Data Center Design and Airflow Management (Insight into Increasing Performance and Efficiency)

Edward Roncoli Venegas
Master of Engineering in Mechanical Engineering
Dr. Rafael Salgado
Mechanical Engineering Department
Polytechnic University of Puerto Rico

Abstract — *The formation of hot spots in data centers is usually caused by the inability to properly distribute the airflow and not for the lack of capacity by the cooling system. Airflow management is essential to reduce the energy consumption of a data center. Designing an efficient facility requires the development of an appropriate configuration that will provide the best possible techniques for air management. This can be accomplished by designing the right air conditioning infrastructure, developing a strategic layout arrangement, and controlling the rack density. Guidelines were developed to help achieve a maximum return temperature and a larger* ΔT *that can increase the effectiveness of the cooling unit's heat exchangers, lowering operational costs. Eliminating the mixture of hot and cold air represents a viable option for reducing the PUE of the data center, as well as increasing the lifespan of the IT equipment.*

Key Terms — *Air Management, Containment, High Density, Targeted.*

INTRODUCTION

In simple terms, a Data Center can be seen as the brain of a company, where all the servers, phone lines, and internet connections are managed. As a result, it must be reliable and maintain with a series of unique qualities, in order to assure the proper functioning of the plant operations. Nonetheless, there are three major operational and financial constraints that make an impact on data center performance; power, cooling and space. A data center can consume 100 to 200 times the amount of electricity that is used in common office spaces [1]. When using this much power, cooling becomes a priority as the energy gets released to the space in the form of heat.

The increase in temperature, inside the room, can cause equipment failure. Proper design and airflow management is essential to preserve the lifespan of the IT equipment. Heat removal, however, is one of the least understood processes for data centers and IT rooms [2]. The IT equipment is usually air cooled through the process of convection. About 50% of the heat that is released by the servers comes from the microprocessors and almost 100% of the electricity that powers the equipment is converted into heat [2]. To remove the heat from the equipment, the microprocessor takes cool air from the room and releases hot air through the exhaust.

Considering the large amount of equipment that can be inside the room, many hot airflow paths can develop, releasing heat into the data center. Getting all the heat out of the room requires an air conditioning system that is properly designed. However, as the loads become larger, it gets harder to determine which design opportunities can reduce the operating costs and increase performance and reliability. As a result, it is not uncommon to find data centers designed as scaled up versions of standard office spaces. This type of design causes the mixture of hot and cold air, which brings the formation of hot spots inside the room. Consequently, to keep the equipment from failing, IT professional are forced to lower the temperature inside the room, driving up the electricity bill.

Designing a data center should be performed in a case by case basis, considering the particular necessities of the space. Therefore, this article discusses the design of a data center under a particular scenario. A series of guidelines were developed to offer insight into increasing the efficiency of the cooling system. Furthermore, the conditions of an existing inefficient data center will be used as a baseline or standard model and enhancements will be performed to develop a more efficient design. This will be accomplished by focusing on redesigning the air conditioning system infrastructure, developing a strategic layout arrangement, and controlling the rack loading or density. Improvements in these three areas will help overcome the three major operational and financial constraints (power, cooling and space), resulting in lower energy consumption.

AIR MANAGEMENT

Designing a data center requires the development of an appropriate configuration that will provide the best possible techniques for air management. This involves the elimination of the mixing of cooled air supplied to the room and the hot air rejected by the equipment. Ultimately, designing with effective air management practices will prevent the formation of hot spots and reduce the consumption of energy.

The Refrigeration Cycle

The extraction or removal of the heat inside the room will be achieved by the use of the refrigeration cycle, in which a refrigerant is moved through a process of evaporation, change of pressure, condensation and flow regulation, as seen on Figure #1. The refrigerant used in the refrigeration cycle is designated by the American Society of Heating, Refrigeration, and Air Conditioning Engineers (ASHRAE). In the cycle, the warm air from the data center is forced to pass, by the use of a fan, through the evaporator coil. The coil is been supply with cold liquid refrigerant that absorbs the heat from the room, changing the liquid refrigerant into a cool gas.

