INFLUENCE OF VARIATION IN CPU UTILIZATION ON THE RACK LEVEL FAN CONFIGURATION AS A COOLING TECHNIQUE FOR HIGH END SERVERS

by

SHREYAS NAGARAJ

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

MASTERS IN MECHANICAL ENGINEERING

THE UNIVERSITY OF TEXAS AT ARLINGTON

May 2014

Dedicated to my family and friends

ACKNOWLEDGEMENTS

First, I would like to thank my supervising professor Dr. Dereje Agonafer for his continuous guidance and support over the years of my study and research at The University of Texas at Arlington. It has been a continuous learning process under his expertise. I am thankful to Dr. Haji-Sheikh and Dr. Kent Lawrence for evaluating my work as committee members. I am extremely grateful to Dr. Veerendra Mulay from Facebook Inc. for his technical guidance provided through my tenure at the University.

Special thanks go to John Fernandes and Rick Eiland for being my technical mentors in accomplishing this work and Bharath Nagendran for defining computational and base line tests. I would further like to thank the Facebook team in UTA and entire EMNSPC team for their constant support and assistance in conducting my research. The support, belief and encouragement received by my friends have made my stay at UTA a memorable one. I am grateful for all the support given by Sridhara Madhugiri and Sudha Madhugiri for supporting and encouraging at different times during my masters in UTA.

Finally, I would like to express my fullest gratitude to my parents for always believing in me and providing me with the opportunity to purse my dreams. I thank almighty god for providing me the strength and inspiration.

April 18, 2014

ABSTRACT

INFLUENCE OF VARIATION IN CPU UTILIZATION ON THE RACK LEVEL FAN CONFIGURATION AS A COOLING TECHNIQUE FOR HIGH END SERVERS

SHREYAS NAGARAJ, M.S.

The University of Texas at Arlington, 2014

Supervising Professors: Dr. Dereje Agonafer

The data center industry has experienced significant growth over the past decade with the introduction and explosion of online banking, social networking and entertainment services. As a result, power consumption of such facilities continues to grow at a rapid pace. It has become imperative that energy savings and efficiencies be pursued in these components at various levels within the data center facility. This project aims to achieve the same by replacing internal server fans with larger, more-efficient fan units at the rear face of the rack. This study will be conducted by using a cluster of 1.5U Intel based Open Compute servers.

With the introduction of higher fan diameters at the rack, the fans will be characterized experimentally for its flow impedance, air flow rate, and its effect on die temperature and power consumption for various utilization levels. Since the utilization of the servers is not the same throughout the rack, it becomes important to study the impact on the server components. The experimental methods utilized in

the new rack design configuration will be then compared with the existing chassis fan configuration determining the performance of the proposed system.

This study will be used to establish guidelines between server or rack level deployment based on the utilization the servers are running at the stack. Thus conclusively, this study shall demonstrate the use of larger fans over server level fans, which shall save cooling power at the server level and rack level.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

Figure Page

CHAPTER 1

Introduction

A data center is a room used to house a large number of servers and computers associated for computing and data storage. It includes power supplies, data communications connections, environmental controls and security devices. Large data centers are similar to industrial scale operations and use as much as electricity utilized by a small town.

Figure 1.1. Data center.

The data center industry has experienced significant growth over past decade and electricity used by data center's has become a critical issue in recent years as demands for new internet services [1] (search engines, music downloads, video-on-demand, social networking and communication) have become more widespread. As a result, there is an increase in data center growth which in turn has increased the power consumption. Due to this, energy savings and efficiency improvement has become crucial at various levels in the data center industry.

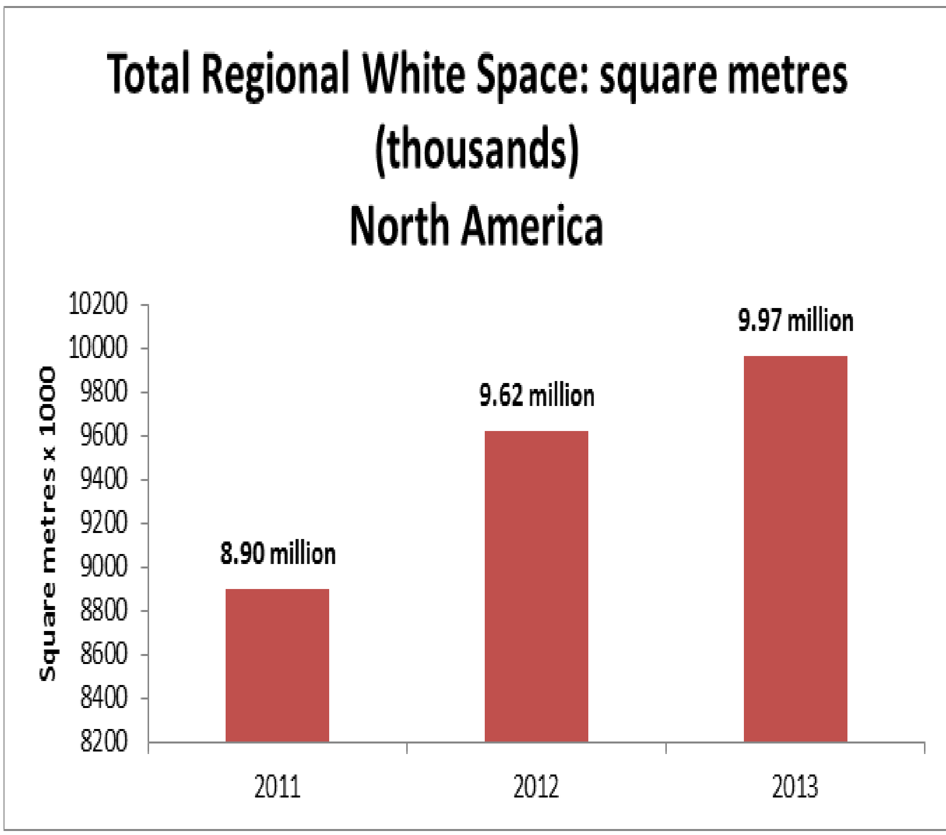

Figure 1.2. Data Center Industry growth.

Energy efficiency is a priority, [2] but many data center operations still have backward financial structures and make common errors on airflow management. Hence, more companies are trying to increase the server inlet air temperature and measuring PUE's effectively. Most of the energy used in the data centers is utilized to cool the IT equipments which radiates heat when powered. With the increasing power densities of the IT equipments, it becomes more challenging to run the data center efficiently.

1.1 Motivation

The power consumption in data centers can be categorized into two power i.e. static power and dynamic power. Static power is used by the IT equipments of the data center and the dynamic powers are the cooling power utilized by CRAC units. In this study, the servers are also classified as IT power i.e. used by the printed circuit boards and the components associated with it and the dynamic power involves the fan power utilized in the servers. With any small percentage in the reduction of either powers will scale up to huge power savings to the companies since a data center has several number of servers.

This study focuses on the dynamic power of the servers. The power consumed by the server fans will be studied and will be compared with the proposed rack level configuration of the fans. In the proposed fan configuration, the small chassis fans are replaced with higher diameter fans .The work will be defined initially by CFD work and will be experimentally validated.

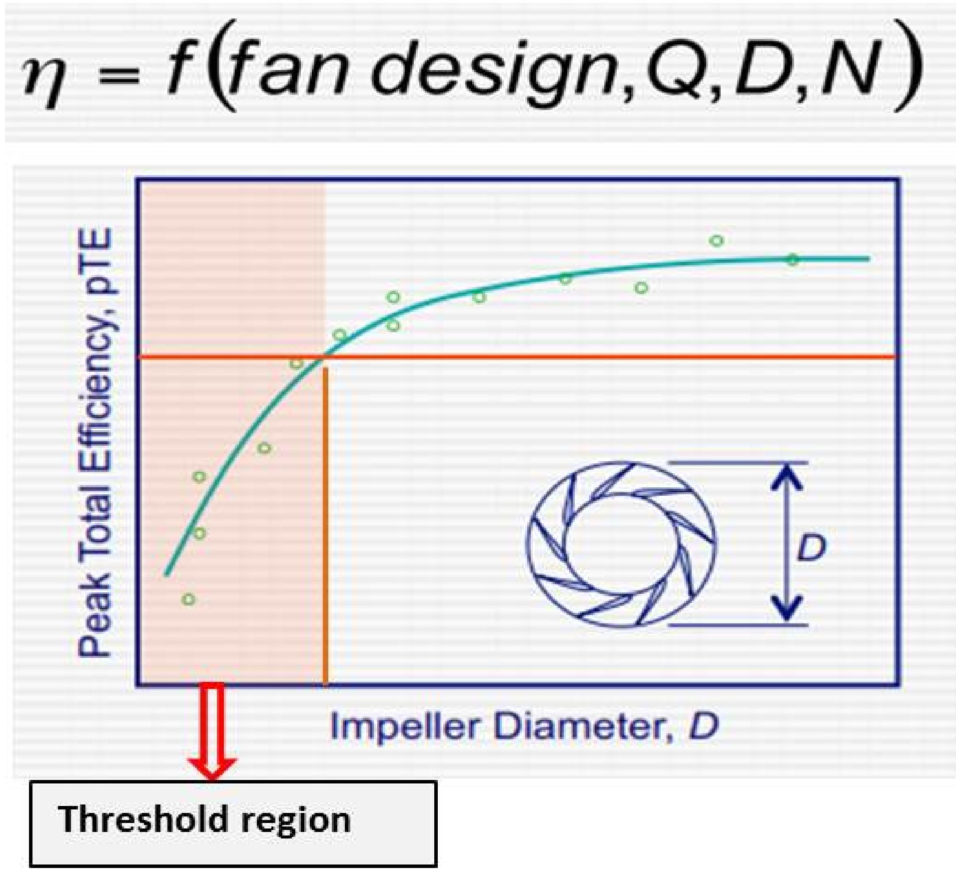

Figure 1.3. Advantages of higher diameter Fans.

With the introduction of higher diameter fans, [3]there are many advantages. The picture above suggests that efficiency of the fan can be maximized after surpassing the threshold region. This will be a great benefit considering the cooling power of the servers can be reduced for a server by some margin which in turn reduces the cooling power of the rack by significant amount. The other advantages also include higher air moving capacity of the fans which reduces the PCB components of overheating and also increasing the reliability of components.

