CAREER EPISODE 1

INTRODUCTION

CE 1.1 In this career episode I would be describing my project about designing an efficient cooling solution for large computing infrastructures. The project was for the University of Sydney in collaboration with AECOM Company running from Aug 2009- Aug 2011 in Sydney, Australia. I was working on this project as a PhD Student. The company provides fully integrated technical and management support services offering management services in the architecture, construction, economics, energy, government, oil and gas.

CE 1.2 The final project findings were also published in the Applied Thermal Engineering . Data centres have grown substantially and their growth has resulted in astronomical increase in energy consumption as much as hundred times more than office usage. Server sizes are getting smaller and becoming more efficient but smaller space footprint means more servers can be installed in the same space which stress the power and cooling requirements. Dense server racks and inefficient cooling can increase energy consumption severely.

CE 1.3 As heat dispersal in data centres has increased many times over, any inefficiency of cold air circulation would cause hot spots and stress out heat management systems and efficiency of cooling systems. Thermal management of computer data centres is a challenge and ensuring optimal temperatures in data centres an challenge.

CE 1.4 This project is about the study of an operational data centre, measuring temperatures inside the data centre using thermometer sensors and using numerical modelling the results from modelling are compared to the results from sensors. Adjustments are made to the numerical model so that the model is able to replicate the temperature as captured by the sensors. Hot spots could this be identified and model perfected to return the presence of hot spots given the inputs of heat sources from the server racks.

CE 1.5 The hot spots removal require interventions in the cooling flow redesign and alternate cool air flow to reduce the demand on air-conditioning. Cooling effectiveness solutions help in reducing air-conditioning power and further the design of the cooling flows can be used for making a more efficient design for the upcoming data centres of the future.

Commented [BF1]: I was based at the University of Sydney, and just collaborating with AECOM. Is there a need to write about AECOM? No need to mention about the University of Sydney?

Commented [BF2]: And other journals and conference proceedings

Commented [BF3]: Why have not used my answer for Question 4 in the questionnaire?

"The rapid growth in data centres - large computing infrastructures containing vast quantities of data processing and storage equipment - has resulted in their consumption of up to 100 times more energy per square metre than office accommodation. The decrease in processing server sizes and the more efficient use of space and server processing are challenging data centre facilities to provide more power and cooling, significantly increasing energy demands. Energy consumption of data centres can be severely and unnecessarily high due to inadequate localised cooling and densely packed server rack layouts. Therefore, an efficient thermal management of high-powered electronic equipment is a significant challenge for cooling of data centres.
To highlight the importance of some of these issues, in this project, I studied an operational data centre.
I performed the field measurements of temperature and conducted numerical analysis of flow and temperature fields in order to evaluate the thermal behaviour of the data centre and identify undesirable hot spots. To rectify the problem, I proposed and examined a few practical design and remedial solutions to improve the cooling effectiveness to allow a reduced air-conditioning power requirement. The findings I obtained in this project lead to a better understanding of the cooling issues and the respective proposed solutions allow an improved design for future data centres.
"

Commented [BF4]: These are redundant, use my sentences I gave in the questionnaire. This is not a research paper, it is career episode and no need for too many information on data centres.

CE 1.6 My organizational chart for this project was as follows. I was supervising 8 undergraduate students and 2 masters' students.

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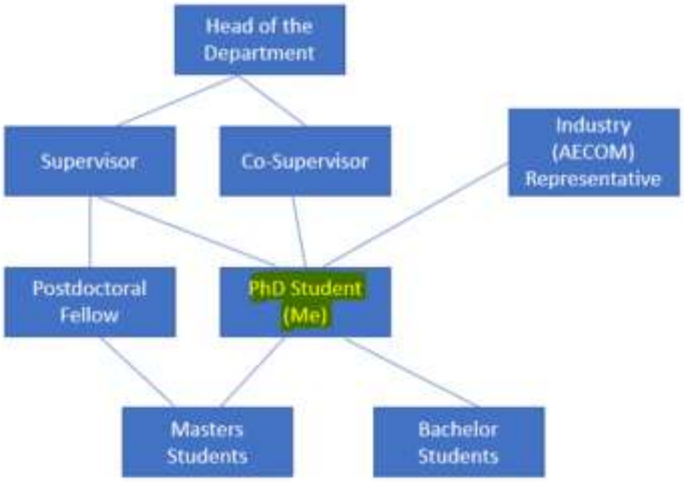


