04 Optical Illusions in the Quest to Reduce the Internet's Energy Bills

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Data centres are huge warehouse-sized facilities with thousands of computers that form the backbone of Internet services like Google, Facebook, Amazon, Dropbox, etc. Between 2000 and 2010, the global electricity consumption of data centres was increasing by 11% per year to 27 GW in 2010, or 1.3% of the total worldwide electricity production.

While this global growth has slowed somewhat in recent years, Ireland has seen a rapidly growing presence of data centres. In 2016, Irish-based data centres consumed 250 MW of electricity – as much as 8% of the national electricity production. Eirgrid expects this number to surpass 15% by 2019.

In a typical data centre, over a third of the total energy goes to the cooling system, which is designed to keep the computers running without overheating. In our cooler Irish climate, some data centres work without mechanical refrigerators, relying only on the outside air to cool the data centre halls. This saves some energy on cooling, but the computer fans then need to work harder to pump greater volumes of air through the servers.

For most large data centres in Ireland, this is the case. However, in an ideal situation, there would be some way of recuperating the hundreds of megawatts used by the computers themselves, which is now discarded into the atmosphere. Since most of the heat is being generated in the processors (CPUs), thermal management research is currently focusing on developing smart ways of extracting heat directly from the CPUs.

Measuring flow fields – In the Fluids & Heat Transfer lab in the Department of Mechanical and Manufacturing Engineering, my team studies the fundamentals of adaptive flow manipulation at solid/fluid interfaces. The overarching goal is to develop reliable cooling methods that can modulate local heat transfer rates and redirect flows towards the hottest components, to respond to rapid changes in computational loads. This applies both to large-scale air cooling (the size of computer servers, racks or entire rooms) down to small liquid-cooled heatsinks of the same size as computer processors (a few cm2), with micro-scale flow passages for the liquid coolant to extract heat from the electronics in precise amounts and locations.

An important challenge in developing new adaptive convective cooling technology is the need to visualise and quantify complex turbulent flow fields. Understanding convective cooling starts with fluid mechanics, yet air currents and small eddies in water flows are invisible. We use computational fluid dynamic (CFD) simulations to predict how the flow behaves, but the final proof is in measuring it in real life, with enough detail in space and time to truly understand and optimize thermal flows.

Measuring flow fields takes a bit of optical trickery, whether it is air or water, large or small scale. We customise pulsed lasers and LED lighting systems with high-speed cameras to track micrometre-sized tracer particles in air or liquid flows. Using particle image velocimetry, we are able to measure accurate turbulent flow fields alongside heated surfaces in fine detail.

Traditionally, a heat-generating electronic component like a CPU processor has been air-cooled by a 'heatsink'. This passive metallic heat exchanger spreads the heat generated by the CPU chip out to a larger surface area, so that it can be transferred to a surrounding airflow. Heatsinks tend to have rows of thin parallel plates or fins that protrude out into the flow. The air is forced through a series of narrow passages that promote fine-scale mixing, and allow it to absorb and carry away the heat. Because of the complex internal structure of heatsinks, flow field measurements inside heatsinks are particularly challenging. Therefore, we use another optical illusion and match the liquid coolant's refractive index to that of transparent heat sink models, making the pulsed light pass through complex 3D models unobstructed, allowing us to measure more accurately right at the solid/fluid interfaces and around corners.

Tim Persoons received his MSc and PhD from KU Leuven, joined the School of Engineering in 2006 as research fellow, and was appointed Assistant Professor in Engineering in 2013. He is a visiting faculty member of the NSF Cooling Technologies Research Center in Purdue University, and investigator in SFI ESIPP and CONNECT. Tim has published over 100 articles in peer-reviewed journals and conference proceedings. His research focuses on multi-scale convection and flow control for electronics thermal management and sustainable energy technologies.
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Fig 1. Cylinder array in cross-flow in a water tunnel test facility with refractive index matching for unobstructed velocity measurements in complex geometries, such as advanced heatsinks

Fig 2. Laser sheet flow visualisation of a synthetic jet emanating from a circular cylinder

Fig 3. Cylinder with embedded synthetic jet flow control actuator, mounted in a water tunnel test facility, with laser sheet illumination from below to visualise flow near synthetic jet orifice using 50 micron polyamide PIV tracer particles

Fig 4. Electro-hydrodynamic or plasma actuation for low power enhanced natural convection cooling

Our measurement facilities are designed and built in-house using advanced manufacturing and the help of skilled technical and experimental support staff.

Along with industrial partners (Nokia, Analog Devices, and General Electric), we are looking at different ways of manipulating flows using oscillatory or 'synthetic' jets , other pulsatile flows or acoustics, or even magnetic or electric fields. All of these methods act on boundary layers, and allow us to gently 'nudge' flow fields in the desired direction, or increase or decrease heat transfer as needed, with minimal effort.

Such adaptive flow control technology could mean big energy savings for electronics cooling in data centres, but it also has applications far beyond electronics. Examples include drag reduction for ground or marine transportation and avoiding separation on aircraft wings, for next-generation large passenger aircraft.

