DEVELOPMENT OF A METHODOLOGY AND SAMPLE PREPARATION TO EVALUATE RELIABILITY OF OIL COOLED DATA CENTER

by

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Abstract

DEVELOPMENT OF A METHODOLOGY AND SAMPLE PREPARATION TO EVALUATE RELIABILITY OF OIL COOLED DATA CENTER

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Liquid immersion cooling is not a new concept which is slowly emerging as an alternative solution to conventional chilled air cooling systems for data centers. The main idea is to build a body of knowledge to help industry make more informed regarding mechanical reliability of IT equipment in mineral oil immersed systems. The goal is to develop a testing procedure for evaluating the reliability of electronic packages and components when immersed in mineral oil. PCB's, chip packages, passive components like capacitors, inductors, resistors, diodes, cables and wiring form the most important parts of a server used in data centers. The main focus is on the PCBs, chip packages, PVC jackets and passive components used in a server. The strategy is to evaluate the change in material properties (young's modulus, coefficient of thermal expansion (CTE)) and some electrical properties (capacitance, resistance, voltage drop, etc) which determine the mechanical and electrical performance of PCB'S and passive devices respectively after cycling in oil in comparison to control samples in air. Dog-bone shaped samples of PCB's obtained from open compute servers and also the samples of passive devices and cables generally used in data centers are prepared. Accelerated Thermal Cycle (ATC) test based on 'ATC JEDEC' standards which is used for air cooling has some limitations, and as there is a huge difference in a ramp rate of air and oil, this cannot be used for oil

cooling. The degradation mechanism of the electronic components of server, PCB’s, and passive devices in particular due to immersion in oil will be investigated. The test samples will be placed in air as well as aged in mineral oil. This methodology explains the analysis of the change in the electrical and mechanical performance in passive devices and PCB’S respectively , compared with that of their performance before cycling.

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Chapter 1

Overview, aim and objective

1.1 Overview

Data centers are the brain of any organization which hold lots of information and perform the most critical tasks in the whole organization. All the data is processed through the data centers and is stored for future use. Eventually, data centers use almost half of the power the whole organization. As the data center does almost most difficult tasks, its components also get heated up very easily and high heating of these equipment is not recommended as it might damage the equipment which would cost the company more as the work comes to standstill. To overcome this, cooling of the equipment was introduced and the main aim is to focus on the cooling of the equipment to keep the work going on and the running of the organization. Cooling of the data centre can take up to a major share (over 30%) of the total energy consumed by the data center [31, 32].

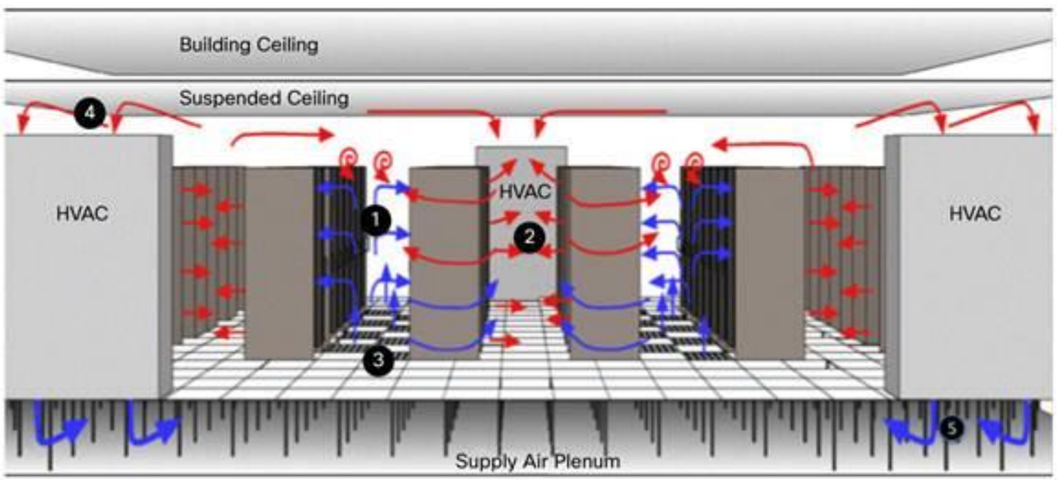

Figure 1.1 Data center air cooling method [33]

Air and fluid are the two heat exchange media that are utilized for cooling server farms. The cold fluid in a data center supplied by computer room conditioning and cooling (CRAC) where the chilled air goes through the raised floor then by means of pressure contrasts through the IT equipment to evacuate the heat, at long last coming back to the CRAC to be cooled as appeared in Figure 1.1. For the most part, the extensive air volume that needs to oversee and flow is truly costly and the capacity of the heat and thickness of air is little in comparison with the fluid [7]. This has given birth to the utilization of fluid cooling in some data centers. Utilizing fluid as a part of data centers is a promising methodology that has preferences of taking care of high density of heat. In any case, with fluid cooling there is an increment in infrastructure, i.e. pipe work, and leakage recognition, and it might offer challenges in simultaneous upkeep and also different dangers. Some fluid cooling systems convey the fluid near the rack [34] different strategies depend on bringing the fluid into the rack itself, yet not in an immediate contact with the semiconductors [35]. Another procedure depends on drenching the server into dielectric fluid [36]. The dielectric fluid is in direct contact with the microelectronics to enhance the heat exchange performance and it doesn't allow the electric release to take place. The dielectric fluid has an alleged dielectric quality that is adequately vast to go about as an electrical protector [37].

This study concentrates on the submerged server idea, in which the server is in an immediate contact with the dielectric fluid as appeared in Figure 1.2. The CPU produces the warmth which is led towards the heat sink then actually by convection by the dielectric fluid. At that point, the dielectric fluid chills off by means of the cool plate where the chilled water goes through a channel.

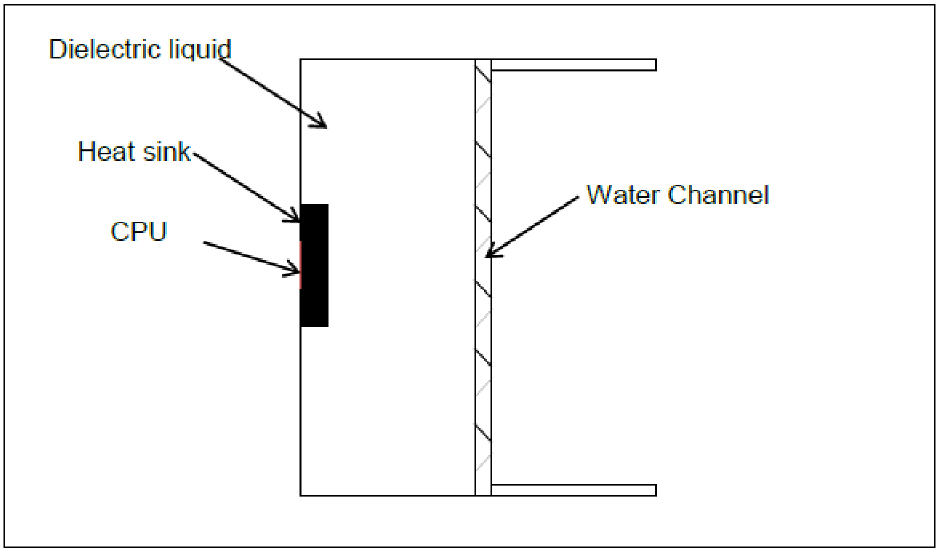

Figure 1.2 Immersed server diagram

The server is shut and there is no pump or blower inside the server so the heat exchange happens by regular convection. In the event of cubic and rectangular fenced in areas with one wall hot while the other is cool, there have been various examinations [38-40]. Liquid stream conduct in rectangle fenced in areas has been concentrated on for the scope of rectangular perspective proportions, from 1 to 40 and the studies demonstrated that for Rayleigh number (Ra) > 107 the liquid got to be turbulent [41]. For chip or warmth source in rectangular fenced in area Phan-Thien [42] examined three warmth sources on rectangular walled in areas and the outcomes demonstrated that the temperature can drop by up to 10% with the ideal warmth source area. Chang [43] performed a 3D rectangular model and changed the chips area with differing Rayleigh number from 103 to 106, where the liquid is thought to be laminar. The outcomes demonstrate that the most astounding normal chips temperature is for putting the chips vertically.

Then again, there are a couple studies that have been doing for the enclosed area with fins inside it to enhance the rate of heat exchange. For the cooling fins joined on walls, Frederick [44] numerically concentrated on diverse Rayleigh numbers fluctuating from 103 to 106 for 3D regular convection in a 3D shape, where the cooling fins were put on a level plane on the hot divider. Nada [45] has examined rectangular enclosures in areas tentatively in both level and vertical angles furthermore by changing the fin separating and fin length on the hot surface. The outcomes in their study demonstrate that the rate of heat exchange expanded by expanding the fin's height. Ycel [46] numerically examined 2D common convection in vertical rectangular closed in area with cooling fins put on the cool wall. They found that the increase in the quantity of fins and length can intensify the heat exchange.

In this work, the fundamental model is the submerged it equipment, where they are loaded with mineral oil. The point and goals of the study in this thesis are displayed in the following area. The outline of the proposition is described in this part.

1.2 Aim and objective

This thesis aims at studying the reliability of IT equipment immersed in mineral oil and to develop a methodology for oil immersion. The objective of this work is stated below.

1. To focus on the understanding of the impact of mineral oil immersion on the reliability and operability of servers and electronic components
2. To find an approach that is through material testing and analysis.
3. To focus on the differences in the heat capacitance of mineral oil and air.
4. To hypothesize the outcomes when the equipment is made to undergo various numbers of cycles.
5. To initially conduct an experiment on the equipment immersed in oil using the standardized environment of that used for air cooling – testing the Accelerated Thermal Cycling [ATC] feasibility and evaluate the results of the ATC trial testing of oil immersion and comparison of it to air cooling

6. To focus on the developing a correct methodology for oil immersion and scrutinize and plan for the procedure of the experiment.
7. Preparation of the samples that are required to test on the instruments for any material change.
8. To Evaluate change in material properties (e.g. Young's modulus, CTE, etc.) after exposure in mineral oil (compare to control samples in air). Investigate any failure modes (if any) that occur in devices. Evaluate change in electrical performance of passive devices after cycling in oil (compare to control samples in air).

Chapter 2

Literature review

2.1 Introduction

The main idea behind this research is to find out a methodology for immersion cooling using mineral oil and to measure the operational efficiency of the IT equipment when immersed in oil. The main focus is on PCB boards, passive components (transistors, diodes, resistors, etc.), wiring and cables. These components form one of the most important ones in analyzing the material compatibility when brought in contact with mineral oil. The study focuses on developing a methodology that would best fit for oil immersion. The main idea is to build a body of knowledge to help industry make more informed regarding mechanical reliability of IT equipment in mineral oil immersed systems. The goal is to develop a testing procedure for evaluating the reliability of electronic packages and components when immersed in mineral oil. This chapter gives a brief idea about various cooling systems, data center, high end servers and their major components.

2.2 Data center

A typical data center is a group of computer servers networked together which is to be used by particular organization for storage processing and distribution of large amounts of data. It consists of a main computer, network systems and server and components [1].

A data center is usually in requirement of extensive backup systems of power supply, cooling equipment, redundant data communication connections, different security devices, environmental controls. Early computing systems with complex operations and maintenance required a special environment to operate. From the computer rooms in the beginning of the computing industry to the present cloud computing have been using data centers on a large scale from business to government organizations to scrutinize, store and analyze large amounts of data. It is like a brain for the company and the place where the most typical and difficult processes are worked out.

Usually data centers can be the size of a room to the size of many floors or can be of a whole building. There are several cabinets onto which servers are mounted usually and arranged in single rows which form as corridors also called as aisles in between them. Some of the servers are IU to the servers that occupy many square feet [2].

The data center info can be divided into,

Architectural information

Structural information

Mechanical information

Electrical information

According to the mechanical engineering design, some of the systems that are important are,

Heating, Ventilation and Air Conditioning (HVAC).

Humidification and dehumidification equipment.

Pressurization equipment.

Electrical engineering focuses on aspects like switching and bypass from power sources, utility service planning, distribution, uninterruptable power source (UPS) systems, whereas, infrastructure addresses the data center cabling, voice, modem, keyboard, signaling systems and other data communications. Environmental control is also given an importance in data centers.

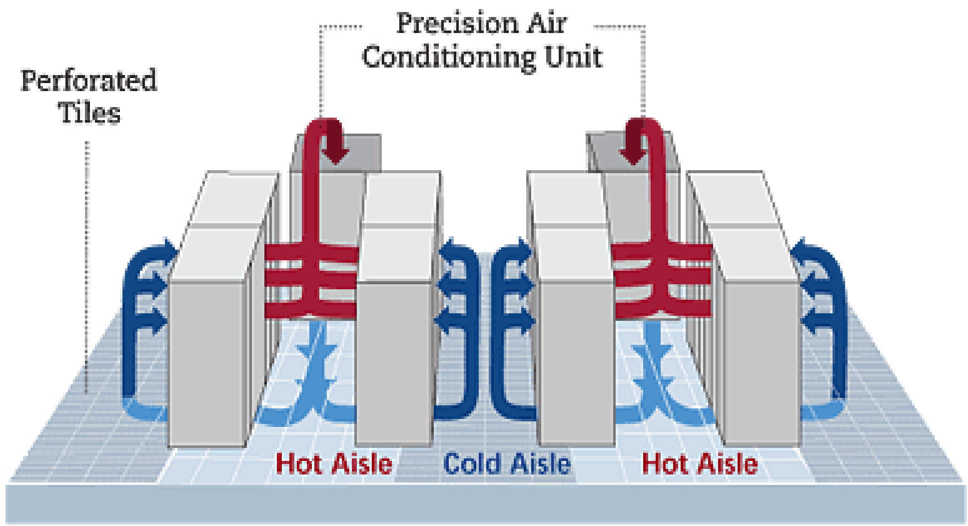

Figure 2.1 Typical data center layout [3]

2.3 Data center cooling systems

With the rise in the levels of heat and power densities, data center cooling systems have been changing with time. While selecting the correct cooling system for the data center becomes a crucial point, it is also equally important to look into other aspects of cooling system design which can add up to the expenses of the company and organization. With the decrease in the size of the electronic IT equipment, the heat each component releases has been increasing as it becomes more compact. Hence it becomes very important in selecting the right and traditional cooling system design.

