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Experimental Study of Improved Chassis and Duct Redesign for Air-Cooled Server

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***Abstract*— In the United States, out of the total electricity produced, 2% of it is consumed by the data center facility, and up to 40% of its energy is utilized by the cooling infrastructure to cool all the heat-generating components present inside the facility, with recent technological advancement, the trend of power consumption has increased and as a consequence of increased energy consumption is the increase in carbon footprint which is a growing concern in the industry. In air cooling, the high heat-dissipating components present inside a server/hardware must receive efficient airflow for efficient cooling and to direct the air toward the components ducting is provided. In this study, the duct present in the air-cooled server is optimized and vanes are provided to improve the airflow, and side vents are installed over the sides of the server chassis before the duct is placed to bypass some of the cool air which is entering from the front where the hard drives are present. Experiments were conducted on the Cisco C220 air-cooled server with the new duct and the bypass provided, the effects of the new duct and bypass are quantified by comparing the temperature of the components such as the Central Processing Unit (CPUs), and Platform controller hub (PCH) and the savings in terms of total fan power consumption. A 7.5°C drop in temperature is observed and savings of up to 30% in terms of fan power consumption can be achieved with the improved design compared with the standard server.**

Keywords—thermal management, air cooling, chassis design, duct optimization, fan power, data center, airflow optimization

I. Introduction

Data centers are facilities where a large volume of data is processed and stored. Data centers have the requisite processing and storage capacity to satisfy this demand. Today's businesses are migrating to cloud computing services and utilizing Artificial Intelligence (AI) in their everyday operations, and data centers have become the foundation of these operations. This has led to the development of high-power processing units that are packed together inside a server leading to a rise in server power density to meet data processing and storage requirements. As a result, the cost of cooling data centers grows. A study [1] showed that the primary cost driver of a data center is the cost of power and cooling infrastructure of this IT equipment, thus it motivates the thermal engineers to improve the cooling efficiency of the equipment and to lower the cost of operation. According to the survey report of the Uptime Institute in 2020 [2], the average rack power density in the data center is approximately 8.4 kW, and most of the data centers are cooled using air cooling as it is cost-effective and reliable. In air cooling, the inlet air temperature and air fan speeds are two crucial factors among many other factors for an air-cooled data center [3] an "open" system. In an air-cooled server, fans are placed in push or pull configuration to cool the components inside the server, for push configuration the fans are placed at the inlet side of the server and push the cold air towards the components, and for pull configuration, the fans are located at the exit of the server and pull the hot air inside the server to the outside. With fans in push configurations, airflow characteristics play an important role in defining how well the component inside the server is being cooled by directly affecting the heat transfer rates. These fans also need to overcome a certain amount of system impedance caused by the components in the server. For 1U servers with fans in a push configuration, the hard drives are generally placed at the front of the server, and then these fans are placed in between the hard drives and the motherboard, as the cold air enters the server from the front it cools the hard drives first and then this air is circulated inside the server by the fans to cool the high heat dissipating components such as CPU's, DIMM's, etc. As this air is passed through the hard drives first, it is slightly warmer than the inlet temperature and the fan speeds which are controlled based on the CPU case temperature, the higher air temperature leads to a higher CPU case temperature and causes the fan speeds to ramp up and utilize more power. This issue needs to be resolved and an optimal approach is by improving the ducting to provide better airflow and optimizing the chassis to bypass the cold air through hard drives and thus decreasing the system impedance for the fans to overcome.

Research has been performed to understand the effects of ducting to increase thermal performance. A study [4], examines the effects of flow bypass provided on a straight fin heat sink in the rectangular duct, showing that the heat sinks thermal performance is greatly affected by the flow bypass and change in the approach velocity of air. This study [5], improve the existing duct design on a high-end open compute web server subjected to significant thermal shadowing, the improved design resulted in a 39% savings in cooling power but also increased the system impedance by the new duct. A comparative study [6] on a 1U server showed that the case temperature for high heat dissipating components was significantly dropped by improvising the ducting to provide better airflow to the CPUs. In a CFD study, [7] on a 3U server where the author optimized the air duct and provided partitions to reduce the resistance, in doing so the flow rate through each fan was increased and with the reduction in static pressure, the fan noise was also reduced. The fan power consumption was reduced from 20.8% to 15%. A study [8] shows the impact of the fan's location on the cooling efficiency of the server, their study showed that the location of the fans can greatly affect the flow field of air and the internal recirculation of air can be eliminated, and a 65% reduction in fan power consumption without any significant increase in the component temperature. A study [9] shows a V-cut ball valve design that increased power savings via both computationally and experimentally.

