

IMMERSION COOLING OF HIGH END DATA
CENTER SERVER AND VALIDATION
THROUGH EXPERIMENTS

by

HARSH PATEL

Presented to the Faculty of the Graduate School of
The University of Texas at Arlington in Partial Fulfillment
of the Requirements
for the Degree of

THE UNIVERSITY OF TEXAS AT ARLINGTON

May 2013

Copyright © by HARSH PATEL 2013

All Rights Reserved

To my father P.S.Patel and mother Tiniksha Patel who made me and it is all because of their trust and
blessings what I am

ACKNOWLEDGEMENTS

This is my opportunity to acknowledge and be thankful to those people who contributed in the completion of Master's education and thesis work.

Special tribute goes to my advising professor Dr. Dereje Agonafer who helped me in each and every step and constantly motivating me and throughout my coursework with appropriate guidelines. I also want to acknowledge my committee member, Dr. Kent Lawrence and Dr. Haji Sheikh who spent their valuable time to serve in my dissertation

I am especially grateful to Dr. Veerendra Mulay for their interest in my research and for helpful suggestion and comments each and every week. I would like to thank each and every member of my EMNSPC team at UTA who encourage me and helped me throughout my thesis work. I would like to thank John Fernandes and Eiland Richard, PhD students whose constant mentoring helped me a lot and spent their valuable time to teach me in my thesis work. I wish also thank to Sally Thompson for taking care of all official paperwork and encouragement.

Finally, I would like to express my deep tribute to father who keep faith and trust on me, inspired me and sponsored my entire education and give me lessons how to live life in each and every phase. I would like to thank my mother and my sister for their patience and sacrifice. I would like to thank God who backed me and whose blessings always helped me throughout my career. I wish also to thank to my roommates, seniors, my relatives, my several childhood friends who always there with me and inspired me and with whom I spent so much enjoyable time and constantly giving advice during my course work.

April 12, 2013

ABSTRACT

IMMERSION COOLING FOR HIGH END DATA
CENTER SERVERS AND VALIDATION
THROUGH EXPERIMENTS

HARSH PATEL, M.S.

The University of Texas at Arlington 2012

Supervising Professor: Dereje Agonafer

Despite recent improvements in data center cooling efficiency such as hot and cold aisle, air side economizer, air cooling may not have the capacity to cool high end racks such as from IBM's NetBAY42 (150Kw and above). Increasing computer capabilities in data center has resulted in increase in rack power density per square ft as indicated by the latest uptime. The cooling of such high powered servers and corresponding racks poses a significant challenge to thermal engineers.

The use of immersion cooling is novel approach for data center cooling. In this study after some modification high powered server is fully immersed in mineral oil which works as a coolant. Various parameters like total server power consumption, temperature of all heat generating components like CPU case and die, VRDS, are measured. The benchmark for this study is conventional air cooling where server power measured at different CPU utilization. Corresponding liquid cooling experiments are done by cases where Junction temperature kept same as air cooling or pumping power is kept the same as that of air cooling. The results are then compared showing that liquid cooling has better promise.

TABLE OF CONTENTS

ACKNOWLEDGEMENTS.....	IV
ABSTRACT.....	V
LIST OF ILLUSTRATION.....	VIII
Chapter	Page
1. INTRODUCTION.....	1
1.1 Data center.....	1
1.2 Data center cooling system.....	3
1.3 High end datacenter server.....	5
1.4 Packaging level.....	6
1.5 Open compute server.....	6
2. IMMERSION COOLING.....	10
2.1 Test setup.....	11
2.2 Instrument setup.....	11
2.2.1 Test case parameter.....	12
2.2.2 Hardware setup.....	12
2.2.3 Linux commands.....	12
2.2.4 Temperature measurements.....	15
2.2.4.1 Omega thermocouples.....	15
2.2.4.2 Data loggers.....	15
2.2.4.3 Agilent data loggers.....	15
2.2.5 Total server power measurement.....	16
2.2.5.1 Staco variac.....	16

2.2.5.2 Yokogawa CW121 power meter.....	16
2.2.6 Di-electric liquid.....	16
2.2.7 Hydraulic Pump.....	17
2.2.7.1 Pump power calculation.....	17
2.2.8 Heat exchanger.....	18
2.2.8.1 Radiator calculation.....	18
2.2.9 Flow meter.....	19
3. EXPERIMENT PROCEDURE.....	20
3.1 Experiment 1.....	20
3.2 Experiment 2.....	22
3.2.1 Server modification.....	22
3.2.1.1 Removal of fans.....	22
3.2.1.2 Hard-drive exclusion.....	23
3.2.1.3 Thermal interface material removal (TIM).....	23
3.3 Experiment procedure.....	24
3.4 Experiment 3.....	26
3.4.1 Test 1: Fix the pump power.....	29
3.4.2 Test 2: Fix the junction temperature of CPU.....	29
3.5 Experiment using two radiators.....	30
4. RESULTS AND COMPARISONS.....	33
5. CONCLUSIONS.....	50
5.1 Future work.....	51
REFERENCES.....	52
BIOGRAPHICAL INFORMATION.....	54

LIST OF ILLUSTRATIONS

Figure	Page
1.1 Typical Datacenter layout [1].....	2
1.2 CRAC/CRAH unit of Datacenter [2].....	4
1.3 Cooling Energy consumption in data center.....	5
1.4 Heat load distribution [3].....	6
1.5 Open compute Intel V1.0 server [4].....	8
1.6 All components of motherboard [5].....	8
1.7 Major heat generating components [6]	9
2.1 Different design cases	12
2.2 Output of mpstat command.....	13
2.3 Output of free command.....	13
2.4 Output of hir command.....	14
2.5 Server with thermocouples.....	15
2.6 Multiplexer with Agilent 3470A data logger.....	16
2.7 Crustal plus technical oil from STE [7].....	17
2.8 MCP35-X pump [8].....	18
2.9 MCRX20-QP radiator [9].....	19
2.10 FLMH-1410AL flow meter [10].....	19
3.1 Experimental setup with all components.....	22
3.2 Server without fans.....	23
3.3 Hard-drive connected externally.....	24
3.4 Both CPUs without TIM.....	24
3.5 Server with Oil.....	25

3.6 Server with Oil.....	25
3.7 Experiment setup.....	27
3.8 Control of the fans.....	28
3.9 Control of the pump using Agilent DC power supply.....	28
3.10 Experiment setup with two radiators.....	30
4.1 Comparison chart for VRD temperatures between air cooling and immersion test.....	31
4.2 Comparison at 10% utilization.....	32
4.3 Comparison at 30% utilization.....	32
4.4 Comparison at 50% utilization.....	33
4.5 Comparison at 70% utilization.....	33
4.6 Comparison at 98% utilization.....	34
4.7 Comparison of server power at 10% CPU utilization.....	35
4.8 Comparison of server power at 30% CPU utilization.....	36
4.9 Comparison of server power at 50% CPU utilization.....	36
4.10 Comparison of server power at 70% CPU utilization.....	37
4.11 Comparison of server power at 98% CPU utilization.....	37
4.12 Comparison of case temperature at 10% CPU utilization.....	38
4.13 Comparison of die temperature at 10% CPU utilization.....	38
4.14 Comparison of case temperature at 30% CPU utilization.....	39
4.15 Comparison of die temperature at 30% CPU utilization.....	39
4.16 Comparison of case temperature at 50% CPU utilization.....	40
4.17 Comparison of die temperature at 50% CPU utilization.....	40
4.18 Comparison of case temperature at 70% CPU utilization.....	41
4.19 Comparison of die temperature at 70% CPU utilization.....	41
4.20 Comparison of case temperature at 98% CPU utilization.....	42
4.21 Comparison of die temperature at 98% CPU utilization.....	42
4.22 Comparison of case and die temperature at 98% CPU utilization for case 1.....	43

4.23 Oil temperature of inlet and outlet of server for case 1	43
4.24 Total server power consumption comparison at 98% utilization for case 1	44
4.25 Comparison of case and die temperature at 98% CPU utilization for case 2	45
4.26 Oil temperature of inlet and outlet of server for case 2	45
4.27 Total server power consumption comparison at 98% utilization for case 2	46
4.28 Tabular comparison of both cases	46
4.29 Total server power comparison for both tests	47
4.30 Junction temperature comparison for both tests	48
4.31 Oil temperatures at inlet and outlet of servers	48
4.32 Comparisons for the test using two radiators	49

CHAPTER 1

INTRODUCTION

The main objective of this research is to lower the power consumption of server and reduce temperature of all major heat generating components via using the immersion cooling method as a cooling method for data center servers. Experiments are used to validate this approach. This chapter gives brief idea about data center, various Cooling systems, high-end servers and their major components.

1.1 Data center

A data center is centralized facility used for the storage of computer associated components such as high end servers, back-up power supplies, chillers, cabling, security controls, air-conditioning, fire and water detection systems and redundant data connection. Data center house IT equipment like computer servers that process the data and to save them, network equipment which is used for communication. It also house power consumption equipment to maintain operating condition.

For some companies data center may be simple structure or rack of equipment and for other it might be room consists of many cabinets depending upon their operation. Basic business related goals for datacenters such as lowering the total cost of operation, rapid expansion of application, Flexibility of computing resources. 50% money of all I.T companies will go to data center. Now a day's data center are essential in various sectors like academic, government, business systems.

Usually data center have typically raised floor, no window and fresh air with cable runs underneath to supply power to servers and carry the cables that connects cabinet together. The reason behind that data centers are designed for IT equipment. Typical layout of data center can be seen in Figure 1.1

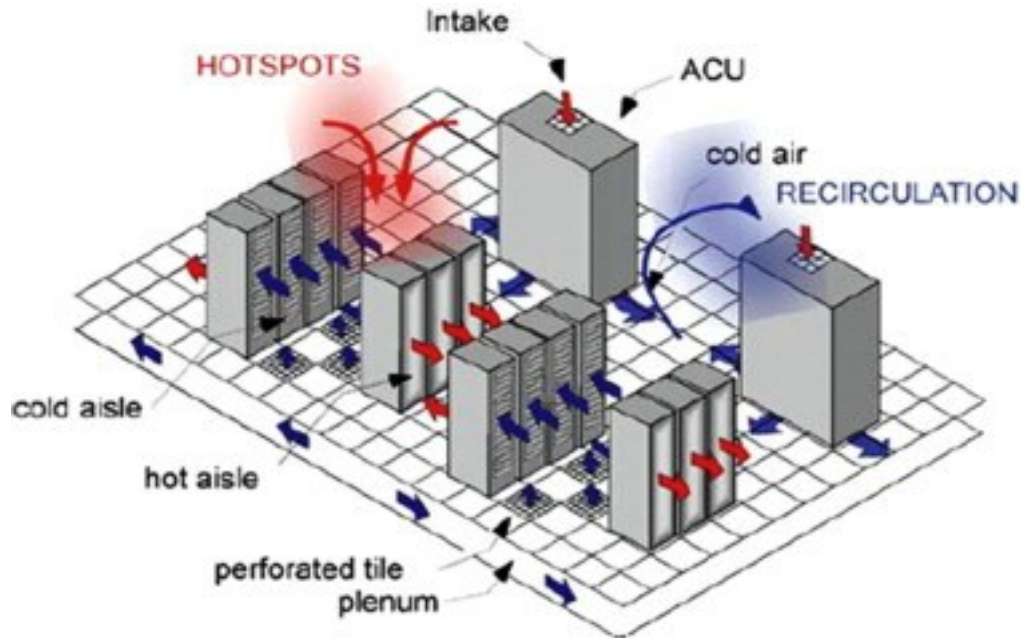


Figure 1.1 Typical Data center layout [1]

The Telecommunication Industry Association (TIA) divided data centers which cover following

- Wiring infrastructure
- Space requirement and layout
- Tired reliability
- Environmental consideration

Functional Requirements of Datacenter:

1 Location: A place to store severs, locate and networking devices

2 Power: Power needed to run the entire system

3 HVAC: Temperature controlled environment with few related parameters

4 Cabling: Connectivity provided to other components

Several environmental considerations include operating temperature, humidity levels, electrical-mechanical system classification, fire suppression. Task for mechanical engineer is to maintain the interior atmosphere of data center such as heating, air-conditioning, ventilation, humidification of equipment and so on. Main aim of this design is to save cost and space with ensures increase in power unit efficiency (PUE) and meet all business requirements and objective. In Modern design of data center includes scaling IT loads.

1.2 Data center cooling systems

Selecting the right cooling method for data center is essential part of data center. As the latest electronics equipment becomes smaller and consuming same or even more electricity more heat is generated in data center, So that precision cooling methods are designed to extract this unwanted heat to the atmosphere and to meet the need of high density computing. Cooling system consumes about one third power of data center.

A brief example of traditional cooling systems:

- Computer Room Air Conditioner (CRAC): Refrigerant based installed on data center floor and it connected to outside atmosphere. Fans are used to move the air throughout center and delivers cool air to servers. This chilled air passes through tiles and racks and heated up. Typical layout of CRAC unit can be seen from figure 1.2
- Computer Room Air Handler (CRAH): In this system chilled water based installed on data center floor and it connected to chiller plant which is installed. It generally used for large datacenters.
- Humidifier: It replaces water loss before the air exits the A/C unit and usually installed within CRAC/CRAH units.
- Centralized Air Handling

- Air side economizer: It uses outside air to cool datacenter if the temperature of ambient is lower than or equal to system temperature.
- Water side economizer: It uses evaporative cooling of cooling tower and creates chilled water for cooling

Study shows that Compressors used in chiller unit consumes 41% cooling power which is followed by CRAC unit fans which is 28%. Server fans utilize 14% of the total energy require to cool system and cooling tower and pump consumes 13% and 4% of total cooling power respectively.

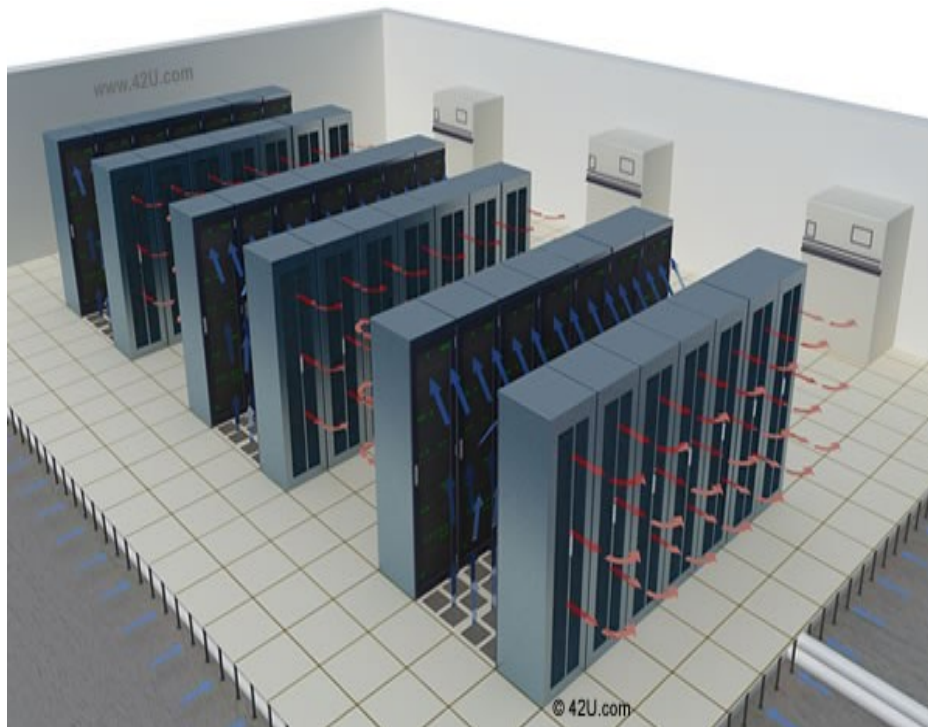


Figure 1.2 CRAC/CRAH unit of a data center [2]

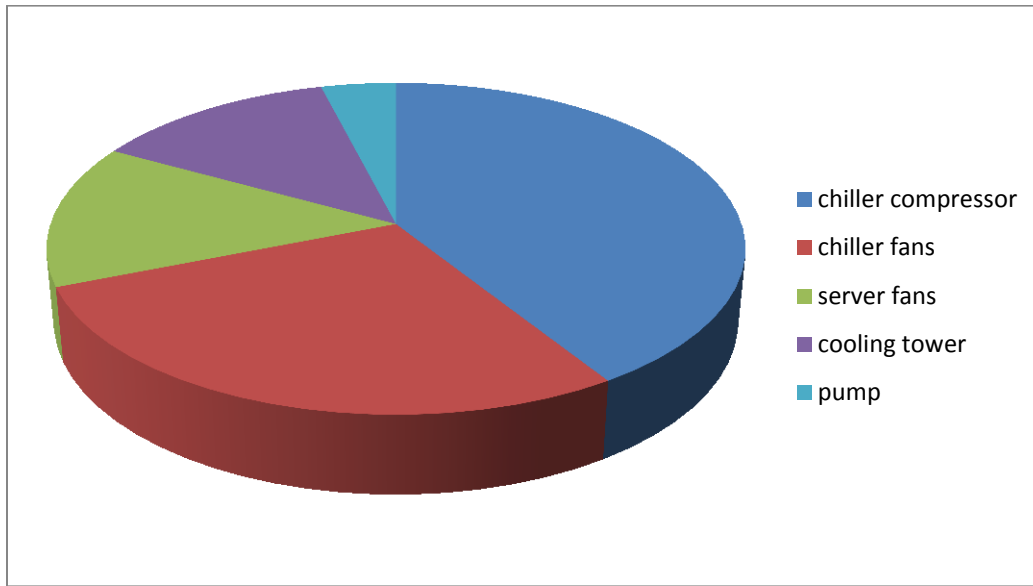


Figure 1.3 Cooling energy consumption in data center

1.3 High end data center servers

In the datacenter to run multiple programs to fulfill request of other users in network, these high end servers are designed which are high power consuming and high density hardware system. These servers are designed of different sizes as depending upon their requirement for system. As per Moore's law number of transistors on integrated circuits doubled after every 18 months, this server contains around one hundred millions of transistors and this number increasing respectively

High end servers are essential part of data center .Thermal management of these server are main concern of all IT industries. As number of chips increasing heat flux is also increased with both server power dissipation and packaging density so heat load per square feet of server foot print also increased. In figure 1.4 it shows that how heat load is increased per product foot print in past 20 years.It shows for servers only heat load per server footprint increased about 50X in last 15 years.