CE 1.7 My Work Responsibilities were:

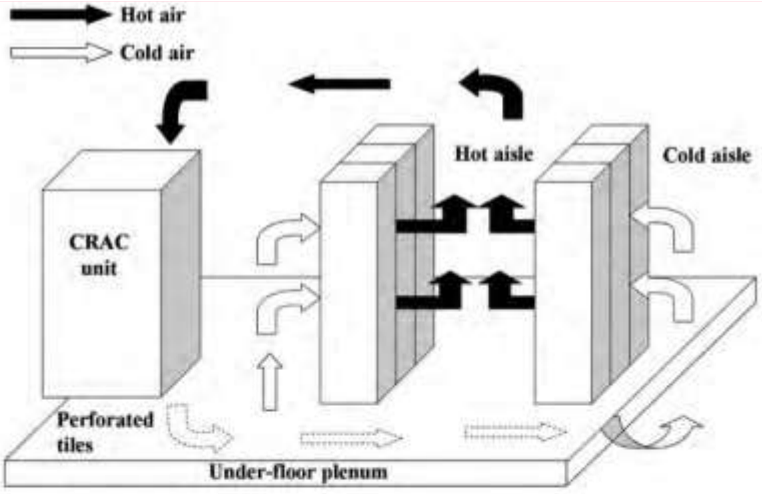
- Supervising 8 Bachelors Students plus 2 masters students
  - Guiding Students on conducting their simulation results and accurately undertaking field measurements.
- Organizing weekly meetings with the team
  - Overseeing meeting agenda and recording meeting minutes and presenting research findings to the supervisor/co-supervisor.
- Arranging meetings with the industry partner
  - Presenting and discussing my experimental results obtained from operational data centres.
- In charge of CFD simulations and optimization process
  - Making sure that pre-processing, solver and post-processing elements were accurately conducted.
- In charge of Experimental investigation of the project
  - Conducted field measurements of temperature and velocity in operational data centres by an experimental apparatus. Leading the in designing the experimental apparatus, installing of data loggers with

thermocouples and accurate measurements of temperature and velocity.

PERSONAL PERFORMANCE

CE 1.8 Data Centres contain a mixture of servers, racks, switches, routers and storage devices. As the demand for processing power climbs the high performance servers come with high density racks and servers that consume high amounts of power and exhaust high levels of heat.

CE 1.9 Thermal management cannot be done in traditional fashion but dedicated computer room air-conditioning (CRAC) is required that deliver cold air through perforations in the raised floor. The cold air is targeted towards the server racks and serves to maintain the optimal cold temperatures.



Hot-aisle/cold-aisle configuration.

CE 1.10 The dense server processors are packed by thousands inside single rack and can consumer in the range of 30kW and more for less than one metre square covered area. Reliable cooling is required for individual chips and processors to keep temperatures from climbing beyond the safe zone.

CE 1.11 The flow distribution requires multiple parameters for correct prediction. Even though Computational Fluid Dynamics (CFD) analyses help but because of the intervention of the cables and cool water distribution network the flow distribution become highly complex and difficult to predict.

CE 1.12 As see in the figure the data centre racks are alternated between hot and cold aisles where cold air is forced via CRAC units through the perforations inside the plenum and dowsing the racks housing servers, networking equipment and cabling. Hot exhaust air goes to the ceiling where CRAC intake units siphon off the hot air to restart the cycle.

CE 1.13 Efficient data centres now reuse the wasted generated heat for space heating. IBM has introduced zero emission data centre technology which reduces usage by 40%. Recycling waste heat helps in reducing CO_2 emissions by 85%. IBM's proprietary cooling liquid technology keeps the temperature at optimum level for its heavy duty blade based servers.

CE 1.14 The hot spots removal in a data centre room requires interventions in the cooling flow redesign and alternate cool air flow to reduce the demand on air-conditioning. I studied cooling effectiveness solutions in an operational data centre to help in reducing air-conditioning power and furthered the design of the cooling flows to be used for making a more efficient design for the upcoming data centres of the future.

Commented [BF6]: No need for too many information om data centers. This can be deleted.

CE 1.15 My research showed that energy usage in data centres tends to spike and result in hot spots as the cooling air doesn't get to the data centres uniformly. Hot spots identification, and ensuring that these spots are avoided with efficient cold air flow distribution helped in reducing energy consumption and providing better energy efficiency.

