Proceedings Paper:

Kadhim, MA, Al-Anii, YT orcid.org/0000-0002-4382-1998, Kapur, N orcid.org/0000-0003-1041-8390 et al. (2 more authors) (2017) Performance of a mixed mode air handling unit for direct liquid-cooled servers. In: 2017 33rd Thermal Measurement, Modeling & Management Symposium (SEMI-THERM). Annual IEEE Semiconductor Thermal Measurement and Management Symposium, 13-17 Mar 2017, San Jose, CA, USA. IEEE , pp. 172-178. ISBN 9781538615317

https://doi.org/10.1109/SEMI-THERM.2017.7896926

Performance of a Mixed Mode Air Handling Unit for Direct Liquid Cooled Servers

Mustafa A. Kadhim*[1,3], Yaser T. Al-Anii[2,3], Nikil Kapur[3] , Jonathan L. Summers[3], and Harvey M. Thompson[3]
[1] Mechanical Engineering Department, University of Babylon, IQ
[2]Mechanical Engineering Department, University of Anbar, IQ
[3]Institute of Thermofluids, School of Mechanical Engineering, University of Leeds, UK
Woodhouse Lane, Leeds LS2 9JT, United Kingdom
Email: ml13mak@leeds.ac.uk

Abstract

Datacentres energy consumption constitute a large portion of the global power consumption. Particularly, a large amount of this power is consumed by the datacentre cooling system. Subsequently, many innovated cooling technologies have been developed to reduce the energy consumption and increase the cooling performance. In this work, an experimental setup was designed and constructed which comprises a direct liquid-cooled server, rack-level cooling and compressor-free external cooling system. The study tracks the heat generated from IT processes to the environment. In addition, the power utilization effectiveness (PUE) and the air handling unit (AHU) performance were investigated. These objectives were studied under different datacentre operation scenarios, and AHU configurations.

Keywords

Datacentre, evaporative cooling, compressor free cooling unit design, direct liquid cooled servers.

1. Introduction

The increasing requirements of datacentre applications are driving the demand for high performance IT infrastructure, which in turn is increasing the heat dissipation and cooling load from IT units, leading to greater power consumption to maintain the datacentres in a safe operational condition. As a result, the need for more effective, economic, environmental and efficient cooling techniques has become critical.

The Power Usage Effectiveness (PUE) metric is widely used in datacentre energy-efficiency assessment. It is defined as the ratio of the total energy consumed of a datacentre to the energy consumed by the IT equipment. Although the PUE represents a useful metric to reflect energy consumption, however, it represents effectiveness not efficiency. For that, many datacentres use their own calculation of PUE for marketing purposes [1]. The datacentre cooling power consumption increases dramatically with higher PUE and becomes higher as more servers being evolved [2]. Subsequently, finding higher and efficient cooling technique is urgent to reduce PUE.

The traditional approach to cooling datacentres is to circulate cold air over the IT equipment. The heat dissipated by the servers is initially transferred to the passing cold air then extracted to the computer room air conditioning (CRAC). This heat is then exchanged with a refrigeration chiller plant which is using refrigerant that condenses using cooling tower [3-5]. Such a cooling configuration in datacentre was found to be consuming 50% of the required IT power consumption with a high energy portion consumed by the CRAC unit and chiller plant [5-7]. The major drawbacks of using this technique in datacentre are the high value of PUE (PUE~2), air contamination on the electronics and the required effective arrangement of the IT racks to achieve efficient cooling [2, 8-10]. However, the limitations of air cooling methods are leading to increased uptake of liquid cooling methods which are closer to the heat sources [3, 4, 7, 11-13].

Recently, two promising approaches have been developed to improve the cooling and energy efficiencies. These techniques based on hybrid cooling or fully liquid cooling. The hybrid liquid cooling includes using a heat exchanger either at the back of the server rack (which is called rear door heat exchanger strategy) or at the top of the server rack above the cooled aisle (which is called over heat exchanger) [14, 15]. This technique, which is based on water/air heat exchanger, is found to be significantly improving the cooling efficiency of datacentres by eliminating the hot spot problems and reduce the need for the CRAC units [14, 16].

The direct liquid cooling is based on bringing the heat transfer liquid in direct contact with the heat generation source (i.e CPUs). This method has demonstrated a very high energy saving and cooling efficiency compared with the air cooled based servers as the convective heat transfer using direct liquid cooling is much higher which leads to a lower hot spot temperatures and higher performance of transferring heat out of the IT environment [10, 17]. It is also found that the power required to transfer the heat to the environment is 45% less for direct liquid cooled system than air cooled system [18].