CHAPTER 2

Fan Characteristics

2.1 Background

Fans in servers are devices which are used for cooling electronic components by creating air to flow through the system. They deliver air at definite rpm and flow rate. Fans create air flow by converting the torque supplied to the propeller shaft to impart kinetic energy to the air flowing across the fan rotor. In doing so, these devices also increase the static pressure across the fan rotor.

The commonly used fans in cooling applications are axial flow. Axial flow fans deliver air flow in the direction parallel to the fan blade axis. These types of fans can deliver high flow rates and produce air flows with high volume and low pressure. They are extensively used for cooling IT equipments.

2.2 Air moving capacity

Air moving capacity of a fan is described by two factors i.e. static pressure and flow rate. When a fan experiences no resistances for the airflow under atmosphere pressure is referred as free flow condition. This represents the maximum flow rate capacity of the fan also known as free flow condition of the fan[4]. When the fans are setup to a chamber such that one end of the chamber is closed and another is subjected to the atmospheric conditions, the fan pressurizes the chamber by forcing the air to the chamber. There will be a point where the fans cannot pressurize the chamber anymore .This point wherein the entire energy is utilized to maintain the pressure in the chamber is called stall point. The picture below gives an idea about the stall point and free flow condition of the fan

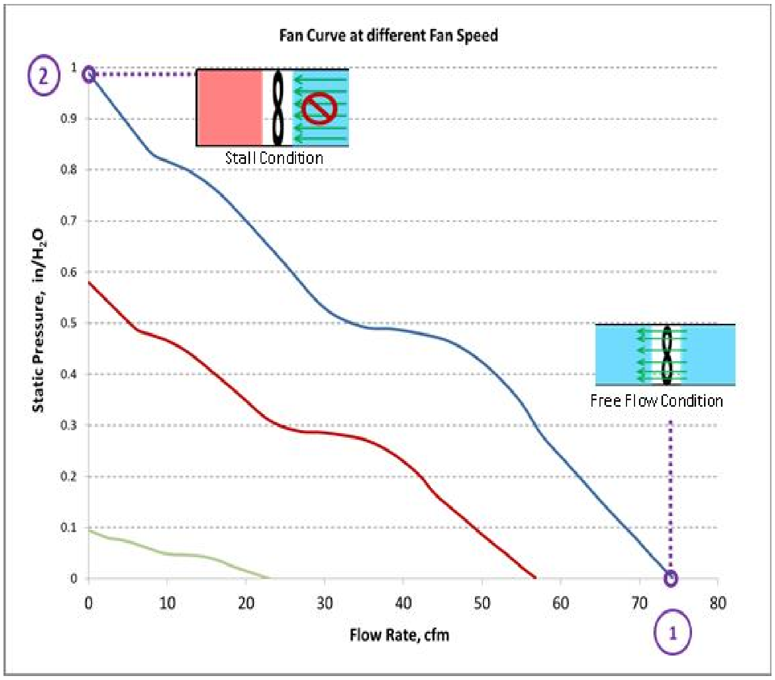

Figure 2.1. Fan Performance curve.

2.2.1 System Resistance and Fan Curve

As we know, air flow through any system or enclosure is based on the resistance offered to the flow causing a drop across the system. The decrease in the pressure is due to frictional force on a fluid as it flows through server components .It is influenced by the velocity and viscosity of the fluid. When the fluid is at high velocity, there is a large pressure drop across the system when compared to the same fluid flowing at lower velocities. Hence it is important to determine the system resistance (internal resistance) of the server.

Similarly, it is important to determine the fan performance curve as it determines the fan performance at different static pressure conditions .Each fan has its own performance curves.

2.3 Operating Point

Using system impedance and fan curve, we can determine the optimum operating point by imposing both the curves and find the intersecting point

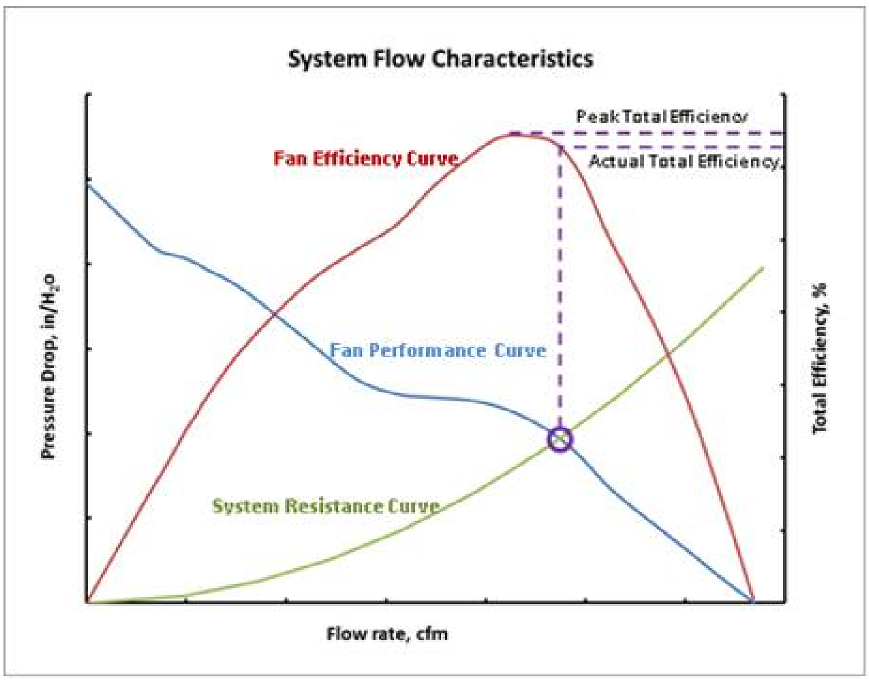

Figure 2.2. Fan Performance curve.

Fans should be selected such that the operating point is closest to the peak total efficiency of the fan as shown in the graph above.

CHAPTER 3

Servers Characteristics

3.1 Introduction

The servers in the today's data center are designed to be efficient, fast and compact. Any reduction in the geometry of the servers will help reduce the data center foot print. The servers are classified in terms of Blade servers and rack mount servers. The blade servers are stripped down servers designed to minimize the use of physical space i.e. several components are removed to save space , reduce power consumption while still mimicking all the functions of a full functional servers .The blade servers share a network connection , power supply and cooling systems

Figure 3.1. Blade server.

Figure 3.2. Blade server in chassis.

The rack mount servers are contained in cases measuring standard sizes which are mounted in a rack inside a cabinet. The rack servers have individual cooling and can operate individually.

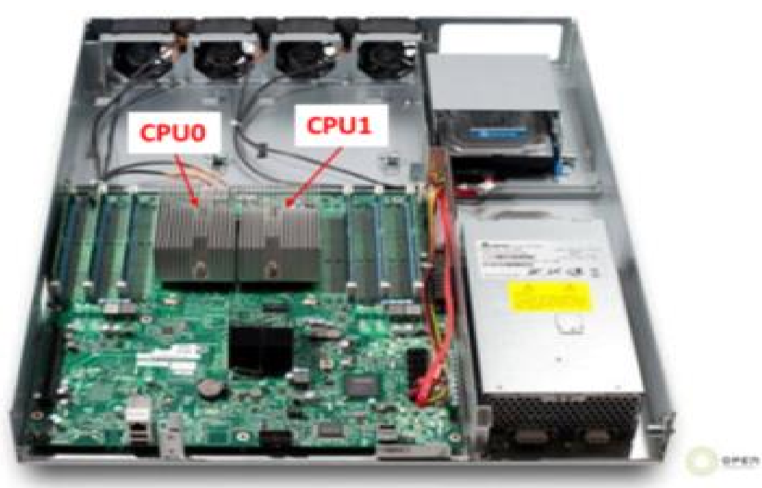

Figure 3.3. Rack mount server.

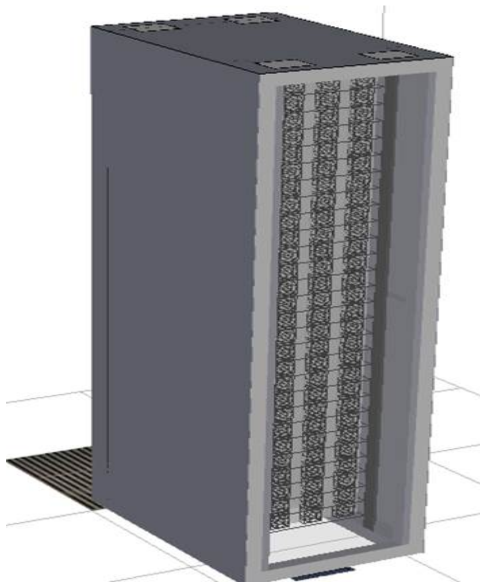

Figure 3.4. Server in chassis.

3.2 Server under consideration

The system under study is an Intel based Open Compute 1.5U server as shown in figure above. The server has two CPUs (Intel Xenon 5650) with each one having a Thermal Design Power of 95W socket motherboard with 18 DIMM slots. The two CPUs contribute major part of the thermal load and therefore, this server is referred as a CPU dominated server. Two heat sinks are mounted on each CPU to enhance heat transfer and thus contribute primarily to the flow obstruction. A ducky is provided at the top of the server which channelizes the flow through major heat generating components. There are four fans installed at the rear end of the chassis to compensate for the pressure drop and maintain the required flow rate through the servers. Each fan has dimension of 60 x 60 x 25.4, facilitated with a Pulse Width Modulation control and a hall sensor to detect fan speed on real time basis. There is an on-board fan control algorithm which controls the fan speed based on the feedback from the hall sensor output. The fan control algorithm has a designated target die temperature, based on which PWM signal increases the fan speed to draw additional air to cool the heat sinks

3.3 Current Scenario and Modifications

The server fans which are housed inside the server chassis make the flow independent with the neighboring servers. Four servers are stacked as a laboratory arrangement to mimic the rack .The figure below shows the arrangement how the servers are stacked.

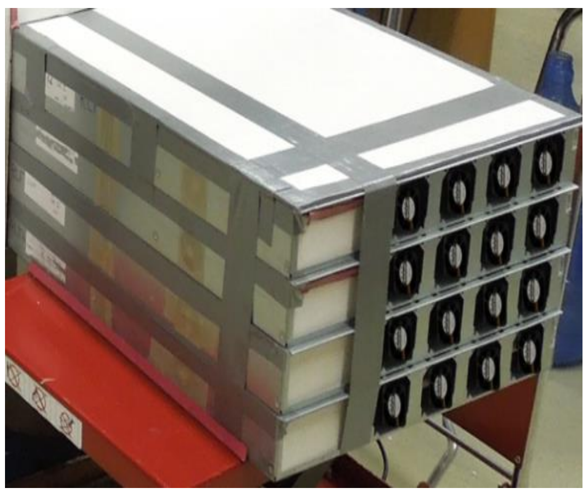

Figure 3.5. Server stack.

