.05kW**
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
			Total load	**330.67kW**	**234.80kW**
			Total PUE	1.477	1.138
			MFLOPS/W	**674.7**	**950.2**
			Total cooling	**98.17kW**	**11.77kW**
			Power saving		**95.88kW**

MFLOPS/W is based on the full facility.

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

Chi, Y. Q. *et al* (2014, March). Case study of a data centre using enclosed, immersed, direct liquid-cooled servers. In *Semiconductor Thermal Measurement and Management Symposium (SEMI-THERM), 2014 30th Annual* (pp. 164-173). IEEE.

Advantages of liquid cooling

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- 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 leek 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 < 5kW 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
- Thanks to Colleagues and PhD students who contributed to the current research.
- Many thanks for the financial and in-kind support from
  - The University of Leeds Digital Innovations Hub

ICEOTOPE™

Airedale
APPLIED THERMAL INNOVATION

CoolIT SYSTEMS

European Commission

Technology Road mapping
EU funded PEDCA
Project number: 320013