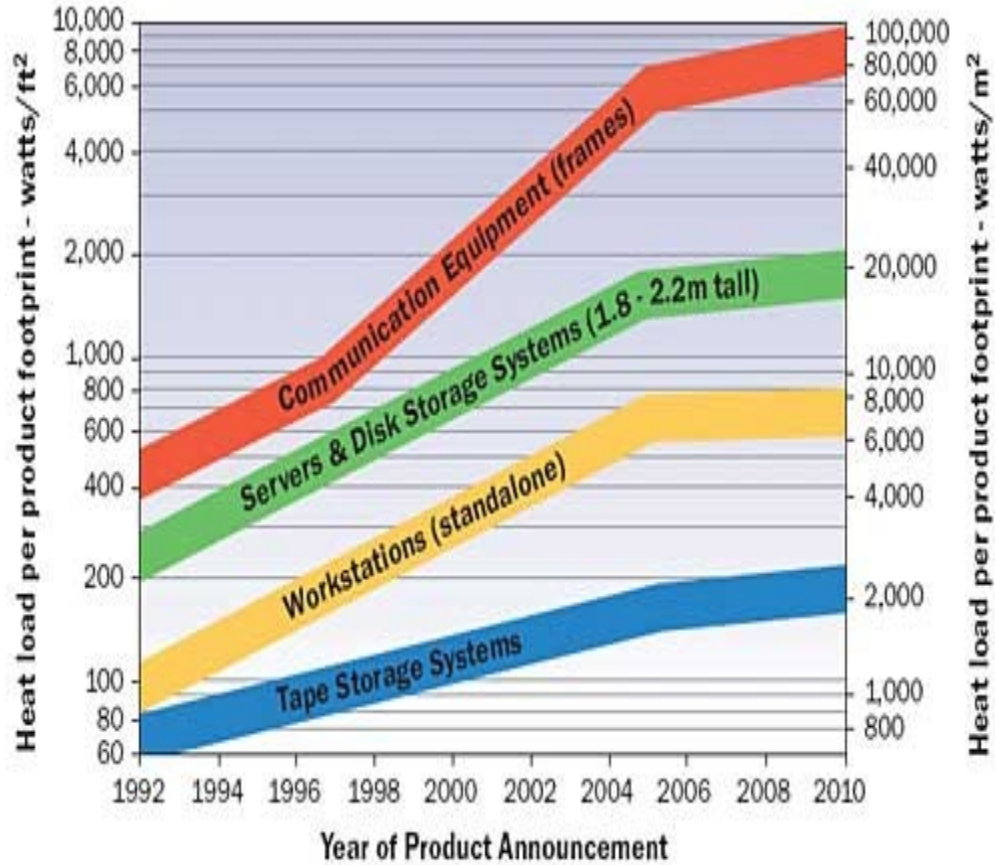


Fig 1.4 Heat load distribution [3]

1.4 Packaging level

For benefit of technician packaging is divided into 5 levels

- Level 0 : Gate to gate connection with silicon die
- Level 1 : Connection from chip to package constitutes level 1
- Level 2 : PCB (printed circuit board) connection from component to component or an external connector
- Level 3 : In this level Motherboard connected with PCB including backplanes
- Level 4: Rack comes in this level as it connects entire system
- Level 5 : connection between physically separated system like Ethernet LAN

1.5 Open Compute server:

For this research I used Open compute Intel based wildcat server which is provided by Facebook Open compute project. Open compute project is set of techniques which reduces total energy consumption, Improve efficiency and reliability and makes the operation easy way.

The chassis is made from Zinc plated steel and it has heights of 66mm and it designs to accommodate other components of motherboard. This motherboard uses two CPUs manufactured by Intel, both of them have thermal design limit of 95W. Operating power range of motherboard is between 10.8V and 13.2V Height of server is 1.5 U which is usually 1 Ufor all typical servers. Main advantage of this is to increase the area so we can use taller heat sinks which will provide better heat transfer as it directly proportional to area. Inlet temperature condition is in between 65F to 95F. There are 2 temperature sensors at front end and rear end of the server to measure inlet and outlet temperature respectively. All Fan rpm varies from 1100 to 7000 RPM with 10% tolerance limit. Motherboard dimensions are 13*13 inches. To ensure all connection PCB thickness should not exceed 2.4 mm.All components should place according to their specifications. Open compute server can be seen from figure 1.5

Major component of the motherboard are

- 2 Intel Xeon 5500 or 5600 processors at max 95W which are connected in series
- 3 channel DDR3 memory interface
- 3 DDR3 slots for both CPUs 0 & 1
- 18 DIMMS slot
- Temperature sensors
- Voltage regulator device(VRDs)
- Power supply unit
- Hard disc drive
- Fans: Motherboard has 4 fan connectors at rear end of server which ensures adequate cooling in the chassis

- Heat sinks: both CPUs support customized heat sinks. Both heat sinks are mounted using two screws.

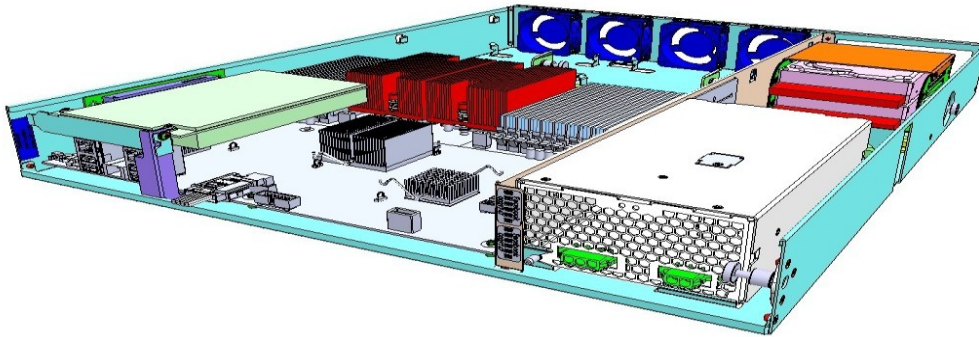
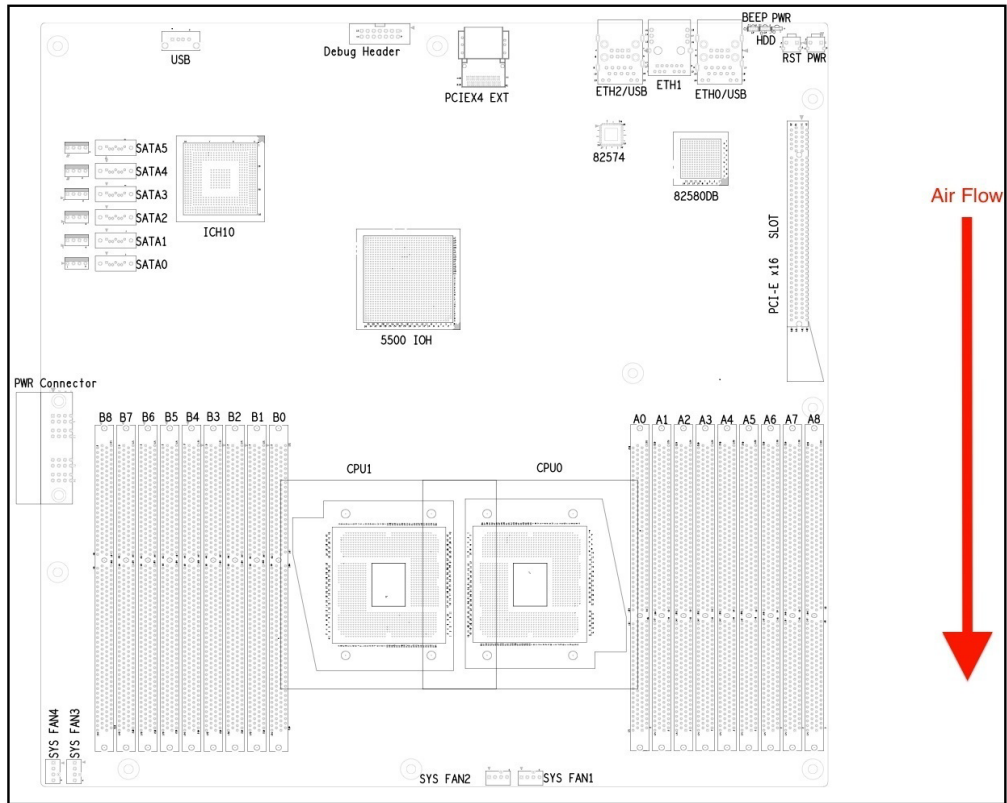


Figure 1.5 Open compute Intel v1.0 server [4]

Typical layout of Intel Motherboard server with all components and with major heat generating components can be seen from Figure 1.6 & 1.7 respectively.



Figure 1.6 all components of motherboard [5]



CHAPTER 2

IMMERSION COOLING

Immersion cooling is novel method of data center cooling which features total submersion of data center server in a coolant which is non-conductive liquid coolant. So basically cooling would be come in type of water cooling. Conventionally air cooling is used to cool the data center.

Immersion cooling works on a principle of convection heat transfer. Convection usually occurs in liquid and gases and is one of the major modes of heat transfer and mass transfer in fluids. In convective heat transfer heat is transferred by movement across fluids and it basically includes bulk motion and motion by the each individual atoms and that hot fluid is caused to move away from heat generating source. We can divide convection in so many terms like,

- 1) Free convection
- 2) Forced convection
- 3) Buoyant convection
- 4) Granular convection
- 5) Thermo magnetic convection
- 6) Capillary action

Among them natural (free) and forced convection are very dominant. I used these two approaches for cooling in immersion method in my research.

- Natural convection: In this mechanism, heat is transferred without any external force but heat moved only by differences of density of both medium fluids which is occurring due to difference in temperature gradients. In that fluid which we are using will become hot and its temperature

- will be rise so it will become less dense and will flow in upwards, another fluid which is basically cool, moves and replaces hot fluid. Then cold fluid gets heated and cycle repeats and heat transfers from bottom to top. So we can say that in natural convection dominated factor which affects most for transfer is density of both fluids. Heat transfer co-efficient is low in this type of convection as there is not much velocity in fluids.
- Forced convection: In this mechanism, heat transfer occurs by using any external forces using fan, pump or any device which can produce suction and this force forces the fluid to flow over surface or in a tubular channel and cools it. In this method amount of heat energy which transfers is very high so it is considered as most efficient method of convection. Such as fluid radiator system and movement of propeller in fluid are typical example of forced convection.

2.1 Test setup

This research work gives detailed idea about submersion cooling with experimental results. All the experiments are conducted in three parts

Stage 1: Testing of Intel production level wildcat servers with pre-installed fans on it. So basically test will comes in type of air cooling and it will considered as base test and all the results are compare with this test.

Stage 2: Testing of same server in a liquid coolant after some modification of server so it will comes in principle of natural convection as liquid is open to atmosphere and cooling will occur only because of density difference.

Stage 3: and in the last test using external pump and radiator and some other instruments same test carried out by using principle of forced convection as we are creating external force to circulate that coolant.

2.2 Instrument Setup

Several instruments and methods must be setup to execute the perfect test that includes installing Linux tools because server operates on that to record and monitor data, create scripts using various pre-

installed commands in Linux to run the test and setting up external hardware for collecting data and acquisition.

2.2.1 Test case parameter

In this research, servers are tested with % CPU utilization which starts from 10% to maximum 98% with each interval of 10 whereas % Memory utilization and ambient temperature kept as a constant parameter.

Design points	%CPU
DP0	10
DP1	20
DP2	30
DP3	40
DP4	50
DP5	60
DP6	70
DP7	80
DP8	90
DP9	98

Figure2.1: Different design cases

2.2.2 Hardware setup

Temperature measurement instruments

- Omega thermocouples: to measure temperature of all major components
- USB data logger: to measure ambient temperature
- Agilent 3472A data logger

Power measurement

- Yokogawa CW121 power meter
- 280V AC variac

2.2.3 Linux commands

Various commands are used to measure %CPU, %Memory, Case temperature of both CPUs like free, mpstat, hir, lookbusy and all these are inserted in one script which runs all throughout the process.

1) mpstat

It is Linux command used to calculate total processor loading utilization, and reports the activities of each CPU on a data center server. mpstat displays overall CPU % statistics like % idle, % CPU, % sys, % soft on a server. Typical example of an output of mpstat command is shown in figure.

6:08:22 AM	CPU	%user	%nice	%sys	%iowait	%irq	%soft	%steal	%idle	intr/s
6:08:24 AM	all	42.91	0	2.72	0.13	0	0	0	54.24	25002
6:08:26 AM	all	92.27	0	5.96	0	0	0	0	1.77	24082.59
6:08:28 AM	all	92.56	0	5.19	0	0	0	0	2.25	25081.91
6:08:30 AM	all	92.85	0	5.06	0	0	0	0	2.08	24903.48
6:08:32 AM	all	92.89	0	5.06	0	0	0	0	2.04	25057
6:08:34 AM	all	92.92	0	5	0	0	0	0	2.08	25026
6:08:36 AM	all	93	0	4.96	0	0	0	0	2.04	25037
6:08:38 AM	all	92.92	0	5.04	0	0	0	0	2.04	25153.77
6:08:40 AM	all	93	0	4.96	0	0	0	0	2.04	25004
6:08:42 AM	all	93.12	0	4.83	0	0	0	0	2.04	25015.5
6:08:44 AM	all	93.12	0	4.83	0	0	0	0	2.04	24871.14
6:08:46 AM	all	93.14	0	4.86	0	0	0	0	2	25022
6:08:48 AM	all	93.17	0	4.81	0	0	0	0	2.02	24998.5
6:08:50 AM	all	93.17	0	4.81	0	0	0	0	2.02	25132.16
6:08:52 AM	all	93.23	0	4.75	0	0	0	0	2.02	25028

Figure 2.2 Output of mpstat command

2) free

This command in Linux provides information about total amount of memory utilization while in each %CPU utilization and it also provides amount of free memory, cache memory, shared and buffered memory as well in the test. Typical example of an output of a free command is shown in figure.

Fri	Feb	20	6:08:22 EST	#####		total	used	free	shared	buffers	cached
Fri	Feb	20	6:08:22 EST	#####	Mem:	12036	245	11790	0	0	13
Fri	Feb	20	6:08:22 EST	#####	Swap:	1907	0	1907			
Fri	Feb	20	6:08:22 EST	#####							
Fri	Feb	20	6:08:24 EST	#####		total	used	free	shared	buffers	cached
Fri	Feb	20	6:08:24 EST	#####	Mem:	12036	1206	10829	0	0	14
Fri	Feb	20	6:08:24 EST	#####	Swap:	1907	0	1907			
Fri	Feb	20	6:08:24 EST	#####							
Fri	Feb	20	6:08:26 EST	#####		total	used	free	shared	buffers	cached
Fri	Feb	20	6:08:26 EST	#####	Mem:	12036	2177	9858	0	0	14
Fri	Feb	20	6:08:26 EST	#####	Swap:	1907	0	1907			

Figure 2.3 Output of a free command

3) hir

This tool gives the detail idea about thermal parameters like both CPUs case and die temperatures, Fan speed of all the four fans at each specific interval of time. Typical example of an output of hir command is shown in figure. It is very important tool in this experiment. If CPU temperature increases to some extent value then motherboard gives PWM signal to fans so it will ramp up and runs at some higher speed to cool it down and if CPU temperature falls below the threshold value it gives PWM signal and reduce the duty cycle so fan runs at normal pre-specified speed. Typical output of a hir command is shown in figure 2.4.