The dimensions of the chassis and the location of the components are also important parameters in the server thermal design. A study [10], showed the impact of chassis perforation and internal recirculation on the thermal performance of a 2U server experimentally, and it was shown that the flow rate can be increased by 25% by sealing the gap between the fans and covering perforation on the sides of chassis. A study [11] presented numerical scale simulations based on local and global dimensional analysis using thermodynamics and aerodynamics for enhancing the energy efficiency of data centers he optimized the shape and opening angle for the server fins by analyzing the vorticities, and temperature change rate, in his study he demonstrates that the server fins play a vital role in cooling the active servers quickly. A study [12] showed that a Collaborative Expendable Micro-slice Server (CEMS), which is a customized server had a lower power consumption when compared to a commercial server for a given workload. In air cooling, there is a generation of the vortex, which lowers the heat transfer from the server components to the cooling air. A study [13] showed that the formation of a vortex and shedding of velocity and thermal fields are more pronounced in the case when the angle of attack is a right angle, and the value of the axis ratio is lower. A study, [14] showed that when a flow passes through an object on the ground, a wide region of wake flow is created, in this region part of the air deflects in a downward forming vortex and thus sweeps the ground in reverse flows. This study [15] shows the trajectories of airborne contaminants using CFD modeling in a rectangular flow domain. Further literature work[16-18] was reviewed that showed the effects of improved design on the overall performance and many types of research are done on improving the server design by changing the component layout and modifying the duct to improvise the airflow to help the design engineers during the initial phase of designing but do not focus on how to improvise the cooling efficiency for the current servers which are already in operation without any major revision to the structure or components design layout. When designing a new duct, it is important that the airflow pattern is observed and any vortex formation in a duct is eliminated to avoid any air recirculation inside the server.

This study is an extended work [19] where an improved duct was designed to overcome the recirculation of air inside a 1U server and eliminate the vortexes formed inside the duct, and side vents are provided on the chassis, providing a bypass for the air to enter from the sides than from the front where the hard drives are placed. In this study, the new duct is manufactured and experimentally tested with the vents provided on the sides. In this study, it is experimentally shown that the bypass on the sides can significantly improve the cooling, when the temperatures for the main components such as Central Processing Unit (CPU), Platform controller hub (PCH), and Dual In-line Memory Module (DIMM) are compared with the standard 1U server without any modification as a direct indicator.

II. Experimental Setup

A. Improved Duct

According to a prior simulation study [20], it was discovered that the initial default duct installed in the 1U Cisco C220 air-cooled server (shown in figure 1) was unable to provide adequate cooling due to the formation of a vortex over the top end of the duct, to outwit the issues of the original duct and to provide streamlined airflow for efficient cooling of the components a new duct was designed. From the study of the Effects of guiding vanes on the aerodynamic performance of vortex vertical axis wind turbine [21], the formation of these vortices can be eliminated by the installation of vanes on the top plane of the duct. From the previous CFD study [20], it was shown that with new duct and side vents installed, the airflow had a more streamlined flow, and the recirculation of air was reduced. The side vents helped cool air to enter the server from the sides and travel the path of least resistance as shown in figure 5 which shows the streamlined flow from the fans via the duct.

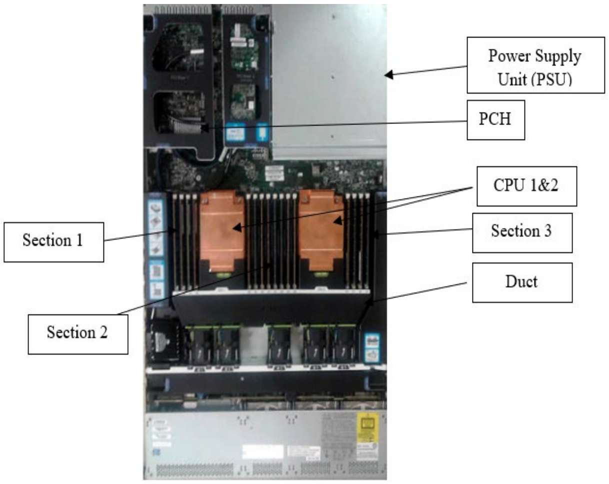

FIGURE 1: CISCO 1U SERVER WITH DEFAULT DUCT

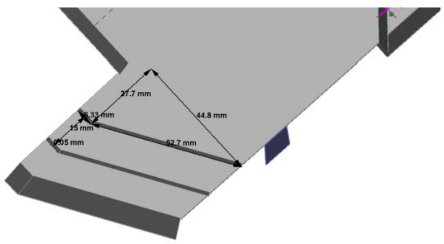

FIGURE 2: A CLOSER VIEW OF THE VANES INSIDE THE DUCT[19]

These vanes can direct the airflow stream more toward the components such as heatsinks and DIMMs. As illustrated in figure 3, thin walls are added within the duct to prevent excessive airflow in gratuitous space from eluding vortex formation thus increasing the output velocity of the air and improving flow direction. The optimal duct was created using an HP Jet Fusion 580 series 3-D color printer, which operates on the powder bed fusion concept. Complex housings and enclosures may be printed easily at low to medium-scale manufacturing utilizing the MJF technique with PA12 Nylon powder material. The finished products have a tensile strength of 48MPa and a heat deflection of around 175 ºC. Figure 2 shows a closer view of the vanes and figure 3 shows the manufactured duct used to perform the experiments in this study.