Some of the cooling systems that have been in existence are explained below,

- Computer Room Air Conditioners (CRACs): Warm air is converted to cool air by taking off the heat from warm air.

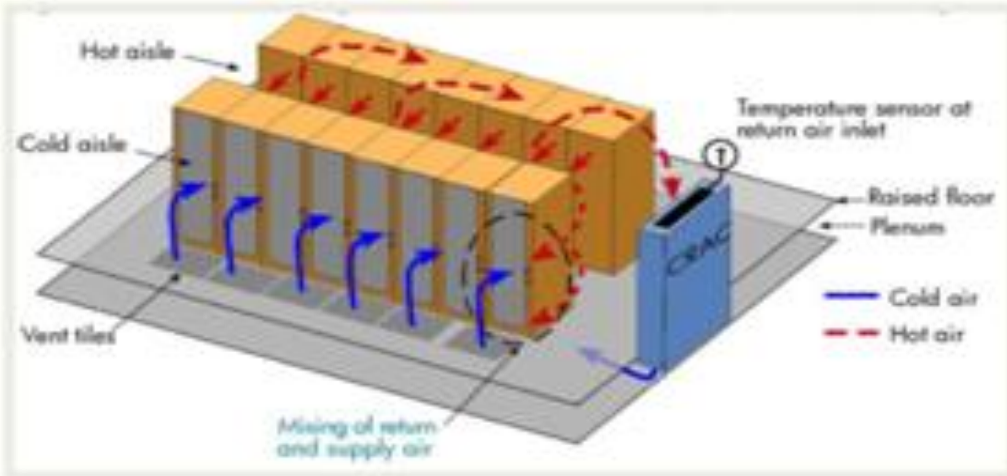

Figure 2.2 CRAC unit of a data center [4]

- Air side economizer: It basically consists of the windows opening where fresh air is let in to be used as cooling substance.

- Water side economizer: It is also uses the air from outside which gets combined with the evaporation effects, by which the liquid is cooled eliminating the use of chillers.
- Computer Room Air Handler (CRAH): It is generally used in higher commercial organizations. Chilled water is supplied to the CRAHs by the chillers and the cooled air is blown over a cooling foil that has chilled water.

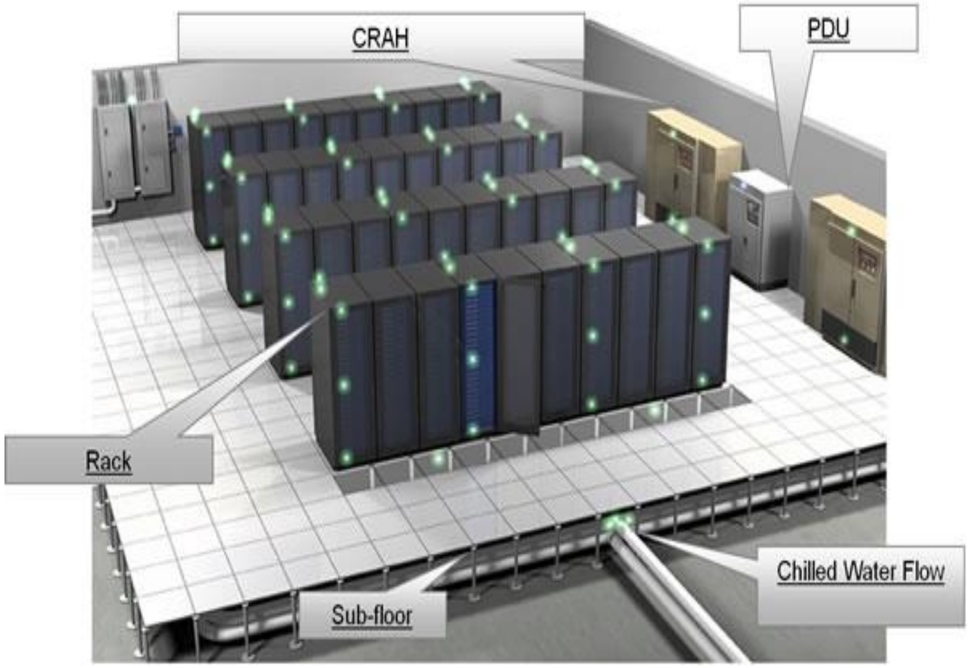

Figure 2.3 CRAH unit of a data center [5]

2.4 Energy utilization in a data center

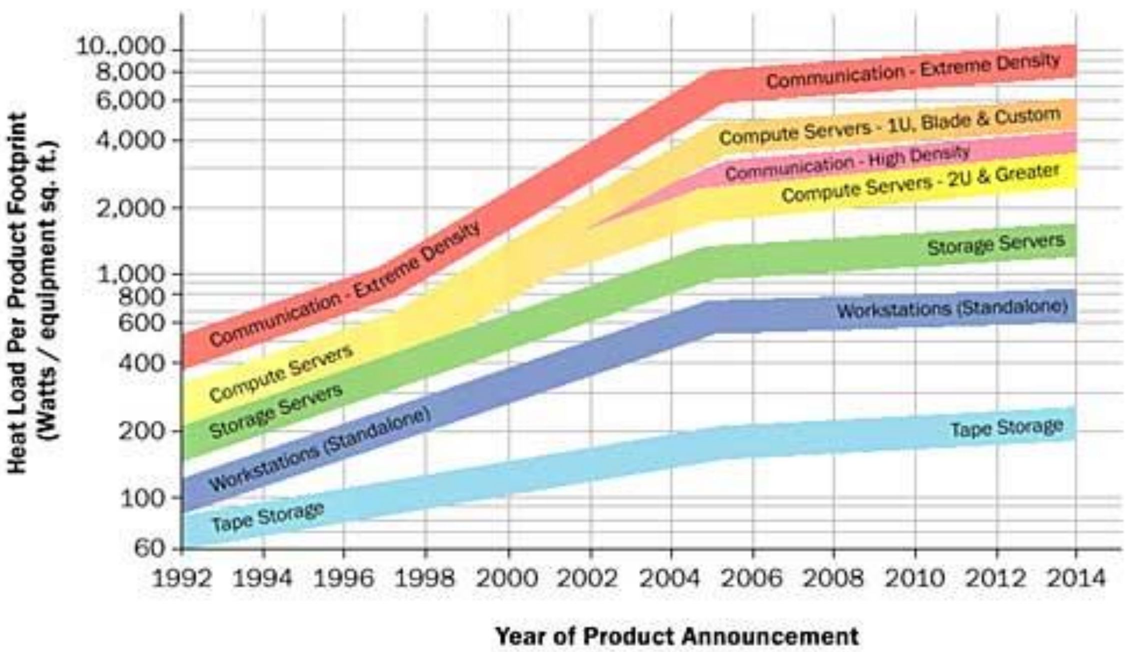

Figure 2.4 IT heat load distribution [6]

The expansion of space of the data centers particularly does not affect its growth and development which gave rise to the increase in the power density of the data a centers. Fig 2.4 depicts the chart which has six digital equipment classifications with projected trends till the year 2014. This chart provides general idea on the data center's power consumption and Pacific Gas and Electrical Company [7] estimates that range up to 50 times that of general office space. A heat load density of the server of the computer by 2011 was increased to 40kW/m2 where it was 3kW/m2 in 1992. By 2014 it was expected to increase another 10kW/m2 which adds up to 50kW/m2 [7].

2.5 Energy used for cooling

The data centers are very big components using which most of the work is done and due to this huge amount of heat is produced by takes in lots of electrical power. This heat produced by the data centers can be removed which otherwise might damage the components.

To remove this heat, cooling units have to be used and this requires more electrical power. These cooling equipment when they take out the heat, have to be cooled back to take out more and more heat which requires more energy. Hence, the operating costs of the data centers are higher than the cost of construction and are approximately equal to the amount of power utilized and the quantity of heat removal [8].

Fig 2.5 depicts the usage of energy in billion kWhr/yr in the years 2000 and 2005. It shows that the utilization of energy in total worldwide data centers has doubled from 2000 to 2005. IT load takes up to 80 billion kWhr/yr of the total energy out of which almost 80% is consumed by variety of servers like high-end, mid-range and volume servers and about 10% is taken up by communications and another 10% for storage. Cooling equipment uses almost half of the energy available.

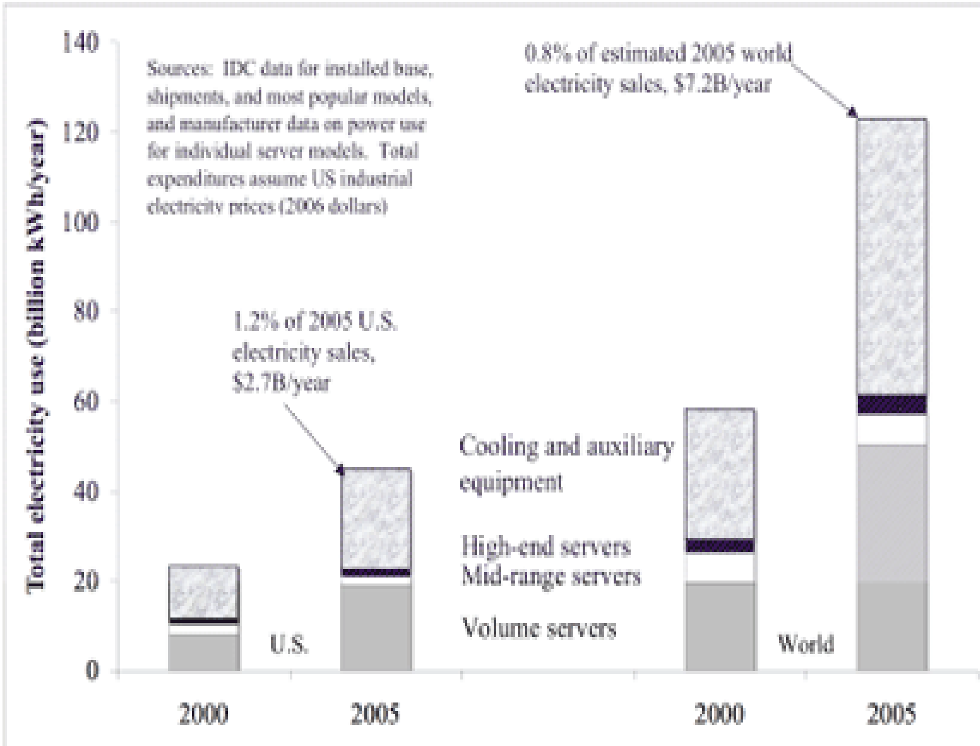

Figure 2.5 Energy use of worldwide data centers from 2000 to 2005 [9]

Fig 2.6 tells us about the study that was performed by Rasmussen [10] for the Lawrence Berkley National Laboratories and APC Corp. This pie chart shows the statistics of the utilization of power by data centers and is divided according to the data usage. This shows that the cooling equipment takes up to 1/3rd of the total utilization.