This paper considers the rejection of heat from direct liquid cooled servers through the use of an air handling unit that can operate wet or dry. It demonstrates the compromise that must be struck between increasing the IT efficiency and energy consumption.

2. Experimental Set-up

The experimental setup can be divided into two parts as shown in figure 1: IT environment side and outdoor heat rejection system side.

3.1 IT environment side:

Thirty Sun Fire V20z servers from circa 2005 are used to represent the IT. Each server has 2 x AMD Operton 64-bi processors running Debian Ubuntu. Traditionally, these servers were designed to be air cooled as shown in figure 2a. However, in the present configuration, all heat sinks and fans are replaced by direct contact liquid-cooled technology manufactured by CoolIT as shown in figure 2b [19]. The thirty servers are fitted in a single rack, as shown in figure 3. The cooling loops are joined through one passage making their way to the secondary loop of a coolant heat exchanger (CHx).

The CHx is also provided by CoolIT and consists of layer plate type heat exchanger, pumps, valves, fitting and sensors as shown in figure 4 [19]. There are two pumps connected in series on the secondary loop and programmed to operate at different speeds according to the temperatures and load.

3.2 Outdoor heat rejection system side:

The primary loop of the CHx is connected to an air handling unit (AHU). The AHU is designed to utilize spray evaporative cooling to boost heat exchanger capacity. It consists of three fluid loops as shown in figure 1: a processing water loop, an air side loop and a spray water loop.

1. Processing water loop: the water coming from the CHx enters in hot condition to the AHU where it rejects heat before being pumped back to the CHx. A filter and a pressure vessel is connected to the loop to prevent any contaminations and regulate the loop pressure respectively. A bypass loop is used to regulate the process water flow rate and temperature that entering to the AHU's heat exchanger.
2. Airside loop: The rejected heat is carried by the passing air through a tunnel to the external environment. The AHU was designed as an open circuit wind tunnel of 1103 X 1197 mm^2 and consists of:
    - Inlet air section
    - Heat exchanger unit
    - Visualization section: perspex panels is used to view into the HE section.
    - Spray water drain: is used to collect the over sprayed water to be quantified and estimate the evaporation rate.
    - Axial fan: provides variable air suction pressure.
3. Spray Water loop:

    Six spray nozzles are located upstream to the heat exchanger in a rack system. These nozzles are used to atomize the water to droplet diameter in the region of 15-30 microns. The spray water flow rate is measured to define the performance. The spray is activated under certain conditions of weather and datacentre operational load.