4) Lookbusy

This tool generates fixed stress on a server with specified memory active on a server. It used to apply specific utilization to the server. Command line for this tool is “-lookbusy -c 80 -m 2000”. It means after using this values -c 80 -m 2000 server utilizes 80% load and constant 2000 MB memory allocation over the test.

Frequency:2000000		
Loop:903		

* Health Status Monitor V3.0 *		

*Project: F01/F02	*	
*Author : Derrick Huang	*	

This is F02		
TIME Record @ Fri Feb 20 06:08:22 2004		
CPU0 Therm Margin: 57 [?] [?]		
CPU1 Therm Margin: 0 [?] [?]		
CPU0 Case Temp : 32 [?] [?]		
CPU1 Case Temp : 35 [?] [?]		
CPU0 Die Temp : 38 [?] [?]		
CPU1 Die Temp : 96 [?] [?]		
Right Outlet Temp: 32 [?] [?]		
Left Outlet Temp: 31 [?] [?]		
Inlet Outlet Temp: 28 [?] [?]		
CPU0 VR P count=0		
CPU1 VR P count=0		
CPUVcore1[?]0.960		
CPUVcore2[?]0.952		
AVCC-P3V3[?]3.392		
3VCC-P3V3[?]3.392		
VIN1-P1V5_DDRP1[?]1.520		
VIN2-P1V5_DDRP2[?]1.520		
3VSB-P3V3_STB[?]3.376		
VBAT-P3V3_VBAT[?]3.056		
SYSTEM FAN1: 1548		
SYSTEM FAN2: 1757		
SYSTEM FAN3: 1704		
SYSTEM FAN4: 1591		

Figure 2.4 Output of a hir command

2.2.4 Temperature measurement:

2.2.4.1 Omega thermocouples: Temperature measurement of all major components is necessary for testing. So for that T type, copper insulated thermocouple, precision fine wire thermocouple is used which is 0.010 “diameter,72” in length and from OMEGA ENGINEERING. It measures temperature ranges up to 480C. In testing, thermocouples are attached to all major heat generating components like VRDs, DIMMS, and chipsets. To avoid confusion thermocouples are specified with different colors. Server with thermocouple chart can be seen from figure 2.4.

2.2.4.2 USB data loggers: These data loggers are used to measure temperature at inlet and outlet of the server and it also gives idea of relative humidity and ambient condition in the test. It placed at front and rear end of the server.

2.2.4.3 Agilent data logger: All the thermocouples which are instrumented in the server are connected to different port of multiplexer and that multiplexer goes to Agilent 3470A data logger. It can be seen from figure 2.5.By using that pre-installed software in the system we can configure thermocouples and monitor surface temperature of all parts at a specific interval of time continuously. All the temperature data can be saved automatically throughout the test.

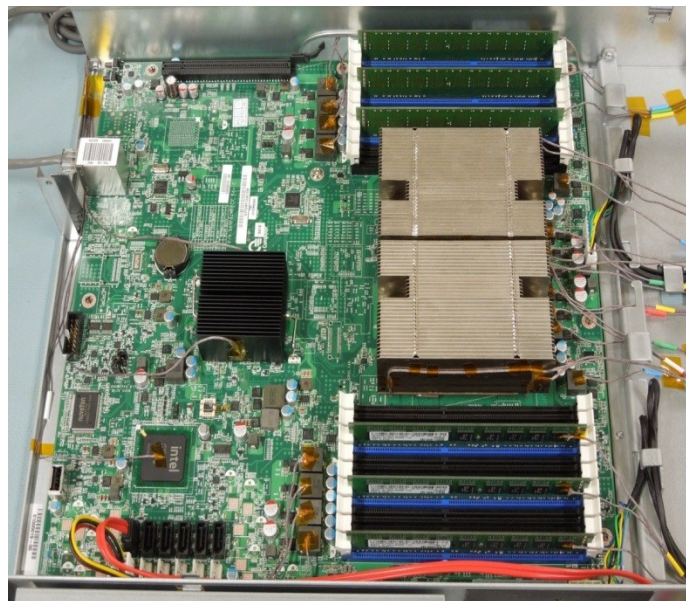


Figure 2.5 Server with thermocouples



Figure 2.6 multiplexer with Agilent 3470A data logger

2.2.5 Total server power measurement

2.2.5.1 STACO VARIAC

In this test 120V input Variac transformer is used to control voltage to the server and it has voltage limit of 0-280V.

2.2.5.2 YOKOGAWA CW121 power meter

To measure total power consumption by server YOKOGAWA CW121 clamp on power meter is used. It supports single phase- three phase and two wire-four wire connection and can measures up to 495V. The software with it allows you to set the power meter's measurement parameter with computer and we can record power values even at 1-second interval and can be saved as well.

2.2.6 Di-electric coolant

As in immersion cooling, liquid works as a coolant and server will be kept inside the liquid so it is necessary to use Di-electric liquid. The reason behind that is if coolant is electrically conductive then it will create short-circuits as soon as it touches with high powered component of motherboard. Mineral oil (as all of them are di-electric) used as a coolant in this entire experiment. CRYSTAL PLUS 70FG manufacturer by STEOIL is used and it is an odorless, tasteless white mineral oil which has density and

specific heat of 0.85 and 1.67 KJ/Kg.K respectively and it doesn't ignite till 180C. Oil can be seen from figure 2.6



Figure 2.7 Crystal Plus Technical oil from STE [7]

2.2.7 Hydraulic pump

For doing experiment by principle of forced convection some external force required to move fluid over the test server. So it needs any hydraulic pump to circulate that mineral oil over entire circuit. So in this testing one small centrifugal pump used for that purpose. Some parameter needs to consider for that like flow meter, Suction head, mass density, viscosity of mineral oil. After doing some back hand calculation it recommends to use MCP-35X pump from manufacturer named SWIFTECH. It is PWM operated pump so it can allow variable speed control after controlling the fan from 1300 to 4500 RPM and very compact as well. Technical specification and calculation are shown below. And schematic diagram of pump can be seen from figure 2.6

Technical specification:-

- 1) Nominal voltage: 12VDC
- 2) Maximum head: 14.7 Ft
- 3) Maximum flow rate : 4.5 GPM
- 4) Temperature range: up to 140F
- 5) Maximum pressure : 1.5 Bar
- 6) Maximum power: 18 watts

2.2.7.1 Pump power calculation:

Equation: $P_h = q \rho g h / (3.6 \times 10^6)$ (Where P_h = hydraulic power in KW)

(Assume max flow rate $Q = 0.33$ GPM , Total head required is 0.5 ft, Mass density = 855 KG/m^3 and Viscosity = 70 SUS [*From technical data sheet of oil] putting in this equation Pump power required is 2 watts)

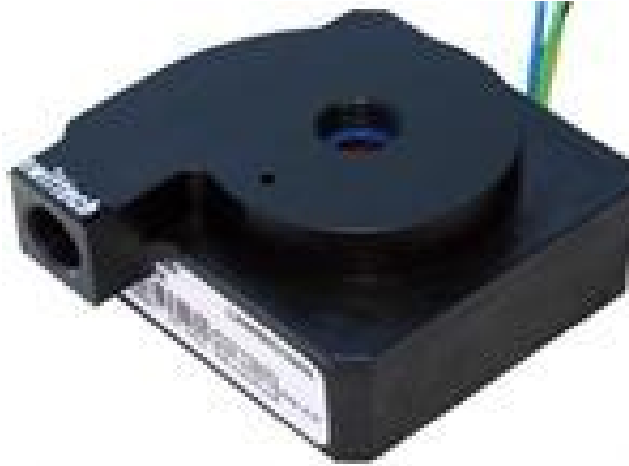


Figure 2.8 MCP35X pump [8]

2.2.8 Heat exchanger

In the test oil will get warm because of heat generated in components so heat removal from oil is necessary from that oil to assure better cooling. So we need to use any heat exchanger for this purpose. In this research Liquid-Air heat exchanger radiator used. Few thermal parameter needs to considered like heat capacity of mineral oil, Temperature difference required, Total amount of heat removal. After doing some calculation MCRx20-QP from SWIFTECH used. For better thermal performance two radiators are used in series. This is low-noise optimized, heavy duty radiator which required two fans in 120mm diameter for throwing air to fins. Radiator can be seen from figure 2.7

2.2.8.1 Radiator calculation:-

Equation $Q = m \cdot c_p \cdot \Delta T$ Where (Q= Heat removal required)

(Let say we want maximum temperature difference of around 10C and heat capacity of mineral oil is 1.67 KJ/kg K and $Q = 300$ watts, consider as maximum server power consumption so we want to remove this much amount of heat from radiator. After putting all this data in equation we got mass flow rate of 0.33 GPM which is valid as after compared with hydraulic pump calculation)



Figure 2.9 MCRx20-QP radiator [9]



Figure 2.10 FLMH-1410AL flow meter [10]

2.2.9 Flow meter

Flow meter is essential component in experiment circuit as flow rate of mineral oil throughout experiment effects to temperature reduction of oil so we need to vary flow rate and keep sense the flow rate at which we are getting best performance and it need special flow rate as we are using oil instead of water because viscosity of oil is greater than water. FLMH-1410AL from OMEGA is used for that. It is special meant for measure oil flow and works on a principle of variable area flow meter. It can be seen from Figure 2.8

CHAPTER 3

EXPERIMENT PROCEDURE

3.1 Experiment 1

In first experiment Intel's Production Level Wildcat server (PLWS) tested with conventional air cooling method. In this setup all the four pre-installed fans are used to blow air from server. Server is connected to local desktop computer system using LAN connector then a shell Linux script deploys command code. The script contains all information about test like total time run of test, all the commands free, mpstat, hir, pre-determined cooling period between all % loading condition. Entire test run was about 22 hours, Each test run long for 7hours and this test run repeated for 3 times. It took 30 minutes to run each design points and after that there will be 30 minutes pre-cycle and post-cycle period. The reason behind pre-cycle and post-cycle is to cool server and reach at initial condition.

The 'mpstat' command and the 'free' command records data for % CPU loading and % memory utilization for a time interval of 2 seconds respectively throughout the test. In each run different CPU utilization is applied from 10% - 98% in increments of 10 and 2000 MB of memory applied constantly. The system health monitoring mode measures all the CPU temperature for a time interval of 2 seconds as well and also controls fan rpm according to loading on the server.

The server is attached with 18 omega thermocouples to measure surface temperature. Agilent 3470A keeps the record of surface temperature measurement throughout the test for a interval of 5 seconds. Ambient temperature and relative humidity kept constant about 22.5C and 65% and it kept recorded by USB data loggers which are placed in front side of the server.

CW121 power meter measures power meter for each time interval of 10 seconds and records the data and save it in the system.

Both CPUs are attached with two extruded heat sinks which designed only for that particular server and Thermal interface material of TC-5622 from Dow-conning is used in between surface of heat-sink and heat spreader to reduce air gap between them and to improve thermal performance of heat sink. In each test run data of Total server power consumption, Surface temperature, %CPU,%Memory measured and average of all three runs are calculated and plotted. And all this data will be considered for base line test for other tests.

After turn it on the server and connected with LAN, start logging temperature results it will show initial surface temperature and after that turn on the power meter. It will also start collecting total server power consumption and will show server power at no loading condition. Total power consumption will be in range of 80-90 watts. Specify enough time to start the test as you need to start all this things first. So finally at pre-specified time in Linux script test will start.

For first hour it will be run at no condition after that “DP0” executed and 10% CPU loading will be applied to server so according to that temperature of all the components will also start increasing and as per fan-algorithm in motherboard all fans will ramp up to about 1500 rpm to cool down the server. Total server power will also increase accordingly that. It will be possible to observe all this data as test approaches. It will take 30 minutes to finish first loading condition. After that there will be post-cycle of 30 minutes in that server comes in initial condition before next loading condition starts.

After that “DP1” will execute in that 20% CPU loading will applied and so on till it finishes “DP9” in that CPU will load at 98% condition and fans will run at maximum rpm of 9500 rpm and server will consume total power in range of 220-240 watts and first run finishes so it will take 7 hours to finish the run.

In the Linux script the same command script will be executed 3 times in a row so test will not be over. As soon as first run finishes second run will be executed and cycle continues. After 22 hours all the 3 run finishes and server will automatically turn-off itself. Data will be saved automatically. In the entire test we don't need to collect any data manually or even no need to touch the any component of the system as well. Schematic diagram of test set up with server, fans, stacovariac, power meter is shown figure 3.1.

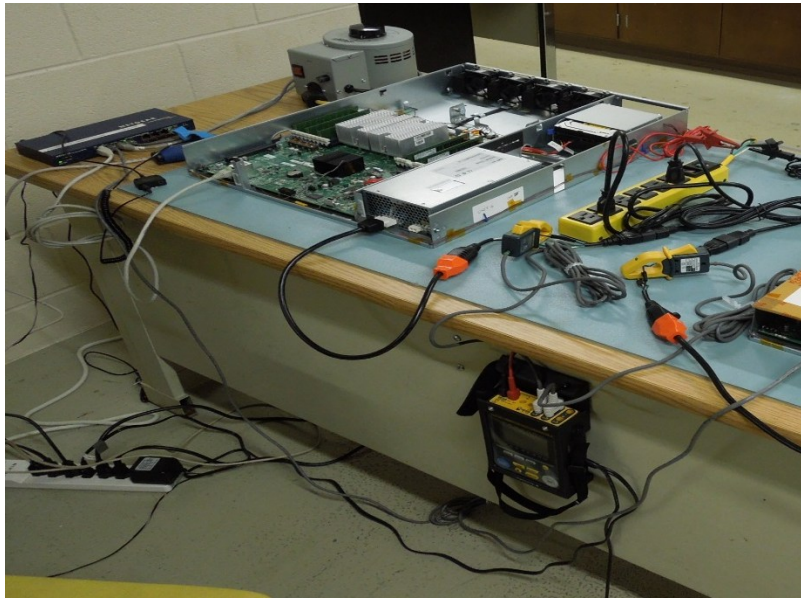


Figure 3.1 Experiment set up with all components

3.2 Experiment 2

After finish of first experiment with air cooling and using fans and collecting all data, next test is conducted using Mineral oil. In that some modification of server is necessary.

3.2.1 Server modification [11]

Although open compute server directly coming from factory, we can't directly submerge it in mineral oil so we applied few modifications in it. All the modifications are necessary for this testing. The modification process is quick and inexpensive. As depending on server, it can finishes in just few minutes as well.

3.2.1.1 Removal of Fans:

Obsolete in fluid cooled environment, all four server fans are removed entirely from the chassis as we can't run fans in server and as of this fan power consumption will be zero which is almost 3-5% of the total server power consumption. Power supply unit also has a fan on it to cool unit so removal of that fan is also necessary as power supply unit will also submerged in oil. Server without fan can be seen from figure 3.2



Figure 3.2 Server without fans

3.2.1.2 Hard-drive exclusion:

We can't submerge even hard drive as well in mineral oil. We can run the server without fans but without hard-drive it is not possible to run it as hard-drive saves all the data from server. So for solution of it we will connect hard-drive from external. In the first test it connected in chassis itself but here we will put outside of server and it is not supposed to touch oil to hard-drive so we need to take care of that as well. Server connected from external can be seen from figure 3.3

3.2.1.3 Thermal interface material removal (TIM)

Thermal interface material assists heat sinks to fill air gap in between them and CPUs and improve heat transfer as well because of high thermal conductivity. As it contains oil there is chance of dissolve in mineral oil so we can't use TIM in this experiment so we need to clean surface of heat sink and heat spreader from CPU and install as it is.

Still if you want to apply thermal interface material application of INDIUM is another solution. It comes in solid piece which sticks with surface of heat sink and also safe for submersion. There is no application of Indium in this experiment. CPUs without TIM can be seen from figure 3.4



Figure 3.3 Hard-drive connected externally



Figure 3.4 Both CPUs without TIM

3.3 Experiment procedure

In this test one plastic container is used to pour mineral oil-dielectric coolant in it which is in size of 24.5*21*4 inches. In that container modified server is placed. Same Linux script used which used in air-cooling method. First start Agilent 3470A data logger so it will start logging surface temperature. It supposed to be ambient temperature at that time now. USB data loggers are used to measure ambient condition in front end of the server, in the entire test ambient temperature was about 22-23C. Few thermocol blocks are used in between space of fans and motherboard and in space of hard disc. The reason behind to use those block is so we can reduce amount liquid required in this experiment.

