Improving data centre efficiency in Ireland

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December 2020

INSIGHTS SERIES PAPER NO. 5

The Insights Series has been developed to highlight key findings arising from Energy Systems Integration Partnership Programme (ESIPP) research in decarbonised energy systems. These publications share new insights into various aspects of energy decarbonisation that have been gained from a multidisciplinary team of researchers in ESIPP from institutions across Ireland.

The aim of this Insight paper is to present the insights from five research papers on data centre energy efficiency and to make policy recommendations to ensure emission targets are met. Results of these papers highlight that there is potential for improvements within the cooling solutions, especially in the design phases. Increasing the share of renewables will aid the decarbonisation of data centres decreasing the environmental impact further.

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Context

The Energy Systems Integration Partnership Programme (ESIPP) is a research programme, funded by Science Foundation Ireland and industry, and delivered by a multidisciplinary team of researchers from University College Dublin, Trinity College Dublin, NUI Galway, the Economic and Social Research Institute (ESRI) and Dublin City University. The research programme has three strands: (i) addressing operational and technical aspects of the network, (ii) identifying energy solutions for people in their homes and businesses, and (iii) informing energy policy and infrastructure investment to enable energy decarbonisation. One focus of research in ESIPP has been on methods to minimise power consumption of data centres in line with EU and Irish policy. In this Insights series paper, some findings from ESIPP research papers on data centres are presented. They should provide insights to policy makers and industry stakeholders on future pathways to reduce electricity consumption in the sector.

Data centres are building facilities used to accommodate, interconnect and operate IT and network telecommunication equipment whilst providing storage, processing and transport services (Oró *et al.,* 2015). They accommodate a range of sectors (including manufacturing, financial services, animation, retail and global business services) and activities that are increasingly reliant on digital capabilities such as online transactions and cloud computing, which are seen as critical components of the modern, connected economy. Data centres have developed due to the ever increasing creation, storage and utilisation of digital data, the associated installed capacity which has resulted in the consumption of power growing at an unprecedented rate (Beckford, 2018; Fitiwi and Lynch, 2020).

Across many countries, the uncertain, yet increasing presence of data centres poses a challenge for generation and transmission network planning. In 2015, data centres in the EU were estimated to consume 78 TWh of electricity, 2.5% of total EU electricity use (Koronen *et al.,* 2020). As part of Ireland's national enterprise policy objectives to become a digital economy hotspot in Europe, successful implementation of data centres will require improvements to current energy efficiency and energy demand. In 2018, data centres in Ireland consumed approximately 15% of national electricity (Gibbons *et al.,* 2019; Government of Ireland, 2019) emitting ~1.72 billion tonnes of carbon dioxide emissions annually from the consumed electricity on the Irish grid (Gibbons *et al.,* 2019).

The most energy intensive stage of data centre operations occurs when almost all electrical power supplied is converted into waste heat through a cooling system to keep components below critical temperatures. **Figure 1** highlights a typical mechanical refrigeration chiller cooled data centre layout which is commonly used, however not a universal type of cooling infrastructure**.** For mechanical cooled systems, a third of the total power consumption is needed for the cooling infrastructure as facilities reach their cooling limits in High Performance Computing (HPC), and as a result power density in data centres has plateaued. Due to the cooling process and energy costs scaling with ambient temperature levels, numerous companies have invested in data centres in Ireland over recent years, as 80% of annual temperatures remain under 27°C which has the ability to efficiently cool the data centre (Gibbons *et al.,* 2019). In recent years, due to a higher heat capacity of water, there has been a steady research interest in liquid-cooled HPC. Liquid-cooled systems have the added ability to extract high grade waste heat for a secondary purpose through a heat transfer enhancement process. They are often cheaper to operate and are silent and offer the possibility of waste heat capture and reuse in other activities such as within district heating systems (Sakanova *et al.,* 2019; Tuckerman and Pease, 1981). However to see a substantial reduction in the amount of electricity required and emissions produced, investment will need to be made into the efficiency of data centres. Through improvements in energy efficiency there remains scope for further research to investigate the technical and economic feasibility for recuperating some of this waste heat produced for district heating and improved demand-side flexibility, minimising the environmental implications of data centres.