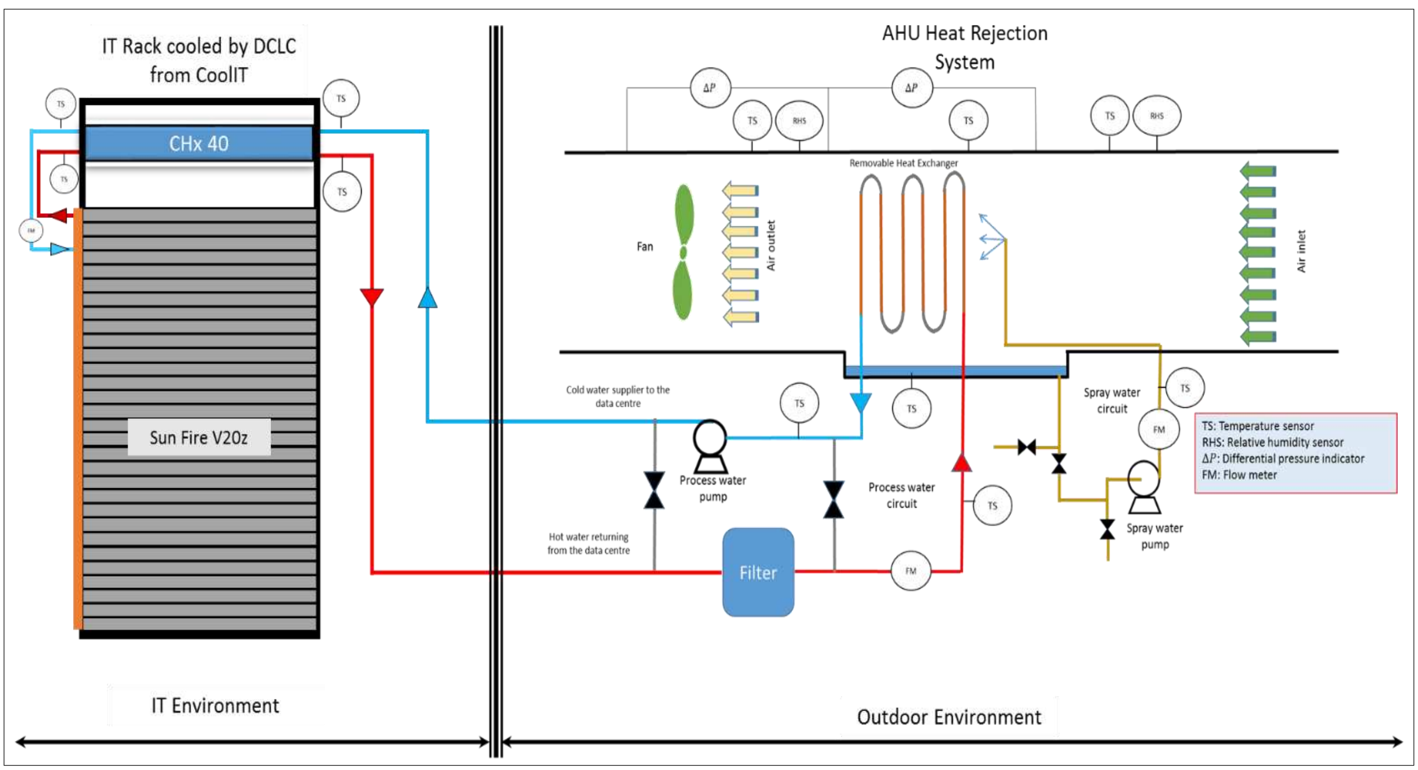

Figure 1 Datacentre design layout

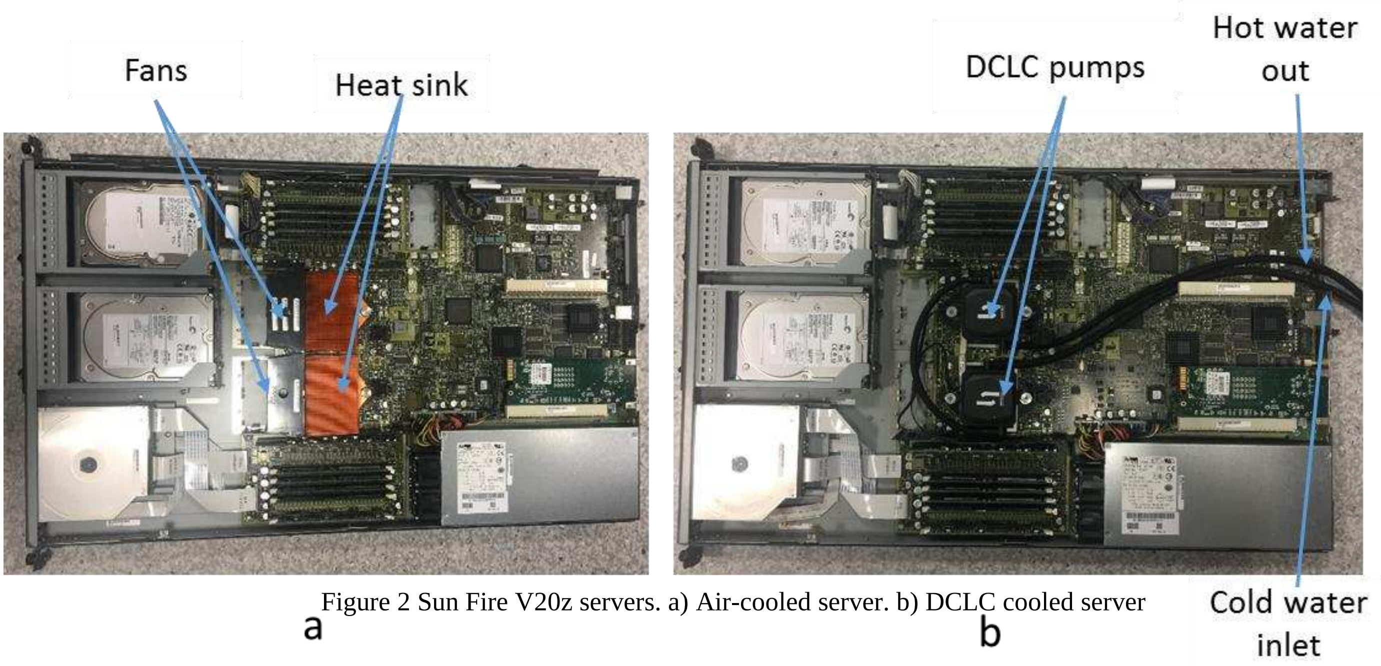

Figure 2 Sun Fire V20z servers. a) Air-cooled server. b) DCLC cooled server

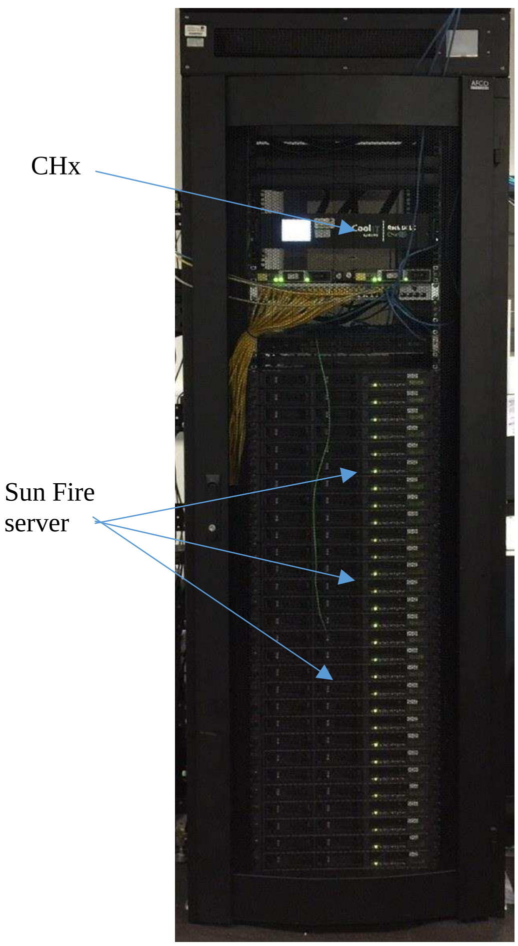

Figure 3 Sun Fire servers rack represents datacentre

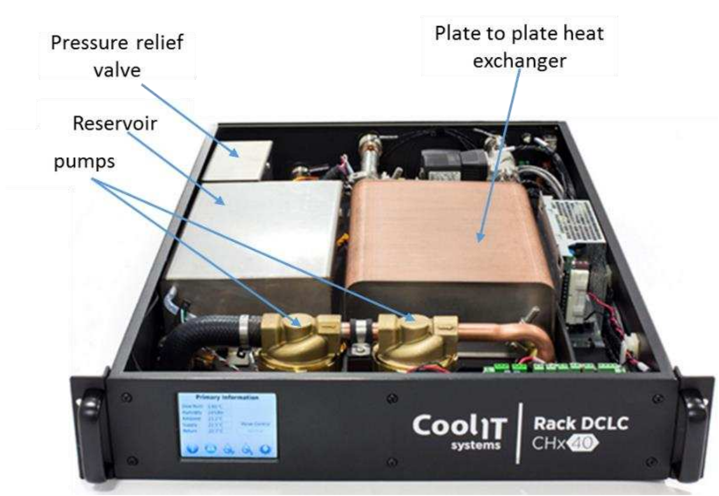

Figure 4 CHx from CoolIT

3. Methodology

To evaluate the overall operational performance of the system many temperature, flow rate, pressure drop humidity, and power sensors were installed.

The servers contain temperature sensors to measure the CPUs die temperature, rams temperature and the environment temperature inside each server. The power consumption of a selective servers were also measured using logged watts meter. The power consumption and flow rate of the fans that used for cooling the rams and the power supply were investigated separately and fan characteristics curve was obtained.

The CHx contains a logged inlet and outlet temperature sensors on both primary and secondary loop. It also contains power consumption meter and flow meter. All of these sensors are logged and can be accessed remotely to download the data.

The AHU contains temperature, flow rate, pressure and humidity sensors as well as power meter (as shown in figure 1). All of these sensors are logged and can be accessed via a central programmed panel.

The IT load is generated using stress under Linux. Various IT loads are created by scripts to simulate real datacentre operation over certain periods. In addition, the response of the AHU operation is monitored regarding the power consumption and cooling efficiency. Furthermore, the capability of the AHU is explored for various air and spray flow rates.