Subsequently, the vaporized refrigerant is send to the compressor where the pressure increases. As the gas is compressed, its temperature also rises. By regulating the pressure, the refrigeration system can boil the refrigerant at lower temperatures, making it easier to push the heat around the cycle and into the condenser. Inside the condenser, the coil operates at temperatures higher than air. As a result, the air passing across the coil will be heated and the temperature of the refrigerant will drop. Contrary to the evaporator, a fan will exhaust the hot air to the outdoor. Finally, the refrigerant exits the condenser as a hot high pressure liquid into the expansion valve where the flow is regulated and the pressure decreases to optimal levels. The refrigerant reenters the evaporator and the cycle is repeated. Heat will continue to enter the evaporator and exit the condenser.

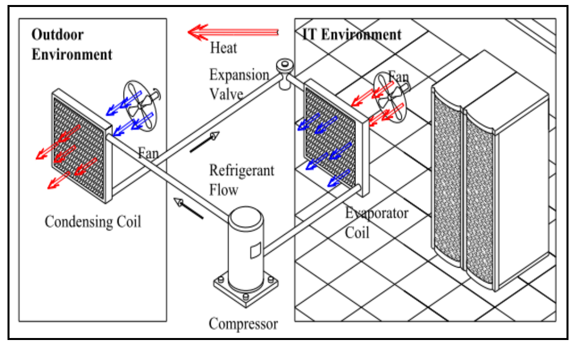

Figure 1
Components Used in the Refrigeration Cycle [2]

Heat Removal Methods for IT Environment

There are five common methods that can be used to remove heat from the IT environment. All of them use the refrigeration cycle. Some of them relocate the components outside of the room and add additional loops of liquids, such as water, to make the heat extraction process more efficient. The following methods were evaluated in detail and considered for implementation in the design. The advantages and disadvantages of each are explain below.

The first method is an Air Cooled Self-Contained System (1 piece), where all of the components of the refrigeration cycle are enclose in a single (1 piece) unit inside the data center. With this system, the exhaust air must be removed to the outside by the use of ducts or rejected into a drop ceiling, if one is available. There are both advantages and disadvantages for using this system. Self-contained systems have the lowest installation cost. The unit is factory sealed and can provide the highest reliability. Moreover, due to their simple component arrangement, no installation of equipment on the outside is required. On the other hand, their capacity to remove heat from the space is limited, up to 15KW [3]. For this reason, they are usually installed in wiring closets, laboratory environment and data centers with moderate requirements.

The second method is one of the most commonly used for small and medium size data centers. They are known as Direct Expansion (DX) Air Cooled Systems or split systems (2 piece). DX Systems operate by having part of the components, involve in the refrigeration cycle, on the inside of the room in the Computer Room Air Conditioner (CRAC unit). The other half is on the outside of the room, located inside the condenser unit. There are both advantages and disadvantages for using this system. Although DX systems have the lowest overall cost and are easy to maintain, they typically can only be used on wiring closets, computer rooms and small to medium data centers where the cooling requirements are moderate. In addition, only one CRAC unit can be attached per condenser. Furthermore, they require the proper installation of piping. Long distances and high altitudes between the room and the outdoor environment should be considered to avoid experiencing reliability issues.

The third method is the Glycol Cooled System, which works similar to a self-contained system in that all of the components are enclosed in the same housing. However, the condensing coil is replaced by a smaller heat exchanger that contains a water and ethylene glycol solution. This mixture can remove heat much easier than air and reject it to the outside via a fluid cooler. Moreover, this type of system has several advantages. All the refrigeration components are factory sealed, which provide better reliability. Also, Glycol pipes can be used for longer distances than refrigerant lines in air cooled systems and can service more than one air conditioning unit. On the other hand, the system does present some disadvantages. For example, additional components such as pump package and valves are require. These can increase the cost of installation when we compare it to air cooled systems. In addition, glycol maintenance is also required. This method typically can only be used in small to medium data centers where the cooling requirements are moderate.