After that turn-on the server and connect to network using LAN cable. Then pour coolant in that container. In this experiment about 4 Gallons of mineral oil used to cool the server. Basically Oil pour till

it reaches height of heat-sinks. Then after pre-determined time test starts. It is same test in that all the design points from “DP0” to “DP9” are tested 3 times each and it will end after 22 hours in this test as well.

As there are no fans on server entire cooling will be based on di-electric coolant. Plastic container is opened to atmosphere from top so Oil will directly expose to atmosphere. And fluid will be stationary in entire test so heat transfer will be based on natural convection method and cooling occurs because of density difference of Oil. Same server used which tested in previous experiment in this test as well. Oil is dielectric so we won't see any electronic component damage or short-circuit even if we are running it at high power. Experiment setup of server with oil is seen from figure 3.5



Figure3.6 Server with Oil

3.4 Experiment 3

After conducting experiment using natural convection, next step is to set up experiment using forced convection method. In this method some external force required to make possible heat transfer. In previous experiment fluid was stationary throughout the experiment so fluid will be hot because of heat generated by components of motherboard. If by any we can remove that heat from oil then we can better and improved thermal performance.

To apply external force one centrifugal pump is used. Using this pump fluid will be circulate over the surface of motherboard and for cooling it liquid-air heat exchanger is used in this experiment. Radiator MCRX-20QP from SWIFTECH is connected as heat-exchanger. Each radiator can host 2 fans. 120 mm diameter fans are used in radiators which can runs at 1400-4500 RPM. And for circulating purpose one small pump MCP35X from SWIFTECH which has maximum discharge of 4.5 GPM and suction head of 14.7 Ft is used .One Oil flow meter FLMH-1410AL from Omega is used to measure flow rate of Oil over this experiment.

In this experiment first hot fluid will come out from the container and it goes to hydraulic pump from that by pumping action it passes from flow meter so we can check flow rate of oil at any time. After passing through this pump it goes to radiator for cooling purposes by using two fans it will get cooled then it goes back to container. To measure liquid temperature two thermocouples from omega are used at inlet and outlet of container. Both thermocouples are attached in hose and connected to multiplexer. Using this we can check the temperature of hot fluid and how much cooling we are getting from radiator.

At start of the test, first turn on the server and waited for few times and it supposed to be running at idle condition. In that container all the chassis parts are removed from motherboard and power supply. In this test 3 Gallons of mineral oil is used. Then priming of the system is necessary so all the air trapped in the system can be taken out because it might effects on performance of pump and radiator. Then pump was started at its operating voltage range and current by using Agilent DC power supply until the flow rate of oil stabilize in the system . We can observe the temperature of oil at inlet and outlet of the container and it will take some time to reach both the temperature at some value then turn on the fans of

radiators by using DC power supply at 12V DC and 1.5A. Now wait for few minutes so we can observe noticeable difference in oil temperature by cooling it even it will be stable after some time. Then apply %CPU loading of 98 and run the test for 30 minutes and record all data. In this experiment Pump power, flow rate of oil and rpm of radiator fans kept constant throughout the experiment. Test setup can be seen from figure 3.7 with all components.

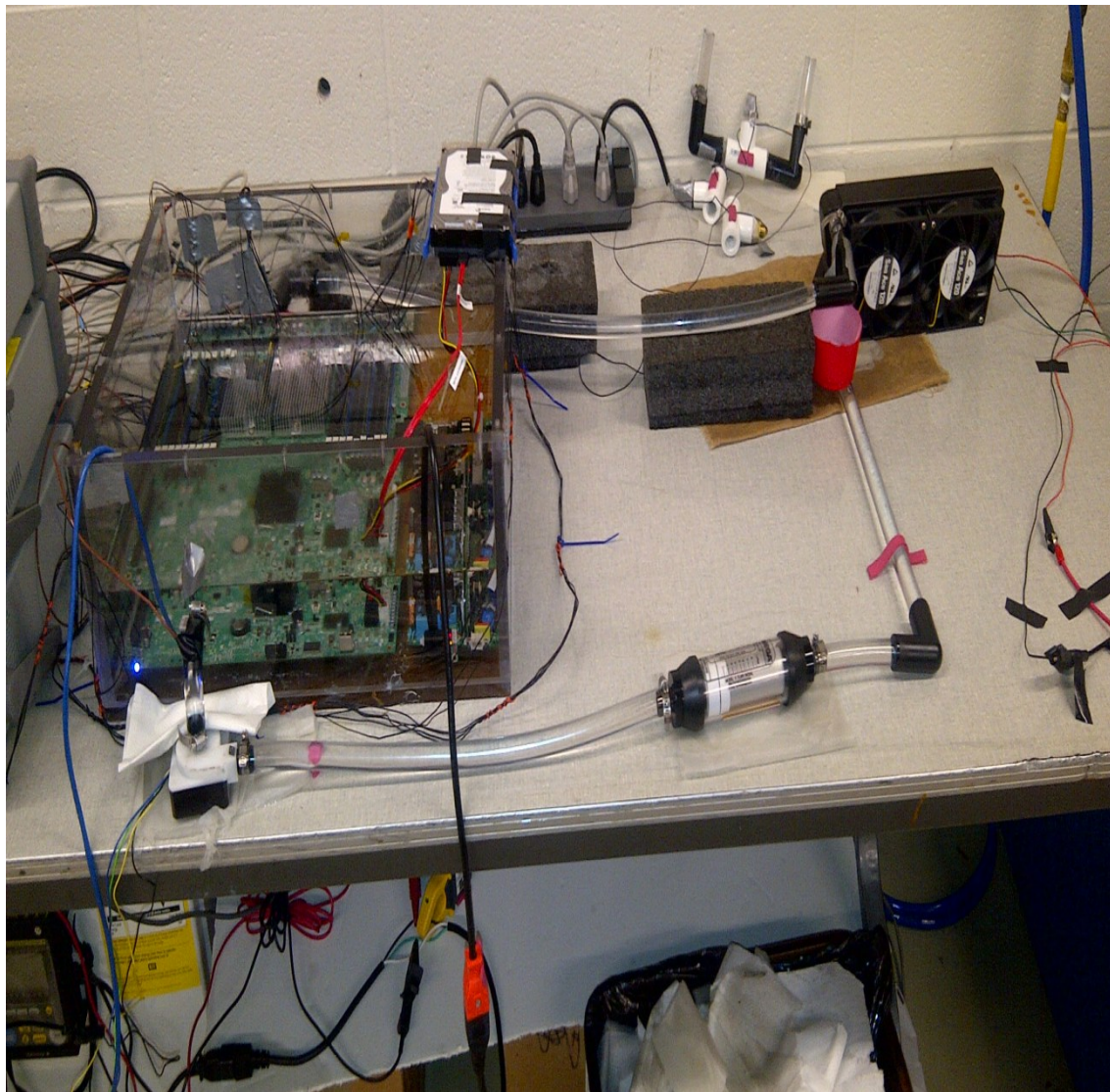


Figure 3.7 Experimental setup

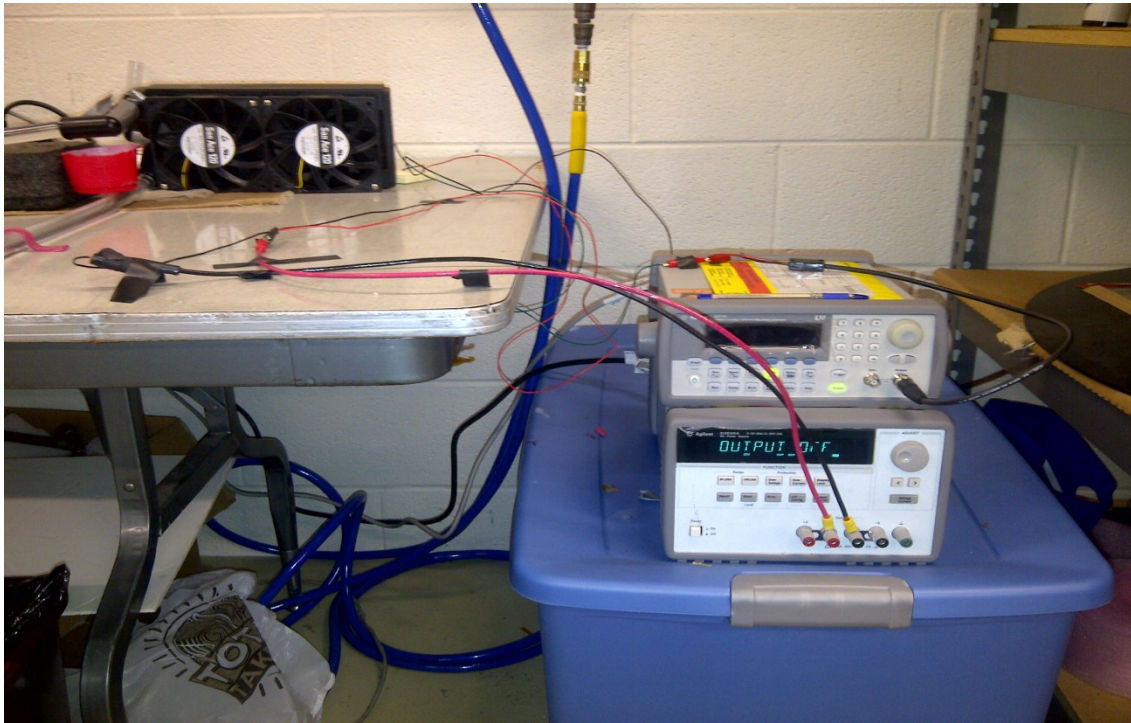


Figure 3.8 Control of the fans



Figure 3.9 Control of the pump using Agilent DC power supply

3.4.1 Test 1: Fix the pump power

In first test in forced convection pump power kept constant in the test. Basically in Air cooling at 98% CPU utilization, motherboard fan runs at around 3100-3200 rpm at this rpm each fan consumes about 3.192 watts so total fan power will be 12.76 watts. So objective of this approach is to keep that cooling power constant and compare CPU0 case and die-junction temperature.

After turning on the server wait for few times before start pump and radiator until system get stability. Then turn on the pump so oil will be circulated in the system. After few times both temperature at inlet and outlet of server will be same as there is no heat transfer in the system yet. Then apply pump power of about 12 watts. Operated voltage and current where about 8.71V and 1.41A approximately, using that power flow rate of oil is around GPM. Now turn on the fans of radiator so heat will be removed and there will be temperature drop at inlet of server. We can observe theses temperature data from Agilent data logger. Wait for few times so that temperature drop will maintain some constant value. Then apply %CPU loading of about 98 using lookbusy command and record case temperature, Total server power and temperature data. In throughout experiment pump power and as such as flow rate of oil kept constant. Test runs for 30 minutes.

Command line for 98% utilization: `-lookbusy C98 [12]`

3.4.2 Test 2: Fix the case temperature of CPU

In this test case and die temperature of Oil kept constant. Objective of this approach is to keep case temperature as constant value as in Air cooling results and vary the pump power and using that data compare cooling power required in both the test.

First start the test and give CPU loading of 98% to the server then wait for few minutes to reach the system stable. Then turn on the pump and radiator so there will be temperature drop between inlet and outlet of the server after that try to control the case temperature by varying the oil flow rate and pump power. In air cooling average case temperature was around 62-63°C. In this experiment at flow rate of 0.25 GPM, CPU case temperature reached at 62-63°C. Controlling of the pump can be seen from figure

3.9

3.5 Experiment using two radiators

So after that both cases one more set of experiment carried out by using two radiators. Using second radiator inlet temperature of mineral oil drop down till average 24.9°C , and same test carried out and then results compared after that.



Figure3.10 Experimental setup with two radiators

CHAPTER 4

RESULTS AND COMPARISONS

	CPU1									CPU0							
	Base test				immersion test					Base test				immersion test			
	VRD 8	VRD9	VRD10	VRD11	VRD 8	VRD9	VRD10	VRD11		VRD 8	VRD9	VRD10	VRD11	VRD 8	VRD9	VRD10	VRD11
DP0	38.29	41.29	41.61	42.05	33.47	32.91	32.96	32.77		33.36	39.3	40.64	40.47	33.36	32.52	32.97	33.09
DP2	53.69	61.63	63.26	62.63	35.46	36.03	36.66	35.99		45.44	60.08	61.75	61.03	35.51	35.63	36.03	36.52
DP4	52.86	62.08	64.21	62.56	36.31	37.98	39.1	39.84		44.35	61.27	62.73	61.47	37.97	38.81	39.25	40.07
DP6	51.64	61.08	63.35	61.14	40.2	41.46	42.2	41.27		43.39	60.58	61.71	60.22	40.24	41.19	41.75	42.7
DP9	40.8	48.47	50.47	48.44	41.24	42.45	43.22	42.25		34.27	48.38	49.03	47.8	41.28	42.25	42.83	43.71

Figure4.1 Comparison chart for VRD temperatures between air cooling and immersion test