The effectiveness of the heat exchangers can be obtained by averaging the recorded value. The procedure of calculating the effectiveness is called the number of transfer unit (NUT) which is defined as the ratio between the heat rejected (Q) to the maximum heat transfer (Qmax) in either side of the heat exchanger [20].

$$e = \frac{Q}{Q_{max}} \qquad where\ 0 \le e \le 1 \qquad (1)$$

Where, Qmax calculated from the following equation:

$$Q_{max} = C_{min}(T_{hottest} - T_{coldest}) \qquad (2)$$

Cmin is the minimum heat capacity when compare both fluids in the heat exchanger.

$$\boldsymbol{C_{min} = compare\ between} \begin{cases} (\rho c_p)_{cold} \\ (\rho c_p)_{hot} \end{cases} \qquad (3)$$

4. Results

Experiments are conducted with different datacentre operational load scenarios and different AHU configurations. The key results of interest are the heat transfer calculations from the CPUs to the heat rejection system. In particular, the response of the AHU to any difference in IT load perturbations is highlighted. Figure 5 shows a sample of the heat rejection in the secondary and primary loops of the CHx, the heat arriving to the heat exchanger of the AHU and the heat carried by the air to the environment. The IT produces a total heat (Qs) which is supplied to the secondary loop of the CHx. The CHx heat exchanger carries the heat to the primary loop (Qp), which is transferred to the AHU heat exchanger by water (Qw) and finally carried away by the passing air (Qa) to the external environment. The result was taken on conditions of auto mode AHU and the severs operationof idle for 10 minuts then stressed 100% utilization for 1 hour an then left for 1 hour idle operation. It can be noted that the heat generated from the servers increased instantiniously as the servers stressed, then continue at specific value of about 4.25 kw with some flaxtuations. It can also be seen that the heat generated drops dramatically as soon as the strees finishes. However, the primary loop is found to follow the stress sinario in a fast pace with lower heat than the secondary loop. This behaiviour can be due to the effectivness of the CHx heat exchanger wich is found to be about 0.6 for all the test period as shown in figure 6. On the other hand, The heat arrived to the AHU shows a noticable delay compared with the server stress sinarios. It can be seen from figure 5 that the AHU needs more than 30 minuts to disspate the heat after the end of the stress. It is also found that the effectivness of the AHU heat exchanger is about 0.66 over the test period as shown in figure 7.

This time respond delay between the heat rejection sytem and the IT equipment varies depending on the cooling system and the distance between the datacentre and the heat rejection system as well as the effectivness of the heat exchangers in the loop. It is also neesarilly to consider the delay in the design of the heat cooling system as it increases the hot spot temperatures in the CPUs espially in the osilating loads on datacentres.

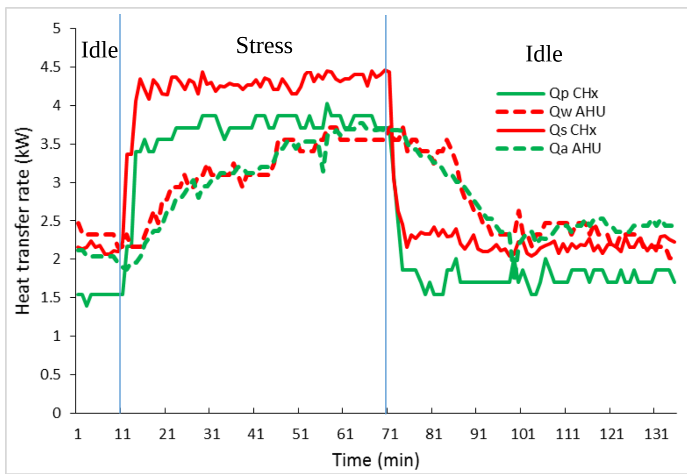

Figure 5 Heat transferred from the CHx to the AHU

The results explore the variation of PUE for the system based on calculating the power consumption of the IT and the total power consumed for cooling. This cooling power consumption is divided into three different heat transfer parts. Firstly, the server cooling level includes two main categories which are the CPU and the RAM. The current configuration of the servers only allows the CPUs to be cooled by the direct contact liquid. However, the RAMs are cooled by air which is pressurized by the server fans. The power consumption of the fans in each server is found to be between 3.44 to 6.66 Watts depending on the temperature of the RAM. This is calculated using the fan speed-power curves for each operational scenario to enable the power consumed by the fan for all the thirty servers to be measured.

Secondly, CHx power consumption includes the power consumed by two internal pumps on the secondary loop of the flow. These pumps have variable speeds that respond to the cooling requirements. As a result, the power consumption of the CHx is found to be in the range of 98 to 107 W.

Finally, the power consumed in the AHU is divided into three parts.

Process water pump: The power consumed by the pump is almost constant over the experiments period as the flow rate is kept constant of about 0.37l/s.