CE 1.16 Data centre studied for this project covered a space of approximately 360 m^2 enclosed space with 1 feet of deep space under which ran the computer cabling and cooling pipes and which contained the perforated tiles distributing cold air in the data centre. Racks were taken as heat sources and heat rising and heat flows from the racks' front and back areas was inputted into the model. See diagram below for illustration on how the heat flows across the data centre.

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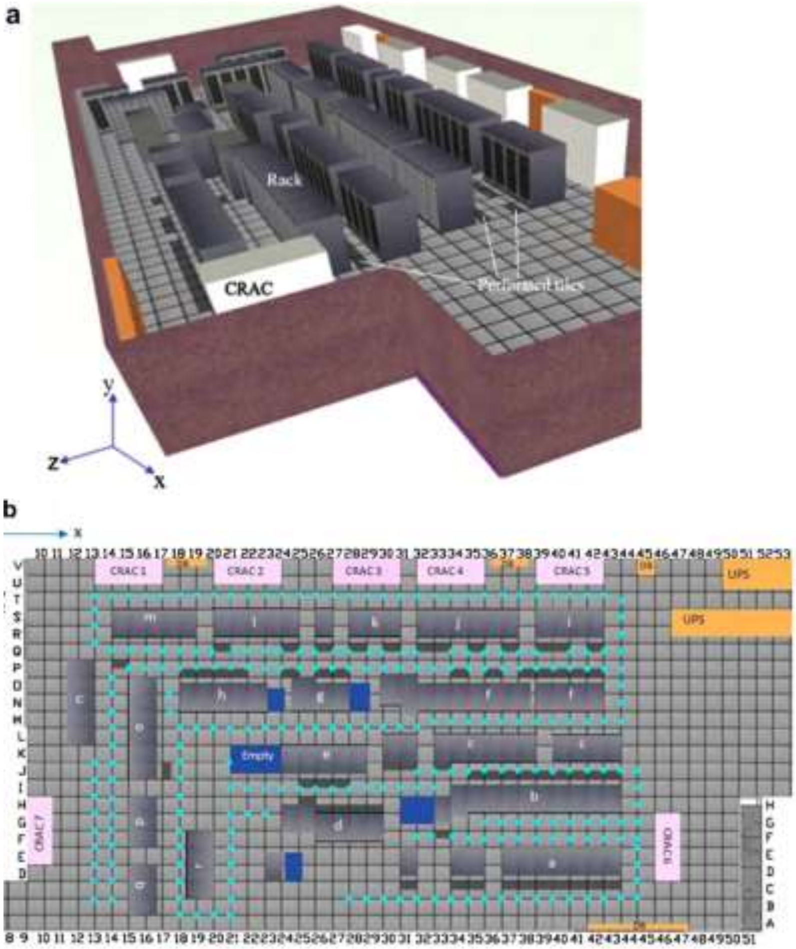

Figure 1: Data Centre Layout

CE 1.17 I estimated the flow of the cold air on the manufacturer's specifications of how much air volume would be supplied by the flow rates in all the air-conditioning units using the volume of 5.5 m^3/s at a temperature of 16 degrees Celsius. I assumed that there would be no substantial airflow leakage and floor bars would be lined up on z axis, and air flow straightened by the grill along the x-axis. Total of 102 racks in the data centre would be accounted for in the model with air flows that are not uniformly distributed.

CE 1.18 I led my team members to perform the temperature measurements in the data centre using K-type thermocouples. I designed the experimental apparatus with K-type thermocouples attached on it. The Figure 2 shows the schematic layout of thermocouple. 8 thermocouples were attached to a frame with data loggers and one laptop. For measurement at heights the stand was fitted with horizontal frame with sensors to capture temperature at top of the racks

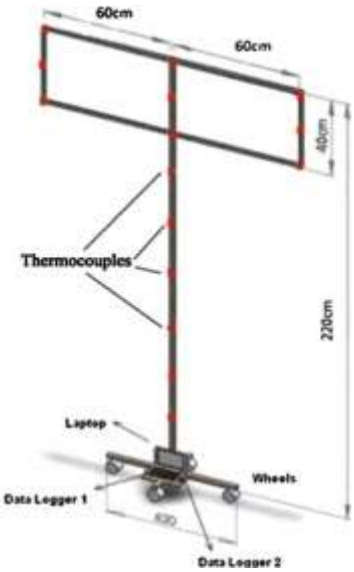

Figure 2: A schematic of the experimental apparatus

CE 1.19 I measured temperature along 1400 measurement points (597 measurement points from 0 to 160 cm and 768 measurement points from 180 to 220 cm), at 10 different heights between 0 and 220 cm (see above figure 1b), recorded by two data loggers. Measurements were performed after installing blanking panels onto the vertical blank spaces in rack enclosures for preventing hot air from recirculation, and cold air from bypassing the server racks.