In each server, there are four 60 mm fans, so across the stack there are 16 60 mm fans. Since this study evaluates the effect of introduction of higher diameter fans, the stacked servers fans are replaced with 9 80 mm fans. Since the 80 mm fans cannot be enclosed inside server, these fans will be mounted at the rear end of the server as shown in figure below.

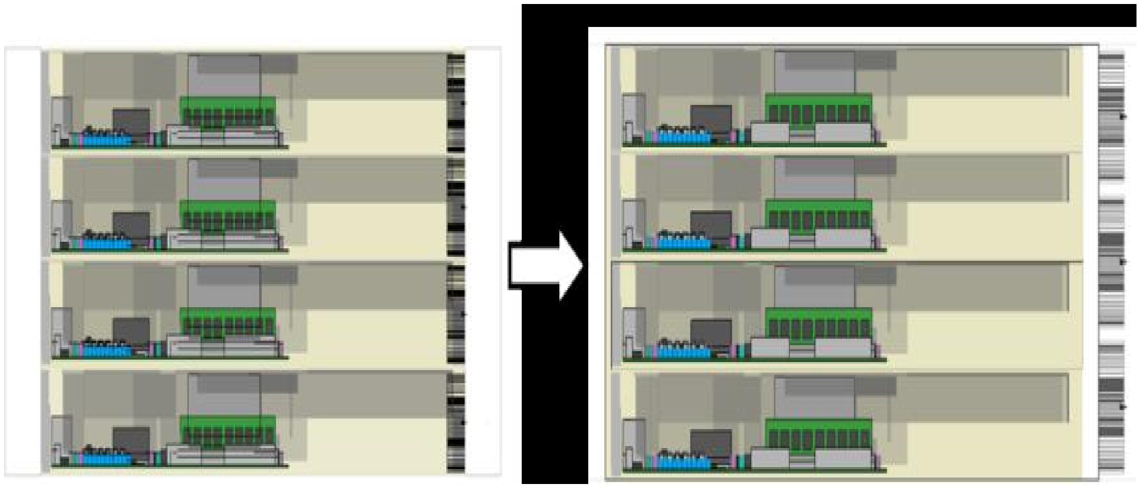

Figure 3.6. Proposed model.

3.4 Flow Characteristics

To understand the server behavior, it is important to understand the flow characteristics of the servers first. So a single server with existing 60 mm fans is referred to as base line case. Experiments were conducted to obtain data to determine the static pressure of the server, flow rate across the server and individual fan curves.

For this study we have only focused only the motherboard section of the server since the power supply and the hard disk is partitioned by a small sheet of metal. The other reason for just considering the motherboard section is it is cooled by an independent fan. Hence the flow through the power supply side does not affect the flow through motherboard section.

3.4.1 Flow rate across server

The fans in the servers are actually controlled by adjusting the PWM. The fan speed is measured and plotted against flow rate. The flow rate of the server is obtained for various speed .The maximum flow rate across the server is achieved when the fans are running at full capacity. The experiments are conducted three times for repeatability of the values and the values are plotted below.

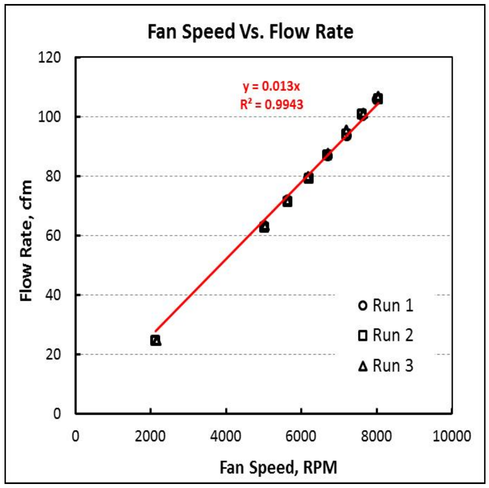

Figure 3.7. Relationship between Flow rate and fan speed.

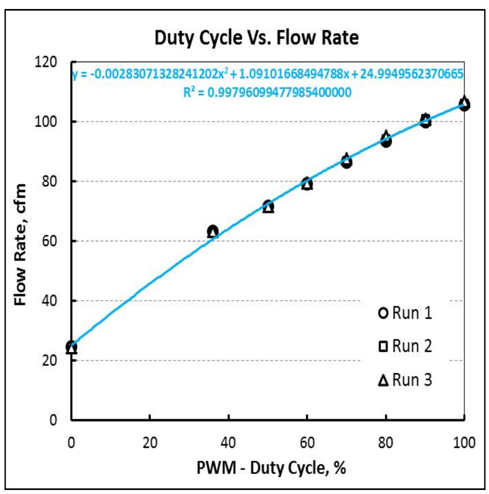

Figure 3.8. Relationship between Flow rate and Fan duty cycle.

Experimental Results – Flow rate		
PWM Duty Cycle	Fan Speed	Flow Rate
%	rpm	Cfm
0	2161	24.40
36	5032	63.19
50	5642	71.49
60	6189	79.50
70	6710	87.49
80	7204	95.23
90	7648	100.86
100	8054	106.64

Figure 3.9. Flow rate of the server for various fan speed and PWM duty cycle.

3.4.2 System Resistance Curve

The server is mounted on the airflow bench and the nozzle is directed towards the downstream section of the bench. With this setup we can determine the system resistance of a single server. The selection of the nozzle should be appropriate to the corresponding flow rate; otherwise it will not correspond to the appropriate flow rates. The setup is shown as per the figure below and the corresponding results are tabulated and plotted below.

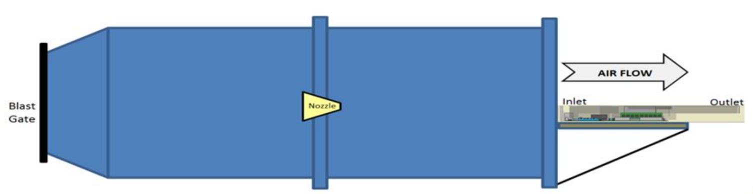

Figure 3.10. Test bench setup.

Experimental Result – System resistance	
Flow rate	Static Pressure
cfm	in/H_2O
0.0	0.000
24.0	0.013
42.9	0.043
61.3	0.083
79.3	0.136
97.3	0.198
115.1	0.273
133.4	0.358
151.0	0.456
169.1	0.565

Figure 3.11. Pressure drop values for various flow rates.

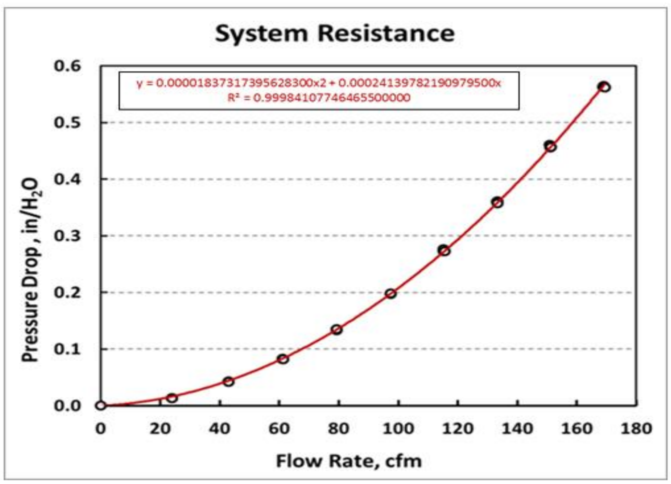

Figure 3.12. Static pressure.

CHAPTER 4

Fan Selection

4.1 Fan Selection

From the server characteristics chapter, we have experimentally determined the static pressure of the server and the flow rate of the fans present in the server. The values were 0.622 in H2O and the maximum cfm of the fans was 37.4 cfm. In order to choose a higher diameter fan, we need to choose a fan whose maximum cfm is more than the required cfm of the present fan and the fan which overcomes the static pressure of the system. The fans should be so selected that the maximum power consumption per server shall not exceed 20W.

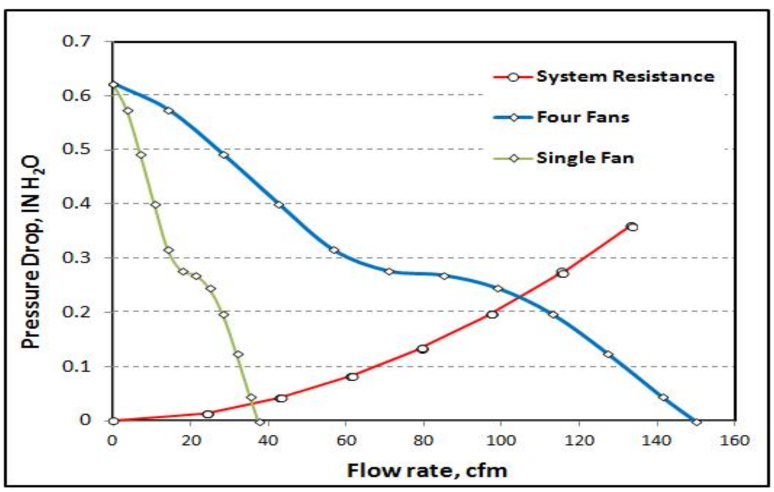

Figure 4.1. Flow selection criteria.

Number of fans across the width	1	2	3
Number of servers to be catered	5	2	4
Manufacturer	ebm-papst	Delta Fans	Sanyo Denki
Model No.	A1G280-AA79-11	QFR1212EHE	9GA0812P2H0011
Frame	Circular	Square	Square
Dimension	Ø 280 x 77.7	120 x 120 x 38	80 x 80 x 32
Max. Flow Rate (CFM) per Fan	1065	173.83	77.7
Number of fans	1	2	9
Total CFM	1065	347.66	699.3
Pressure Drop (in/H2O)	0.779	0.844	1.18
Power (W) per fan	90	12	7.08
dBA	63	59	54

Figure 4.2. Fan considered from manufacturers catalogue.