AHU fan: This is the major part of power consumption in the cooling system. The fan speed varies (from 250 to 1000rpm) depending on the conditions that the AHU is set to and the datacentre operation mode. The power consumption of the fan is from 256 to 1158 W.

Spray pump: The spray pump power consumption varies from 0 to 197 W depends on the requirement and the operational modes of the AHU and datacentre in addition to the weather conditions

The direct contact liquid cooling (DCLC) system is found to achieve a PUE of 1.25 and 1.17 for the dry and spray cooling respectively. This is due to the different power consumption of the AHU and the IT unit as shown in figure 8.

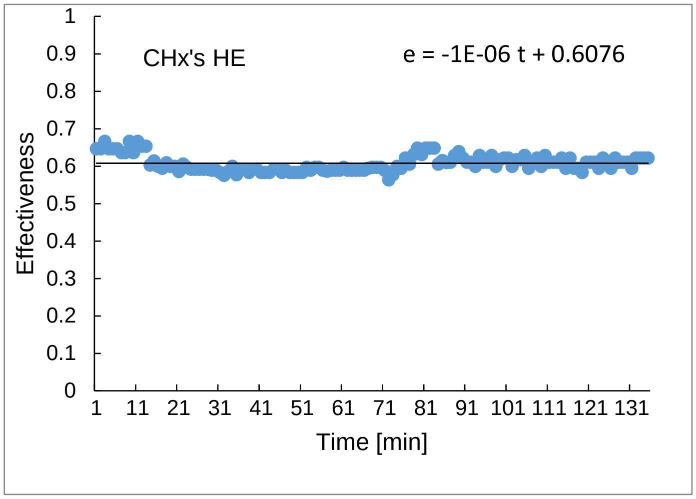

Figure 7 Effectiveness calculation of the CHx

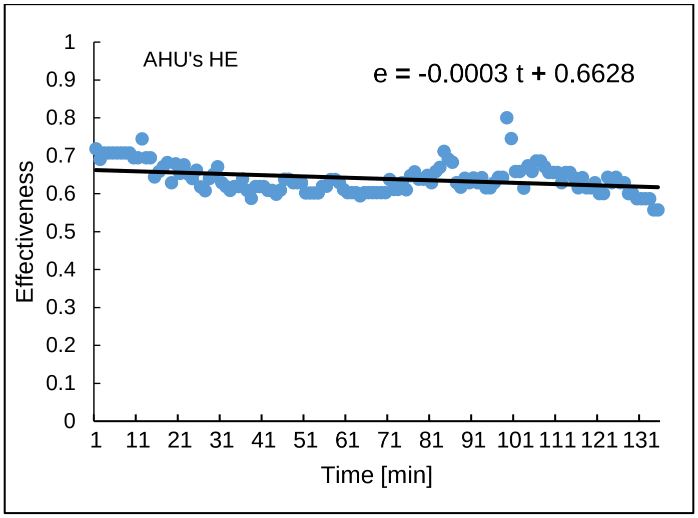

Figure 6 Effectiveness calculation of the AHU

The current design of the AHU allows to control the inlet water temperature to the datacentre under long term of different server loads. Figures 8 and 9 show the operational history of the AHU and the power consumption under 6 hours of different loads:

1st hour- of 15 minutes idle operation and 5 minutes 100% utilization stress pulses.

2nd hour- of 15 minutes idle operation and 15 minutes 100% utilization stress pulses.

3rd hour- Idle operation

4th hour- 25% utilization.

5th hour- 50% utilization

6th hour- 75% utilization

7th hour- 100% utilization

This load scenario mimic the actual operation al load of a real datacentre. The set point temperature was set to 20oC experiments so that the AHU has to regulate the temperature of the datacentre with both modes of dry (figure 8) and wet (figure 9) conditions.