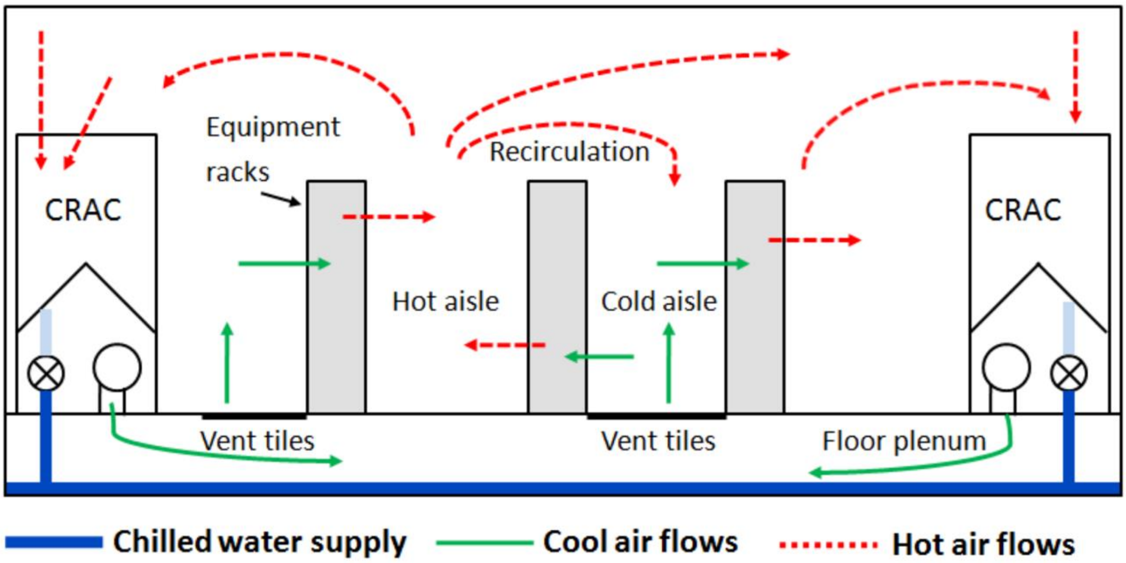

Figure 1: Overview of a typical raised floor data centre (Source: Zhou *et al,.* **2011). CRAC stands for computer room air conditioning units.**

Research Description

The Insights Series aims to provide information on particular topics drawn from our research activities in a non-technical format. This series enables us to provide unique perspectives on important energy topics by bringing together different research findings gained through a multidisciplinary research approach. Over the duration of the ESIPP project, researchers have published several papers on data centres. For the purpose of this insights paper, we have focused on five publications discussing the technical and economic aspects of data centre energy use. A summary description of each of the individual studies is provided in this section below.

Due to the rapid increase in energy consumption of data centres, improved cooling solutions and techniques need to be developed and implemented. **Study one** calculates the potential for energy recuperation by a server-level internal layout optimization for a hybrid air/liquid-cooled server. This study combines a multi-objective genetic algorithm (MOGA) and entropy generation minimization (EGM) techniques to incorporate the multiple objectives involved in this task. This study also examines the cooling performance and waste heat recovery potential to improve the efficiency of data centres (Sakanova *et al.,* 2019).

Optimization analysis is performed for energy savings and improved heat recovery for a hybrid air-liquid cooled server as cooling systems have the greatest potential to reduce energy demands. **Study two** focuses on the effect of two different baffle[1] designs on the air-cooling efficiency in the server, and on the potential of waste heat recovery at the server outlet. A 2D computational fluid dynamics (CFD) model was employed to perform a numerical convective heat transfer analysis of the server. EGM in conjunction with a MOGA are employed to evaluate the cooling system ability to minimize the pumping power and unify the air outlet heat stream while keeping the server component temperatures below prescribed constraints (Battaglioli *et al.,* 2019).