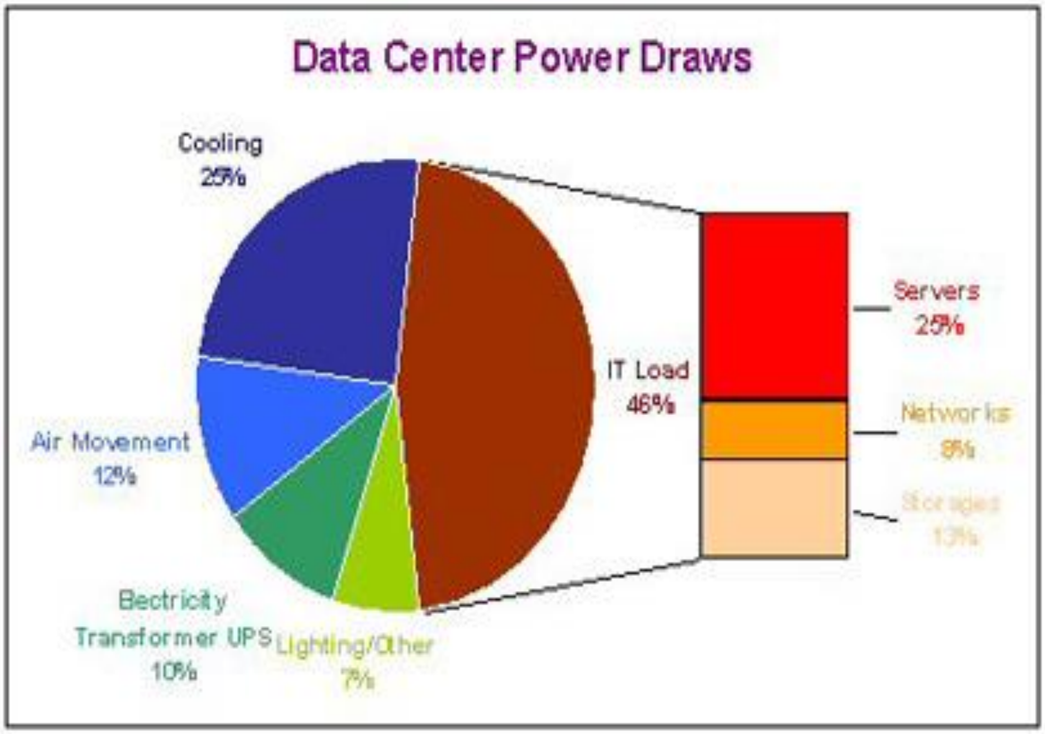

Figure 2.6 Electricity consumption of data centers [11]

Chapter 3

Cooling systems

3.1 Introduction

This section audits cooling systems embraced in server farms. The expanding interest for digital services has prompted high development in server farms what's more, their vitality utilization. A critical bit of server farm energy is consumed by the cooling framework. Server farms can be cooled by either air or fluids, or even a mix, to transport the heat far from the microelectronic parts. Air and fluid cooling strategies are attended to in this section, and fluid cooling is arranged into three fundamental routines; secondary passage heat exchanger, indirect fluid cooling (cold plate) and direct fluid cooling (submerged server) which will be clarified altogether in this section.

3.2 Methods of cooling

In the past the energy expenses were unimportant for the server farm associations. This was because of the low rack densities with low energy costs also, lower interest of past years. The associations in this manner did not dither to oversize the equipment to maintain a strategic distance from the danger of lack of limit storage capacity and downtime. In any case, now this is not the situation, as over sizing and over particular practices will cost an association in abundance and will both waste energy and increment the carbon foot impression. The decrease of the energy utilization, for example, the cooling energy was the best arrangement. At the heat source level there are two heat exchange media, air and fluid.

3.3 Air cooling

In a normal server farm, there are various racks, information stock and organizing hardware that are vertically adjusted. Computer room air conditioners (CRACs) at the edges of the server farm are utilized to cool the server farm gear [12].

An independent air cooling framework is made in the CRAC, in which the air is coursed inside of the server farm space as appeared in Figure 2.2. The heat is uprooted through a chilled water circle. The pump conveys the chilled water to the CRAC units from the chillers situated outside the facility. The chilled water is conveyed to the CRAC units. The air is ignored the heat exchanger loop (fin and a tube) by the blower in the CRAC unit. This air is at that point went into the server farm. A percentage of the CRAC units have a fan that works at variable rates to shift the temperature, however, others have the fan working at a settled velocity and the air temperature is changed through the variety in the chilled water value. This supply temperature is changed as indicated by the temperature of the returning air, which is recognized by the sensors on the CRAC return. The CRAC frameworks may be composed as a „down flow‟ or the „up flow‟ framework as indicated by the cooling plan of space. The up flow framework is designed for an office or a telecom gear office. It produces cool air through the conduits that are passed through space to the supply diffusers put on the roofs. The air has flowed through the racks, which expels the heat from the electronic gear inside the server. The warmed air is returned back to the CRAC units through the front or the sides of the unit. Server farms want to utilize down flows rather than the up flow framework in the CRAC units which, sends the air through into the plenum. This framework is known as the raised floor plenum server farm.

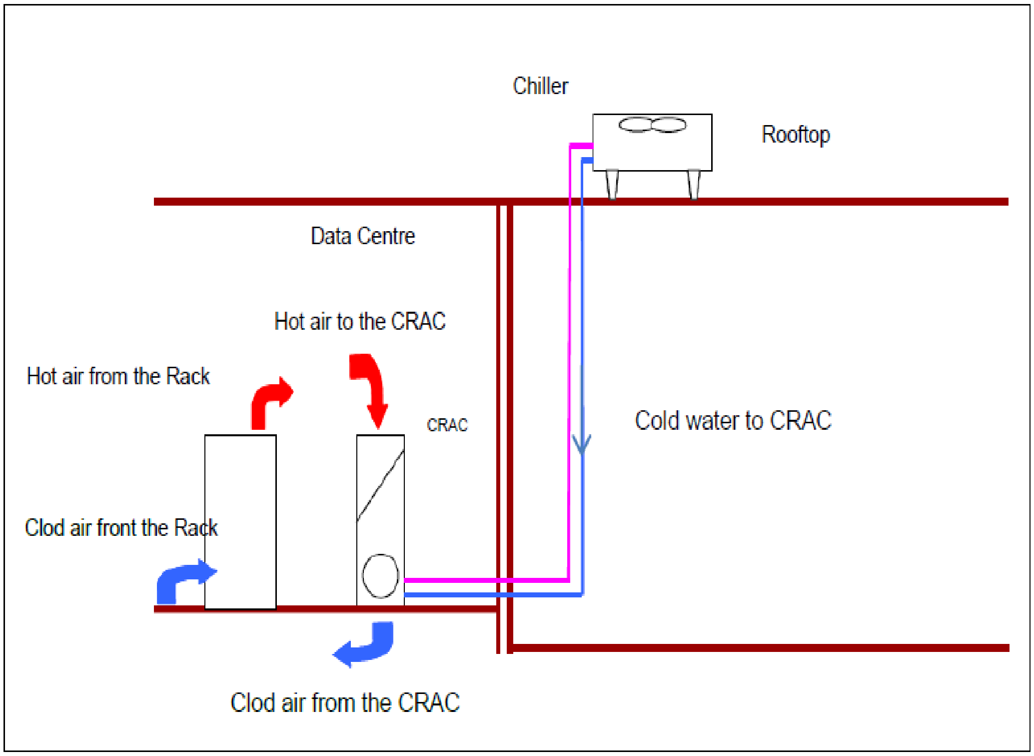

Figure 3.1: Standard air cooling [13]

The rack conveys numerous electronic fenced in areas which go about as heat sources so the air distribution in and around the rack as appeared in Figure 3.1 is imperative keeping in mind the end goal to enhance the cooling execution. There are two controlling rules that ought to be considered to enhance the server farm wind current [14]:

1. There ought to be no obstacles that square the wind current.

2. There ought to be no blending between supply icy air and return hot air.

In the resulting areas, some basic arrangements will be discussed are utilized on a normal premise to take care of the above issues.

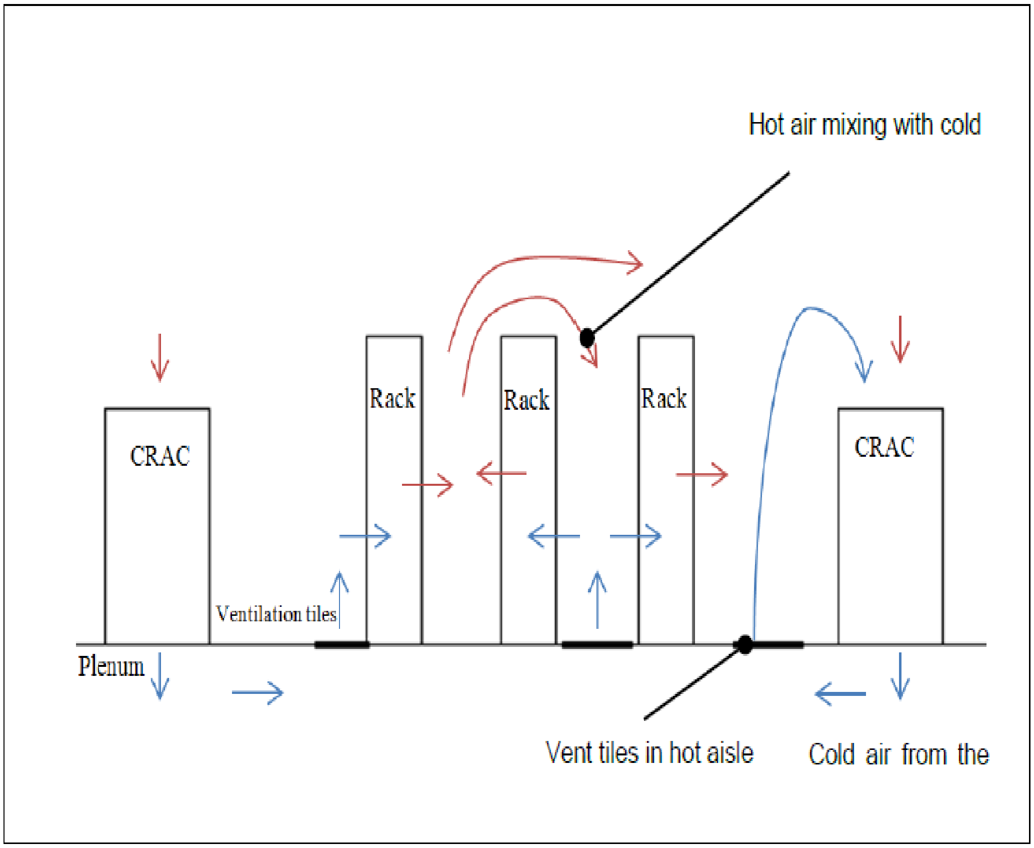

Figure 3.2: The wind stream recalculation in server farm [15]

3.3.1 Hot Aisle and Cold Aisle Layout

As appeared in Figure 2.3, the cool passageway and the hot walkway idea is used to discrete the chilly air supply from the hot air return, which could result in the diminished work required from the CRAC [7]. The cool air is passed up the CRAC (Computer Room Air conditioning) framework. The cool air is gone through the tiles from the plenum. The tiles are set before the racks, which is the cold path. The chilled air then goes through the racks and is warmed by the server and after that and the air inside the hot path is returned to the CRAC. The air is cooled again by the CRAC by utilizing the chilled coils set inside the CRAC. Along these lines the blending of the cold and the hot air is diminished, expanding the proficiency [8].

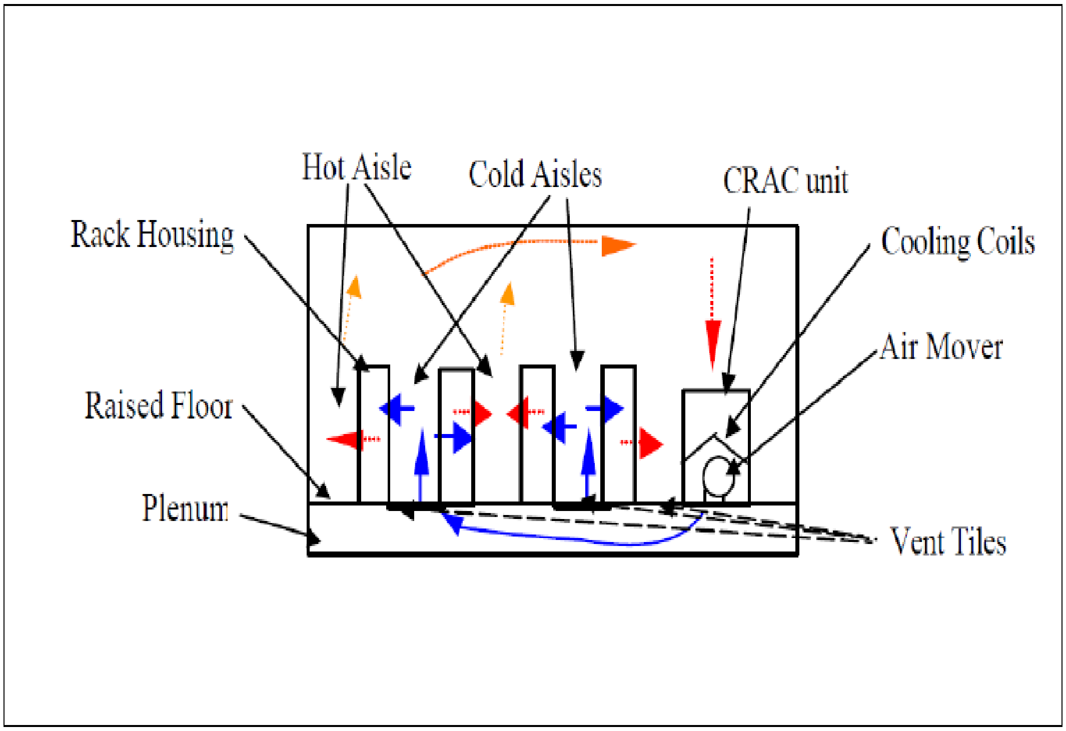

Figure 3.3: Hot aisle cold aisle design [16].

Wang [17], has depicted and tried different designs. These systems are connected to control the server farm design as for the racks and CRACs without evolving bases. These systems have been utilized to enhance the air conveyance from CRACs to racks without blending the hot and cold air stream hot and icy walkways designs could be actualized to streamline the server farm cooling proficiency.

3.3.2 Aisle Containment

Aisle containment is a compelling type of airflow administration that prompts the ideal utilization of the cold air. There are two sorts of air control utilized as a part of server farms:

1. Hot aisle containment.

2. Cold air containment.

These two frameworks give a cooling procedure that can be changed in accordance with higher temperatures with a specific end goal to spare vitality. These frameworks can likewise supply substantial burdens under safe working temperatures. It decreases humidification furthermore, dehumidification costs. This permits fitting size modification and helps in expanding efficiencies [18].