The fourth method is the Water Cooled System. Similar to other methods, the Water Cooled System has all the components of the refrigeration inside the room. As the name implies, water is the fluid used to remove the heat from the IT room, by operating a cooling tower. The cooling tower uses a fan to help in the evaporation of condenser water, which releases heat in a similar way to how the human body is cooled by the evaporation of sweat. One of the advantages of this method is that the refrigeration components are factory sealed, which provide better reliability. Also, the condenser piping can travel long distances and provide service to many air conditioning units, from the use of one cooling tower.

The use of condenser water can be less expensive than chilled water. On the other hand, installing a cooling tower can increase the initial cost due to the piping and pump requirements. What’s more, maintenance is expensive due to the treatment and cleaning of water. A cooling tower is typically used to provide many services, which will affect the individual reliability of each equipment. Nonetheless, they typically can be used in small, medium and large data centers with variable requirements.

The fifth and last method considered was a Chilled Water System. In this system, water is refrigerated to about 46◦F and pump from the chiller to the Computer Room Air Handlers (CRAH) units. The hot air from the room is taken by the CRAH units, making the chilled water going through the unit warmer. Subsequently, the warmer chilled water is returned to the Chiller where it is rejected into a condenser that disposes the heat on the outside environment. There are both advantages and disadvantages for using this system. For example, CRAH units are less expensive than Computer Room Air Conditioners (CRAC) units. They can also remove more heat and contain less parts. Furthermore, the piping can be used for longer distances, providing service to an entire building. Chilled water systems are usually very reliable and can potentially have the lowest cost per kW. However, anything below 100 kW of electrical IT loads, can result in very high capital costs for installations [4]. In terms of disadvantages, CRAH units may require humidification options to control moisture inside the room. In this case, it can become a little more expensive than with CRAC units. Nonetheless, a Chilled Water System can be used with medium and large data centers, making them a good choice for designing a more efficient system and improving the standard model.

Cooling System Configuration

The best suitable cooling configuration depends on the size and power of the data center that will be design. Considering that an organization will most likely have medium to large data centers, the configuration must be adapted to accommodate anywhere from 20 to 100 rack enclosures. This is equivalent to using between 28 to 500 kW of electricity in a medium data center. Anything over 100 rack enclosures or 200 kW of electricity should be consider a large data center [3]. For a medium data center with racks averaging more than 3 kW each, a larger space should be taken into consideration to provide better cooling.

Configuration options for chilled water systems are limited to floor mounted cooling systems. CRAH units should be placed on the floor, where a chiller and a cooling tower can provide the adequate service. Nonetheless, the building must have a reliable supply of chilled water. The same configuration is recommended for data centers classified as large. Ultimately, the reliability and availability of the building systems will play a major factor on the system design.

Air Distribution Approach

There are many techniques use today in which air can be distributed inside a data center, however, all of them can be summarize in three approaches: flooded, targeted, and contained. Each approach can be used for supply or return airflow. In a flooded approach, air is freely released by the supply with no particular objective in mind and is recovered by the return as it comes. As a result, hot and cold air become mixed. For most data centers, this approach is not recommended due to the unpredictability of the supply air temperature and its poor energy efficiency.

Another alternative is to use a target approach. This particular scenario can be achieved by the use of perforated tiles, ducts, and the strategic placement of the cooling units. Target approach is more energy efficient than the flooded approach. By significantly reducing the mixture of hot and cold air, about 60% to 80% of the hot air can be capture and returned to the cooling unit for processing. Consequently, the supply air can be more predictable and the distribution is capable of cooling 8 kW per rack [4].

The last approach is containment of the supply and the return air. By using this method, the mixture of hot and cold air is completely eliminated with the help of enclosures. Containment is highly efficient and can capture anywhere from 70% to 100% of the hot air inside the room, making the supply extremely predictable. This translates into lower operational costs. As a result, the distribution is capable of cooling 30 kW per rack [4]. For this particular project, the standard model data center can be improve by implementing a combination of targeted and containment approaches.