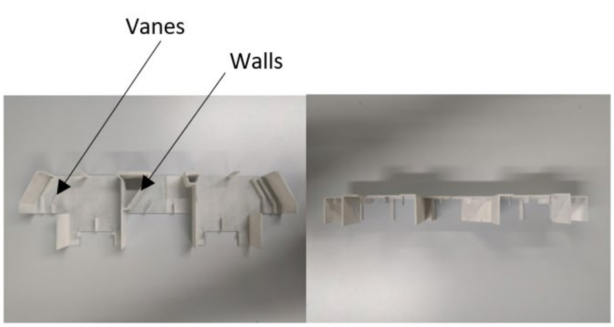

FIGURE 3: 3D PRINTED DUCT

B. *Chassis Optimization*

The server's original design is in the form, where the air is sucked up from the front end and is forced toward the components with the help of fans. As cold air enters from the front end, it first goes through the hard drives before passing through the CPUs and other components; in this design, the air gets pre-heated by passing through the hard drives, reducing air cooling efficiency for the CPUs. To address this, modifications were made on both sides of the chassis between the fans and hard drives, enabling an extra flow of cool air to enter directly from the sides without coming into touch with the hard drives. These modifications are honeycomb perforations designed to increase the Free Area Ratio (FAR). To increase the flow of air into the server, a rectangular hole was pierced on the chassis and covered with a 3D-printed block with honeycomb-shaped perforations which is shown in figure 4.

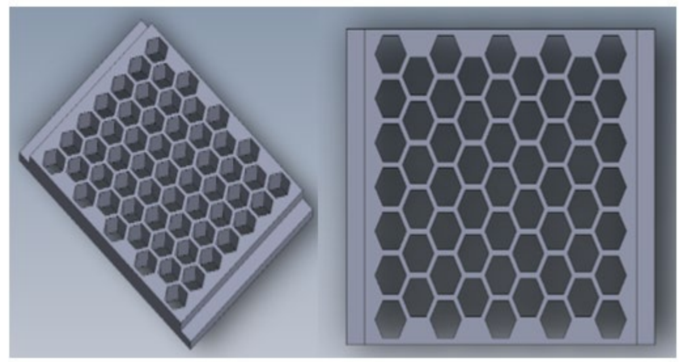

FIGURE 4: CAD MODEL OF CHASSIS SIDE VENTS

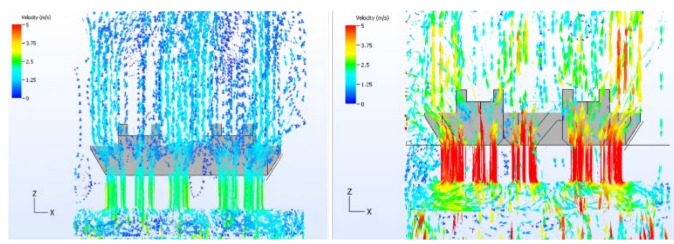

FIGURE 5: STREAMLINE COMPARISON FOR BASELINE(LEFT) AND IMPROVED (RIGHT) MODEL WITH A BOTTOM VIEW OF THE DUCTS

C. *Experimental Procedure*

For the experiment, the server is turned on, and the lookbusy tool is used to increase the server's CPU utilization to 92%, which is the maximum possible utilization, and the memory utilization to 98%, which is the maximum possible utilization; exceeding this utilization may cause the server to overheat and fail unexpectedly. To manually manage the airflow through the server, the server fan's power connections are detached from the motherboard and externally linked to a power source. From the DC power supply, the power has been calculated at different fan speeds. The fan speeds are monitored using the "ipmitool" in the server. The power consumption for all five fans was calculated from the power supply and at different fan speeds, figure 6 shows the power consumed for the fans at different RPMs.