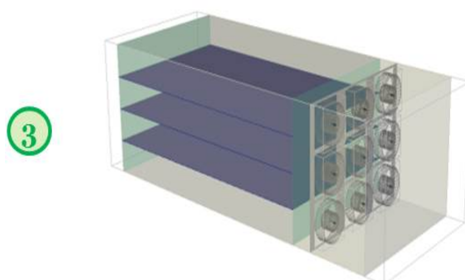

Figure 4.3. Proposed 80 mm model.

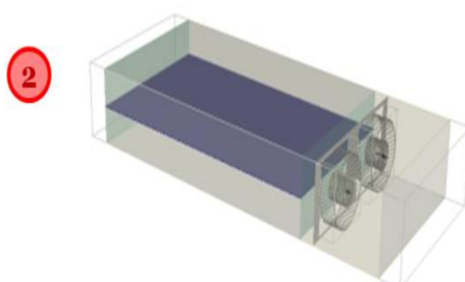

Figure 4.4. Proposed 120 mm model.

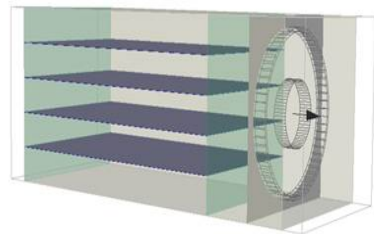

Figure 4.5. Proposed 280 mm model.

The fans which were considered are based [5] [6] [7] on the following parameters are the 3 higher diameter fans listed above in the figure. Amongst the three options, the 80 mm diameter fan is selected for further investigation. The other two options of fans are not considered due to redundancy, as each fan will eliminate the amount of flow required by the servers and eventually increase the die temperature of the server components to the thermal shut down limit.

The number of servers to be stacked is selected as four, based on the form factor of the servers being stacked up and the fan performance characteristics. Eventhough 8 80 mm fan could satisfy the flow requirement for 4 servers, 9 of them are used in order to maintain uniform flow rate across the servers and to compensate during a fan failure scenario.

4.2 Flow Modeling

Modeling of the system of servers and fans is carried out using commercially available software, 6SigmaET from future facilities. The experimental results for system resistance and fan performance are incorporated into the porous obstruction model. A porous obstruction is a simplified model of the actual system which replicates the flow in terms of the pressure drop across inlet and outlet, which is calculated based on the experimental results imparted into it. Using porous obstruction reduces the solving time drastically, but it cannot provide the flow visualization of the actual server, which is not required in this study.

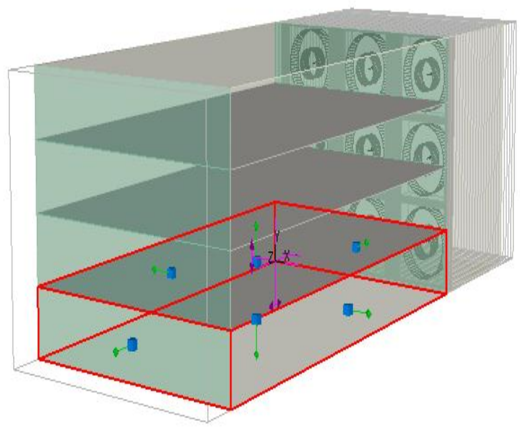

Figure 4.6. Computational defined Model.

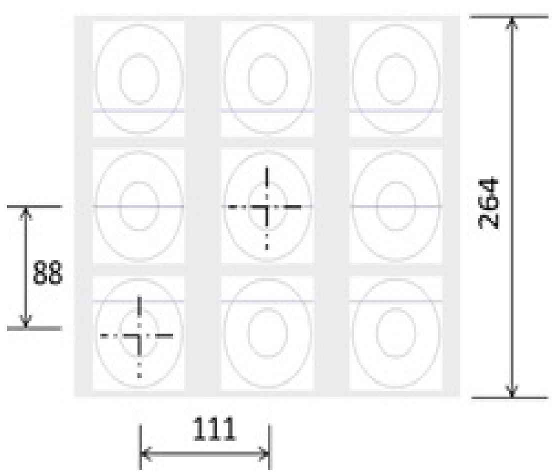

Figure 4.7. CFD Model - Fan spacing dimensions.

4.3 Flow uniformity across servers

In order to understand how the flow is with the introduction of new fans, several simulations were carried out for different fan speeds. As the higher diameter fans cannot be placed inside the server, these fans will be mounted on a fan wall with a clearance between the fan wall and rear end of the server. Figure below shows the variation of flow rate across different servers for various fan speed .The maximum flow rate variation, the maximum fan speed is simulated for various clearance values as tabulated below

Clearance mm	Fan Speed RPM	Inlet Flow rate, cfm				Max. Difference cfm	Total flow rate cfm
		Server 1	Server 2	Server 3	Server 4		
0	8514	133.8	122.4	118	136.7	18.7	510.9
10	8514	128.7	126.7	126.4	129.5	3.1	511.3
20	8514	128.2	127.5	127.3	128.6	1.3	511.6
30	8514	128.1	127.6	127.6	128.3	0.7	511.6
40	8514	128	127.7	127.6	128.2	0.6	511.5
50	8514	127.9	127.6	127.6	128.1	0.5	511.2

Figure 4.8. Flow distribution across different servers for various clearance distance.

The farther the fan wall is placed farther from the servers; the flow tends to be more uniform across the servers. But the fan wall needs to be well contained inside the rack which constraints the fan wall being away from the servers. With a clearance of 20 mm between the server and the fan wall, the flow distribution is uniform enough and is placed well within the rack as referred in the above table.

4.4 Fan Power Measurement for larger fans

4.4.1 Operating Point

Since the fans will be powered and controlled externally, all the fans operate at the same rpm .Nine fans power can be estimated by a single fan. Thus the operating point at various speeds obtained from CFD results, is replicated in an air flow chamber and the corresponding fan power consumption is recorded. The following tables provide the experimental data and the comparison between the target operating points and the operating point obtained from air flow chamber.

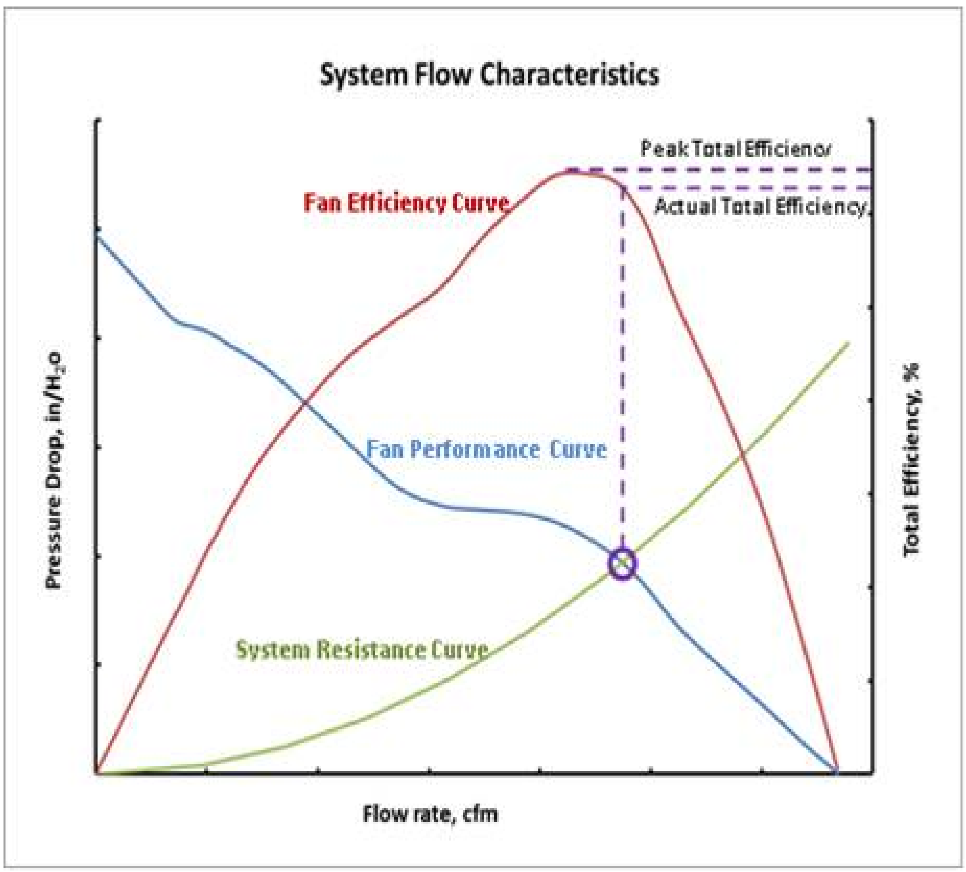

Figure 4.9. Operating Points.

PWM%	RPM @ free flow	Flow rate cfm			Static Pressure in/H2O		
		CFD	Fan Law	Error %	CFD	Fan Law	Error %
100	8514	56.9	55.9	1.81	0.290	0.323	-10.22
90	8207	54.8	53.8	1.90	0.277	0.302	-8.28
80	7722	51.5	50.7	1.64	0.246	0.266	-7.41
70	7137	47.6	46.4	2.49	0.212	0.228	-7.02
60	6517	43.4	42.7	1.72	0.178	0.192	-7.24
50	5904	39.2	38.4	1.97	0.148	0.16	-7.50
40	5318	35.2	34.7	1.54	0.121	0.13	-6.85
30	4804	31.72	31.1	1.96	0.100	0.108	-7.41
0	2635	17	16.8	1.32	0.033	0.034	-2.94

Figure 4.10. Determining Operating Points using CFD.

4.4.2 Flow Rate and Fan Power per Server

The fan power and flow rate for a single server are estimated from the experimental data by extrapolating the results from a single fan. The table and plot shows the power consumption for a single server.

PWM	Run 1		Run 2		Run 3	
	Power	Flow rate	Power	Flow rate	Power	Flow rate
	W	cfm	W	cfm	W	cfm
100%	15.93	124.31	15.93	125.87	15.93	126.81
90%	14.85	119.31	14.85	120.13	14.85	119.12
80%	12.69	112.01	12.69	113.40	12.42	112.01
70%	10.26	103.34	10.53	104.87	10.53	103.70
60%	8.10	94.34	8.37	96.26	8.10	95.15
50%	6.48	86.31	6.48	86.15	6.48	84.35
40%	5.13	75.60	5.13	76.48	5.13	73.98
30%	3.78	67.30	4.05	69.30	4.05	66.60
Idle	1.35	19.46	1.35	19.46	1.35	19.69

Figure 4.11. Flow Rate and Fan Power per Server.