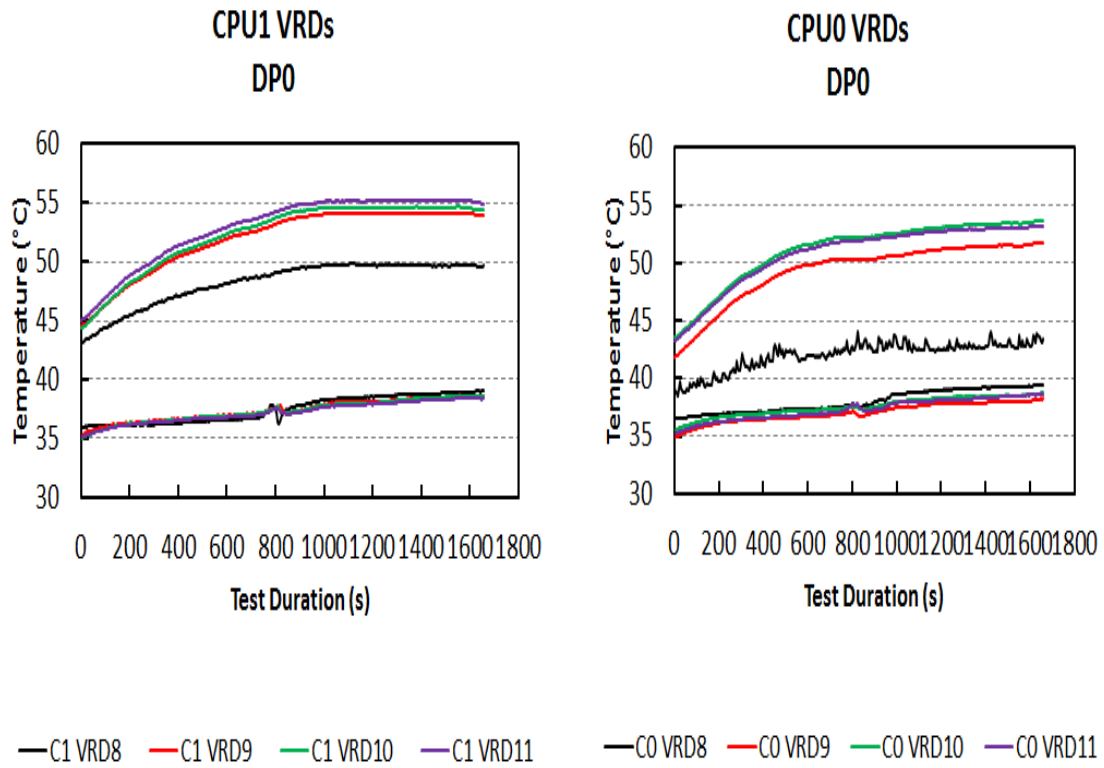


Figure 4.2 Comparison at 10% utilization

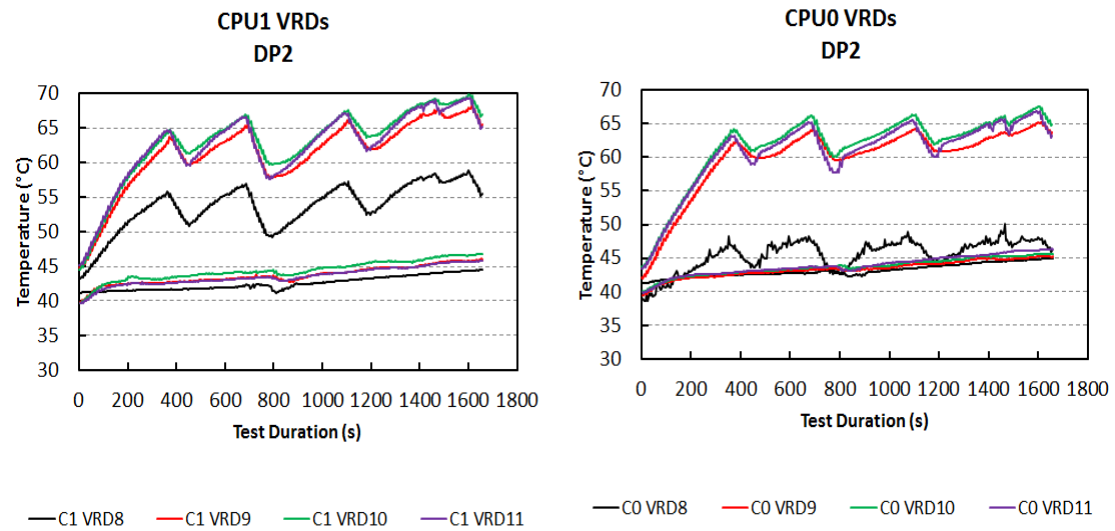


Figure 4.3 Comparison at 30% CPU utilization

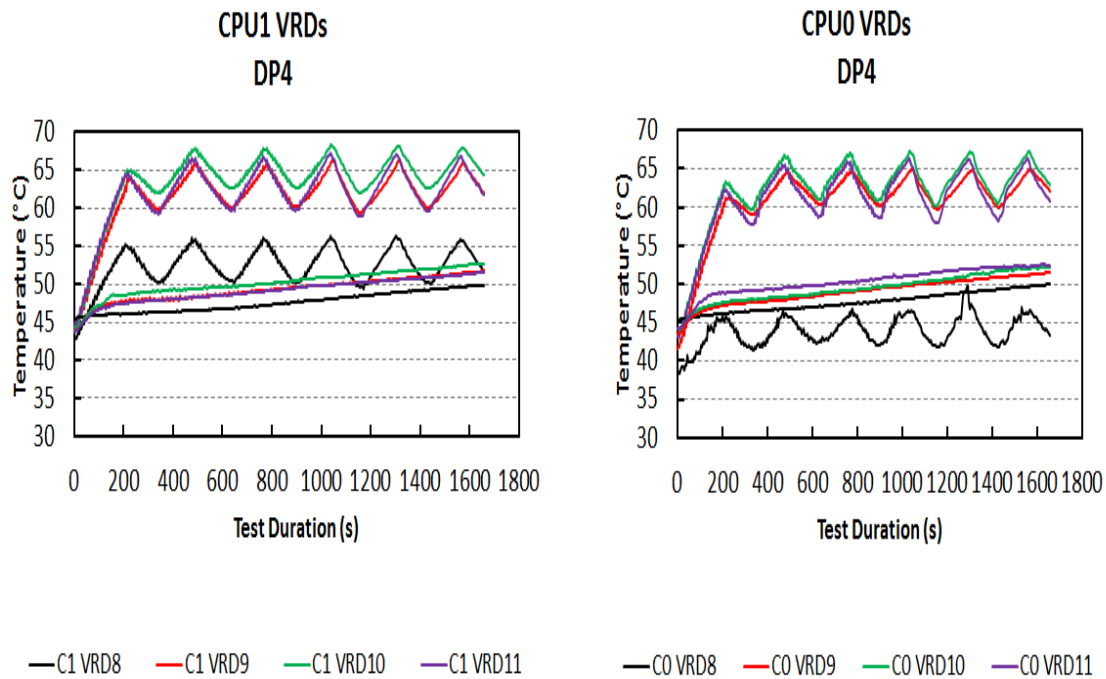


Figure 4.4 Comparison at 50% utilization

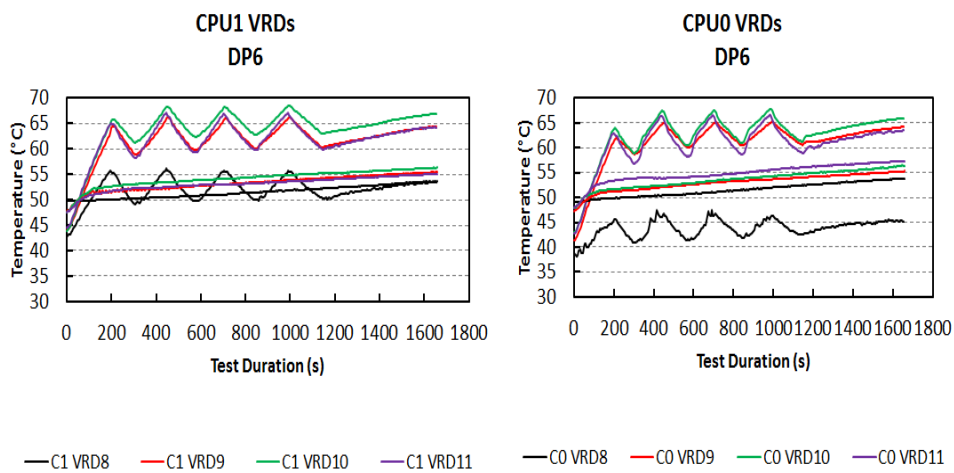


Figure 4.5 Comparison at 70% CPU utilization

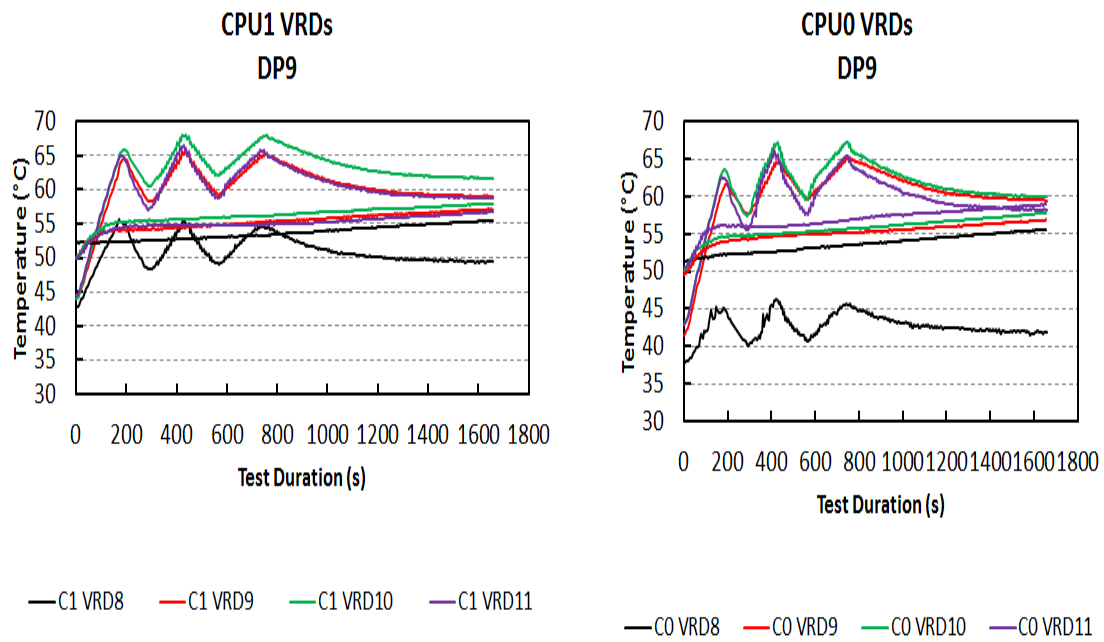


Figure 4.6 Comparison at 90% CPU utilization

SERVER POWER COMPARISON:

Avg power consumption in watts		
	base test	Immersion test
DP0	112.68	109.58
DP2	171.85	170
DP4	205.34	207.73
DP6	215.3	220
DP9	226	219.96