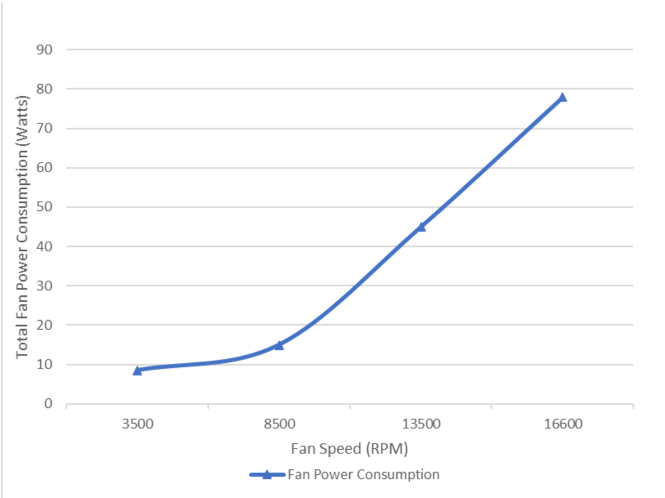

FIGURE 6: FAN POWER CONSUMPTION

The needed airflow for the experiment is examined at three different fan speeds: 3500 RPM, 9800 RPM, and 16600 RPM. To deliver the necessary air inlet temperatures, the server is installed within the environmental chamber. The inlet temperatures for the experiment are 25°C and 35°C. Figure 7 depicts the server within the environmental chamber, and Figure 8 depicts the server with duct and side vents installed.

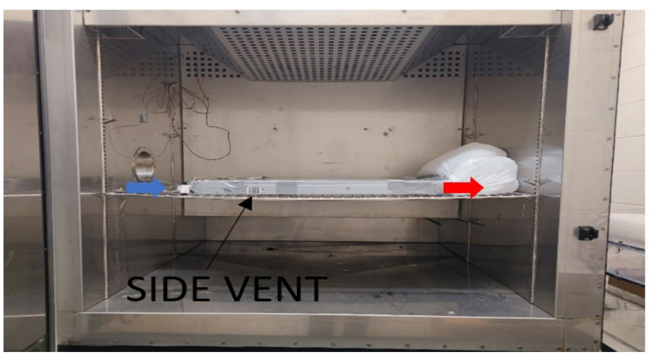

FIGURE 7: SERVER INSIDE AN ENVIRONMENTAL CHAMBER

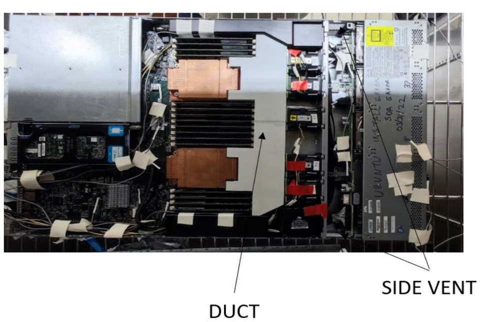

FIGURE 8: TOP VIEW OF SERVER WITH SENSORS

For this study, four cases are considered: the baseline case, in which the server is not modified and the fan speeds are varied for each air inlet temperature, and temperature readings of both CPUs (i.e., CPU 1 and CPU 2), PCH, and the DIMM are taken; the second case, in which the server's duct is replaced with the modified duct, and the same set of experiments are performed; In the third case, server-chassis was modified and was enclosed with honeycomb-shaped perforations. In the final scenario, an upgraded duct and modified chassis with honeycomb-shaped perforations were considered.

III. RESULTS AND DISCUSSION

A. Baseline Experiment

For the Baseline experiment, the server without any modification and the default duct is installed inside the environmental chamber and the airflow is set by externally supplying power to the fans to give the desired fan speeds. All the CPU, PCH, and DIMM temperatures are taken to compare the results with all cases. Since there are sixteen DIMMs, they are divided into left, middle, and right sections as sections one, two, and three respectively, and the average of each section is taken to show the results.

B. Comparision Of Temperatures For Different Components

1) CPU 1 Temperature

As seen from figure 9, for the air inlet temperature of 25ºC, the CPU 1 temperature for the baseline experiment is 67.5ºC for 3500 RPM fan speed which is the idle fan speed, for the improved duct without any server modification, the temperature drops by 1ºC and the temperature of the CPU 1 falls to 66.5ºC, as for the case three which for the modified chassis and with the default duct, the temperature is 64ºC and with the final case four, i.e. with improved duct and redesigned chassis the temperature is now 60ºC, i.e., a 7.5ºC drop from the baseline experiment. The same trend is seen for the higher fan speeds where the temperature of the baseline is at 56.5ºC at 9800 RPM and the temperature for case four is 52ºC, where the fall in temperature is 4.5ºC and for maximum fan speeds the CPU 1 temperature is 53ºC for the baseline and a drop is 3.5ºC. The experimental results show that the temperature for the baseline case at 16600 RPM was 53ºC which was achieved by the improved design (52ºC), i.e., case four at a lower fan speed of 9800 RPM. This shows that the new duct design with the bypass allows cooler air at lower fan speeds, which can lead to saving for the fan power consumed, with an increase in savings, if the fans speed is at 16600RPM the temperature for the improved design and with modified duct, the temperature for the CPU is 50.5ºC and as mentioned in a study, [22] the temperature is a major factor for the failure of electronic components, thus with the improved design, the reliability of the components will also increase as the temperature of the components is reduced for the improved design as compared to the baseline design.