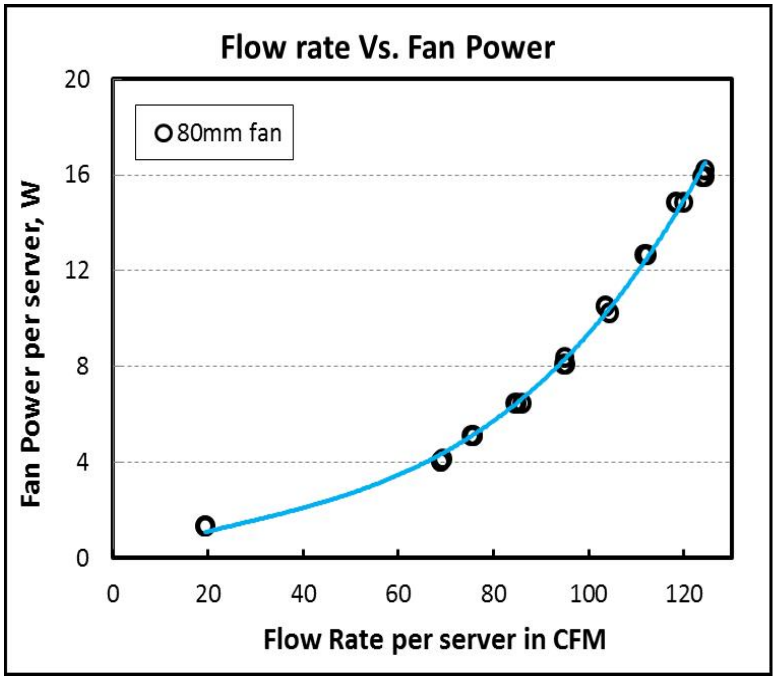

Figure 4.12. Plot for Flow Rate and Fan Power per Server.

CHAPTER 5

Fan Failure

5.1 Introduction

Fan failure study is performed to understand the cooling redundancy available to each server. In the base line scenario case, there are four fans catering a single server and in case of the larger fans, there are 9 fans shared by 4 servers. This study involves experimental analysis for a single server and computational simulations for larger fans.

5.2 Impact of Fan Position in a Failure Scenario on Die Temperature

The objective of this experiment is to study the effect of position of the failed fan on die temperature. In this test, one of the 4 fans is powered off intentionally and the die temperature is recorded and repeated for each of the 4 fans separately. The experiment is repeated when all the fans are functioning and are externally powered and controlled at 50 percent fan duty cycle. The CPU is stressed to 98 percent compute utilization and the test cycle for 3 repetitions as shown in figure below.

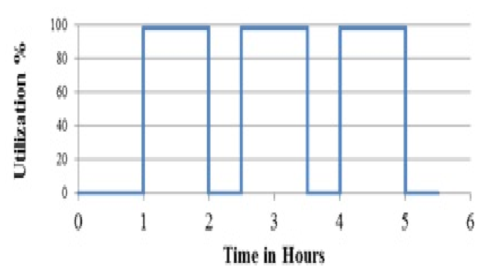

Figure 5.1. Experimental test cycle to study the position of fan failure.

Following are the 5 cases considered for test and the fan numbering sequence is provided in figure below

Case 1 - All fans powered on; Case 2 - Fan 4 powered off; Case 3 - Fan 3 powered off; Case 4 - Fan 2 powered off; Case 5 - Fan 1 powered off;

Figure 5.2. Fan Numbering Sequence.

The experiment is carried out with the server and the die temperature is recorded using HIR command. This command provides the temperature for each core separately. Therefore the die temperature is considered as the maximum temperature for all the cores. The following plot shows the output for CPU0 and CPU1 die temperature for case 1

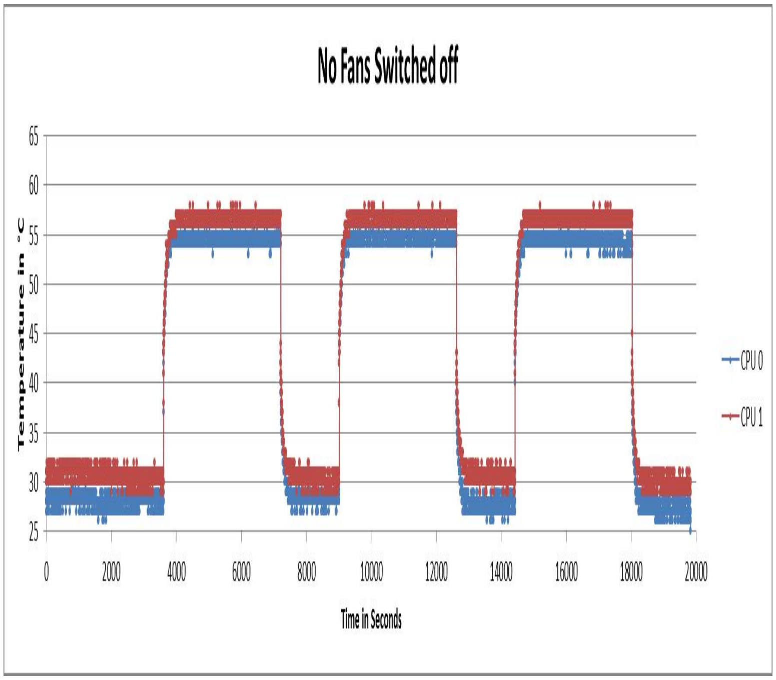

Figure 5.3. Experimental data output when all fans are powered on.

The experiment is conducted at 24 degree C and a synthetic CPU load generator, called look busy, is used. From the results plotted and tabulated, it is clear that the fan failure for this particular configuration does not affect the CPU die temperature. Assuming failure of the fan, the die temperature for CPU0 increased by 6.9 percent and CPU1 by 9.5 percent. The other thing to note here is that irrespective of the position of the fan failure, CPU1 die temperature is consistently higher than that of CPU0, which is due to thermal shadowing effect.

		CPU 0		CPU 1	
All fans powered on	Run 1	54.7	54.5	56.5	56.5
	Run 2	54.7		56.4	
	Run 3	54.1		56.6	
Fan 1 powered off	Run 1	58.2	58.3	61.9	61.9
	Run 2	58.3		62.0	
	Run 3	58.3		61.7	
Fan 2 powered off	Run 1	58.2	58.3	61.9	61.9
	Run 2	58.5		62.0	
	Run 3	58.1		61.7	
Fan 3 powered off	Run 1	58.5	58.5	61.6	61.9
	Run 2	58.4		61.9	
	Run 3	58.5		62.1	
Fan 4 powered off	Run 1	58.4	58.4	61.8	61.9
	Run 2	58.5		62.0	
	Run 3	58.4		61.9	

Figure 5.4. Experimental results for study of impact of fan position during fan failure.

5.3 Fan Failure Analysis of Larger Fans using CFD

Fan failure scenario is predicted for higher diameter using simulations assuming one of the 9 fans has failed. As described in the figure below, the red circle indicates the fan failed and the green circles represent a functional fan. Flow rate through the each server is noted and tabulated for each scenario. Due to the fan failure, there is reduction in the flow rate through the server compared to all functional fans. Comparing the flow rate across different scenario, it can be calculated that the flow rate through 4 servers remain same irrespective of the position of the failed fan.

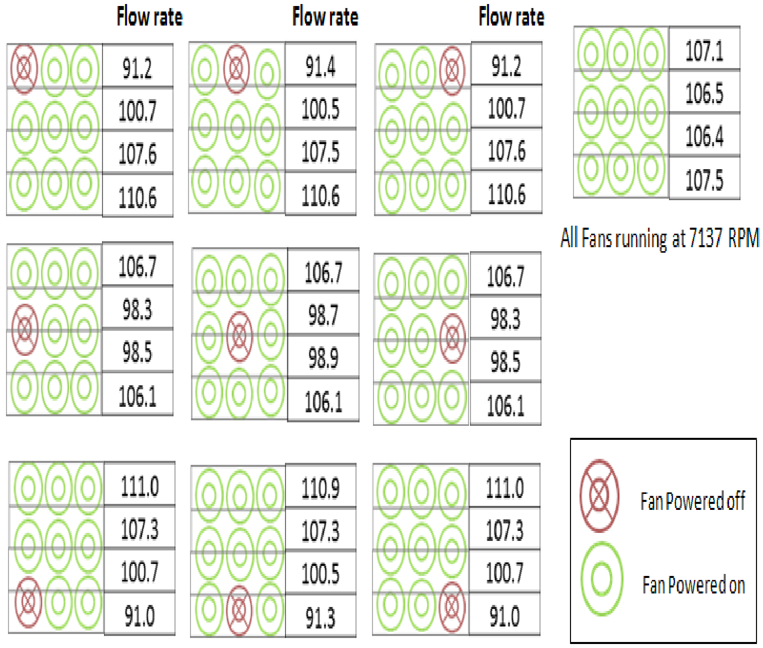

Figure 5.5. Fan failure analysis using CFD for larger fans.

CHAPTER 6

Flow Validation

6.1 Setup

The servers stacked up along with the fan wall is setup on the air flow bench as shown in the figure below to determine the flow required across each servers for different fan rpm . The 80 mm fan rpm are powered and controlled externally using Agilent power supplies and the fan speed are monitored using Agilent data acquisition system. The inlet server temperature is recorded using USB data logger.