CE 1.20 I supervised 3 bachelor students to measure temperature along 1400 measurement points (597 measurement points from 0 to 160 cm and 768 measurement points from 180 to 220 cm), at 10 different heights between 0 and 220 cm (see **Error! Reference source not found.** b), recorded by two data loggers. There was a good agreement between the field measurements and simulation results. Also bottom right of Figure 2) from the numerical simulations in comparison to the field measurements

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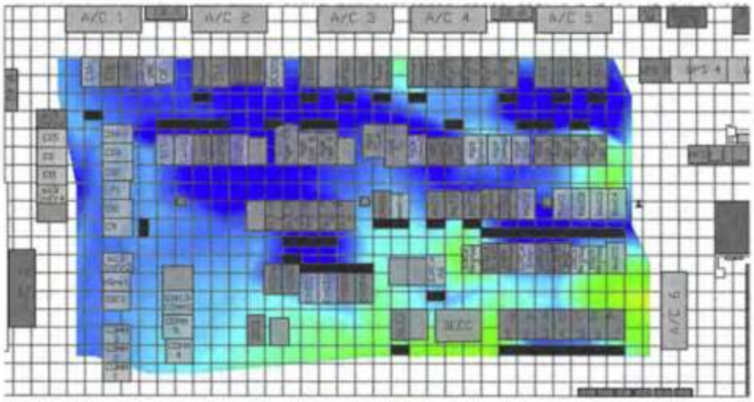

At ground level

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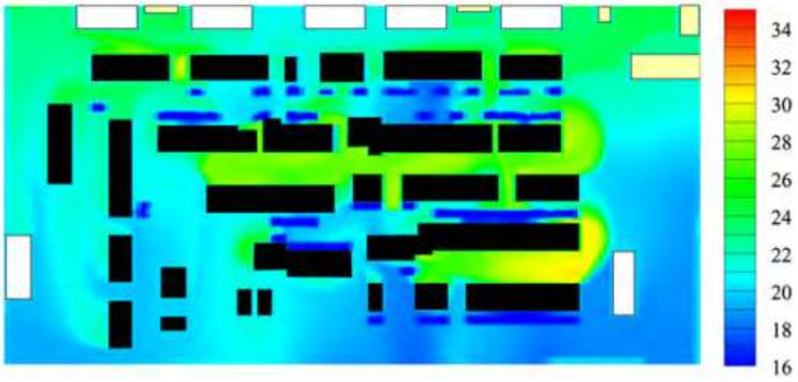
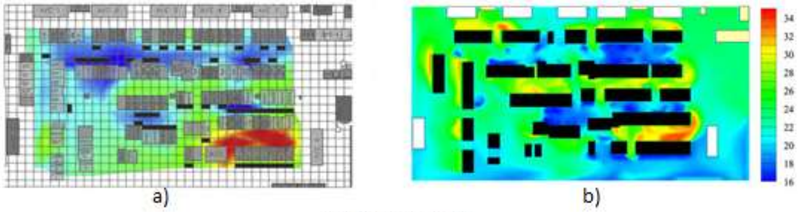


The first figure is the actual temperature and the second is the numerical simulation.



a) b)

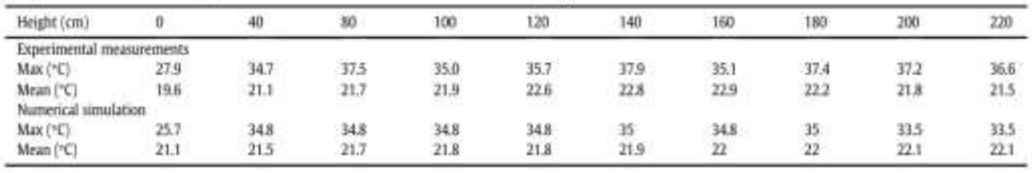
At 140 cm height

Figure 2: Temperature field at 140cm from (a) Experimental measurements and (b) Numerical simulations

It can be seen that the highest temperature are in the data centre is correctly predicted from the mathematical simulations.