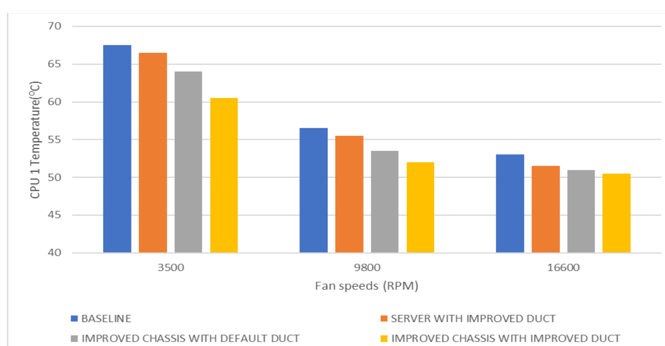

FIGURE 9: CPU1 TEMPERATURE VS FAN SPEEDS FOR 25°C AIR INLET

The air inlet temperature is now raised from 25ºC to 35ºC and a similar trend was observed in figure 10 which shows the temperature for CPU 1 temperature at different air fan speeds, The temperature for the baseline server was 79ºC, for the new duct, the temperature was observed to be 77ºC, with side vents for the server and with the default duct, the temperature for CPU 1 further dropped by 4.5ºC and with the case four where the improved chassis and modified duct was used the temperature was 71º which shows the temperature to be dropped by 8ºC from the temperature observed in the baseline case. For higher fan speeds, the temperature drops by 4.5ºC and 3ºC for 9800 and 16600 RPM. This drop in temperature in the improved design is because now more cold air can enter the server from the sides thus it does not need to overcome the impedance of the hard drives placed on the front side.

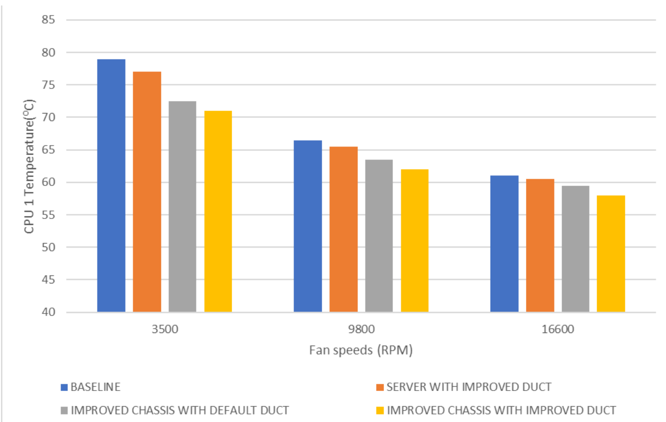

FIGURE 10: CPU1 TEMPERATURE VS FAN SPEEDS FOR 35°C AIR INLET

2) CPU 2 Temperature

The temperature of CPU 2 is compared for all the cases. Figure 11 shows the CPU temperature for air inlet temperature of 25ºC at different fan RPMs. The CPU 2 temperature for the baseline case at 3500 RPM is 72.5ºC and the temperature for the improved duct with the base chassis is 71.5ºC, and for the improved chassis the temperature is 69ºC, and for case four the temperature is observed to be 66.5ºC which shows a reduction in the temperature for the CPU. A similar trend is seen for the higher fan speeds at 9800 and 16600 RPM cases for the CPU temperature, as seen in the case for CPU 1, i.e., the temperature dropped from 58.5ºC to 53ºC for 9800RPM and from 53ºC to 50ºC for the case of 16600 RPM.

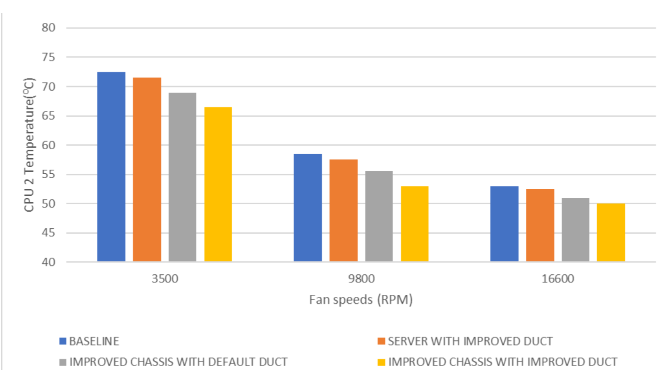

FIGURE 11: CPU2 TEMPERATURE VS FAN SPEEDS FOR 25°C AIR INLET

Figure 12 shows the CPU 2 temperature comparison for 35ºC inlet air temperature, it is seen that a maximum drop of 8.5ºC is seen for the case of low fan speeds as the temperature for the baseline case temperature was 86ºC and dropped to 77.5ºC for the modified server and improved duct, i.e., for 3500 RPM, a 6ºC drop for 9800 RPM, and a 5ºC drop is seen for the highest fan speeds of 16600 RPM.