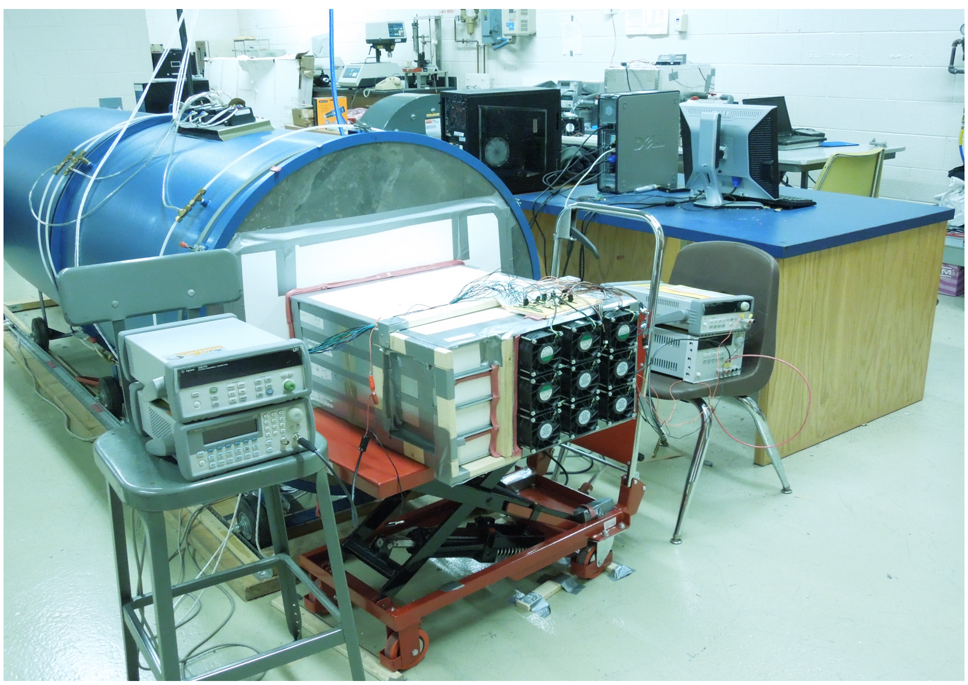

Figure 6.1. Rack setup on airflow bench.

Flow rate of the stack is obtained for various fan speed which is controlled by adjusting the PWM signal. As there are 9 fans in the stack, the fan speed and fan power is measured for all the fans and plotted against flow rate. The relationship is built between the flow rate and fan power. The fan rpms are uniform for all the nine fans and it seems to be within an acceptable deviation of 300 rpm. It is tabulated in the above table and plotted. The comparison is made with 60 mm and for the given flow rate it can be seen that it consumes lesser power than the 60 mm.

For four servers		Estimation for Single Server	
Flow Rate	Fan Power	Flow Rate	Fan Power
cfm	W	cfm	W
77.5	4.0	19.4	1.0
336.8	27.0	84.2	6.8
370.9	33.5	92.7	8.4
409.4	41.5	102.3	10.4
410.1	41.5	102.5	10.4
446.9	51.2	111.7	12.8
449.8	52.8	112.5	13.2
482.8	62.9	120.7	15.7
485.7	62.6	121.4	15.6
516.2	76.7	129.1	19.2
521.9	76.6	130.5	19.2
556.2	93.2	139.1	23.3
558.3	93.0	139.6	23.2

Figure 6.2. Table for fan power estimation.

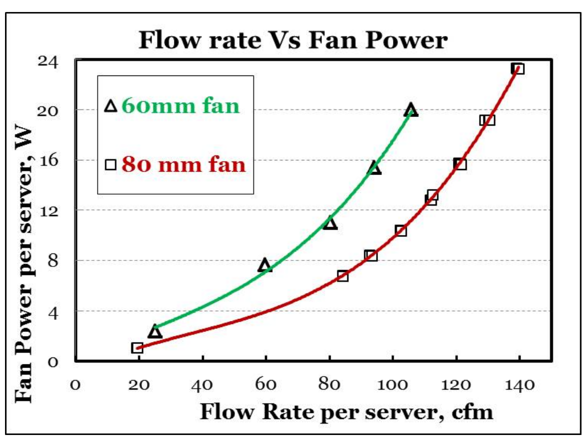

Figure 6.3. Comparison of 60mm and 80 mm power.

6.2 Comparison With CFD values

The experimentally values were then compared with the computational values and can be seen that the values seems to be the same trend and seems to be with 10 percent error.

Fan Speed	Actual Flow Rate per Server (cfm)			Linear Fit Flow Rate per Server (cfm)		
RPM	CFD	Exp.	Diff (%)	CFD	Exp.	Diff (%)
7482	150.1	139.1	7.36%	149.6	137.5	8.05%
7010	140.5	129.1	8.15%	140.1	128.9	8.05%
6541	131.0	121.4	7.31%	130.8	120.2	8.05%
6074	121.4	112.0	7.75%	121.4	111.7	8.05%
5604	111.9	102.5	8.35%	112.0	103.0	8.05%
5146	102.6	92.6	9.70%	102.9	94.6	8.05%
4698	93.4	84.2	9.80%	93.9	86.4	8.05%
1010	18.2	19.4	-6.61%	20.2	18.6	8.05%

Figure 6.4. Comparison with CFD simulation.

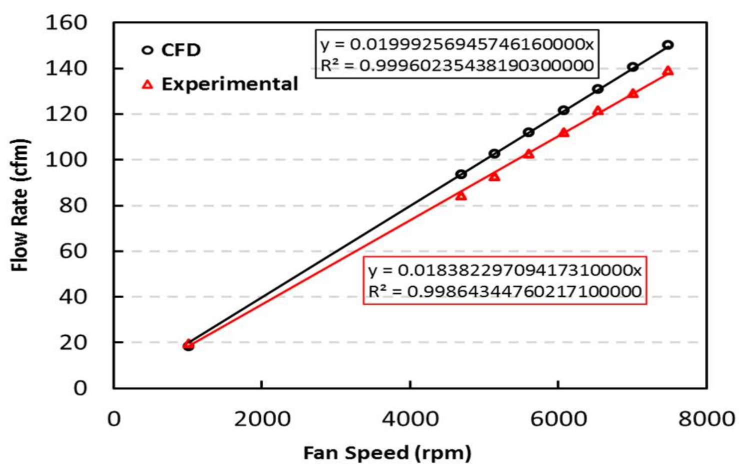

Figure 6.5. Plot for Comparison with CFD simulation.

CHAPTER 7

Thermal Loading

7.1 Setup

After the flow validation, the rack configuration had to be subjected to thermal loading in order to understand the rack configuration behavior and understand the effects on surface components. The test setup consists of 9 80 mm fans and the servers run with the centos 5.5. The test cycle is setup such that all servers start at the same time .The scripts are setup such that they are run three times back to back for repeatability for the values. The CPU's are loaded from 10percent to 98 percent with half hour idle after each design point and two hour idle period after each run. The total time taken for the entire test will be 21 and a half hour. All the data is exported from the servers after the entire test is completed. Look busy command is used as synthetic load generator to load the CPU to various compute utilization levels.

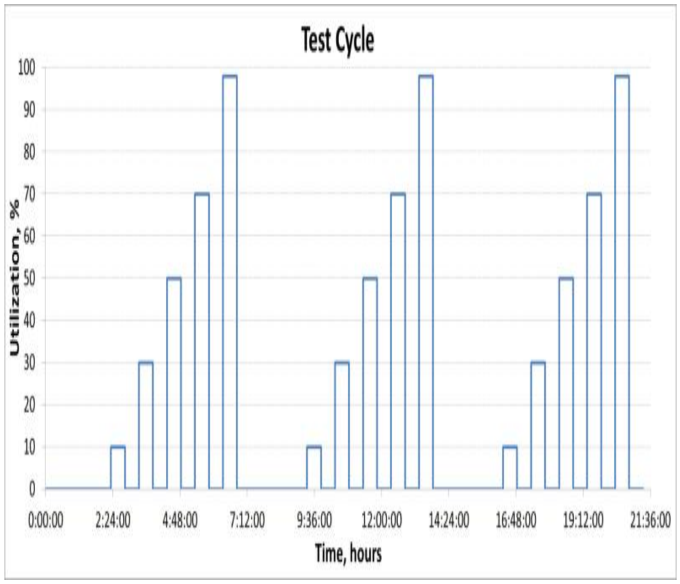

Figure 7.1. Test Cycle.

Omega USB data logger is placed in front of the servers to record server inlet temperature. The Agilent data Acquisition system is placed to record the fan rpms and Yokogawa CW121 power meter to measure voltage at the power strip. The current is measured at 2 servers power supplies and overall as well .All the experiments are maintained at 24 degree C. All the tests are conducted with utilization being same throughout the stack.

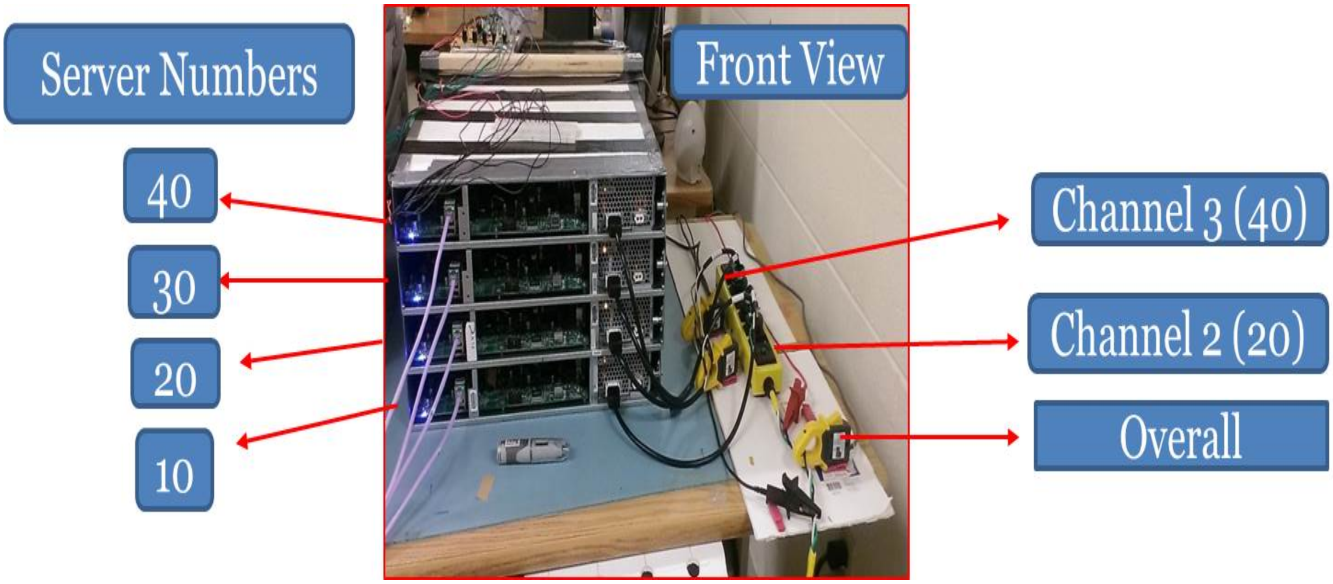

Figure 7.2. Front View of setup.