Data centres have moved to denser and more powerful servers to increase their data handling limits which has resulted in a thermal bottleneck when air cooling techniques are utilized. This problem has also been faced by HPC facilities and solved by the adoption of liquid cooling techniques. High heat fluxes in central processing units require miniaturization of cooling devices to maintain temperatures within a safe limit. Previous studies have focused on numerical, analytical and experimental investigations into microfluidic cooling. These studies have shown interesting results regarding flow pulsation and the use of modulated wall or 'wavy' walls. **Study three** investigates experimentally the combination of the two of these methods. The aim of this research is to

[1] Baffles are flow-directing or obstructing vanes or panels used in some industrial process vessels (tanks).

further investigate the utilisation of flow pulsation and embedded wavy fins within mesochannels for a low Reynolds number[2] case (McEvoy and Persoons, 2019). In addition, this study assesses the potential of these combined aspects for waste heat recuperation from data centre server central processing units. The scope of this work extends only to single phase flows, due to the added complexity of visualization and stable operation of two phase flows at the mesoscale.

Study four discusses the recent developments in data centre cooling technology using Ireland as a case study. This study applies a model of technology diffusion to quantify the scope for reducing energy demand through adoption of a specific energy efficiency technology in Ireland by switching to direct liquid server cooling, which raises the server power density. This paper uses a methodology that can be applied to any existing or emerging data centre cooling technology. Furthermore, this study also considers how energy efficient server cooling technology could be adopted (i.e., diffuse) in the market (Coyne and Denny, 2018).

Study five focuses on quantifying the key economic benefits associated with technology adoption to supply cold water for data centres, hot water for district heating networks and grid storage to facilitate greater penetration of renewable electricity generation sources. Using Ireland as a case study, this study combines information on data centre capacity and the technological parameters of energy efficiency to develop market-level forecasts. Furthermore, this study was also able to take into consideration the indirect economic benefits of transmission through quantification using a power systems model.

Findings/Discussion

The results of these studies discuss the market adoption for new technologies that have the potential to influence future national electricity consumption and the emissions associated with electricity generation.

Studies one and two have combined the MOGA and EGM techniques through a CFD model to evaluate the cooling systems ability to minimize the pump power and unify the air outlet heat stream while keeping the server component temperatures below prescribed constraints (Battaglioli *et al.,* 2019; Sakanova *et al.,* 2019). **Study one** demonstrates that a basic server layout optimization such as changing the memory module angles and spacing could enhance both the cooling effectiveness but also improve the potential for waste heat recovery from the air stream (Sakanova *et al.,* 2019). The maximum reduction in entropy generation rate due to server layout optimization was 15%, while the outlet temperature uniformity can be improved by up to 42%. However, the results from this study may be difficult to replicate in practice due to a more complicated electrical design. The layout of optimisation-based design could be a promising way of improving server-level cooling and increasing the potential for air-side waste heat recovery. **Study two** highlights that both baffle designs under investigation led to an improvement of the convective cooling in the server, reducing the maximum temperatures on the dual in-line memory modules (DIMMs) surface (Battaglioli *et al.,* 2019). Both of the baffle designs studies show a lower total entropy generation rate than that of the baseline server, with relative reductions up to 40%. Temperature uniformity at the outlet is also improved, with a relative decrease in ΔT_{out} of more than 50%. Nonetheless, the average temperature at the outlet is not significantly increased. Overall, the introduction of optimized baffles demonstrates a promising way for improving the server cooling performance, while increasing the potential for waste heat recovery. Using these methods discussed in **studies one and two**, during the design phase of data centres, has the ability to improve energy efficiencies within the cooling process as additional data centres are being developed in Ireland.