In the cold path regulation framework, the whole room will be utilized as the hot air return plenum, while the cold air will be sent through the raised floor plenum to the cold paths. The cool aisle is encased by the cold aisle control which regards the whole server farm as a vast hot air return plenum. At the point when the cold paths are contained, this outcome in the division of the cool and the hot streams inside of the server farm and lessen the blending between the cool and hot air. Figure 3.5 shows the cold course of action and the temperature change look at the criticized air design as appeared in Figure 3.4.

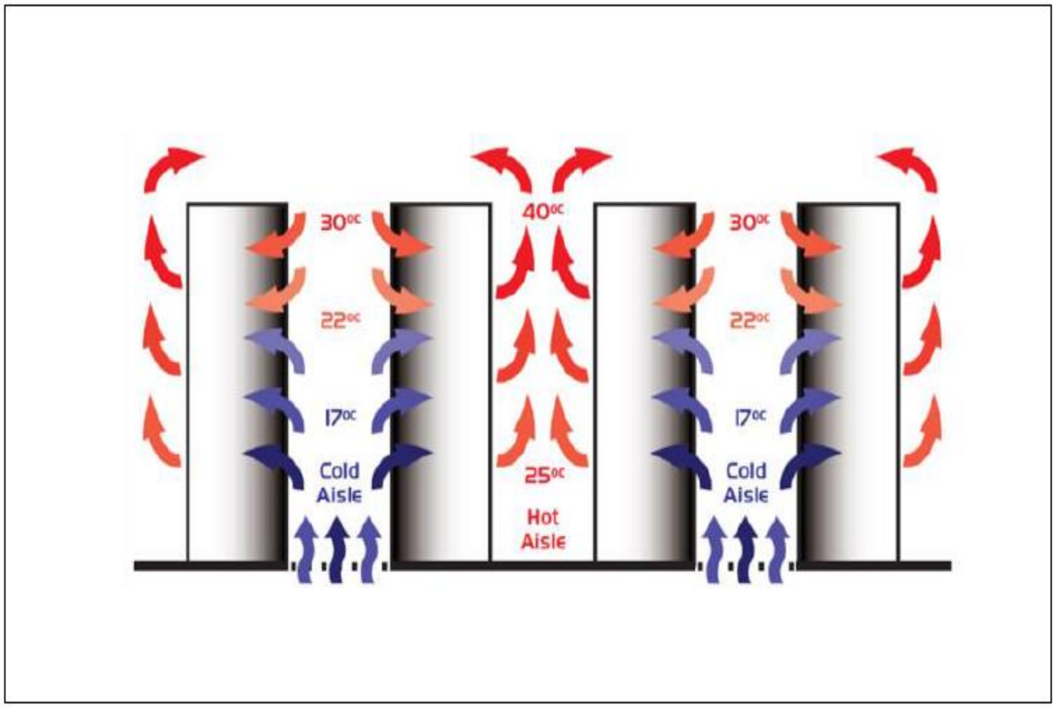

Figure 3.4: Standard Aisle Configuration [19]

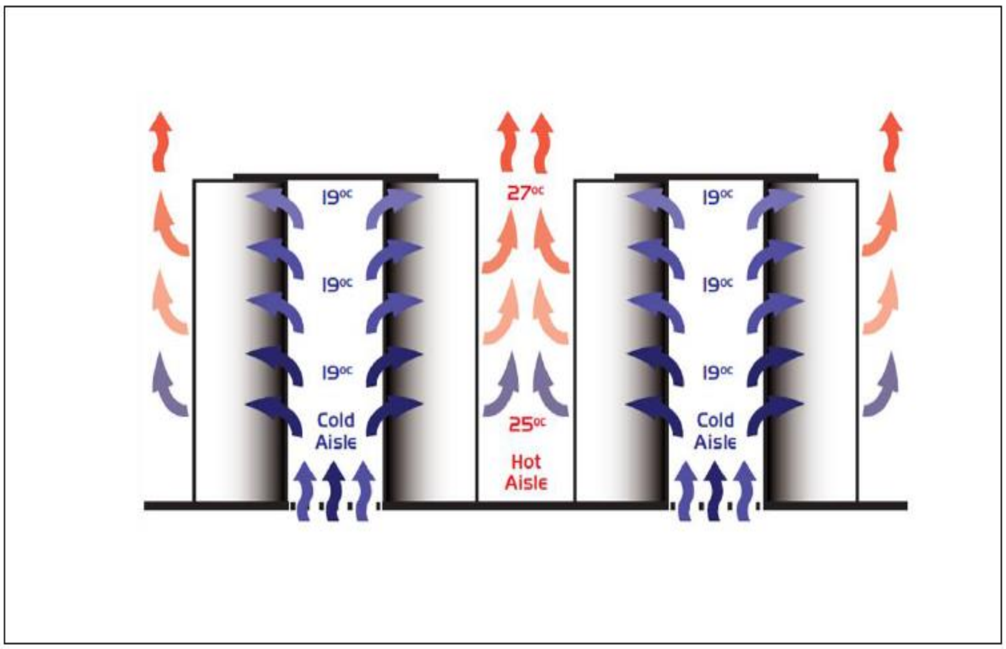

Figure 3.5: Cold Aisle Containment [19].

The hot aisle is encased by the hot air control framework, which gathers the IT equipment's hot given out air and afterward cools it to make it accessible for the air to be taken in by the framework as appeared in Figure 3.6. The hot air regulation framework expands the effectiveness by making an independent framework that can bolster high IT loads. The proficiency of the framework is expanded when the higher temperature air comes back to the computer room air conditioners (CRACs). The air is legitimately conveyed all through the framework when the air floods of supply and return are legitimately isolated.

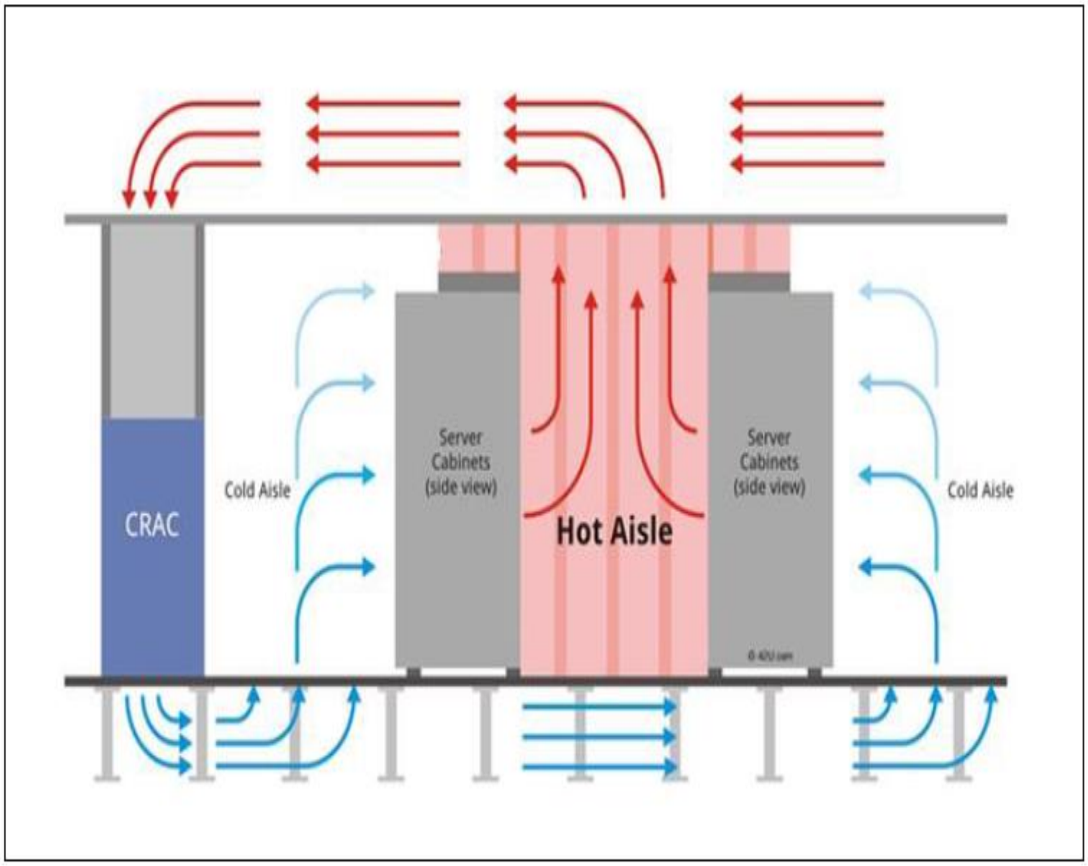

Figure 3.6: Hot Aisle Containment [20]

3.3.3 Blanking Panels

The rack gives an extremely basic capacity separated from simply being a mechanical backing, as it keeps the hot air given out to circle before the rack. The hot air is pressurized to compel it through servers, accordingly if there is a way for it to consolidate with the suction at the equipment intake, it will stream once more into the intake equipment bringing on a stream back. The length of the coursed air is significantly lessened by the rack, which goes about as a natural barrier. This naturally minimizes the admission of hot air into the equipment. Figure 3.7 demonstrates this procedure.

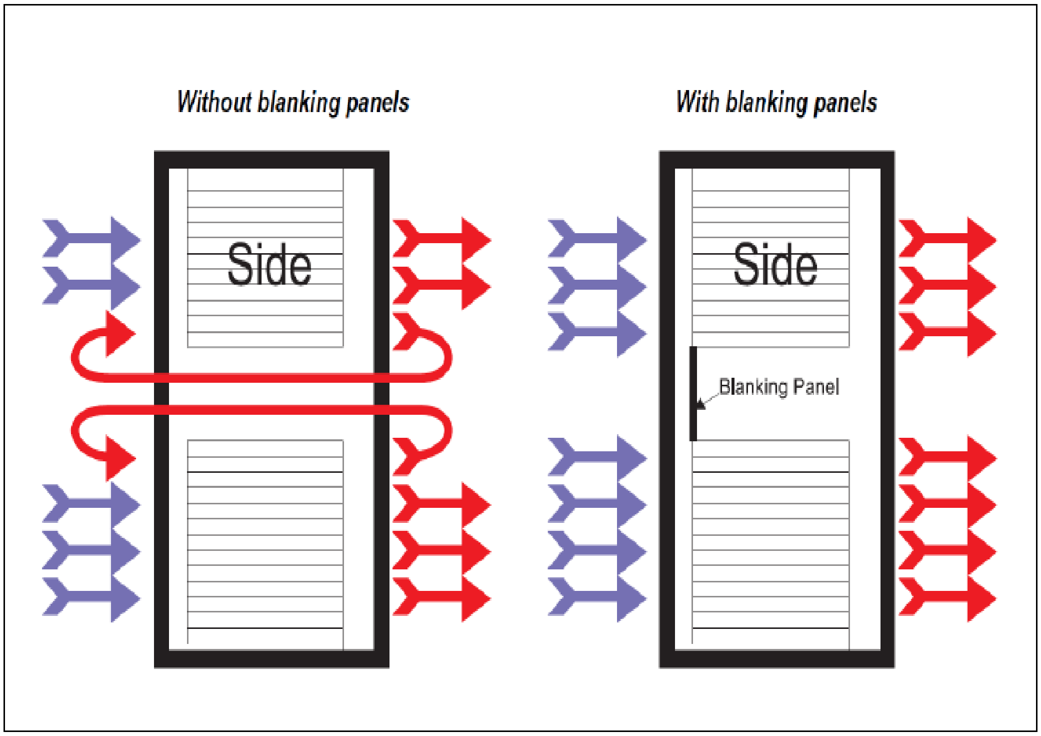

Figure 3.7: Airstreams with and without blanking panels [21].

Regardless of proposals by significant IT equipment producers to incorporate the blanking panels in the framework, it is much frequently observed that 90% of the data centers don't have the blanking panels in their frameworks. This prompts an ascent in temperature by 8°C of the IT equipment [21].

The blanking panels can be effortlessly introduced in all the server farms at an exceptional ease and are useful as they can change the rack air inflow.

3.3.4 Plenum

Server farms having raised floors have the subfloors going about as the plenum or the conduit. This gives a way to the cool air to go from the CRACs to the vented floors which are situated at the front of the racks. The subfloors are helpful as they can likewise go about as intends to convey the services, for example, network cables, cooling pipes and power. In some subfloors, there are fire detection or water frameworks [22].

The energy prerequisite for the framework may expand owing from the obstructions in the ways of the wind streams. These hindrances can be made in the plenum through the cabling and different structures in the way of the air flow. These hindrances make turbulence in the wind air flow in this way expanding the stream resistance. These issues can be lessened with the fuse of the overhead cabling plate for networking. Consideration ought to be taken to join spaces between the floors through appropriately orchestrating cables while setting them in the floor [23].

3.3.5 Vents Location

In the event that the floor vents are not legitimately situated, then the cooled air can get blended with the hot air. The advantages of the hot aisle and the cold aisle framework can be annihilated by the poor area of the conveyance or return vents.

The best positions for the air conveyance vents are close to the equipment intakes, which consequently limits the cool air in the cold aisle however much as could reasonably be expected.

The vented tiles, in the subfloor or overhead air conveyance, ought to be set in the cold aisle only. Any vents close to not working rack ought to be shut in light of the fact that they can happen to be the source of returning air to the CRAC. This returning air diminishes the temperature and builds the dehumidification which decreases the CRAC performance [23].