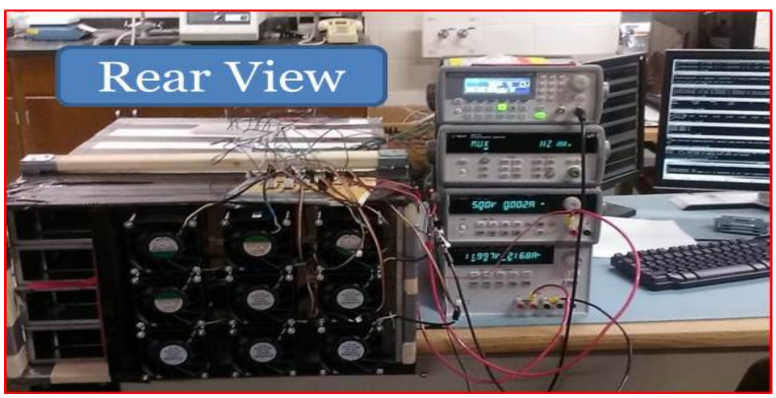

Figure 7.3. Rear View of setup.

The setup is shown as the above picture. The test is conducted from 15 percent to 75 percent duty cycle and the data has been recorded for the entire range and the values are plotted for every duty cycle.

7.2 Results for Constant Utilization

All the tests are conducted with utilization being same throughout the stack .As we see the plots for various duty cycles, there seems to be a similar trend with all temperatures across the stack and the total power consumption seems to be uniform and seems to be overlapping.

7.2.1 Temperature Plots for Various Fan Duty Cycle

The plots for the temperature for different fan duty cycle as follows

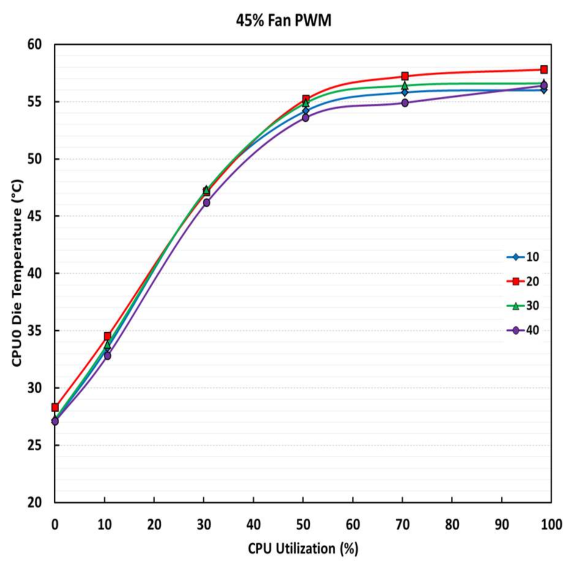

Figure 7.4. Temperature Plot for 45 percent Fan duty cycle.

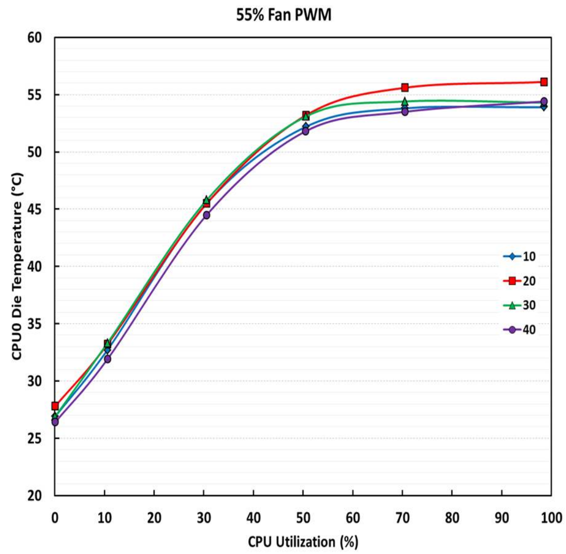

Figure 7.5. Temperature Plot for 55 percent Fan duty cycle.

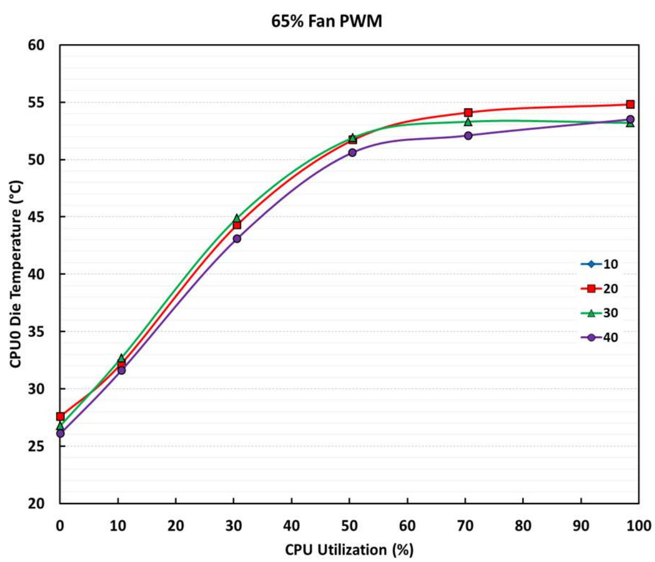

Figure 7.6. Temperature Plot for 65 percent Fan duty cycle.

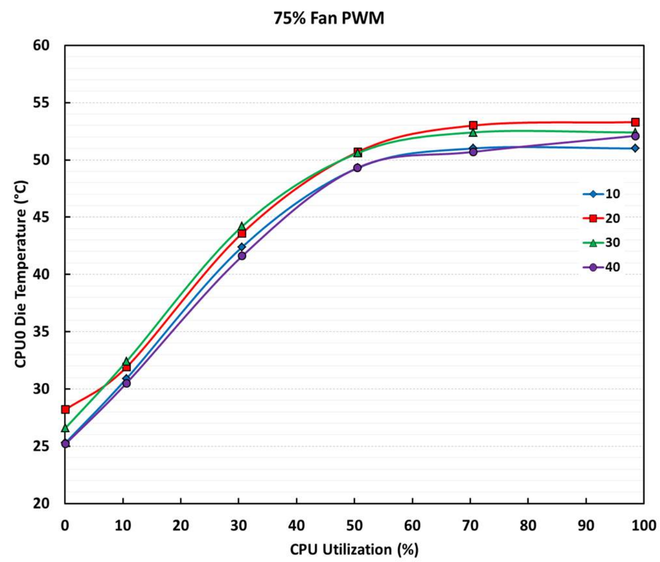

Figure 7.7. Temperature Plot for 75 percent Fan duty cycle.

7.2.2 Power Plots for Various Fan Duty Cycle

The plots for the Power consumptions for different fan duty cycle as follows

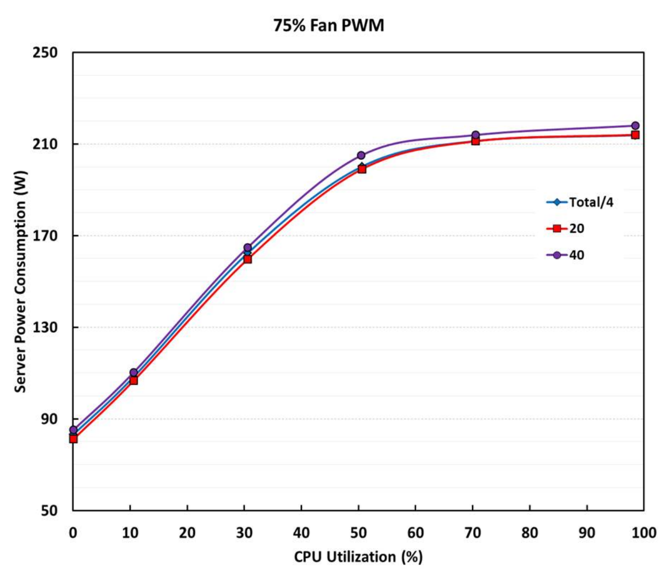

Figure 7.8. Power Plot for 75 percent Fan duty cycle.

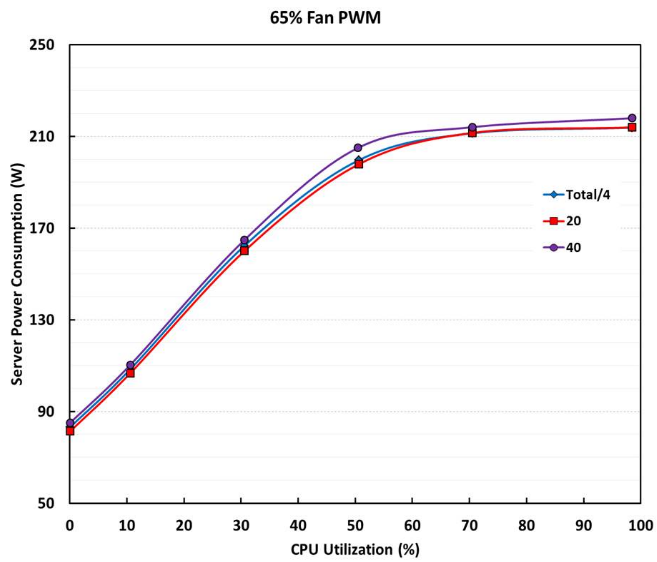

Figure 7.9. Power Plot for 65 percent Fan duty cycle.

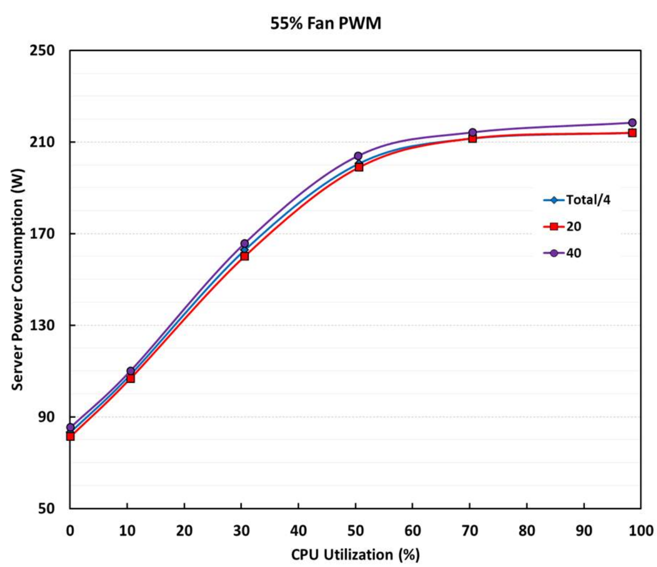

Figure 7.10. Power Plot for 55 percent Fan duty cycle.