DATA CENTER LAYOUT DESIGN

To achieve targeted and containment air distribution approaches, a number of practices were implemented first. Among these are: cold and hot aisle separation, management of the racks internal airflow, integration of the air conditioning system, and containment of the hot aisle.

Cold and Hot Aisle Separation

Having the rows facing in the same direction causes that each row feeds the exhaust air to the one in the front. Two things can happen during air mixing. First, the temperature of the return air decreases, affecting the capacity of the unit. Second, the temperature of the supply air increases, causing recirculation of warmer air into the equipment. Since the temperature across a server can range from 10ºF to over 40ºF, overheating of the equipment is a possibility [1]. As a result, cooling performance can be affected, if air is not managed properly.

A more efficient configuration can be easily achieved, by positioning rows of racks in alternating positions. For example, two rows facing each other, front to front, will create a cold aisle. Likewise, placing two rows facing back to back will create a hot aisle. In terms of spacing, the recommended width for cold aisle is 48 inches, and for hot aisles a minimum of 24 inches. In addition, cold aisles must be at least 14 feet apart from each other, measured from the center of one aisle to the center of the other [5].

Moreover, the equipment must be installed into the racks to manage a front to back airflow distribution that can draw cold supply air from the cold aisles and reject the hot air into the hot aisles. By removing the air mixture, hot spots can be eliminated, significantly reducing the consumption of energy. For non-standard equipment, in which the exhaust is located on any alternate direction, the installation must be address separately to redirect the exhaust hot air into the appropriate direction.

Rack Internal Airflow

Racks are designed, not only to hold the equipment in place, but to accommodate the front to back cooling requirements. For this design, the front and rear surfaces of the racks shall have, at least, 65% open area to pass on the incoming airflow [5]. Extreme high density racks were avoided, to prevent the higher pressure inside the cabinet from pushing the exhaust air around the side and back to the inlet. Furthermore, blanking panels must be installed in open spaces, on the front of the racks, where equipment is missing. This prevents cold and hot air from mixing and creating a short circuit, where air is bypass, as shown in Figure #2, causing the equipment to be overheated.

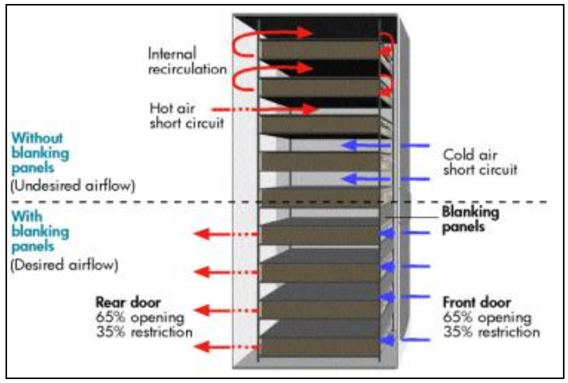

Figure 2
Rack Airflow [5]

Air Conditioning System Integration

The path of hot airflow can become highly unpredictable, as the demand for IT equipment and power increases. Design approaches, such as room, row, and rack based cooling, can be used to address this problem. When using room based cooling, the CRAH units continuously operate to remove the heat load of the room as a hole. Supply and return air is not restricted by the use of ducts and dampers. Raised floors can be used to provide supply air and the hot air can be return with an over head plenum. In addition, with this system the cooling distribution can easily be changed by reconfiguring the floor tiles. Nonetheless, this type of design may be restricted by the shape of the room, rack layout, ceiling height, floor obstructions, CRAH location, and IT loads. Future alternations to the room will require a new design.

Moreover, full use of the CRAH unit capacity my not be possible due to the many air distribution pathways that increase the chances of air bypassing the equipment and returning to the unit. This causes inefficiencies in the performance of the units, which are not able to handle the load of the room, despite having the capability to remove the heat. To prevent this inefficiencies, room based cooling should be used in combination with hot aisle containment for new data centers greater than 200 kW [6].

Another design approach is using a row based cooling configuration, where CRAH units are designated to provide cooling for a particular row.

This approach reduces the distance between the IT equipment and the CRAH units. As a result, the airflow travels shorter distances, increasing efficiency and reducing the CRAH fan power required to move the air. The predictability that comes with this design can help achieve higher power density.