As demonstrated in Figure 2.8, the floor vents that are situated too close to the CRAC units will inevitably start to deliver a negative pressure. That is the air will be moved once more from space to underneath the floor. The vent tile area can be resolved through the utilization of a simple air speed measuring device that will guarantee a proper static pressure [22].

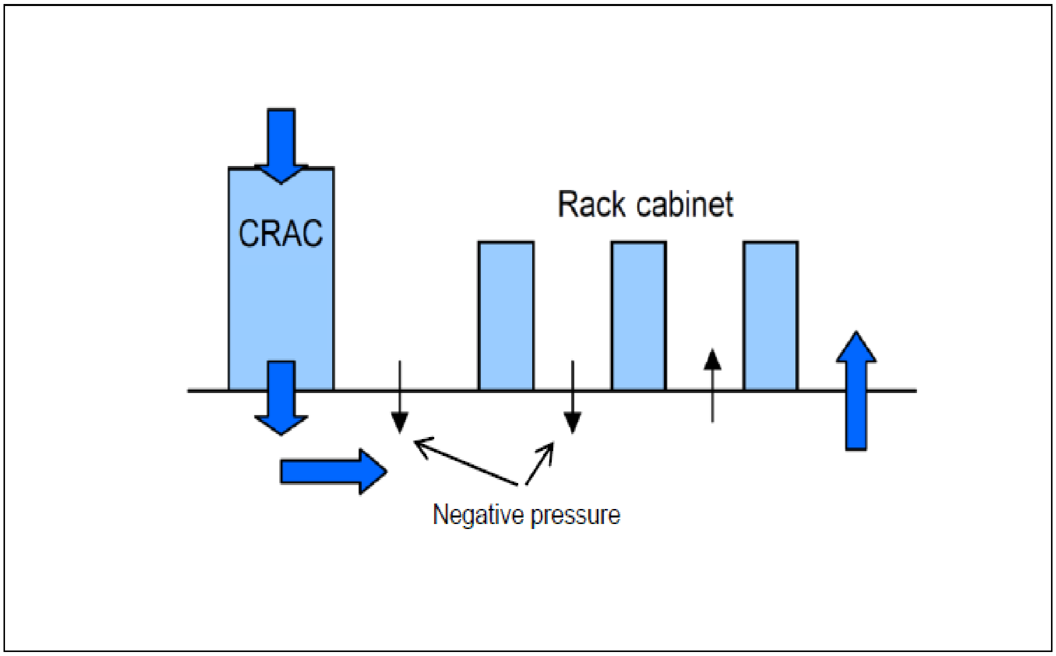

Figure 3.8: Floor vents area [22].

3.3.6 Environmental necessity of air cooling system

The temperature and humidity are required to be in appropriate level to keep the server farm in great working condition. The suitable inlet temperature as indicated by ASHRAEY TC 9.9 benchmarks is somewhere around 15 and 25oC and the humidity are acknowledged in the reach somewhere around 40% and 60%. The IT equipment of server farm could be damaged on the off chance that it works in poor natural conditions [24].

Psychometric graph in Figure 3.9 demonstrates the suggested working condition zone of the server farm. The dry globule temperature for suggested encompass is somewhere around 18 and 27ºC. The allowance working condition envelopes are A1, A2, A3, and A4. Each envelope has a limit of temperature and humidity. Then again, all the envelopes conceal can be utilized for a server farm [25].

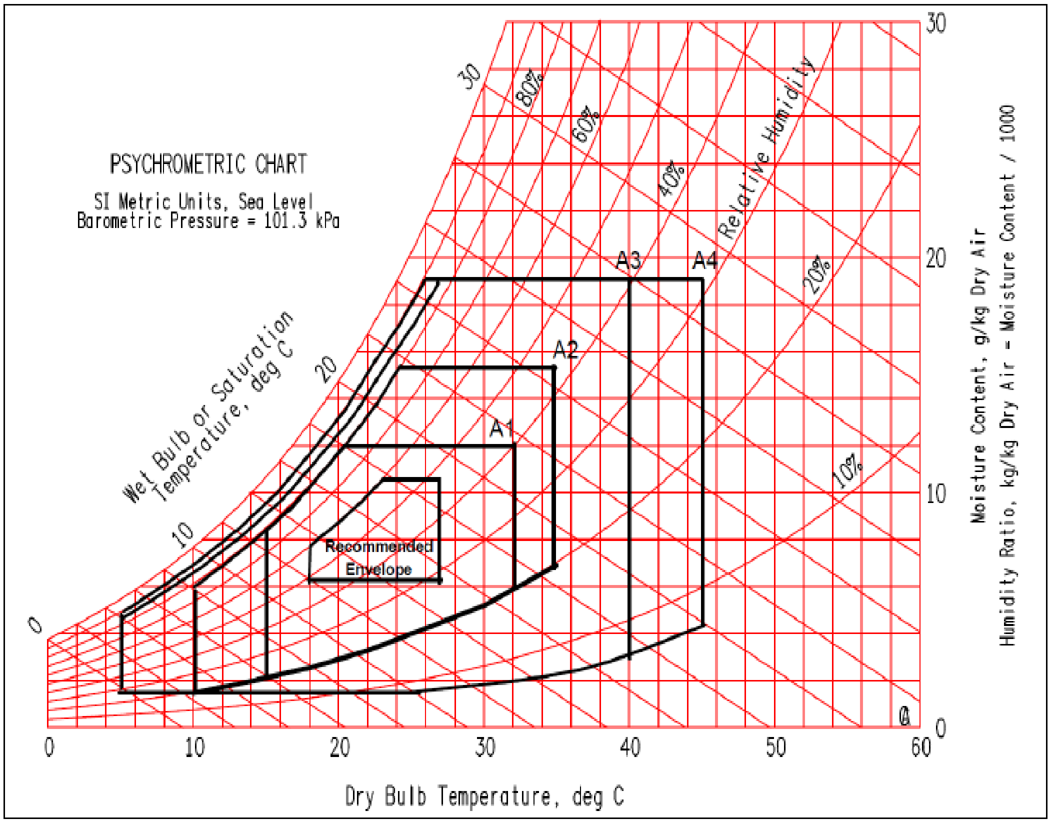

Figure 3.9: Environmental condition by ASRAE for the server farm.

One of the fundamental natural prerequisites for utilizing the air as a cooling medium is keeping the humidity of air at the appropriate level. High humidity in an air for cooling server farm could bring about electrical discharge, however, low humidity noticeable all around could possibly give an electricity produced via friction. Along these lines, in the event of low humidity, humidifier ought to use to expand the humidity in the air. In another case, the dehumidification can be used to lessen the humidity in the air. Humidification and dehumidification cost, so both humidification furthermore, dehumidification ought to be utilized just when needed [26].

Chapter 4

Testing methods

4.1 Introduction

As the electronic equipment have been moving from macro to micro and nano size, the demand for the integration of the system in a fast, better and cheap environment is also increasing. Reliability is not a term that should be taken into account after work is done; it should be made part of the process, development and implementation. Newer methods and systems are to be referred to, so as to access and assure the reliability and quality. In other words, and efficient and reliable system approach must be taken in to account.

4.2 Environmental testing

Thermal cycling is one of the testing method most commonly used to evaluate the reliability of the electronic equipment. There are many standards for this type of testing like Military standards of which many of them have become obsolete, but are still used for benchmark test like MIL-STD-883 [27].

This standard has three levels of a accelerated cycling temperatures,

- Condition A - $55^{0}/85^{0}$c
- Condition B - $55^{0}/125^{0}$c
- Condition C - $65^{0}/150^{0}$c

To comply with the acceptable testing, equipment is usually subjected to condition C and condition B is imposed upon usually assemblies. 1000 cycles was the mark to testify that an assembly is in the quality ranges prescribed. J-21PC, a commercial cycling profile advices a thermal cycle in the range of 0^{o}c to 100^{o}c [27]. The factors that affect the cycles which lead to the failure are typical to dwell, cool down and heating rates within a given temperature range. There was even NASA thermal cycling requirements specified, like the cracking of a solder joint was not allowed for 200 NASA cycles which was -55ºc to 100ºc with 245 minutes duration [27].

4.3 Thermal ageing

Thermal degradation alludes to the chemical and physical procedures in polymers that happen at higher temperatures. Elevated temperature quickens the greater part of the ageing forms that happen in polymers, for example, oxidation, mechanical creep and chemical attack. Oxidation is for the most part thought to be the most difficult issue at the point when utilizing polymers at raised temperatures [28]. The impact of temperature on the oxidation procedures will rely on upon the compound structure of the polymer.

All polymers contain these free radicals because of their polymerization and preparing history. In any case, the centralization of free radicals can be fundamentally expanded by cooperation with light, ionizing radiation or the vicinity of transition metals. Once shaped the peroxide radicals experience slower engendering responses that breakdown the polymer chains. The general degradation procedure will ordinarily include a moderately long induction period amid which little debasement is observed [28]. Toward the end of this period there is a fast increment in debasement prompting a noteworthy lessening in the mechanical properties of the polymer. This induction period is temperature sensitive furthermore, is decreased fundamentally at increased temperatures. The induction time of the degradation procedure can typically be viewed as the serviceable lifetime of the polymer.

Other physical changes can happen in a polymer at increased temperatures, one of the most basic being thermal expansion [29]. Thermal development is reversible and in general does not critically influence the life of a polymer. Nonetheless, in polymer composites the ill-matched between the thermal extension of the polymer lattice and the strands may bring about thermo-mechanical degradation amid thermal cycling.

Comparative mechanisms might likewise happen in glue joints. A sudden brief subjection to high temperatures can bring about phenomena known as thermal spiking.

Chapter 5

Immersion cooling v/s air cooling

5.1 Introduction

What amount of air does it take to keep a PC cool? There is a general guideline utilized as a part of the data center design world that 400 cubic feet for each moment (CFM) of air is required to give 1 ton of refrigeration. One ton of refrigeration is approximately equal to 12,000 British heat units every hour (Btu/h). Given that 1 kilowatt-hour is proportionate to 3,412 British heat units, it can be seen that a huge amount of refrigeration will cool a heap of 3,517 W, or around 3.5 kW. The mass of the heat exchange mathematical statement can be utilized to confirm the standard rule of thumb. Air is supplied from a computer room air conditioning (CRAC) unit in a normal data center at around 18°C (64°F). Presently, 400 CFM of air at 18°C is identical to 228 grams for each second, and the specific heat of air is proportional to 1 J/(g·°C). Settling the mass flow heat exchange mathematical statement above with this data yields an adjustment in temperature of 15°C. Any individual who has remained in the "hot aisle" straightforwardly behind a rack of servers will realize this principle of the thumb is confirmed.

5.2 Air cooling v/s oil flow

Regrettably, we can't dunk a computer in water like a smoldered finger since power and water don't play well together. Mineral oil, then again, has been utilized by electric utilities to cool electrical force dissemination equipment, for example, transformers and circuit breakers, for more than 100 years. Mineral oil just has around 40% of the warmth holding limit and about one quarter the heat conductivity of water, however it has one immense point of preference over water—it is an electrical insulator. It implies that electrical equipment can work while submerged in oil without short circuit. While mineral oil does not have the heat limit of water, regardless it holds more than

1,000 times more heat than air. It implies that the server rack examined before that required 1,200 CFM of air to keep from smoldering up could be kept cool with pretty much 1 CFM of oil. The vitality required to pump 1 CFM of oil is significantly not exactly the vitality required to blow 1,200 CFM of air[30]. In an impeccably planned data center, where the measure of air blown or oil pumped is coordinated precisely to the heat stack, the vitality required to blow air is five times that required to pump oil for the same sum of heat uprooted. In actuality, the measure of air moved through a server farm is significantly more than that required to fulfill the load. This is because of the way that not all of the air blown into a data center goes through a computer before it comes back to the CRAC unit. Since the air is not ducted straightforwardly to the computers' air admissions, it is allowed to find its own particular way back to the CRAC unit, which is regularly over, around, or generally not through a server rack. As we will soon see, it is much less demanding to coordinate the way of oil and to pump only the perfect measure of oil to fulfill a given equipment heat load. Thus, the vitality required to course oil can be more than 10 times not exactly the vitality required to flow air.

5.3 Benefits in addition to efficiency of immersion cooling

One of the benefits of immersion cooling is because of the way that the framework is intended to keep up a steady temperature inside the tank. Since the pump is tweaked to keep up a set point temperature not related to the changes in server workload, the servers live in an isothermal domain. One of the reasons for circuit board breakdowns is because of the mismatch in the coefficients of thermal expansion, or CTEs. The CTEs for the silicon, metal, bind, plastic, and fiberglass utilized as a part of a circuit board are all different, which implies that these materials extend and contract at different rates because of temperature changes. In a domain where the temperature is evolving every now and again because of load changes, this difference in CTEs, in the long run, lead to mechanical breakdowns on the circuit board. Oil immersion decreases this issue by making a temperature-stable environment.

The other side benefit is server cleanliness. Air-cooled servers are basically data center air cleaners. While data centers are generally cleaner domains, there is still some dust and dirt present. Keeping in mind, a regular server rack is attracting an extensive office space brimming with air each moment. Any dust or soil in that air has a tendency to collect in the undercarriage of the servers.