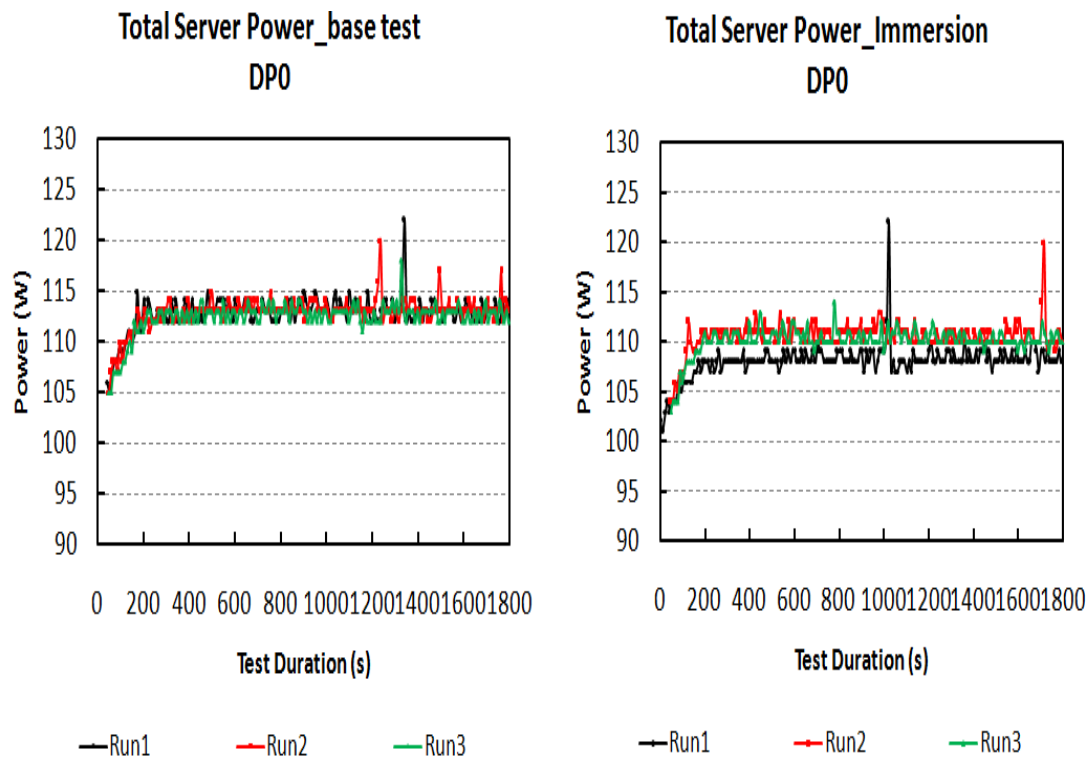


Figure 4.7 Comparison of server power at 10% CPU utilization

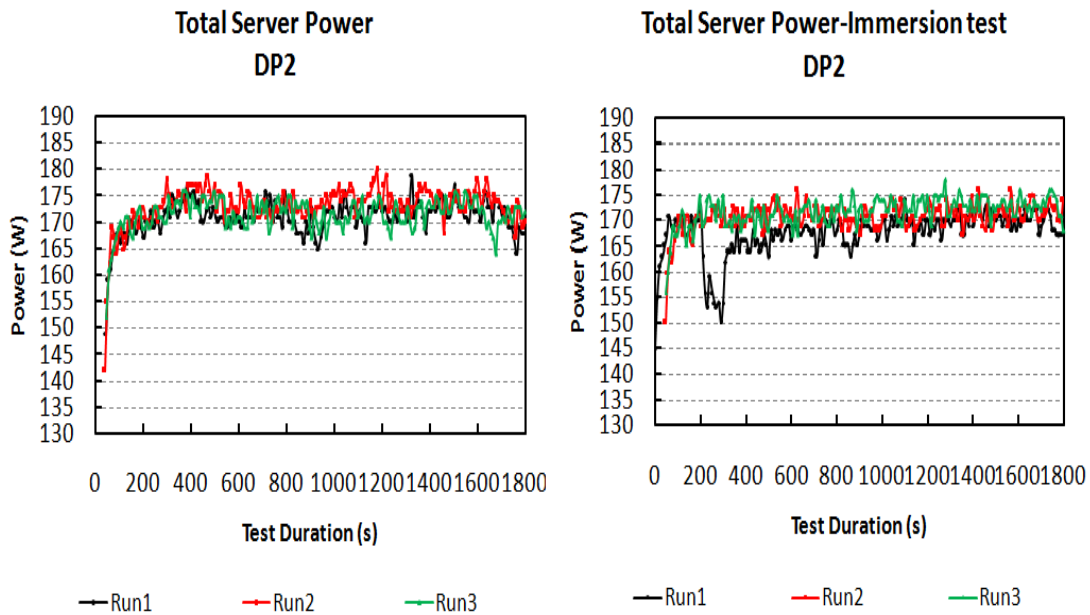


Figure 4.8 Comparison of server power at 30% CPU utilization

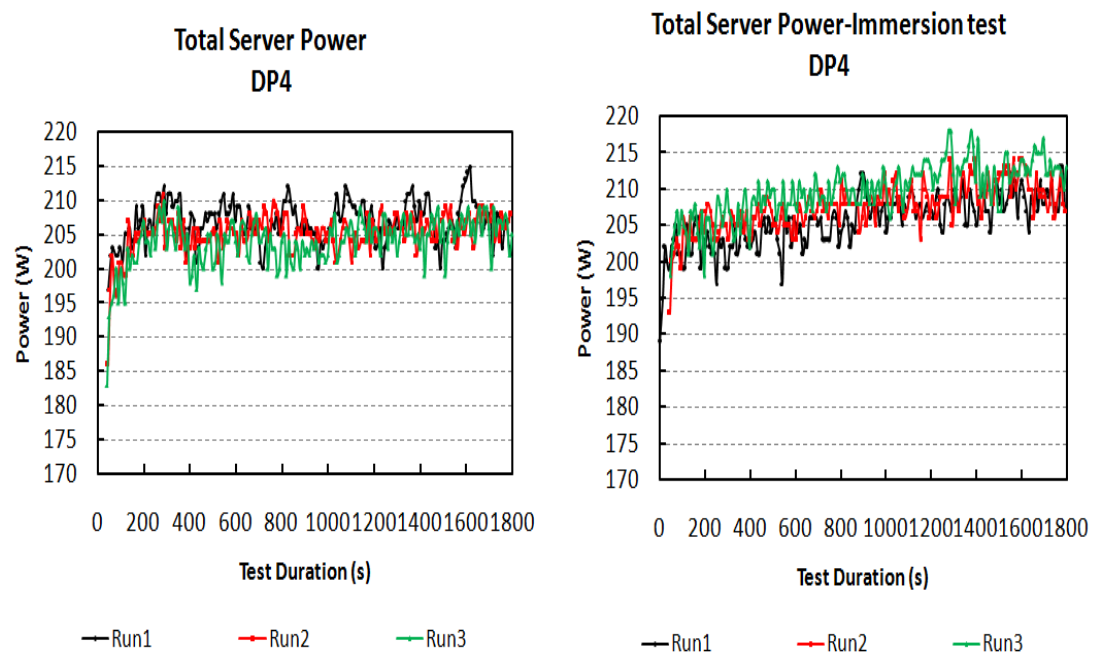


Figure 4.9 Comparison of server power at 50% CPU utilization

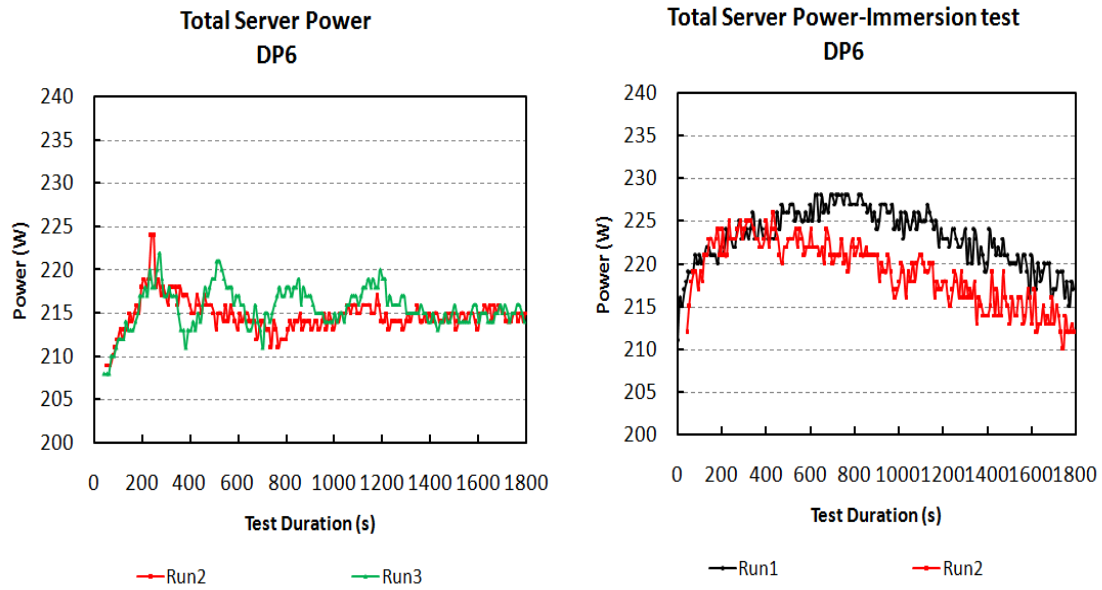


Figure 4.10 Comparison of server power at 70% CPU utilization

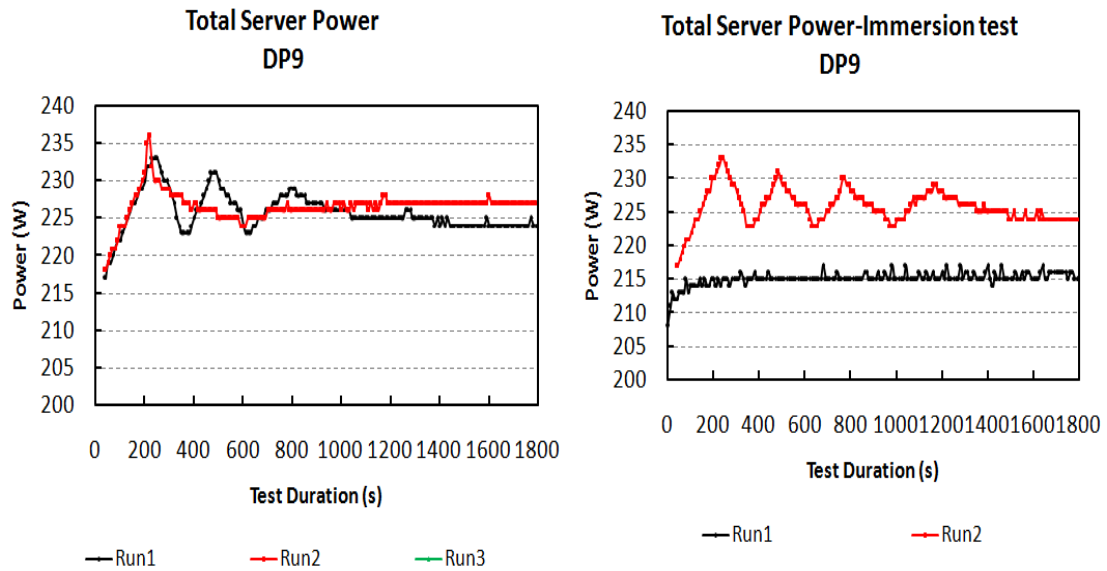


Figure 4.11 Comparison of server power at 98% CPU utilization

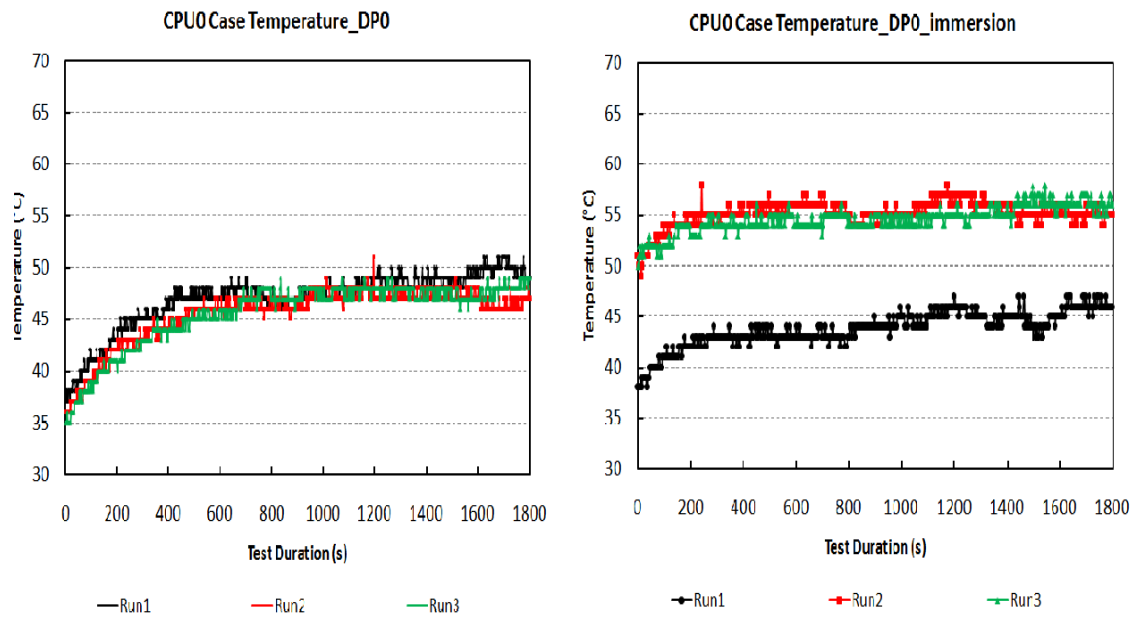


Figure 4.12 Comparison of case temperature at 10% CPU utilization

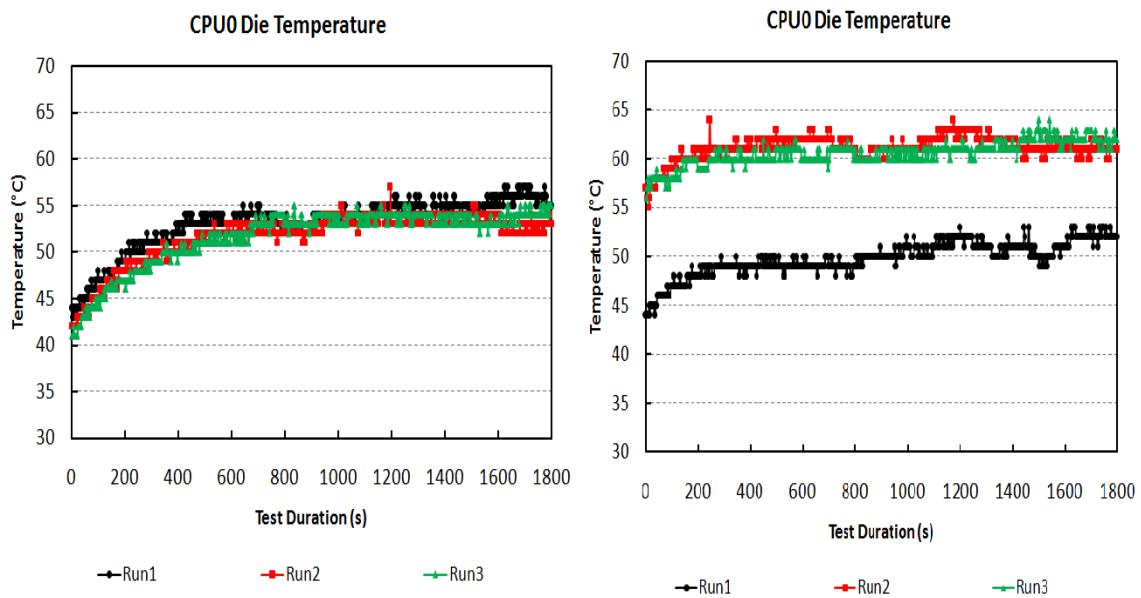


Figure 4.13 Comparison of die temperature at 10% CPU utilization

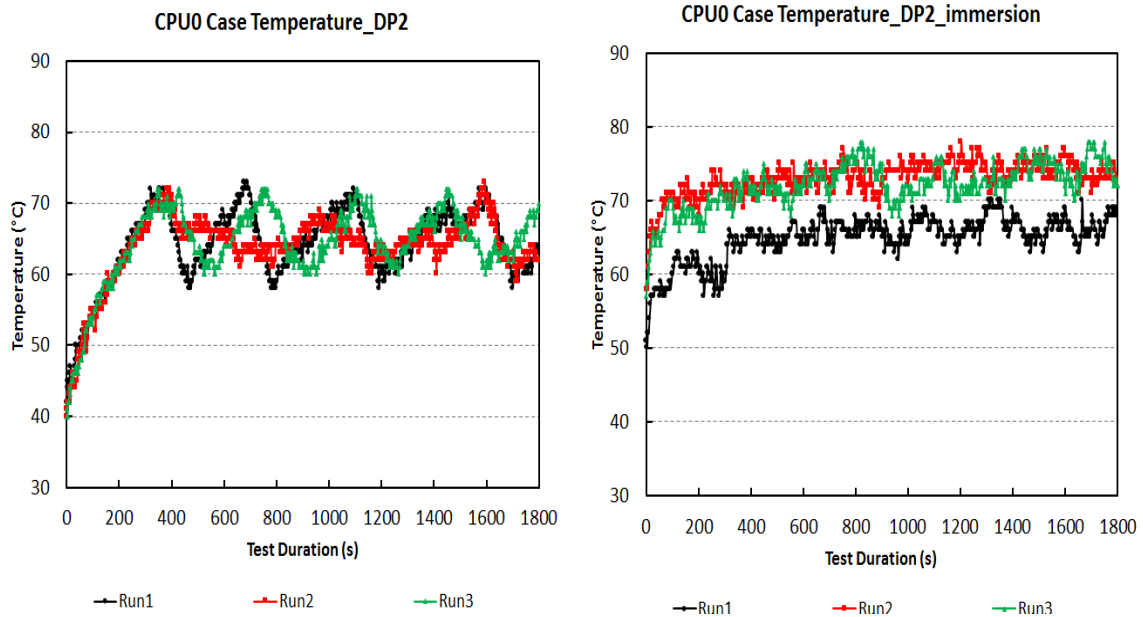


Figure 4.14 Comparison of case temperature at 30% CPU utilization

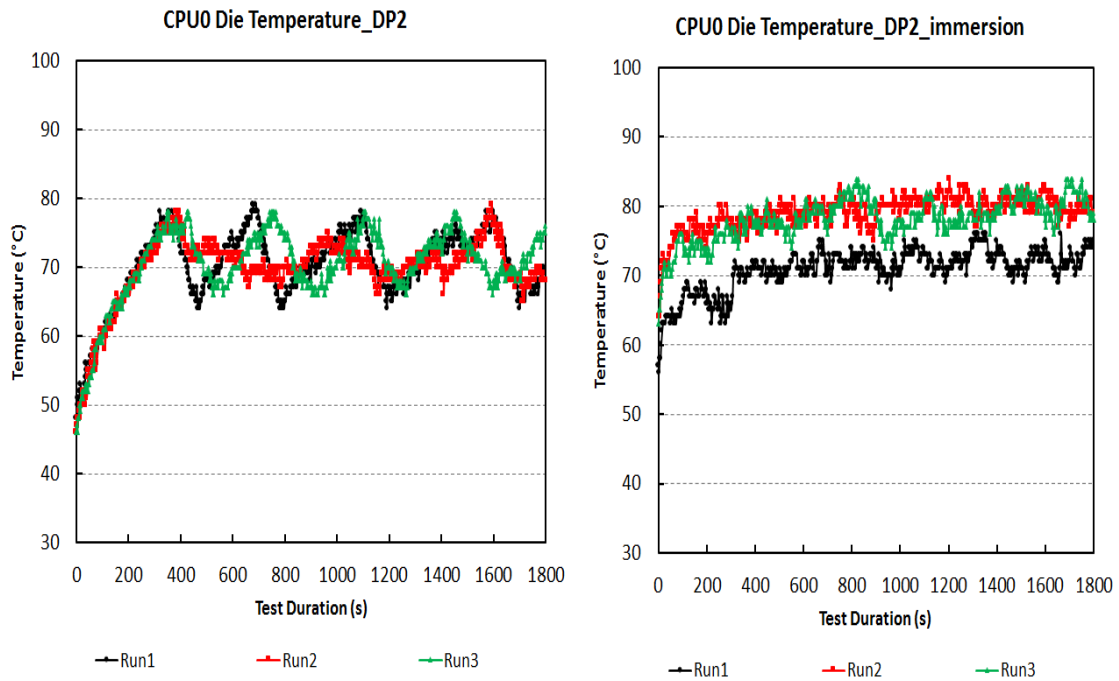


Figure 4.15 Comparison of die temperature at 30% CPU utilization

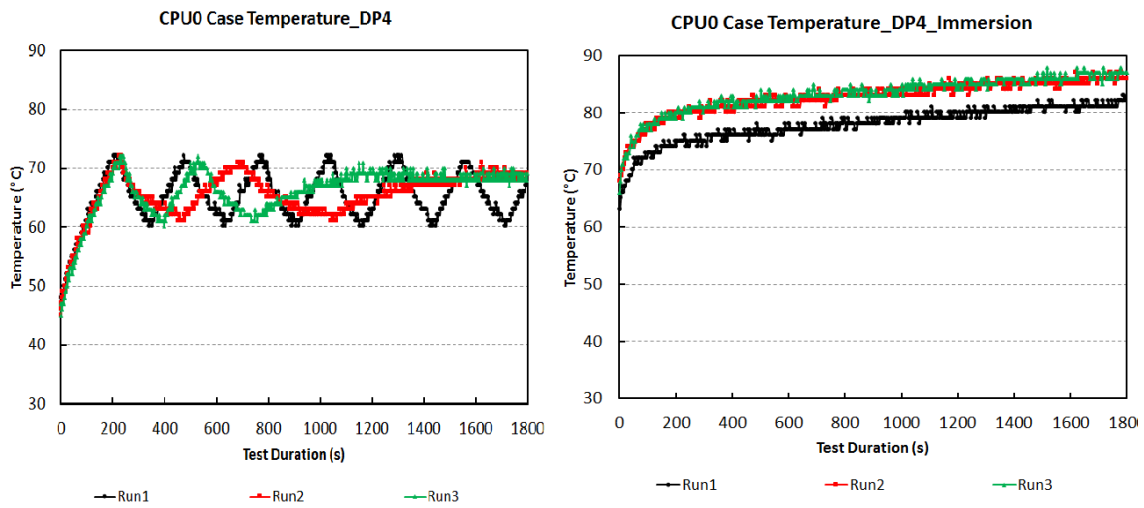


Figure 4.16 Comparison of case temperature at 50% CPU utilization

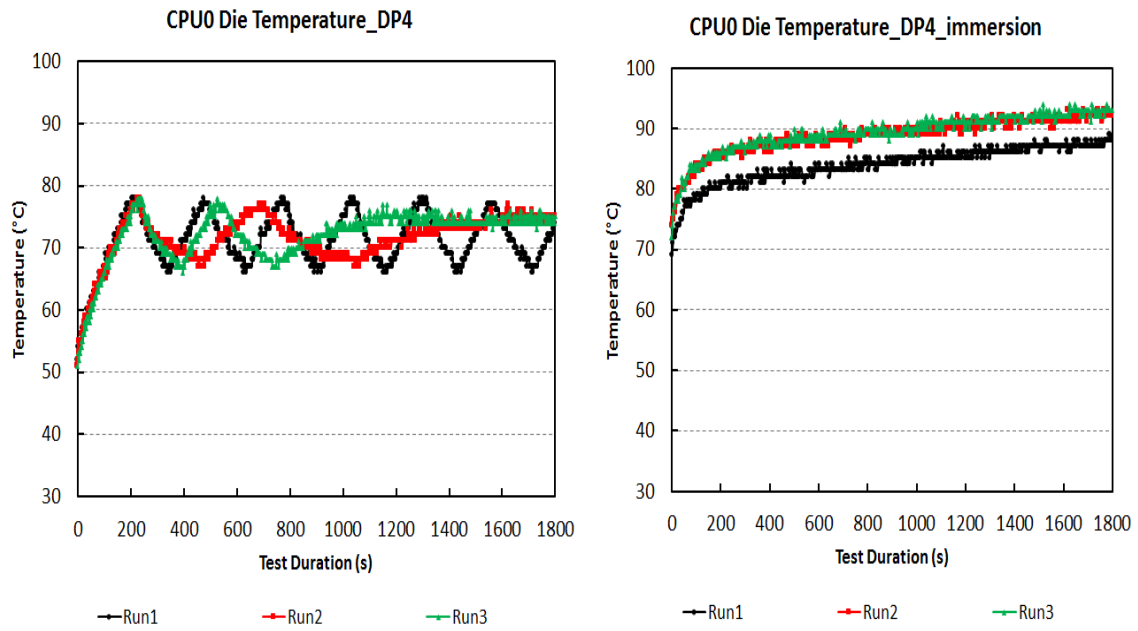


Figure 4.17 Comparison of die temperature at 50% CPU utilization