Furthermore, by targeting a specific row, its requirements can be assess more efficiently. Row based cooling can be implement without the need of raised floor and is recommended for higher density loads of 5 kW per rack or above [6]. In addition, it can be implement alongside with hot aisle containment system.

A different approach is using rack based cooling, where CRAH units are designated to individual racks. For this particular design approach, room constraints are non-existent. The needs of the individual racks can be satisfied. Airflow paths are short, reducing the require CRAH fan power and making the system very efficient. Rack base cooling can achieve the highest power density of the three approaches, by been able to cool up to 50 kW racks [6]. Nevertheless, one of the disadvantages of using this approach is that it requires a large number of air conditioning units and the installation of piping, driving the cost significantly higher.

Ultimately, the pros and cons of the three design approaches were evaluated. Considering the high cost of both row and rack based cooling, it may become difficult for the average company to invest in these approaches. One of the objectives of this design is to develop realistic guidelines that contemplate affordable methods at a reasonable payback period. As a result, room based cooling was used to improve the standard model, due to its easier implementation, ability to change when reconfiguration is necessary, and low cost. Nonetheless, hot aisle containment was implemented in combination with this approach to achieve higher levels of efficiency, provide predictability for the data center, and support high density racks when necessary.

In addition, the placement of the CRAH units should be aligned in close proximity to the hot aisles and in perpendicular direction to the rows. The idea behind this configuration is to reduce the distance the hot air has to travel when returning to the unit. This provides a more efficient air management and can reduce the cost of material in cases where ducts are install.

Containment Design

The application of containment methods provides many benefits to the data center. First of all, containment prevents the mixture of cold and hot air, virtually eliminating hot spots and increasing the reliability of the IT equipment. Similarly, recirculation of hot air inside the racks can be avoided. Avoiding bypass air can improve the cooling capacity of the units by 20%, increasing the differences in temperature between the cold and hot air [7]. By doing so, rack densities can be increase without worrying about the formation of hot spots. Figure #3 shows a thermal picture that was taken of one of the rack rows in the standard model data center. Evidently, hot spots have developed.

Ultimately, all of these can be transferred into energy savings by reducing the need for extra cooling units, and the additional work performed by the compressors and the fans. However, before selecting the containment method, an assessment was performed on the current conditions of the facility and the space under evaluation. A number of possible constraints were examined to determine whether they can be overcome and at what expense.

First of all, a height of at least 2 feet is required to accommodate the installation of a drop ceiling where air can be returned by using the ceiling as a plenum. Similarly, the depth of the raised floor plenum must be at least 2.5 feet to provide enough cool air volume for high density racks. When designing data centers, measures should be taken to limit the amount of cables, conduit, and piping under the floor that can have negative effects on the airflow. The electrical, piping and plumbing design are out of the scope for this project. As a result, the depth of the floor represents a conservative estimate to avoid airflow stagnation.

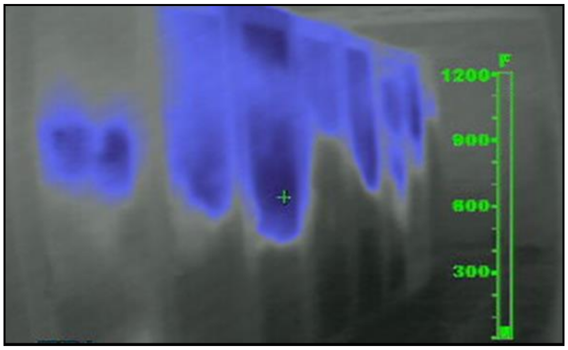

Figure 3
Thermal Picture of Racks

Although structural design, such as the location of the columns inside the facility, may represent a constraint on the application of containment, this is not the case for the space under evaluation. Columns will not interfere with aisle containment or any other equipment inside the facility. In addition, human comfort levels can represent a constraint in the design. Depending on the type of containment applied, the rest of the room may become a return air plenum. Working in these type of environment can become problematic. When redesigning the data center, human comfort levels were taken into consideration. Likewise, containment can caused the aisle to have poor lighting. The implementation of lighting requires the expertise of an electrical engineer. Nonetheless, measures were taken in the design to limit the amount of light that can affect visibility in the aisles, by installing translucent panels/curtains.