The last side benefit of submersion cooling is no noise practically. Submersion cooling frameworks make essentially no commotion. This is not a lesser benefit, the same number of cutting edge air-cooled data centers work close or above the Occupational Safety and Health Administration's suitable points of confinement for hearing protection.

Notwithstanding efficient utilization of cooling fluid and the side benefits addressed above, there is another point of interest to submersion cooling—server thickness. As said before, a normal air-cooled server rack consumes around 10 kW. In some deliberately designed HPC racks, 15–20 kW of load can be cooled with air[30].

5.4 Immersion cooling using less energy and infrastructure

5.4.1 Framework – air cooling

Cooling air is commonly supplied in a computer room with CRAC units. CRAC units are placed on the room raised floor and blow cool air into the under- floor plenum. This cool air then enters the computer room through permeable floor tiles that are put in front of racks of computers. Heated exhaust air from the computers then goes back to the highest point of the CRAC units where it is attracted, cooled, and blown back under the floor. With a specific end goal to cool the air, CRAC units commonly utilize a chilled-water coil, which implies that the computer room needs a source of chilled water. The chilled water (typically 45–55°F) is supplied by the data center chiller plant. At last, the computer room heat is depleted to the climate outside generally by means of evaporative cooling towers.

Oil-submersion frameworks likewise need to oust heat, furthermore, one way is through the utilization of an oil-to-water heat exchanger; this implies oil-immersion frameworks, as CRAC units, require a source of cooling water. The enormous difference, however, is that CRAC units need 45–55°F water; though, oil-submersion frameworks can work with cooling water as warm as 85°F. Since oil-immersion frameworks can work with warm cooling water, they can exploit different passive heat sinks, including radiators, geothermal wells, or close-by waterways.

The takeaway here is that there is a significant measure of costly, vitality hungry base required to make and disperse cool air to keep computers in a data center cool. A lot of this framework is not required for immersion cooling.

5.4.2 Fan power

One of the essential benefits of immersion cooling is the expulsion of cooling fans from the data center. Not just the energy investment funds that outcome from the expulsion of cooling fans is significant, they are aggravated by conceivably removing the need for CRAC units furthermore, chillers. Cooling fans in an ordinary 1U rack-mounted server consume around 10% of the power utilized by the server.

Servers that are cooled in an oil-immersion framework do not require cooling fans. This certainty alone implies that immersion cooling requires roughly 10% less energy than air cooling. Inside server fans, be that as it may, are not by any means the only fans required for air-cooled computers. CRAC unit fans are additionally vital to provide chilly air all through the server farm and present it to the inlet side of the server racks. This CRAC unit fan force must be considered

While deciding the genuine fan power savings that can be acknowledged by immersion cooling frameworks. Table 2 looks at the force required to move 1 W of exhaust heat into a data center's chilled water circle for fan blown air cooling versus pump-driven oil-cooling.

The third section demonstrates this force as a rate of IT specialized load. It demonstrates that the power required to run all fans in an air-cooled framework is equivalent to 13% of the specialized load that is being cooled. This is stood out from the force required to run pumps in an oil submersion cooling framework, which is equivalent to 2.5% of the specialized load that is being cooled. The difference, 10.5%, is related to the net fan power savings accomplished by changing from an air-cooled to immersion cooled data center. This investigation accepts that in both the air-cooled and immersion cooled cases, the cooling framework is coordinated precisely to the load. The last section in table 5.1 utilizes a comparable examination yet expects that the cooling framework capacity is provisioned at double the load. It demonstrates that over-provisioned fan force becomes speedier than over-provisioned pump power. This is further delineated in figure 5.1.

Method of Cooling	Power Required to Move 1W of Waste Heat into Chilled Water Loop (W)	Percentage of Technical Load to Power Fan or Pump (at 100%)	Percentage of Technical Load to Power Fan or Pump (at 200%)
Fan-Powered Air	0.13 W	13%	26%
Pump-Powered Oil Immersion	0.025 W	2.5%	5%
Net savings due to fan removal		*10.5%*	*21%*

Figure 5.1 Power usage for air-cooled versus immersion-cooled data centers

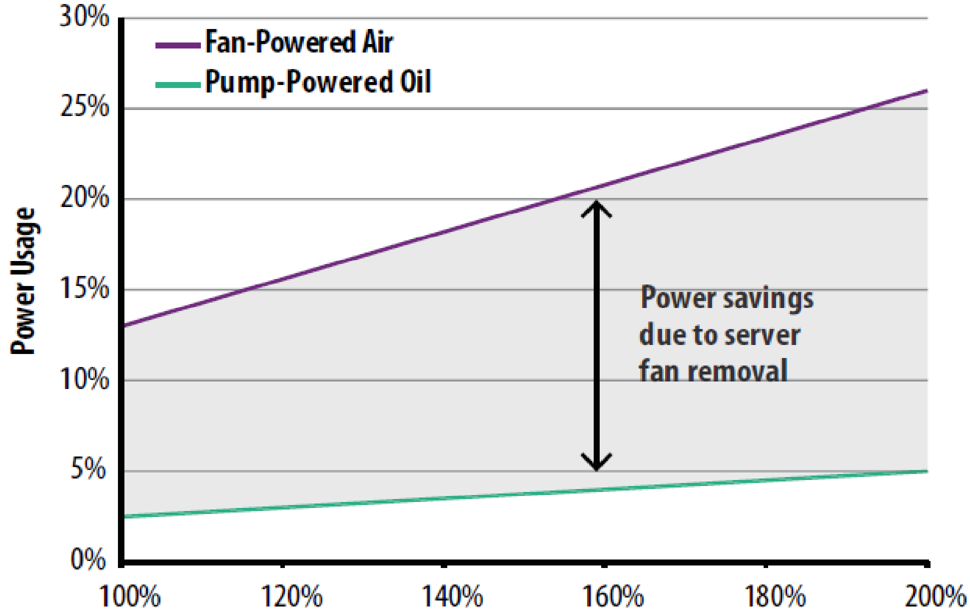

Figure 5.2 Installed fan/pump capacity

Chapter 6

Initial trial and proposed methodology

6.1 Introduction

The main focus in here is to perform an initial trial experiment wherein the environmental conditions used for air cooling are applied to oil immersion cooling. The results/ outcomes are noted down and those outcomes are compared to that of the air cooling. Here the main strategy is to apply the same conditions for air and oil and measure their ramp rates and dwell times and propose a methodology in determining the reliability of IT equipment immersed in mineral oil in comparison with that of the reliability in air cooling.

6.2 Initial trial

Objective is to determine feasibility of Accelerated Thermal Cycling (ATC) tests on oil in environmental chamber based on JEDEC standards. Here the same environmental conditions which are applied to air cooling are applied to oil cooling.

Higher temperature: It is the maximum temperature that a material can withstand.

Lower temperature: it is the minimum temperature the material can withstand.

Ramp rate: the rate at which oil/air gets heated up from its minimum temperature to maximum temperature.

Dwell time: the time in which the substance dwells at a temperature point.

The test conditions that were applied according to the ATC test standards are described below:

- ❑ Cycling test conditions (settings on environmental chamber)
    - T_{HI} = 100°C
    - T_{LO} = 0°C
    - Ramp Rate = 10°C/min
    - Dwell Time = 1hour
    - Oil Volume = 1gallon

Figure 6.1 Initial trial experiment

As seen in the figure 6.1, the initial trial consisted of applying the above mentioned conditions to the oil placed in an acrylic glass container with thermocouples half in air and half in oil so as to ensure that the same conditions are applied both for oil and air and later those readings are taken and compared. The test setup is done in the environmental chamber which allows isolated conditions. The experiment is run for a particular amount of time, where the air reaches its maximum temperature and oil too.

A volume of oil which was one gallon was used. The higher temperature in the chamber was taken to 100ºC. The lower temperature was taken as 0ºc. The dwell time was 60 minutes and the ramp rate was 10ºc per minute.

6.3 Results/outcomes

The dwell time and the ramp rate are different for both oil and air. This can be seen in the graph below.

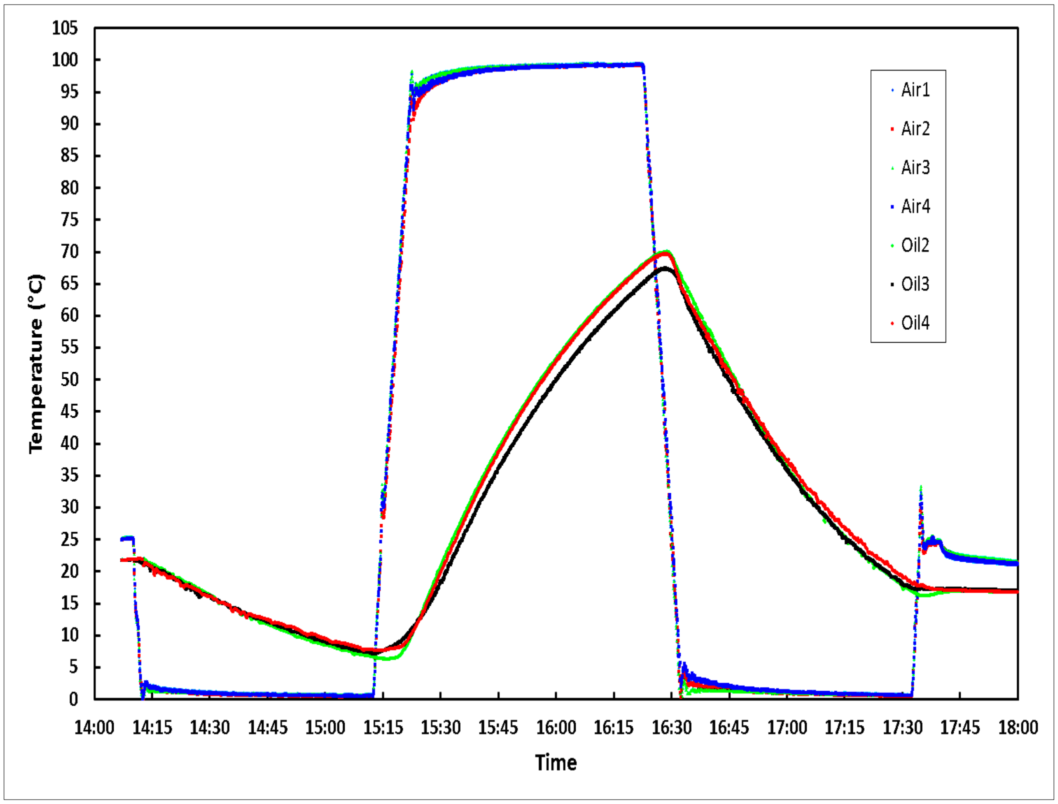

Figure 6.2 Time v/s temperature graph of oil and air

Temperatures from the experiment were taken down and as well the time taken. A graph is drawn between Time and Temperature and the graph is drawn for oil and air. The graph mainly tells us about the ramp rate and dwell time of oil and air when the standard ATC conditions were applied.

The graph depicts:

- The graph shows that the dwell time and ramp times between air and oil are significantly different.
- It depicts that the time oil takes to get heated up/ cooled down is way much greater when compared to that of heating time of air.

- The same conditions and test procedures of air cannot be applied for oil as both have different environment.
- Hence alternate testing procedure is to be established and applied for oil immersion cooling.

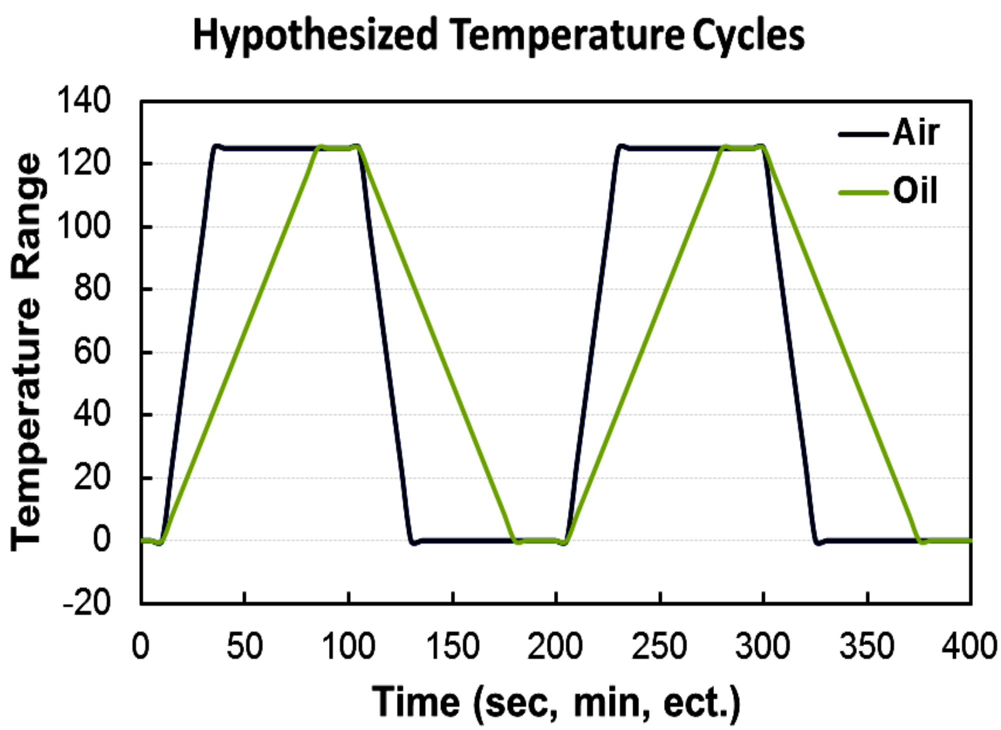

Figure 6.3 Hypothesized temperature scales

The above graph was the hypothesized one which states that due to larger capacitance of oil, cycle times will not be the same between air and oil (i.e. the ramp rates will differ between the two). This was the challenge posed after the initial experiment.