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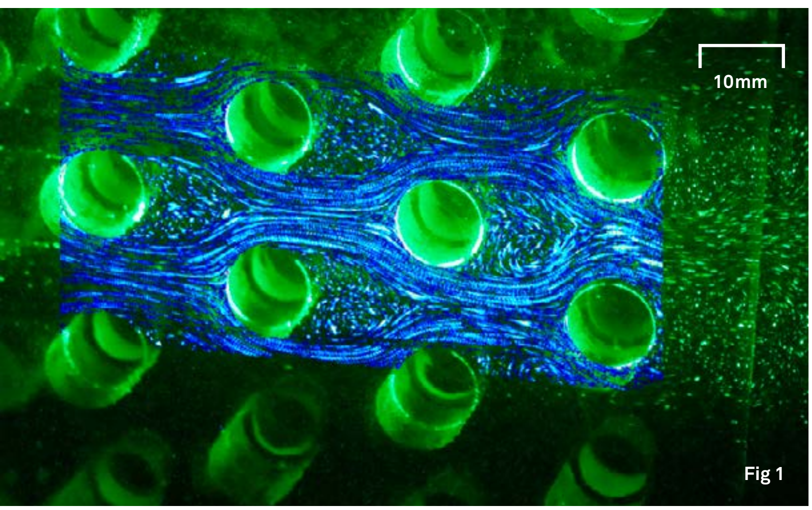

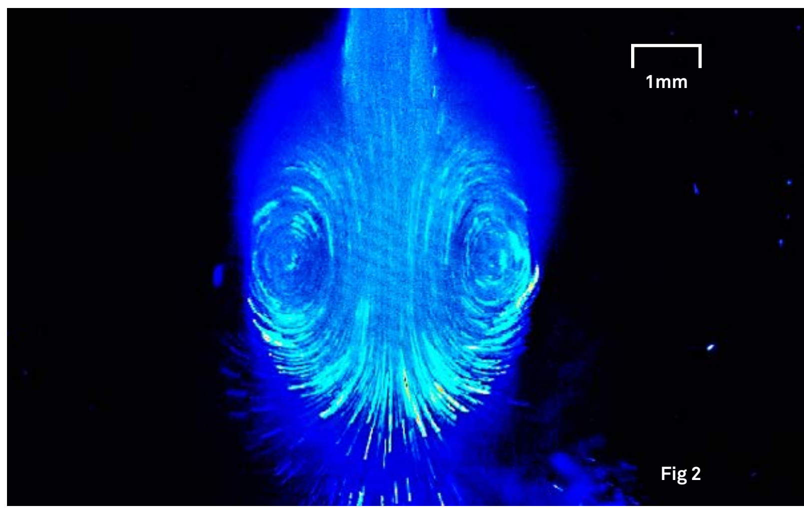

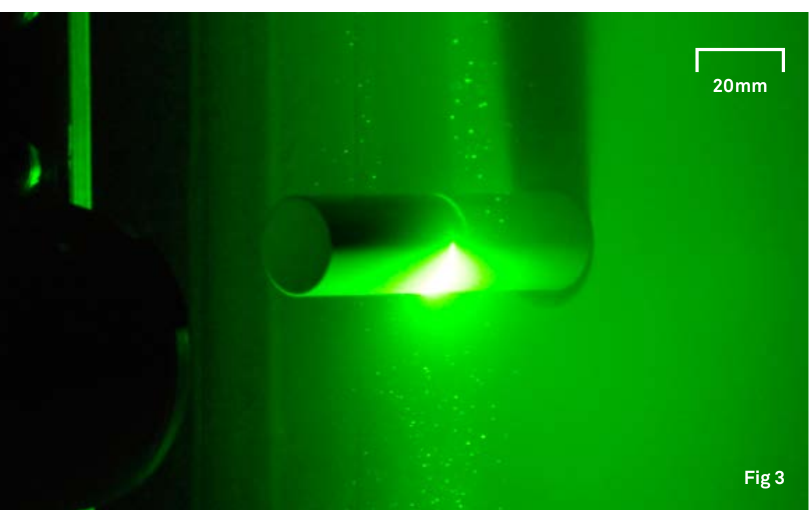

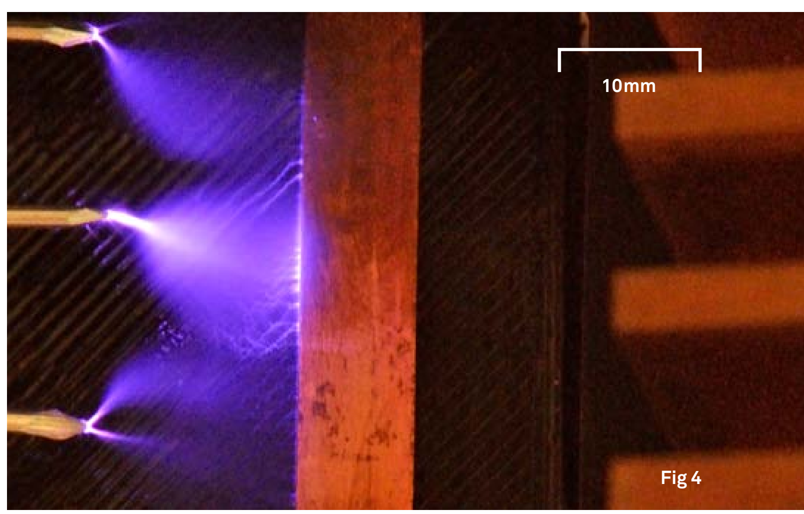

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