CE 1.21 Similarly at 140 cm as well the numerical estimation is very close to the data from temperature sensors. Also from table below the differences between estimates and actual sensor data can be easily seen

Temperature distribution from experimental measurements and numerical simulations, at heights 0–220 cm.



Height (cm)	0	40	80	100	120	140	160	180	200	220
Experimental measurements										
Max (°C)	27.9	34.7	37.5	35.0	35.7	37.9	35.1	37.4	37.2	36.6
Mean (°C)	19.6	21.1	21.7	21.9	22.6	22.8	22.9	22.2	21.8	21.5
Numerical simulation										
Max (°C)	25.7	34.8	34.8	34.8	34.8	35	34.8	35	33.5	33.5
Mean (°C)	21.1	21.5	21.7	21.8	21.8	21.9	22	22	22.1	22.1

CE 1.22 I correctly gauged the hotspots from the generated numbers, and found that in some places the temperature exceeded the recommended thresholds. How data centre was laid out determined the localized temperatures. Temperatures needed to be same as one resulting from the CRAC supply.

CE 1.23 I inferred that the existence of undesirable hot spots was due to the following: insufficient cold air supplied by perforated tiles; improper location of floor vents; insufficient number of the perforated tiles; under-floor obstructions; concentration of the high-density racks in one specific area (racks ‘a’, ‘b’); unused vertical spaces in rack enclosures; lack of exhaust ventilation for the hot air to return to the CRAC; blank spaces inside server racks; airflow non-uniformity through the perforated tiles; and data centre perturbed architecture.

CE 1.24 I proposed and examined a few practical design solutions to improve the cooling effectiveness of the data centre that give a reduced air-conditioning power requirement. I used the supply heat index (SHI) defined by the following equation, where $T_{\text{in, rack}}$ and $T_{\text{out, rack}}$ are average inlet and outlet temperature from a rack, respectively and T_{ref} is the supply CRAC temperature which is fixed at 16 ^{o}C (reference temperature) in the project. The lower the SHI, the better the performance of the data centre.

$$SHI = \frac{\text{Enthalpy rise due to infiltration in cold} - \text{aisle}}{\text{Total enthalpy rise at the rack exhaust}}$$

$$= \frac{T_{in,rack} - T_{ref}}{T_{out,rack} - T_{ref}}$$

CE 1.25 Results indicated that providing cooling and maintaining inlet temperature specifications at different locations in a data centre with ad-hoc heat load distribution can be difficult. Since heat load distribution in data centres can change both in time and space, in ways that are difficult to predict at times, capacity provisioning of CRAC units was crucial.

CE 1.26 Another design I proposed was introducing ceiling ducts where vents were placed on the ceiling (located under the 40 cm deep ceiling plenum) above the hot-aisles (**Error! Reference source not found.**(b)).The vents collected the hot air and conveyed it through the ceiling plenum to the CRACs (conversion of false ceiling space as a means for return airflow).

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And why should you leave (b) here if there is only one design

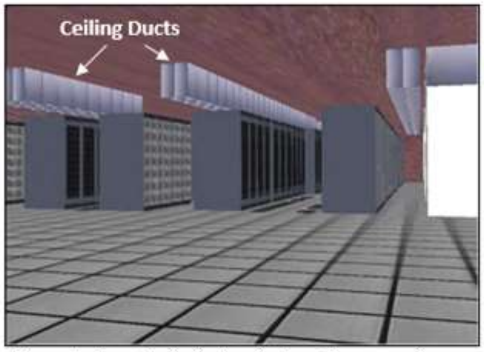

Figure 4: Practical solution designs I proposed

(b)

CE 1.27 The temperature field at height 200 cm for the original case study and other two designs are shown in **Error! Reference source not found.**Figure *3*. With the cold-aisle containment design I could reduce the maximum temperature from about 28 ^{o}C to 21 ^{o}C in aisle J. Attaching 100cm-long ducts to the ceiling vents produced good results as most of the hot regions in the data center were mitigated as seen in Figure *3*.