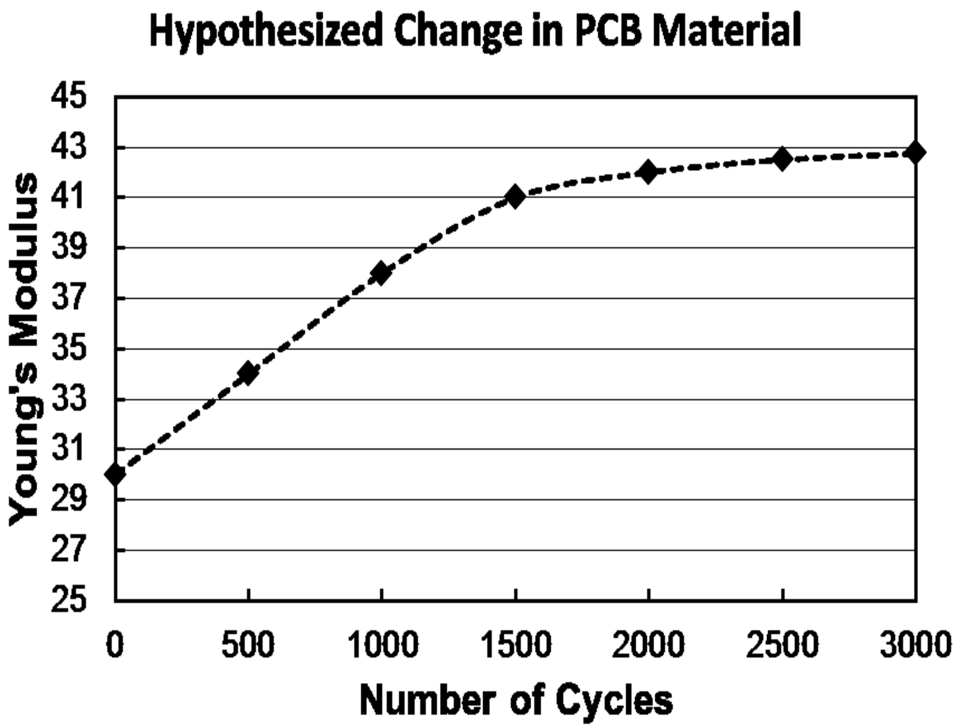

Figure 6.4 hypothesized change in PCB material

The above graph is just a hypothesis which explains how the young's modulus of a Printed Circuit Board (PCB) is affected by the number of cycles it is made to undergo. Samples may be removed from cycling at regular intervals so that time dependent observations/analyses may be performed. We can use acceleration factors to correlate number of cycles to expected MTTF in service.

The above challenges were posed and the possible outcomes and results were hypothesized which concluded that the environmental conditions that are applied to oil cannot be applied to air as the ramp rate and dwell time of both oil and air are different where air takes less time to go from minimum temperature to maximum temperature and whereas oil takes more time to get heated up and the dwell time is more for oil when compared to air. Hence it was concluded from the experiment was that same environmental conditions cannot be applied to oil immersion cooling. So, a new methodology has to be developed where the conditions are suitable for oil immersion cooling of IT equipment to measure the reliability and operability when immersed in oil.

6.4 Proposed methodology

As the conditions of that of air cooling cannot be applied to oil cooling a methodology was proposed for oil immersion cooling. This methodology consists of applying thermal overstress conditions. Initially the ramp rate and dwell time were chosen depending on the JEDEC standards. The higher temperature of the oil was chosen to be 70ºc because maximum temperature that the IT equipment in real time will undergo a maximum temperature of 35ºc to 40ºc and here the maximum temperature is multiplied by two and considered as the maximum temperature in the proposed methodology. The oil to get heated up with respect to time was taken as 10ºc per minute. Dwell time was 160 hours. Eight thermocouples should be taken, out of which four are used for air and four should be used for oil.

The conditions of the proposed methodology are;

A test container will be filled with one gallon of mineral oil.

Volume of the container is (14.5*18*16) inch in length * width *height.

Temperature overstress conditions:

Temperature = 70˚ C

Ramp rate = 5°C/min

Dwell Time = 160 hours

Total Time = 161 hours/cycle

Temperature drop time = approximately30 minutes

4 thermocouples in air

4 thermocouples in oil

Figure 6.5 Environmental chamber.

Chapter 7

Sample preparation

7.1 Introduction

This chapter focuses on the sample preparation which is needed in accordance with the type of instrument used. Here each of the sample is described and about how the sample was prepared and what is the importance of the instruments that are being used in the measurement of the change in the characteristic properties of the equipment immersed in mineral oil.

7.2 IT equipment chosen

The materials that are mainly affected in mineral oil are chosen for the experiment upon which the proposed methodology will be applied and they will be immersed in mineral oil.

Below are the materials that are affected majorly by oil immersion.

Active Components:

Printed circuit boards (PCBs)

Electronic packages

Insulation (PVCs)

Passive components: (resistors, capacitors, etc.)

Switching Devices

7.2.1 Active components

7.2.1.1 Printed Circuit Boards (PCBs)

The first PCB's were "through hole" technology and which replaced earlier assembly techniques like "point-to-point construction". It was invented as a solution to decrease the size and manufacture costs of the IT equipment and as an alternate solution for "wire wrapping" which caused frequent failures and short circuits upon wire ageing. With lines and pads that connect various points together and traces that connect various connectors and components to each other, it isa board that allows signals and energy to circulate between physical equipment.

The boards are either single- sided (with unplated components side) or compact double sided boards. The surface mounting emerged in 1960’s which were small metal tabs or end caps directly soldered and are small PCB assemblies with higher circuit densities. A multi layered board is one entire layer may be mostly solid copper to act as ground plane for shielding and power return.

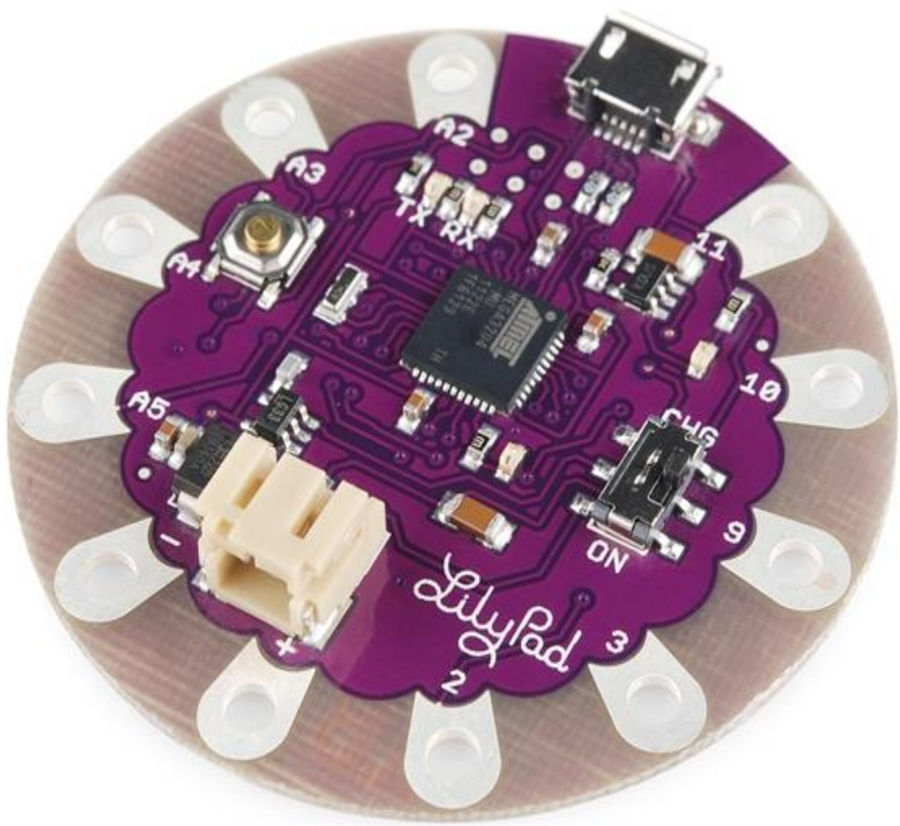

Figure 7.1 Printed Circuit Board [47]

In a practical sense, a PCB can be compared to a ‘layer cake or lasanga’-which has alternative layers of various materials which are laminated together with heat and adhesive so as to form as one.

Materials that are used are:

Laminates

Copper clad laminates which is called as a copper clad laminates.

Resin impregnated B stage cloth

Copper foil

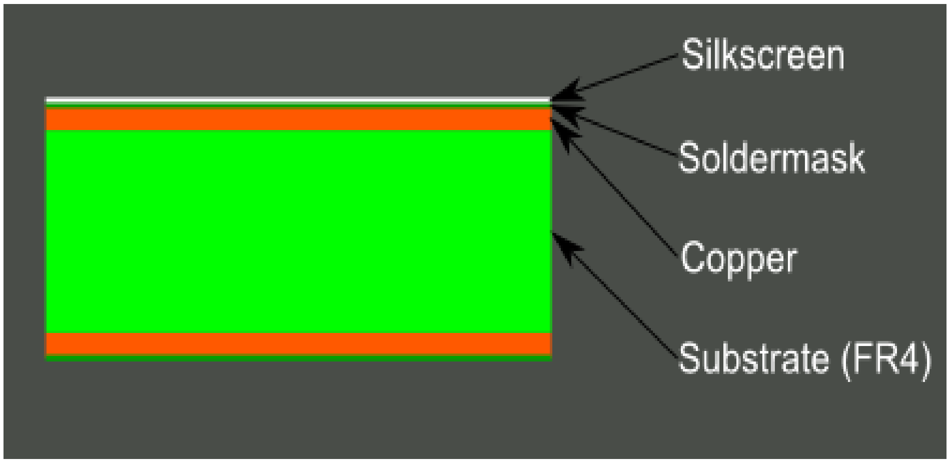

Figure 7.2 Layers of a PCB [47]

PCBs mainly contains green solder mask, FR4 (fiber glass cloth with an epoxy resin binder), white legend(silk screen). It contains approximately 1oz of copper inner layers and up to 2 oz copper weight on outer layers. Thickness varies from 0.031” to 0.125”.

FR4 is a primary insulating substrate; on the both sides of it a thin copper layer is coated. Etched into those copper layers are the circuitry connections and complex circuits are produced in multiple layers.

Thermo – mechanical deformations builds up within the electronic packages due to CTE mismatch between the respective materials within the package as it cools to room temperature which is also called thermal cycling. On the other hand patterning of the copper layers also exerts important influence to the thermo – mechanical behavior of the substrate due to consistent large youngs modulus of the copper at room temperature[48].

Many concerns regarding robustness of a PCB are:

1. Increased war page

2. Solder mask discoloration
3. Blistering
4. Land separation
5. Pad oratering
6. Delamination
7. PTH cracks

Properties of PCBs that are concerned with its damage:

1. Size (larger boards tend to experience higher temperature).
2. Thickness (thicker boards experience more thermal stress).
3. Material (lower glass transition temperature Tg tends to be more susceptible).
4. Design (higher density, higher aspect ratio).
5. Number of reflows.

PCBs are primarily defined by these parameters:[49]

- Out of plane coefficient of thermal expansion (Z-CTE)
- Glass transition temperature (Tg)

  (but no exposure to temperatures above Tg)
- Out of plane stiffness (Ez or elastic modulus)

All these are the material properties of a PCB board are affected by immersion in oil. These PCBs are measured for these properties and are compared to that of air.

Instruments used:

These will be the following instruments that can be used for measuring the material properties mentioned above for a PCB.

INSTRON:

The wide usage of universal testing method was started in 1900s and was used to apply forces to specimens. These are a variety varying from simple to complex systems which are controlled by the computer. Tensile test loads are applied both mechanically and hydraulically. INSTRON was established in 1946, Boston, MA, Harold Hindman & George Burrby .

Instron is an instrument which measures or characterizes material properties of PCBs such as tensile strength, modulus of elasticity,etc. With FEA its possible to simulate the changes that might take place in the reliability of a material due to property changes.