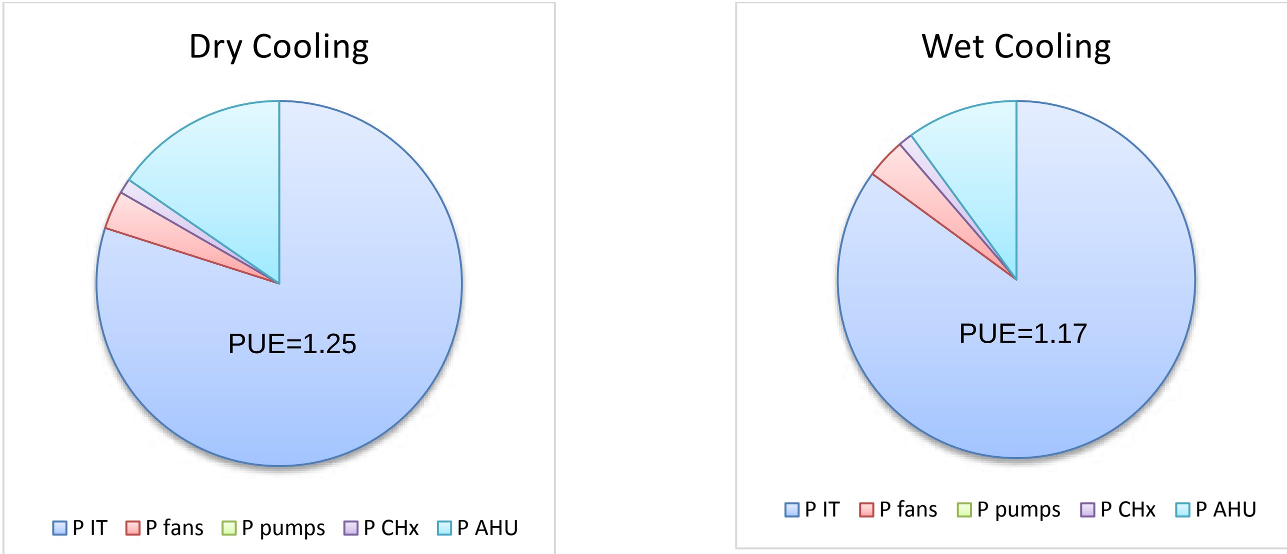

Figure 8 Power consumption portions and PUE

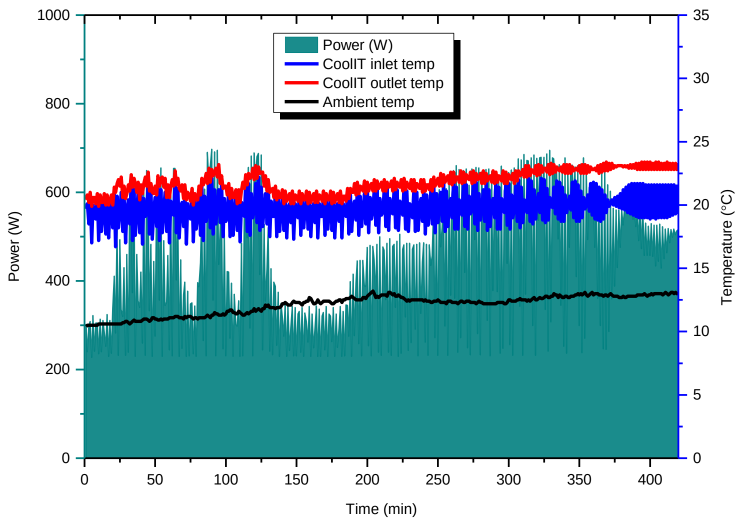

Figure 10 AHU operation under dry conditions

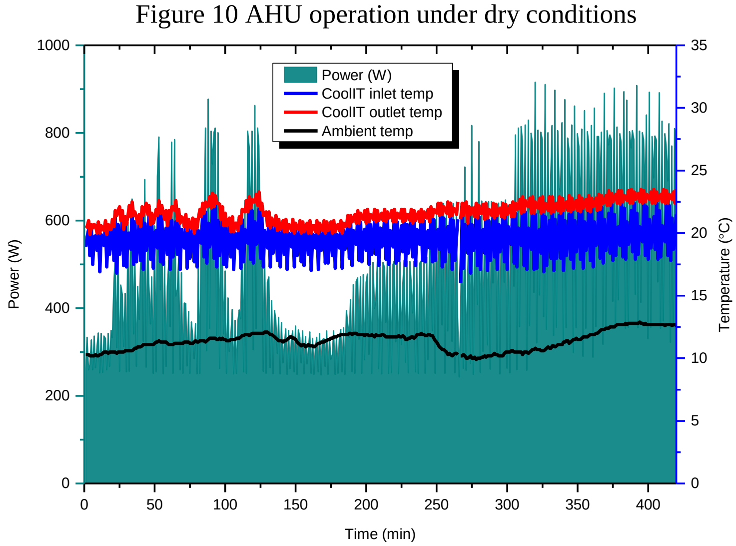

Figure 9 AHU operation under wet conditions

5. Conclusion

This work highlights experimental results from a compresor free DCLC coled datacentre test facility. The heat generated in the IT equipment was tracked from the sources to the heat rejection system. The responds of the AHU to the stresses were invistigated. It is shown that the power consumed by the AHU's fan is the highes portion of the total power supplied to the AHU unit. Thus, utilizing evaporative cooling by spraying the heat exchangers has been found to reduce the PUE of the datacentre and increase the cooling performance of the AHU.