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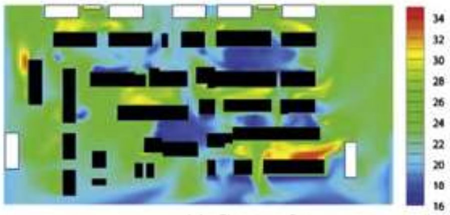
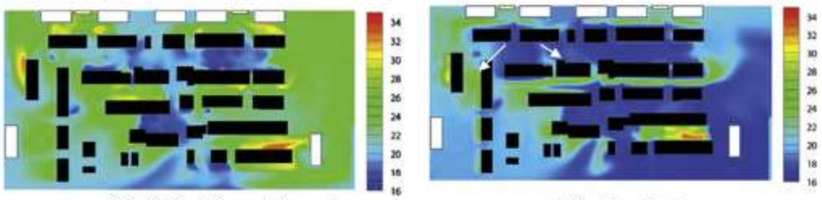


(a) Case study



(b) Cold-aisle-containment (c) ceiling ducts

Figure 3: Temperature fields at height of 200 cm for the original case study and other two design solutions

Commented [BF13]: You did not mentioned about" cold aisle-containment" and you bring its results here????!!!!!

Commented [BF14]: You did not mention about the other one, but you gave the result here

CE 1.28 I followed ASHRAE's thermal guidelines in all steps of my CFD simulations and during the design phase I followed Uptime Institute's Tier as well as ANSI/BICSI 002-2014 Standards.

CE 1.29 I had several trainings on techniques and software pertinent to my project.

- Attended tutorials on employing FloVENT software
- Attended lectures on CFD analysis
- Attended a training session on utilizing infrared thermography

CE 1.30 I had regular interaction with my team via weekly meetings where we discussed ongoing issues, developments and merits of proposed interventions. We also met several times per week on skype and exchanged emails to keep ourselves updated and to keep everyone on track with the project schedule.

CE 1.31 When purchasing data loggers and thermocouples for the experimental part of the project, I communicated with a variety of suppliers and after receiving their bids, I evaluated the bids. I chose the offer that was best aligned to the University's financial requirements and the project requirements.

CE 1.32 I ensured safe work surroundings. The data centre building had fire safety equipment and specialized fire suppression systems in case of fire. Further the air-conditioning equipment had special safety mechanisms for preventing temperature from becoming too low. By introducing practical cooling solutions and saving cooling energy, I could contribute to environmental improvement and help in reduction of the total global greenhouse gas emissions.

CE 1.33 I was in charge of preparing various reports which included minutes of the meeting project progress report, site field measurement reports and project completion reports.

CE 1.34 I regularly visited the library, studied various journal articles on the web and attended international conferences and liaising with scientists and experts in my field of study.

CE 1.35 Some of the prominent journals I researched for completing this study are cited below:

1. J. Whitney and P. Delforge, "Data Centre Efficiency Assessment Scaling Up Energy Efficiency Across the Data Centre Industry: Evaluating Key Drivers and Barriers," NRDC-Anthesis 2014.
2. J. G. Koomey, "Growth in Data centre electricity use 2005 to 2010," 2011.
3. K. Dunlap and N. Rasmussen, "The Advantages of Row and Rack-Oriented Cooling Architectures for Data Centres," American Power Conversion (APC), White Paper2006.
4. V. K. Arghode, V. Sundaralingam, Y. Joshi, and W. Phelps, "Thermal Characteristics of Open and Contained Data Centre Cold Aisle," Journal of Heat Transfer, vol. 135, pp. 061901-061901, 2013.
5. H. E. Khalifa and D. W. Demetriou, "Energy Optimization of Air-Cooled Data Centres," Journal of Thermal Science and Engineering Applications, vol. 2, pp. 041005-041005, 2011.
6. B. Fakhim, M. Behnia, S. W. Armfield, and N. Srinarayana, "Cooling solutions in an operational data centre: A case study," Applied Thermal Engineering, vol. 31, pp. 2279-2291, 10// 2011.
7. V. K. Arghode and Y. Joshi, "Room Level Modelling of Air Flow in a Contained Data Centre Aisle," Journal of Electronic Packaging, vol. 136, pp. 011011-011011, 2014.

CE 1.36 This was an extremely challenging project but I managed to achieve all its objectives. In recognition of the successful outcome of the project, I received Research Excellence Award from The University of Sydney in 2012. The findings were published in international journals and conference proceedings.

SUMMARY

CE 1.37 This project covered the Cooling solutions in an operational data centre. I was working as a PhD student and successfully simulated the hot spots from running data centres. The practical design solutions I proposed in this project were successfully implemented in an operational data center in Sydney as a cost-effective solution resulted in saving cooling power and energy. The previous studies on data centre cooling performance were focused on ideal scenarios. However, for the first time I studied thermal behaviour of operational data centres as a case study and with proposed new cooling solutions designs and techniques for enhance the cooling performance