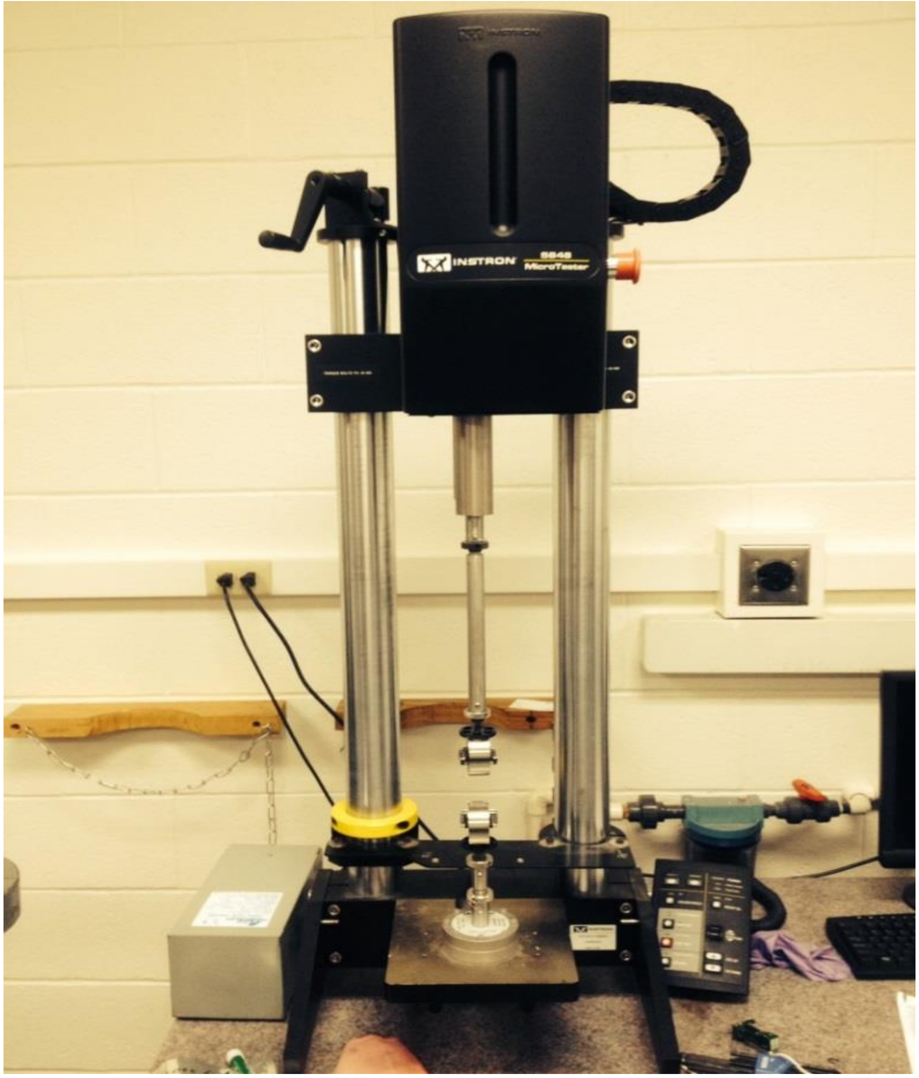

Figure 7.3 Instron machine

TMA machine:

TMA stands for Thermo- mechanical Analysis. This machine is used to determine the glass transition temperature Tg and Coefficient of Thermal Expansion (CTE) of dielectric materials. CTE of a material is measured to determine the change in the expansion behavior and influence of reinforcing materials. It depends on Tg. Thermo mechanical analysis is a technique used in thermal analysis, a branch of material science which studies the properties of the materials as they change with temperature. TMA is a subdiscipline of 'thermomechanometry' (TM) technique [50].

Figure 7.4 Thermo Mechanical Analysis machine

Sample preparation:

The PCB board was obtained and it was cut into a 'dogbone' shape which was convenient for measure the young's modulus on the Instron machine. The following is the dog bone sample, into which the PCB was cut with its measurement accordingly.

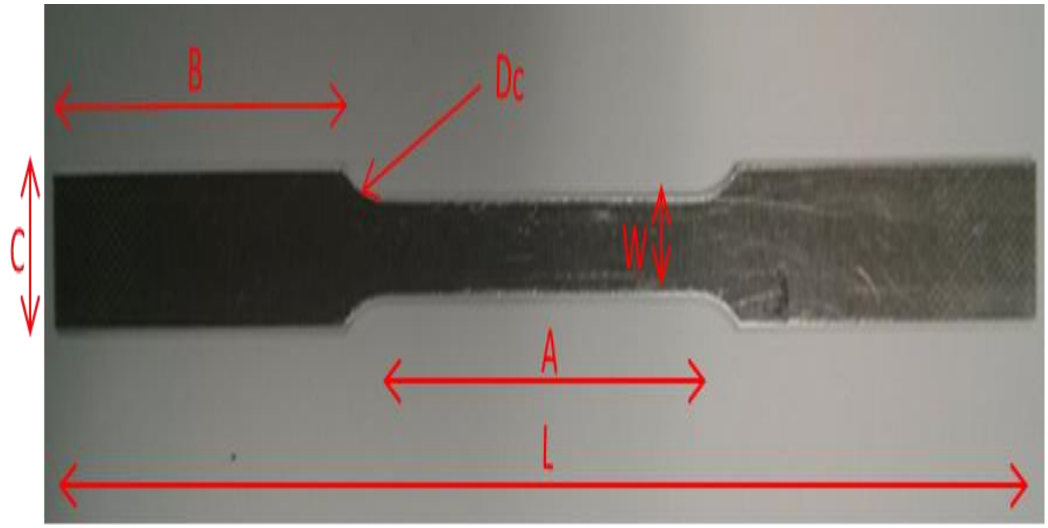

Figure 7.5 Dog bone sample of a PCB board

SAMPLE TYPE	DIMENSIONS
L – Overall length	3.937
C – Width of grip section	0.394
W – Width	0.236
A – Length of reduced section	1.26
B – Length of grip section	1.181
DC – Curvature distance	0.158
R – Radius of curvature	0.236
Material thickness	0.0374

7.2.2 Passive components

Inductors, resistors, transistors, capacitors, etc, make up the passive components of a server.

7.2.2.1 Thick film resistors

Thick film resistors are surface mount devices (SMD). These have a grain containing ruthenium oxide paste and is printed on the screen on to a ceramic substrate [51]. These are hundreds and thousands of time more thicker than the thin film resistors. These are the most used resistors in almost all the electrical and electronic devices and have lower cost compared to others.

Figure 7.6 Thick film resistors

Specifications:

Resistance	1Kohms
Power rating	2W
Tolerance	5%
Temperature coefficient	100PPM/C
Voltage rating	300V
Operating temperature range	-55ºC to +155ºC
Height	0.6mm
Length	2.5mm
Width	1.2mm

Above are the thick film resistors that are used as samples for oil immersion cooling. Property that will be measured in these would be electrical resistance and by use of Multimeter.

7.2.2.2 Polymer capacitors

They are usually small in size and are robust in handling wide variety of technologies. They have conductive polymer as an electrolyte. The ones which will be used in the experiment are cylindrical SMDs(V-chip) style with wound aluminum foils. These have low internal series resistances. These have a higher leakage current properties when compared to other electronic components.

Figure 7.7 Polymer capacitors

Specifications:

Capacitance	270µF
Voltage rating DC	16V
Tolerance	20%
Minimum operating temperature	-55ºC
Maximum operating temperature	+105ºC
Diameter	8mm
Length	6.9mm
Leakage current	864µA

These are the polymer capacitors that will be used in the experiment and the property measured in these is electrical capacitance and is measured using Multimeter.

7.2.2.3 Electrolytic capacitors

Electrolytic capacitor performance is unequivocally influenced by its working conditions, for example, voltage, current, recurrence, and environmental temperatures. At the point when capacitors are utilized as a part of power supplies and sign channels, debasement in the capacitors intensifies the impedance way for the AC current and decrease in capacitance presents ripple voltage on top of the desired DC voltage. Proceeded with the corruption of the capacitor leads the converter yield voltage to drop beneath determinations influencing downstream segments. At times, the combined effects of the voltage drop and the ripples may harm the converter and downstream parts prompting cascading failures in frameworks and subsystems. In principle they form plate capacitors.

Figure 7.8 Electrolytic capacitors

Specifications:

Capacitance	470µF
Voltage rating DC	16V
Tolerance	20%
Minimum operating temperature	-55ºC
Maximum operating temperature	+105ºC
Diameter	6.3mm
Length	5.5mm
Height	5.4mm

These are the electrolytic capacitors that will be used in the experiment and the property measured in these is electrical conductivity using Multimeter.

7.2.2.4 Diodes

It is a two terminal electronic component which has asymmetric conduction. They block current from flowing in the backward direction and act like short circuit for forward current flow and consume some quantity of power when conducting forward current. But these do not completely block the backward current. If the voltage across the diode is positive then the diode is in ON condition and current can flow through. The current should be greater than the forward voltage (Vf) for the current to be anything significant. Diode's Vf depends on which semiconductor material is used to manufacture them. In reverse bias condition the diode is in the OFF mode and the voltage is greater than Vf and the current flow is blocked.

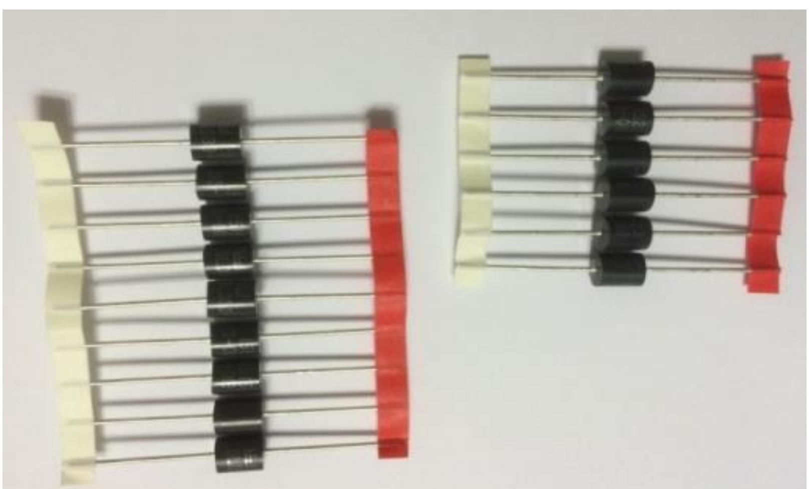

Figure 7.9 Diodes

Specifications:

Polarity	bidirectional
Breakdown voltage	40.6V
Clamping voltage	53.3V

Peak surge current 600A

Minimum operating temperature -55ºC

Maximum operating temperature +175ºC

Power dissipation 8W

Mounting style axial

Termination style axial

These are the diodes that will be used for the experiment and the measured property in these is to see if they allow the current to flow through them or not.

7.2.2.5 Transistors

It is usually a three layered semiconductor sandwich which is either PNP or NPN. These are used to switch electronic signals or amplify them. They are made of semiconductor material with three terminals for external connection. They are interconnected and embedded into chips and are used in thousands and millions. The difference between the NPN and PNP is the direction of the arrow on the emitter. These are generally two diodes where their anodes are connected together.

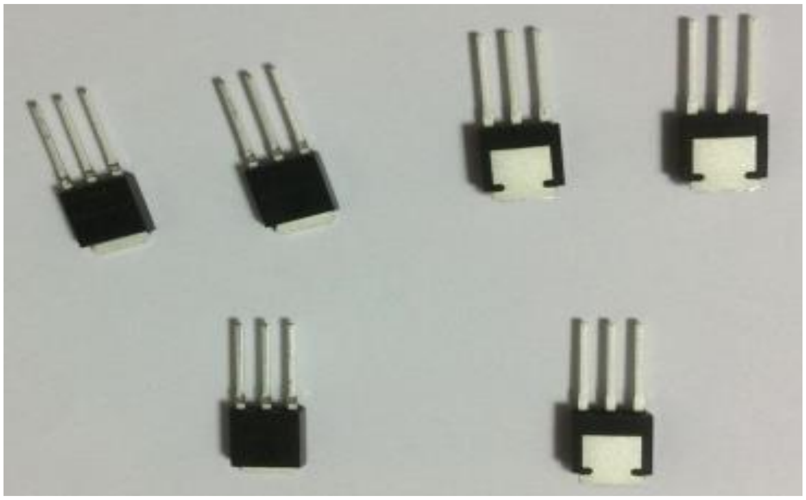

Figure 7.10 Transistors

Specifications:

Configuration	single
Transistor polarity	NPN
Collector-emitter voltage	450V
Emitter-base voltage	9V
Collector-emitter voltage	900mV
Maximum DC collector current	8A
Bandwidth	4MHz
Maximum operating temperature	+150C
Mounting style	through hole

These are the transistors will be used in the experiment and the property measured in them is resistance allowance and is measured using Multimeter.

7.2.2.6 Inductors

It is a passive two terminal component. It is also known as a coil or a reactor and blocks out the changes in the current that passes through it. In an inductor the energy is stored temporarily in the magnetic field of the coil. They follow the Faraday's law of electrical inductance. An inductor is characterized by its inductance. They block the alternating current to pass through. They are usually used in electronic filters where they are used for separating of different frequency signals. They have a magnetic core made up of Ferrite or iron which help intensify the magnetic field.

Figure 7.11 Inductors

Specifications:

Inductance	240nH
Tolerance	20%
Maximum DC current	22A
Maximum DC resistance	1.12mOhms
Height	3mm
Length	8.7mm
Width	7mm

These are the inductors used for the experiment and the property measured is inductance using an oscilloscope.

Chapter 8

Future study

1. To validate the methodology and analyze for more experiments with different environmental conditions.

2. To provide the trend of accelerated degradation of components for oil cooled data centers.

3. Can these Overstress tests be used to evaluate change in fluid properties over time? (I.e. is there leaching of plastics or other materials that influence the fluid?)

4. Change in the properties of Mineral oil because of Thermal Overstress.

5. To allow the components to undergo thermal overstress and removing them from the mineral oil in regular intervals which is thermal cycling.

6. To measure the mechanical properties like elastic modulus on INSTRON and thermo mechanical properties like coefficient of thermal expansion on TMA.

7. To measure the electrical performance of the IT equipment using MULTIMETER and OSCILLOSCOPE.

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