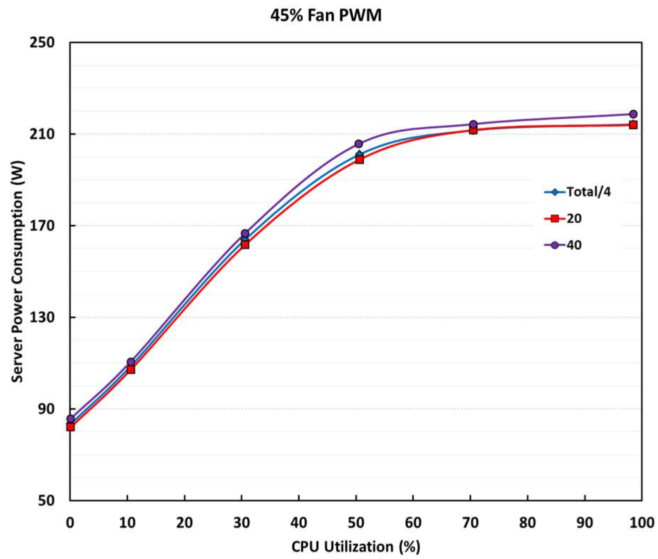

Figure 7.11. Power Plot for 45 percent Fan duty cycle.

In order to understand the plots better, one of the server values were plotted for various fan duty cycle .It can be noted that as the flow rate decreases with the fan duty cycle, the die temperature increases which was expected. The maximum difference of 5 degree C is seen at 98 percent utilization with the variation in fan duty cycle .However with the power plots does not show much variation in the power and seems to be overlapping for the investigated flow range

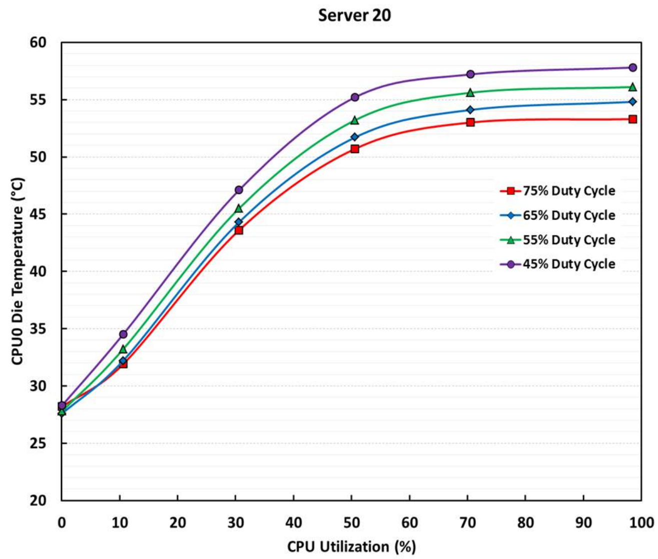

Figure 7.12. Temperature Plot for different Fan duty cycle for server 20.

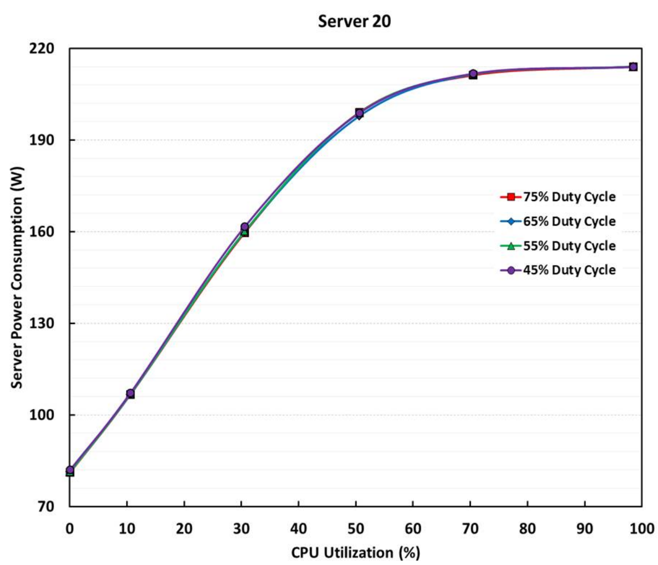

Figure 7.13. Power Plot for different Fan duty cycle for server 20.

7.3 Results for Variation in Utilization

As we all know servers in a rack will not be at the same utilization at all points in a day, it is varied depending on the load described by the data center operator. Hence it is critical to understand how the rack behavior is for different utilization across the stack. For this reason, the stack is subjected to variation in utilization keeping the fan duty cycle constant. Plots below show the temperatures and power for different utilization. When compared with the plots of constant utilization, we see that there is a similar trend in both the plots and the difference between them is minute. The power plots for both seem to be overlapping as seen in constant utilization.

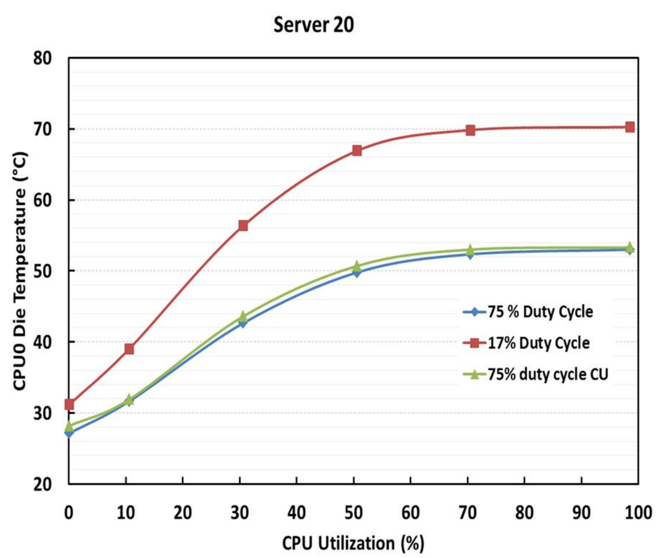

Figure 7.14. Temperature Plot for different Fan duty cycle for server 20.

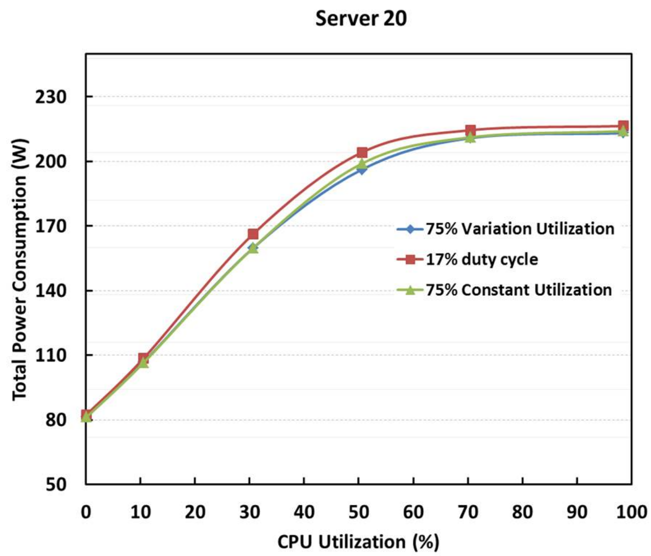

Figure 7.15. Power Plot for different Fan duty cycle for server 20.

CHAPTER 8

Conclusion and Future Work

8.1 Conclusions

With the introduction of higher diameter, there was quite a significant reduction in the fan number and keeping adequate flow through the system. The higher diameter fans normally operate at 40 percent less power for the corresponding flow rate when compared to the 60 mm fan diameter. The servers at the centers have higher die temperature compared to the servers at the extremities. A maximum difference of +5 degree C is seen at highest CPU utilization with the variation in fan duty cycle.

Increase in flow rate does reduce the die temperature but only until a threshold limit. This is due to the fact that the heat transfer is constrained by the inlet temperature just as in the case of a parallel flow heat exchanger. The actual power saving greatly depends on the fan control algorithm which defines a target die temperature.

8.2 Future Work

It will be interesting to see the behavior of other higher fan diameter and see the effects on the motherboard components. Since the fans are powered and controlled externally, it will be interesting to see the behavior of introduction with the fan control algorithm .Since the fan control algorithm is based on fan die temperature.

REFERENCES

[1] D. G. Koomey. (2010) My new study of data center electricity use in 2010. [Online]. Available: http://www.koomey.com/

[2] R. Miller. (2013) Microsoft has 1 million servers. [Online]. Available: http://www.datacenterknowledge.com/archives/2013/07/15/ballmer-microsoft-has-1-million-servers

[3] D. Iyengar. (2010) Numerical and experimental study of the effect of underfloor blockages on data center performance. [Online]. Available: http://electronicpackaging.asmedigitalcollection.asme.org/article.aspx?articleid=1409778

[4] Ametek. (2012) Using multiple fans. [Online]. Available: http://www.rotron.com/techcorner/seriesparallel.aspx

[5] E.-P. I. Inc. (2012) fan. [Online]. Available: http://www.digikey.com/product-detail/en/A1G280-AA79-11/A1G280-AA79-11-ND/1141722

[6] S. D. S. FANS. (2012) sanyo fans. [Online]. Available: http://www.newark.com/sanyo-denki-sanace-fans/109r0612p4j03/axial-fan-60mm-12vdc-470ma/dp/04R7261

[7] D. Fans. (2012) Delta fans. [Online]. Available: http://www.datasheets.com/search/partdetail/QFR1248EHE/Delta+Electronics

BIOGRAPHICAL STATEMENT

Shreyas Nagaraj was born in Bangalore, Karnataka, India in 1988. He received his Bachelors in Mechanical Engineering from JSSATE (a part of Visvesvaraiah Technological University). He worked as a summer intern at Hindustan Aeronautics Limited, Bangalore, in 2009.He was part of the FSAE team that built the FSAE car for the first time in his university and the team that participated in SAE event held in Michigan, USA. He has been a part of the EMNSPC group at the University of Texas at Arlington since 2011.His research involves in thermal management of data center operations. He has worked in experimental and CFD characterization of web cache servers, efficient fan selection, and thermal and power optimization technique. He has gained theoretical knowledge of CFD and worked data center specific CFD codes like 6SigmaDC. He has been part of the EMNSPC group from 2011 October and has got a chance to be involved in various projects for computational and experimental analysis.