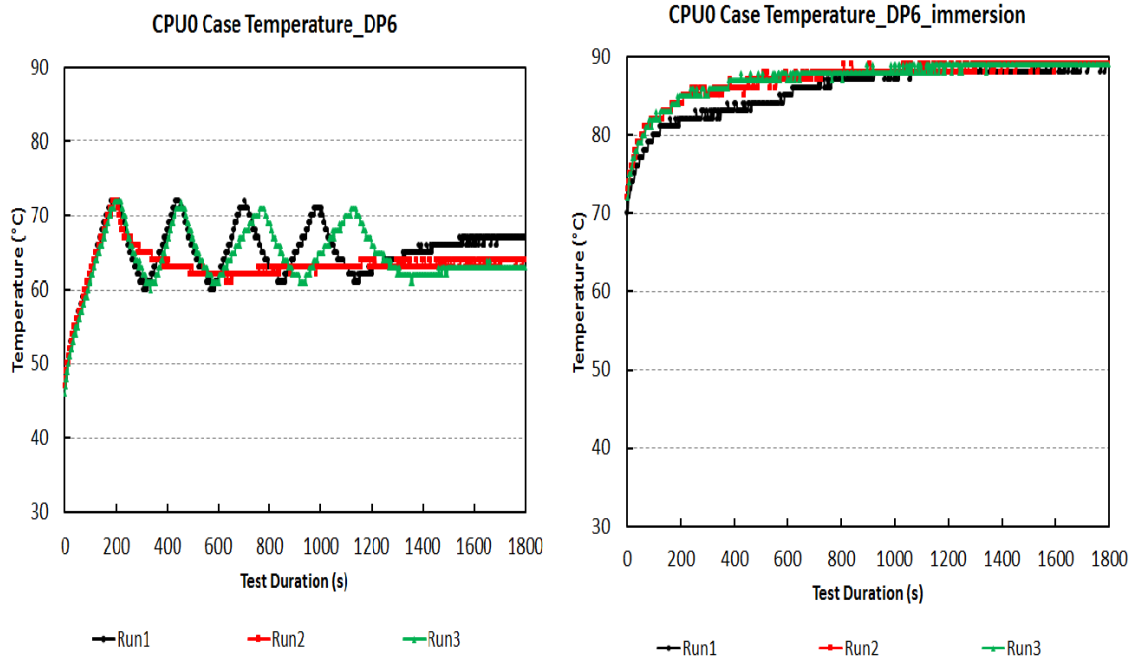


Figure 4.18 Comparison of case temperature at 70% CPU utilization

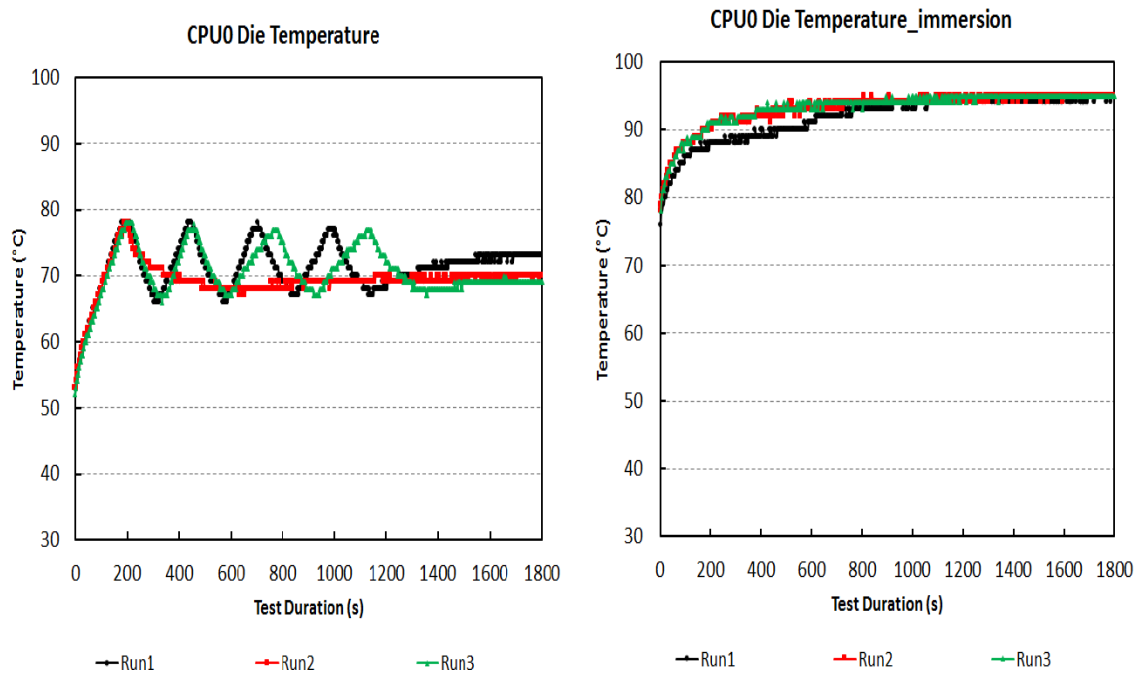


Figure 4.19 Comparison of die temperature at 70% CPU utilization

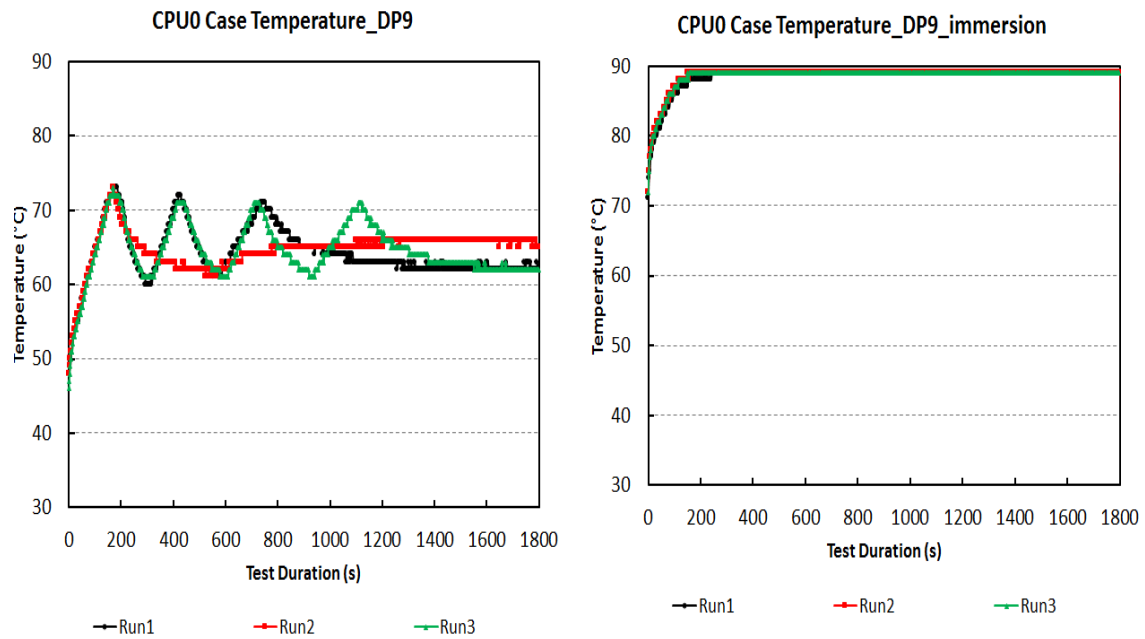


Figure 4.20 Comparison of case temperature at 98% CPU utilization

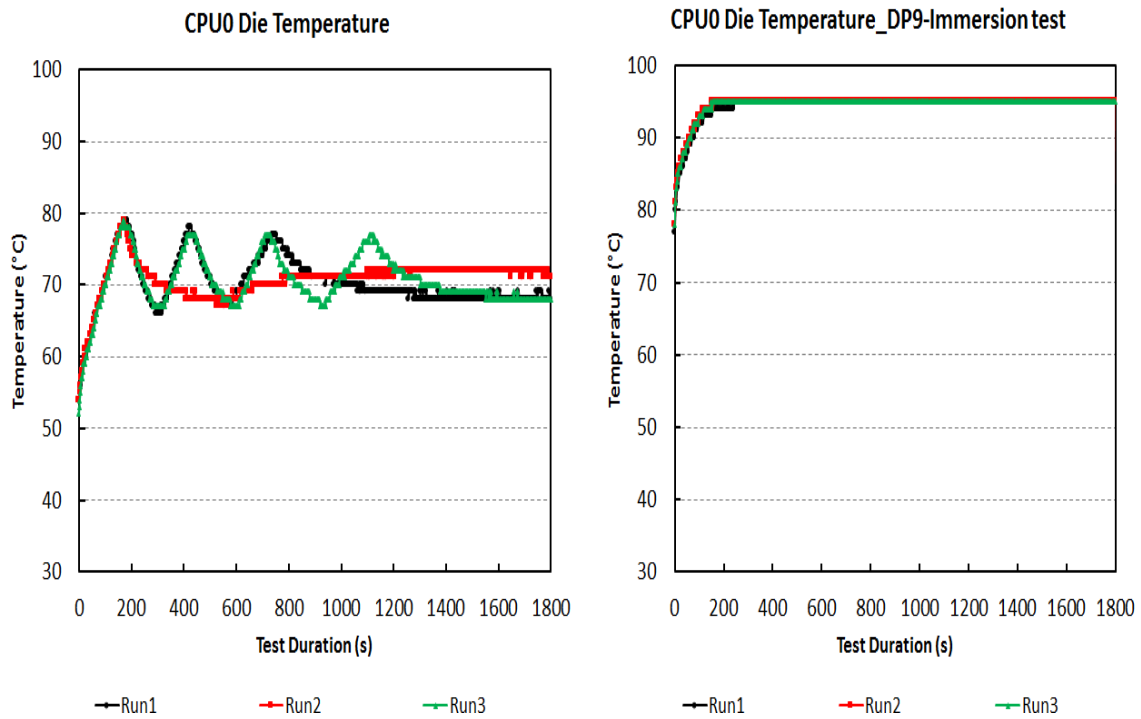


Figure 4.21 Comparison of die temperature at 98% CPU utilization

4.2 Results for Air cooling v/s Forced convection

Test 1: Fix the pumping power of 12.26 watts

1) CPU 0 Case and Die temperature comparison

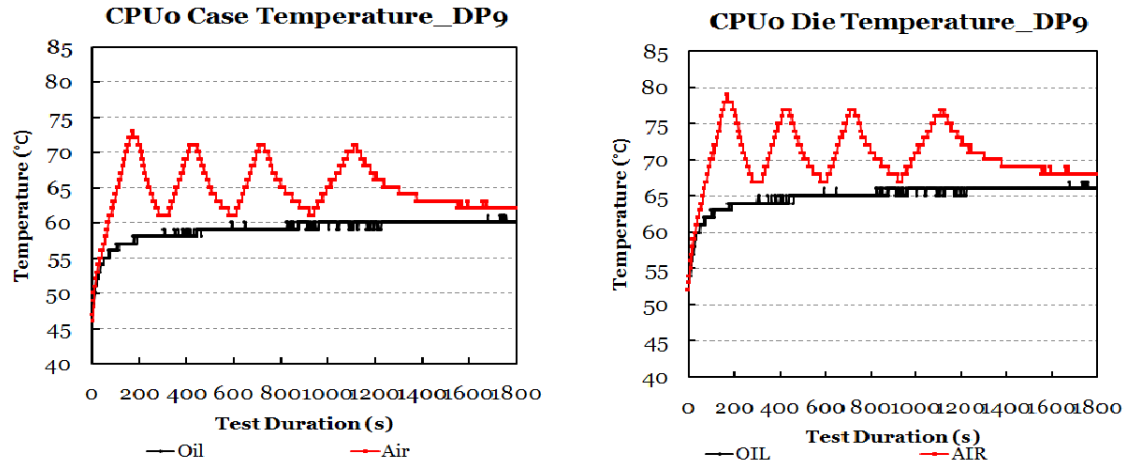


Figure 4.22 Comparison of case and die temperature at 98% CPU utilization for case 1

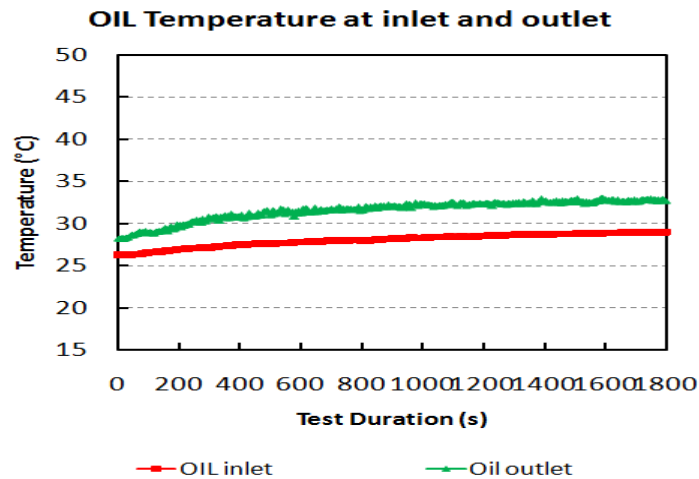


Figure 4.23 Oil temperature at inlet and outlet of server for case 1

2) Total server power comparison

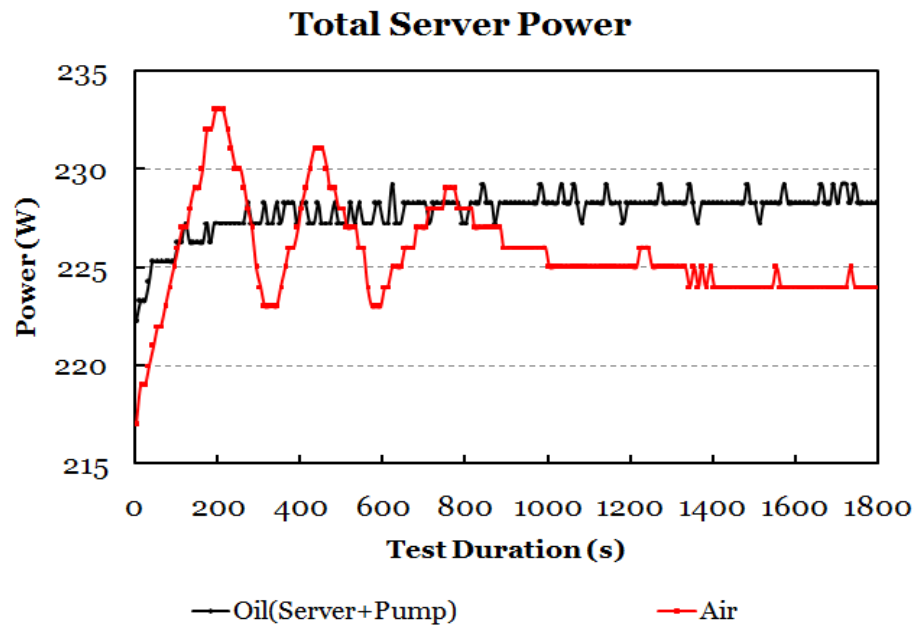


Figure 4.24 Total server power consumption comparison at 98% utilization for case 1

TEST 2: Fix the junction temperature at 62°C

- 1) Case and die temperature comparison:

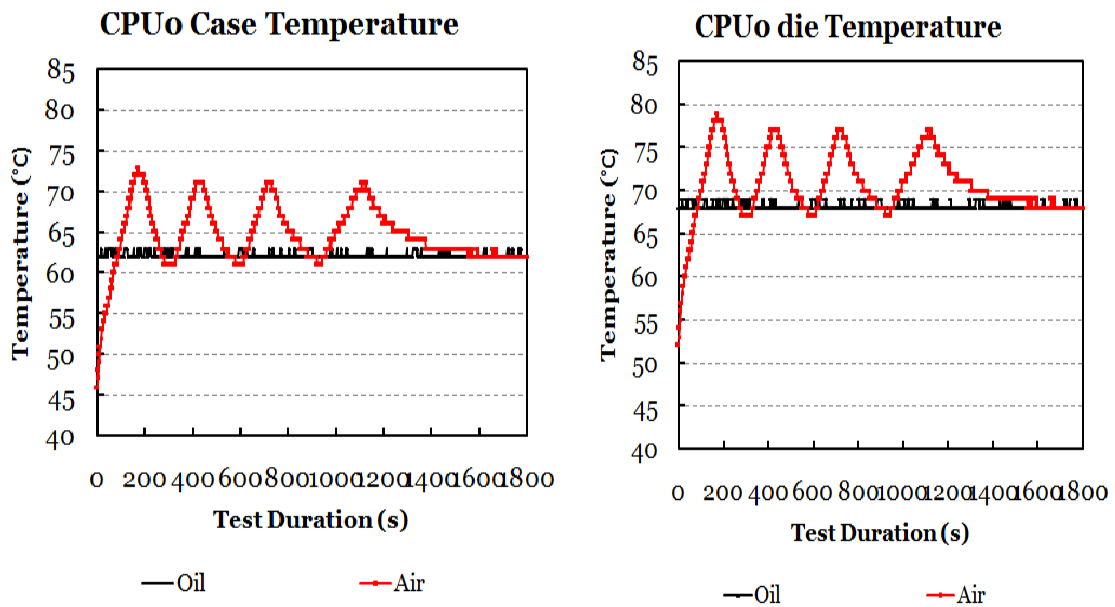


Figure 4.25 Comparison of case and die temperature at 98% CPU utilization for case 2