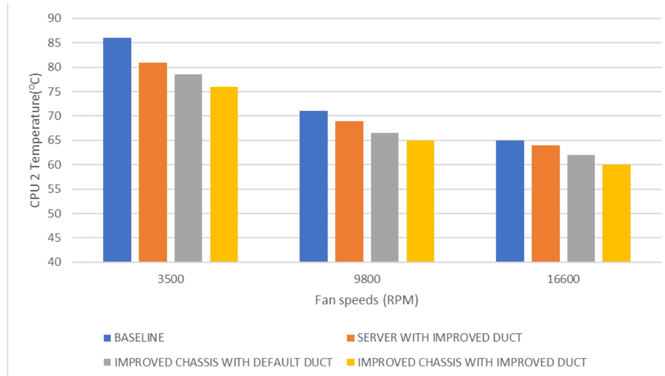

FIGURE 12: CPU2 TEMPERATURE VS FAN SPEEDS FOR 35°C AIR INLET

3) PCH Temperature

For this study, the PCH temperature is also considered as the PCH hub also plays a vital role in controlling the components over the platform and providing the optimum performance of the server. The PCH is located at the back of the server and a pin fin configuration heatsink of aluminum is used to cool the PCH as shown in figure 1. The PCH for the server operates in the range of 66ºC-53ºC from 3500 to 16600 RPM of fan speeds as shown in figure 13 which shows the PCH temperature for various fan speeds at 25ºC inlet air temperatures. With improved ducting and optimized chassis, the temperature range of the PCH falls to 63ºC-50ºC from low 3500 RPM to 16600 RPM of fan speeds.

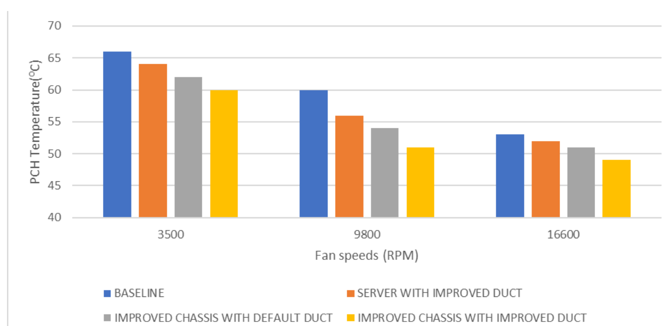

FIGURE 13: PCH TEMPERATURE VS FAN SPEEDS FOR 25°C AIR INLET

Figure 14 shows the PCH temperature for an inlet temperature of 35ºC and as seen for the case of 25ºC inlet air temperature, the operating range of the PCH falls from 77ºC to 73ºC for low fan speeds and from 64ºC to 62ºC for higher fan speeds.

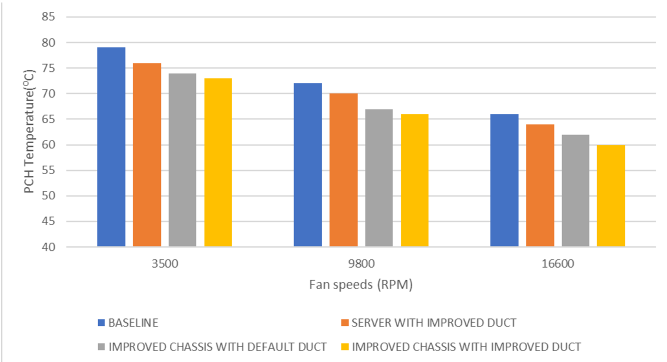

FIGURE 14: PCH TEMPERATURE VS FAN SPEEDS FOR 35°C AIR INLET

4) DIMM Temperature

The average temperature of the four DIMMs located on the left side as shown in figure 2 is taken and compared for the baseline and all the cases. Figure 15 shows the average temperature for the 4 DIMMs located on the left side, i.e., section one for 25ºC inlet air temperature. The average temperature for the baseline case was seen to be 37.5ºC and with increasing the fan speeds the temperature measured was 34.5ºC for the baseline case. For the experiments performed with improvements, the temperature was seen to be dropped by 2ºC-2.5ºC for all the cases. Figure 16 shows the temperature for 35ºC inlet air temperature, the temperature dropped about 3ºC for all the cases. This drop in temperature is because the improved duct is providing more streamlined airflow by eliminating any vortex formation on the top surface of the duct and thus providing better airflow to the DIMMs located on the sides, as shown in figure 16 where (Modi, et al., 2022) show the streamline plot for the CFD results.