Once the assessment is completed, the best containment method for this particular scenario can be selected. It is important to notice that data center units are usually set to supply air at an average of 15 degrees cooler than is necessary, due to unpredictability of supply and return air mixing [8]. As a result, three approaches were considered: cold aisle containment, hot aisle containment, and complete containment.

Experts in the field estimate that, at least, 40 percent of the cold air supply by the cooling units is not able to reach data center servers. One of the reasons for this is that the temperature of the supply air can change by approximately 10 degrees between the floor and the top server intakes [8]. Cold aisle containment solves this issue by separating the supply air from the warm room, making it an extension of the floor plenum, and improving the system efficiency.

On the other hand, the method lacks the ability to control the return air, making it less efficient than hot aisle containment. In addition, containing the cold aisle means that temperatures on the rest of the room could become uncomfortable, having a direct impact on human comfort and possibly other equipment outside the contained aisles. In general, cold aisle containment is recommended when the data center has a raised floor and flooded return, no equipment is on the perimeters, and cooling high density racks is a priority.

A better alternative to improve the standard model is to use hot aisle containment. In practice, this method has the same function as cold aisle containment in that it prevents the mixing of cold and hot air. Nonetheless, hot aisle containment takes a different approach by returning the hot air directly to the cooling units. This tactic can be very beneficial to the data center. The room can get hot very fast. However, by containing the hot air, the increase in temperature has no negative effect on the room environment and human comfort is not affected. On the contrary, the hot air will be at its maximum temperature when it reaches the cooling units. The hotter the air, the more efficient the heat exchange inside the cooling unit and the lower the operational costs. Although having a raised floor is not necessary, having an available drop ceiling return plenum is recommended.

While complete containment of both hot and cold aisles was considered, implementing this approach may result in room imbalances, making it harder to manage. Buildup of static pressure or vacuum can potentially develop. Containing only one aisle can be more reliable, since the room can equalize the pressure on its own and the same result of eliminating the mixture can be achieved.

HIGH DENSITY DESIGN

Ideally, the power generated per enclosure or rack should be the same. In practice, however, this is not the case. The power density can vary significantly, affecting the design of the cooling system. Surveys by the University of California at Berkeley found that, for 90% of data centers, the highest power enclosure or rack is less than 6kW [9]. Providing the required amount of cool air is essential to keep the servers from pulling hot exhaust air from the neighboring equipment and causing the system to overheat.

Floor tiles can be used to deliver cool air to the racks. Nonetheless, careful consideration must be taken to prevent the pressure under the floor from changing and affecting other regions of the room. Increasing the raised floor depth, too much, can decrease the variation in cooling capacity per tile. Also, using one vented tile per rack is not enough to cool enclosures of over 6 kW [9]. As a result, two simple rules were followed in this design. First, high density racks cannot be located close to each other or on any row corners. This keeps the exhaust air from wrapping around the end of rows and infiltrating into the cold aisles. Second, the equipment shall be split among the racks to avoid exceeding the design requirements for power density.

ENERGY ANALYSIS

Following the previous recommendations and design practices is the key in determining the proper cooling requirements of any new or existing data center. To see the effects of the guidelines developed so far, the conditions of an existing data center were studied and used as a baseline. A full analysis of the room parameters was performed, and the most common design flaws were identified with the intention of redesigning a new and more efficient data center of equal size and power. The analysis indicated that the existing data center can be classified as inefficient. The methodology used for classification is based on a metric known as the Power Usage Effectiveness (PUE) and the main goal is to improve this metric.

Baseline Analysis

The data center under evaluation has a 2,320 square feet area and a 12.5 feet ceiling height (floor to roof). Six cooling units, provide a total cooling capacity of 768 kW. There are 48 IT server racks, Power Distribution Units (PDU) and Uninterruptable Power Supplies (UPS), giving a total IT equipment heat output of 271 kW. The chiller and the generator are not located inside the room. As a result, their heat contribution to the room is zero.