Acknowledgement

The Authors would like to thank Airedale Air conditioning, CoolIT, Howard Bateman and the Iraqi ministry of higher education for funding.

References

1. Brady, G.A., et al., A case study and critical assessment in calculating power usage effectiveness for a data centre. Energy Conversion and Management, 2013. 76: p. 155-161.
2. Li, L., et al. Coordinating liquid and free air cooling with workload allocation for data center power minimization. in 11th International Conference on Autonomic Computing (ICAC 14). 2014.
3. Alkharabsheh, S., et al., A Brief Overview of Recent Developments in Thermal Management in Data Centers. Journal of Electronic Packaging, 2015. 137(4): p. 040801.
4. Li, Z. and S.G. Kandlikar, Current status and future trends in data-center cooling technologies. Heat Transfer Engineering, 2015. 36(6): p. 523-538.

5. Iyengar, M., R. Schmidt, and J. Caricari. Reducing energy usage in data centers through control of room air conditioning units. in Thermal and Thermomechanical Phenomena in Electronic Systems (ITherm), 2010 12th IEEE Intersociety Conference on. 2010. IEEE.
6. ASHRAE, T., 9.9. Best Practices for Datacom Facility Energy Efficiency. Atlanta, GA: ASHRAE, 2008.
7. Kheirabadi, A.C. and D. Groulx, Cooling of server electronics: A design review of existing technology. Applied Thermal Engineering, 2016.
8. Summers, J., N. Kapur, and H. Thompson. Design of data centre rack arrangements using open source software. in Semiconductor Thermal Measurement and Management Symposium (SEMI-THERM), 2013 29th Annual IEEE. 2013. IEEE.
9. Greenberg, S., et al., Best practices for data centers: Lessons learned from benchmarking 22 data centers. Proceedings of the ACEEE Summer Study on Energy Efficiency in Buildings in Asilomar, CA. ACEEE, August, 2006. 3: p. 76-87.
10. David, M.P., et al. Dynamically controlled long duration operation of a highly energy efficient chiller-less data center test facility. in ASME 2013 International Technical Conference and Exhibition on Packaging and Integration of Electronic and Photonic Microsystems. 2013. American Society of Mechanical Engineers.
11. Chi, Y.Q., et al. Case study of a data centre using enclosed, immersed, direct liquid-cooled servers. in 2014 Semiconductor Thermal Measurement and Management Symposium (SEMI-THERM). 2014. IEEE.
12. Capozzoli, A. and G. Primiceri, Cooling Systems in Data Centers: State of Art and Emerging Technologies. Energy Procedia, 2015. 83: p. 484-493.
13. Almoli, A., et al., Computational fluid dynamic investigation of liquid rack cooling in data centres. Applied energy, 2012. 89(1): p. 150-155.
14. Schmidt, R. and M. Iyengar. Server rack rear door heat exchanger and the new ASHRAE recommended environmental guidelines. in ASME 2009 InterPACK Conference collocated with the ASME 2009 Summer Heat Transfer Conference and the ASME 2009 3rd International Conference on Energy Sustainability. 2009. American Society of Mechanical Engineers.
15. Schmidt, R., et al. Maintaining datacom rack inlet air temperatures with water cooled heat exchanger. in ASME 2005 Pacific Rim Technical Conference and Exhibition on Integration and Packaging of MEMS, NEMS, and Electronic Systems collocated with the ASME 2005 Heat Transfer Summer Conference. 2005. American Society of Mechanical Engineers.
16. Gao, T., et al. Comparative thermal and energy analysis of a hybrid cooling data center with rear door heat exchangers. in ASME 2013 International Technical Conference and Exhibition on Packaging and Integration of Electronic and Photonic Microsystems. 2013. American Society of Mechanical Engineers.
17. Gao, T., et al., Experimental and numerical dynamic investigation of an energy efficient liquid cooled chiller-less data center test facility. Energy and Buildings, 2015. 91: p. 83-96.
18. Ellsworth, M.J., et al., An Overview of the IBM Power 775 Supercomputer Water Cooling System. Journal of Electronic Packaging, 2012. 134(2): p. 020906.
19. CoolIT. Available from: http://www.coolitsystems.com/.
20. Bejan, A. and A.D. Kraus, Heat transfer handbook. Vol. 1. 2003: John Wiley & Sons.