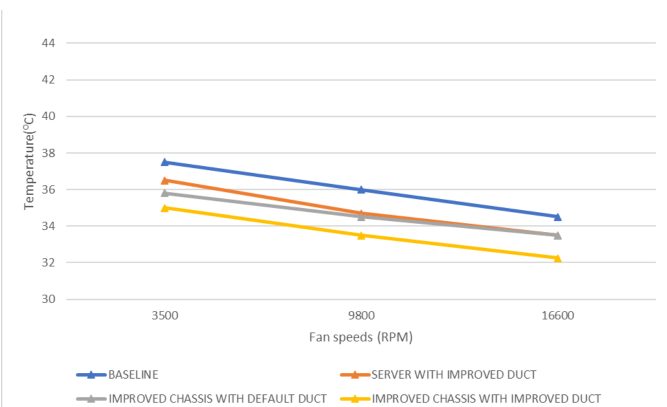

FIGURE 15: SECTION ONE DIMM TEMPERATURE VS FAN SPEEDS FOR 25ºC AIR INLET

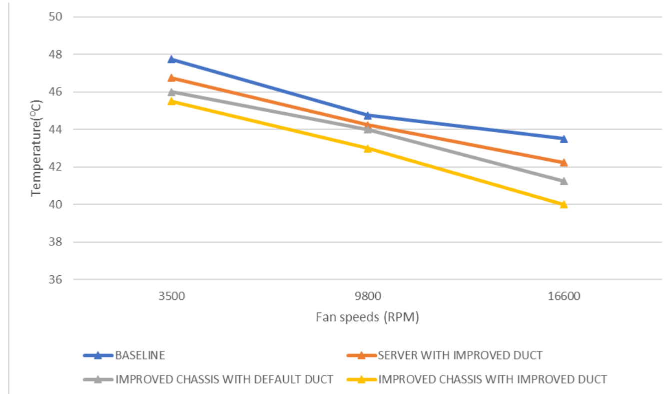

FIGURE 16: SECTION TWO DIMM TEMPERATURE VS FAN SPEEDS FOR 35ºC AIR INLET

The average temperature of the eight DIMMs located in the middle, i.e., between the two CPUs is considered. Figure 17 shows the average temperature of the DIMMs at 25ºC inlet air temperature, it can be seen from the figure, like the temperatures observed in section one there is an average 2ºC drop in temperature from the baseline to the improved chassis and improved ducting. A similar trend is seen in the case of 35ºC inlet air temperature as seen in figure 18.