Study three highlights that an acceptable pressure drop was found for a low waviness number fin, while the enhancement in wall shear and fluid mixing was significantly increased. The effect of varying excitation waveform to an asymmetric one was found to increase the velocity fluctuation due to the impulse-like stroke present in the waveforms with no noticeable increase in pressure drop. Effect of increasing frequency was found to also significantly increase velocity fluctuations, which is an indicator that heat transfer performance

[2] A Reynolds number is the ratio of the inertial forces to viscous forces. It is a dimensionless number used to categorise fluid systems where the effect of viscosity is important to control the velocities of the flow pattern on a fluid. A flow at a low Reynolds number is dominated by laminar (sheet-like) flow, while at high Reynolds numbers flows tend to be more turbulent.

is positively affected. The presence of periodic contractions and expansions coupled with rapid acceleration and deceleration of the fluid due to pulsation resulted in consistent formation of vortical structures at peak pulsatile velocity at the constriction zone. These structures are promising for enhanced mixing and heat transfer, which could eventually lead to novel liquid-cooled heatsinks that enable high grade waste heat recuperation as additional data centres are constructed in Ireland.

Study four and five discuss the different impacts that energy efficient technology adoption could have in Ireland with the potential to reduce national electricity demand by between 28% and 37% between 2019 and 2028, by converting electricity into cooling energy, displacing grid-powered cooling in data centres. This has the potential to reduce lower national electricity demand by between 0.81% to 3.16%, depending on whether the technology could be adopted by future facilities. The methods used here serve as a technology-agnostic resource for researchers that need to perform forecasts under uncertainty with limited information.

In addition, **studies four and five** have highlighted that power system analysis in 2030 suggests that energy efficient technology adoption can reduce system costs by 8.6% (without taking into consideration the capital costs of these technologies). This in turn includes a 6.92% reduction on required renewable energy capacity as energy efficient technologies reduce grid demand. There is also a 3% reduction in emissions, without including savings associated with displacing fossil-fuelled based heating with hot water supply. Furthermore, these studies emphasised that energy efficient technology adoption could supply 12.4 TWh of hot water for use within a 4th generation district heating network. This has the potential to reuse waste material and reduce emission levels within other sectors. Liquid cooling is more suitable for waste heat recuperation, collecting exhaust heat from servers to heat the data centre or be used as part of a district heating system. However, the extra capital cost and additional private and social benefits should be considered as part of any analysis.

Key Insights and Application

Ireland has become Europe's data centre capital and future electricity consumption is forecast to grow. Several challenges will need to be met to ensure EU and Irish emissions reduction and energy efficiency targets are successful for current and future implementation. Results from these studies have already highlighted there is room for improvement in terms of energy efficiency, from which three key conclusions and policy considerations for the future can be drawn.

Firstly, although ideally data centres consume renewable energy as a power source, improvements to the cooling solutions and techniques that reduce electricity demand can contribute towards carbon reduction policies. Ensuring a shift to renewables will aid the decarbonisation of data centres decreasing the environmental impact further.

Secondly, these studies highlight that improvements to the energy efficiency of data centres should be considered in the design phase. These studies have highlighted that there is significant potential to improve the efficiency of data centres, therefore introducing this technology before construction will be beneficial long term. Further investigation will also be required to understand if energy efficiency technology adoption is privately optimal for data centre operators, especially under the context of rising carbon prices.

Finally, the increased presence of data centres has fostered discussions on the additional role they could play in the broader energy ecosystem and should be considered in the construction of future data centres. Although not currently being utilised in Ireland as of yet, it is possible for data centres to be used as part of a district heating system by reusing the captured waste heat. In addition, there is potential for data centres to be placed underwater which could help with the cooling process as well as reducing infrastructure costs. These options should be considered to offset the huge quantity of electricity they will consume.

Acknowledgements: This publication has emanated from research supported (in part) by Science Foundation Ireland (SFI) under the SFI Strategic Partnership Programme Grant Number SFI/15/SPP/E3125. The opinions, findings and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the Science Foundation Ireland.

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