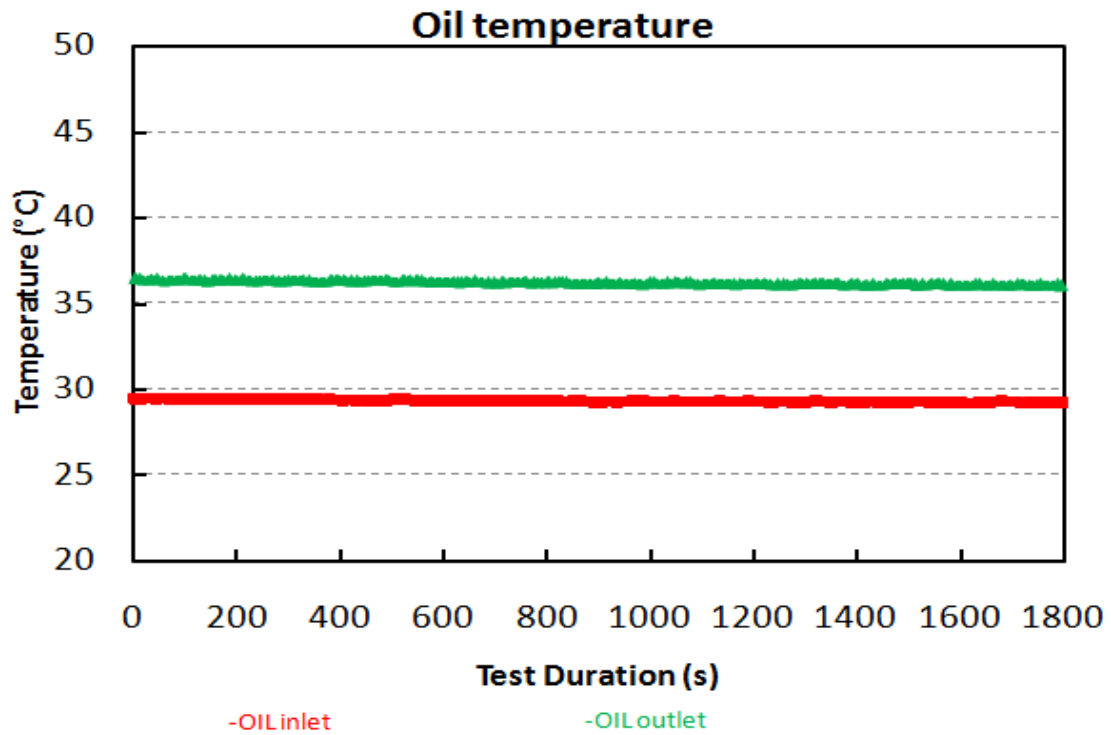


Figure 4.26 Oil temperatures at inlet and outlet of server for case 2

2) Total Server power comparison

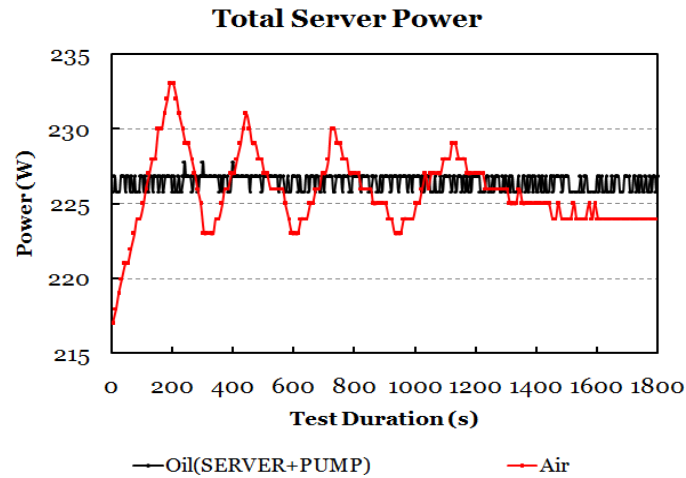


Figure: 4 .27 Total server power consumption comparison at 98% utilization for case 2

Average pump power: 7.81 Watts

Average flow rate: 0.25 GPM

			AIR	OIL				
	CASE 1	CASE TEMP(°C)	63	58				
		DIE TEMP(°C)	69	64				
		Maximum DIE TEMP(°C)	79	67				
		Minimum DIE TEMP(°C)	54	53				
	Fan/Pump Power same	FAN/PUMP POWER (Watts)	12.76	12.21				
		Total server power(Watts)	225.73	227.82				
		Maximum server power	233	229.26				
		Minimum server power	217	222.26				
	CASE 2	CASE TEMP(°C)	63	63				
		DIE TEMP(°C)	69	69				
		Maximum DIE TEMP(°C)	79	69				
		Minimum DIE TEMP(°C)	54	68				
	Junction temp same	FAN/PUMP POWER (Watts)	12.76	7.81				
		Total server power(Watts)	225.73	226.44				
		Maximum server power	233	227.81				
		Minimum server power	217	225.81				

Figure 4.28 Tabular comparisons of both cases

4.3 Results after using two radiators

Total server power comparison:

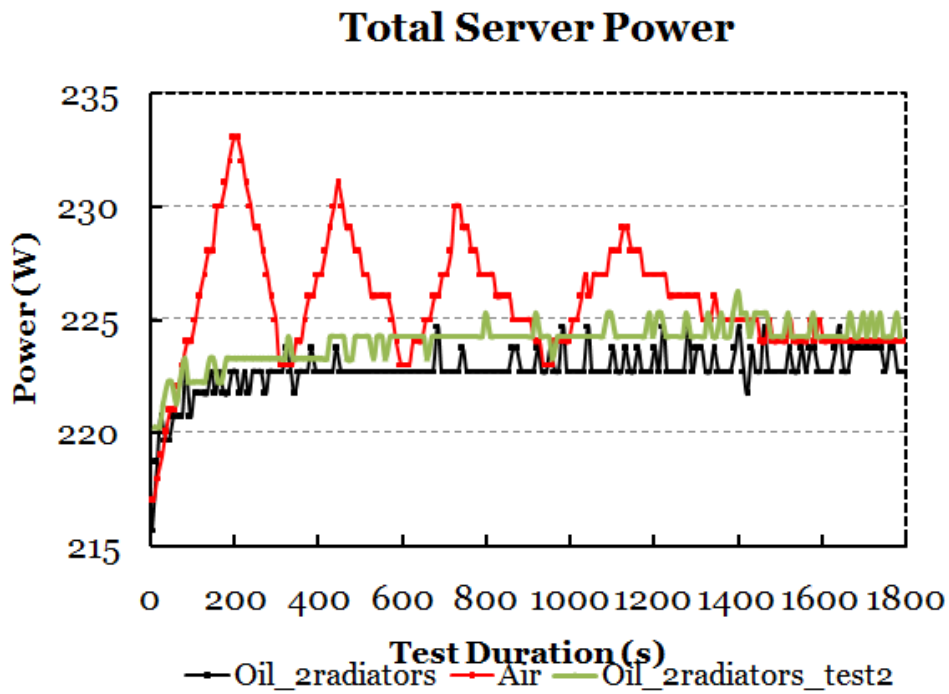


Figure 4.29 Total server power comparison for both tests

Junction temperature comparison:

CPUo Die Temperature-Immersion test

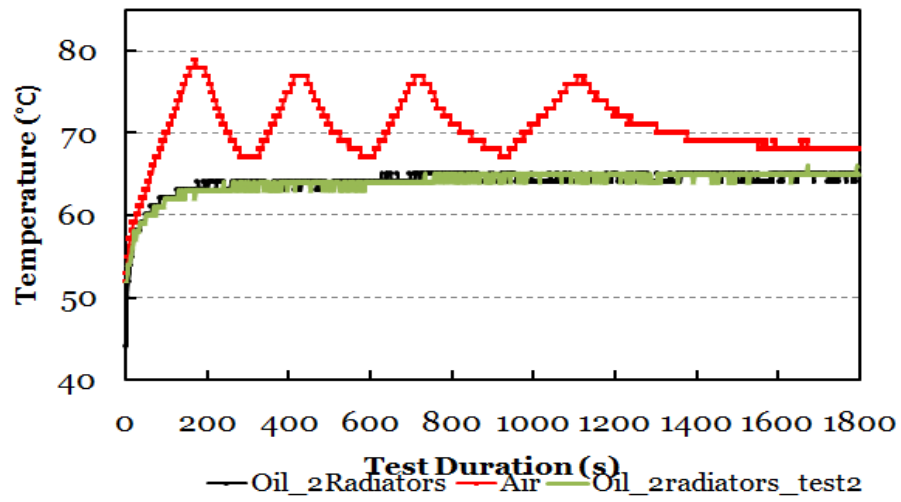


Figure 4.30 Junction temperature comparison for both tests

Oil Temperature

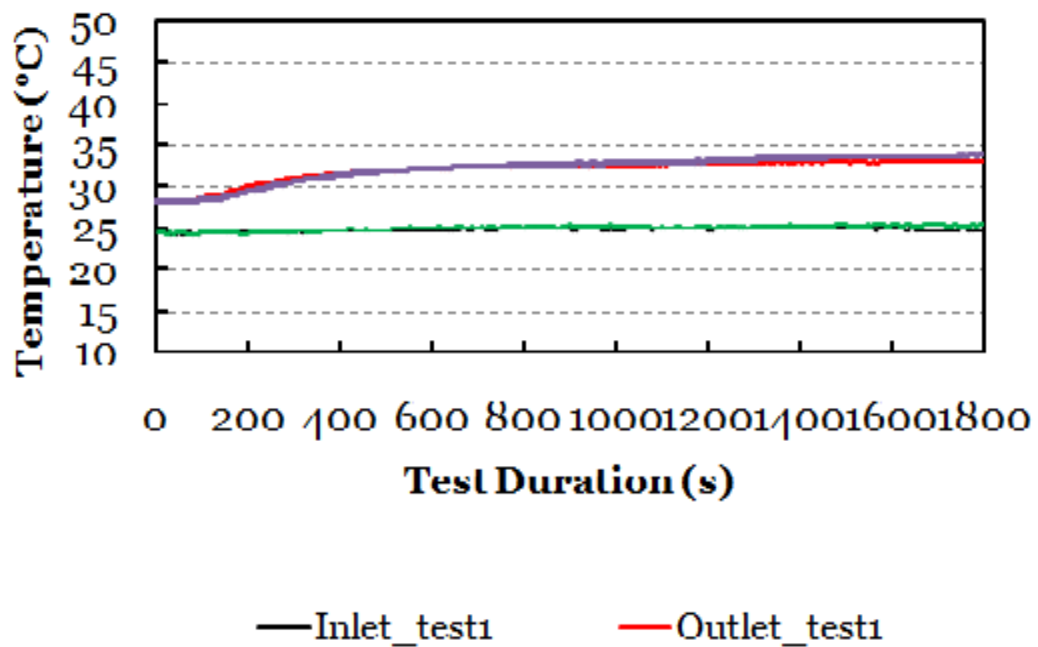


Figure 4.31 Oil temperatures at inlet and outlet of server

	AIR	OIL	Oil-2 radiators,Test1	Oil-2 radiators,Test2
CASE TEMP(°C)	63	58	58	58
DIE TEMP(°C)	69	64	64	64
Maximum DIE TEMP(°C)	79	67	65	66
Minimum DIE TEMP(°C)	54	53	44	52
Average Oil inlet temp		27.99	24.83	25.05
Average Oil outlet temp		31.59	32.06	32.23
FAN/PUMP POWER (Watts)	12.76	12.21	7.7	8.25
SERVER POWER	212.97	216.15	215.05	215.6
Average Total server power(Watts)	225.73	227.82	222.75	223.85
Maximum server power	233	229.26	224.7	226.25
Minimum server power	217	222.26	215.7	194.25

Figure 4.32 Tabular comparisons for the test using two radiators

CHAPTER 5

CONCLUSION

Initially after test with natural convection one thing was concluded that you can run the server in mineral oil. The same server which was used for testing was in the oil for more than 3 months but still there was not a single damage in any of the electronic components so it is safe as well.

After circulating Oil and cooling by using pump and radiator, comparison chart for Die-temperature and pumping power in immersion cooling and air cooling is given below.

CASE 1: Fix the pump power:

$$\begin{aligned}\% \text{ REDUCTION IN JUNCTION TEMPERATURE} &= (70.41-64.97)/ 70.41 * 100 \% \\ &= 7.72 \%\end{aligned}$$

CASE 2: Fix the junction temperature:

$$\begin{aligned}\% \text{ REDUCTION IN POWER} &= (12.76-7.81) / 12.76* 100 \% \\ &= 38.79\%\end{aligned}$$

So if we fix the pump power then we can achieve reduction in junction temperature and as vice versa if we fix the junction temperature then we can achieve savings in cooling power consumption.

After using two radiators and reducing inlet temperature of Oil of about 24.5°C, pump power required to achieve those temperature is less of about (~5 watts) for one server.

If we scale this approach to data center level then we can achieve other benefits as well.

- 1) Excellent circulation of coolant means uniform temperature without generating hot spots.
- 2) It requires very less energy to maintain coolant at 30°C. In data center CRAC units chill water to 7C and then use this water to cool the air to around 23°C. Chilling water requires much energy to remove heat outside.
- 3) Imagine building a data center with no CRACs, no chiller, and no raised floor. It offers efficiency at lowest cost per watt.

5.1 Future work

There was no application of Thermal interface material in this testing so if we use INDIUM film as TIM material then we can achieve some more reduction in junction temperature.

Reliability of this approach is next thing. As in the data center, servers are running 24*7 days we need to figure it out if can get same performance till long time. As there was only single server tested in this study we can increase number of server and increase test period and then compare the results for all of them.

REFERENCES

- [1] Vennesa Lopez, Hendrick F. Hamann , “ Heat Transfer modeling in Data center “ Typical data center layout [Online] available.
<http://www.sciencedirect.com/science/article/pii/S0017931011004467>
- [2] CRAC/CRAH unit of data center, from 42u [Online] available. <http://www.42u.com/cooling/hot-aisle-cold-aisle.htm>
- [3] ASHRAE “Datacom equipment power trends and cooling application “Atlanta American society of heating, refrigerating, air-conditioning Engineers: Inc, 2005.
- [4] Motherboard in chassis, “Open compute “, “Intel motherboard v1.0 specification“ [Online available] <http://www.opencompute.org/wp/wp-content/uploads/2011/07/Server-Intel-Motherboard-Specifications-v1.pdf>
- [5] All components of motherboard.
- [6] Major heat generating components and air flow direction, Open compute, FACEBOOK [Online available] <http://www.opencompute.org/wp/wp-content/uploads/2011/07/Server-Intel-Motherboard-Specifications-v1.pdf>.
- [7] Crystal plus technical oil from manufacturer steoil.
- [8] hydraulic pump mcp35x from manufacturer swiftech , [online available]
<http://www.swiftech.com/mcp35x12vdc泵.aspx>.

[9] Radiator mcpx20-qp [online available] <http://www.swiftech.com/mcrx20-qp-radiator-series.aspx>.

[10] Omega FLMH-1410 AL Oil flow meter [online available]http://www.omega.com/pptst/FLMH_FLMW.html

[11] Server modification [online available]<http://www.grcooling.com/docs/Green-Revolution-Cooling-CarnotJet-System-Pamphlet.pdf>.

[12] “Lookbusy – Synthetic load generator.”

Sampath, Shreyas 2012 Thermal analysis of high end servers and Based on model and experiments, University of Texas at Arlington Thesis

Green Revolution cooling and Texas advanced Computing research poster displayed at SC’11 in April 2010[Online available]<http://www.grcooling.com/docs/Green-Revolution-Cooling-and-Texas-Advanced-Computing-Center-Research-Poster.pdf>

The Carnot jet system Total Fluid submersion cooling for servers from Green Revolution cooling [Online available] <http://www.grcooling.com/docs/Green-Revolution-Cooling-CarnotJet-System-Pamphlet.pdf>

Mineral Oil submerged server from puget systems [online available]
<http://www.pugetsystems.com/submerged.php>

* Technical specification of mineral oil [online available] <http://www.steoil.com/wp-content/uploads/2011/04/70FG-MSDS.pdf>

BIOGRAPHICAL INFORMATION

Harsh Patel was born in Nadiad, Gujarat, India in 1990. He received his B.E in mechanical engineering from Sardar patel university, Anand, India in July 2011, and his M.S. in mechanical engineering from The University of Texas at Arlington in May 2013.

He had been involved in number projects related in area of electronics cooling techniques. His research are includes immersion cooling method for data center servers and had been working for the Facebook research team and actively involved in number of projects like leakage current analysis for servers, testing of servers with different types of heat-sinks, Fan characterization to determine fan curve, Testing servers in different ambient condition using related instruments like Environmental chamber, Air-flow bench.

He joined EMNSPC research team under Dr. Dereje Agonafer in fall 2011 and been involved in projects related to packaging level to server level.