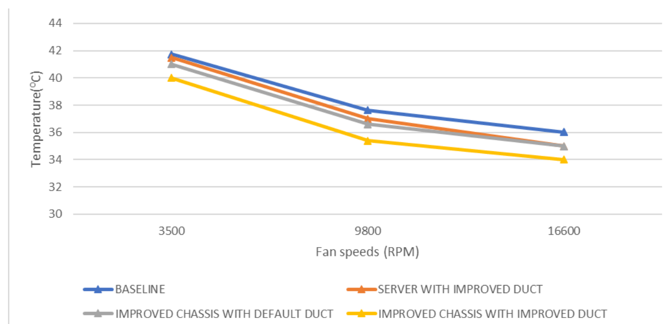

FIGURE 17: SECTION TWO DIMM TEMPERATURE VS FAN SPEEDS FOR 25ºC AIR INLET

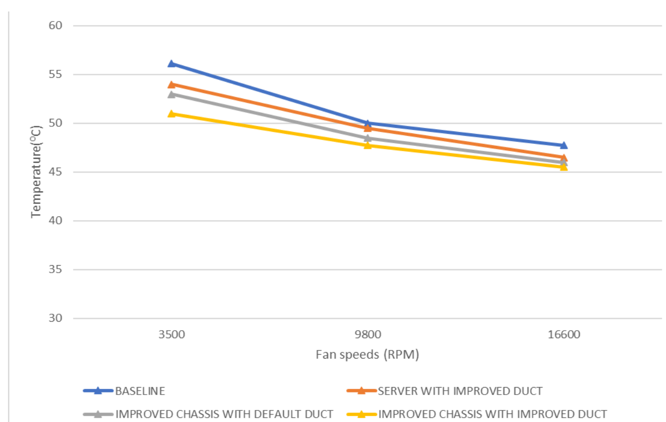

FIGURE 18: SECTION TWO DIMM TEMPERATURE VS FAN SPEEDS FOR 35ºC AIR INLET

The average temperature for the right four DIMMs is taken for the baseline and compared with the different cases. It can be seen from figure 19 for inlet temperatures of 25ºC and 35ºC, that the temperature for the DIMMs drops about 2ºC, i.e., the highest temperature for the DIMM at 25ºC was 38.5ºC for the baseline case and the temperature was reduced to 36.5ºC for the case when the new duct and improved chassis was used and a similar case is seen for the 35ºC where the temperature observed was 48.25ºC for the lowest fan speeds condition and the temperature was dropped to 46.5ºC. As discussed in the comparison for section one, the DIMMs located on both sides are getting cool air due to the efficient design of the new duct.

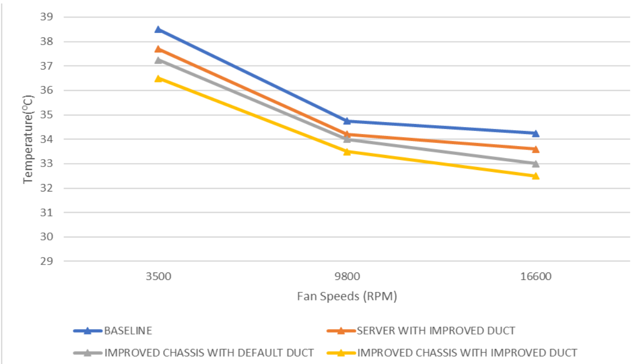

FIGURE 19: SECTION THREE DIMM TEMPERATURE VS FAN SPEEDS FOR 25ºC AIR INLET

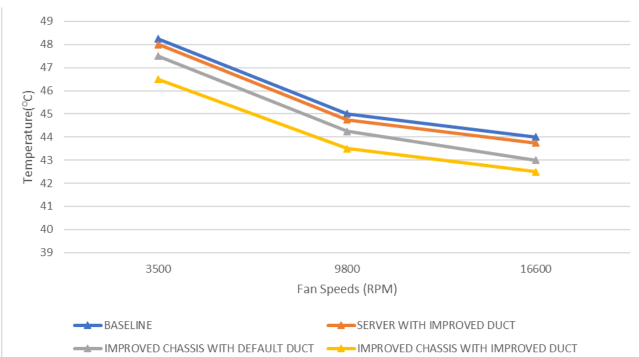

FIGURE 20: SECTION THREE DIMM TEMPERATURE VS FAN SPEEDS FOR 35ºC AIR INLET

C. *Fan Power Consumptions*

The above results show the drop in the temperature for all the major components inside the server, it can also be seen that the temperature measured for the baseline design at maximum stress level is seen as the improved design at lower fan speed. The new fan speed readings are taken from the ipmitool installed in the server and the power is calculated from the input power supply. It shows that the new and improved design could help in reducing the fan speeds and still the temperature is under the permissible limits when compared with the baseline temperatures.

TABLE I. SAVINGS IN FAN POWER CONSUMPTION

Fan Speeds for Baseline	*Total Fan Power Consumption (Watts)*	*Fan Speed for Improved Design*	*Total Fan Power Consumpti on (Watts)*	*Net Savings (%)*
3500	8.5	3500	8.5	0
9800	54	7500	38	29.63
16600	78	9800	54	30.77

Table 1 shows the percentage of savings that could be achieved with the improved design. The temperature measured for the components at 9800 RPM for the baseline case was similar at 7500 RPM for the improved design and at 16600 RPM was comparable to the temperature measured at 9800 RPM for the improved design The reduction in fan power for the improved design can lead up to 30% of savings on total fan power consumption when compared to the baseline server.

IV. CONCLUSION

From the above results, it can be concluded that the duct can be further improved to provide better airflow to the components which require more cooling. The temperature further drops when the chassis is modified, where a bypass is provided on the side of the chassis such that, the cold air could bypass the hard drives placed at the front of the server and thus providing cool air to the main heat-dissipating components such as CPUs, DIMMs, and PCH, which from the above results could be concluded that the temperature of the key components drops with the redesign of the chassis. The implementation of the improved duct and chassis altogether gives a significant drop in the temperature of both CPUs and the PCH temperature. For all the cases, the DIMM temperature also dropped about 2ºC for all different fan speeds from the baseline case. It is observed from the experimental data, that the temperature for the CPUs and PCH seen at maximum fan speeds for the baseline case could be achieved at lower fan speeds and thus reducing the fan power consumption and thus reducing the noise and vibration produced at higher RPMs. It can also be concluded that with the new design, 30% fan power savings could be achieved.

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