While heat output by the lights was considered in the calculations, the analysis does not take into account sources of environmental heat such as heat conduction through external walls or sunlight through windows. Many data centers are located in central zones confined by the air conditioning facility and are not exposed to windows. As a result, the change in temperature is zero and no error results from this assumptions. Nonetheless, if the walls or roof of a data center were exposed to the outdoors, the additional heat entering the room should be accounted. Although most of the heat load for data centers is sensible, latent heat was also taken into consideration. Ultimately, the design is based on a total indoor heat output of 338 kW.

The Cooling Capacity to IT Load Ratio (PUE) for the standard model data center was determined to be 2.8. This basically means that for every 2.8 watts "in" at the utility meter, only one watt is delivered out to cool the IT load. This is a clear indication of inefficient air management and a high level of hot and cold air mixture inside the room. Although the average data center has a PUE of 2, ideally the PUE should be as close to 1 as possible. By using efficient practices, most facilities are capable of achieving, at least, a PUE of 1.6 [10].

Ideal Design Analysis

There are two important parameter that were consider for redesigning the new data center: the total capacity of the cooling system, and the airflow distribution inside the room. Both of these were evaluated simultaneously, since the formation of hot spots is usually as a consequence of the inability to properly distribute the airflow and not for the lack of capacity by the cooling system.

Design improvements were based on the idea that by reducing the mixture of air we can safely increase the supply temperature to ASHRAE standards and increase the ΔT. A larger ΔT makes the heat exchange inside the cooling units more efficient, which results in the effective removal of energy and lower operational costs. Consequently, the amount of airflow (cfm) to the room can be reduce. Figure #4 shows the benefits of increasing the ΔT. As we can see, the same amount of heat can potentially be remove from the room with less airflow (cfm).

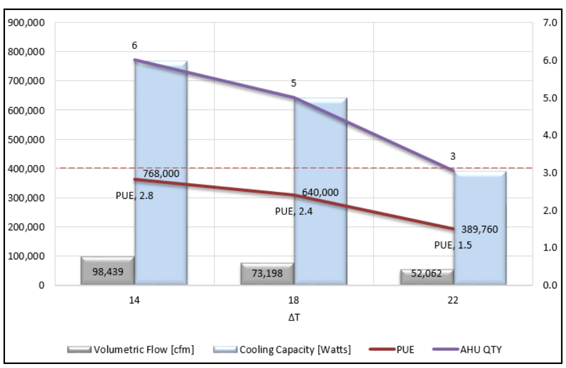

Figure 4
Cooling Analysis

Furthermore, each unit uses a centrifugal blower to supply the airflow. The amount of electrical energy required by the AHU fan can be 5-10% of the rated cooling capacity. In addition, the compressor can account for 20-30% of the rated cooling capacity [2]. By increasing the efficiency of the data center, only three Air Handling Units are necessary to keep the servers from overheating. The other three units can be turned off or be redundant and used when the demand for IT equipment and power increases. This represents a viable option for reducing the energy consumption inside the room. Ultimately, the PUE of the data center can be decreased to 1.5, putting it in the category of very efficient.

To achieve this, the following parameters are recommended. The optimal ambient temperature range is 68° to 75°F and should not exceed 85°F. This range takes into account the system reliability by keeping the IT equipment safe from overheating in case of HVAC failure or downtime. The temperature at the server inlet can vary, depending on the layout of the room. Temperature sensors are recommended in each aisle as a precaution [11].

Similarly, the recommended temperature range provides better control over the relative humidity level in the room. The optimal humidity level is between 45% and 55%. Water condensation can caused corrosion when relative humidity levels are too high. On the other hand, equipment can be susceptible to electrostatic discharge when the relative humidity is too low. A monitoring system that can provide early warning alerts at 40% and 60%, and critical alerts at 30% and 70% is recommended [11].

Last, the recommended air pressure for computer rooms is in the range of 0.03 to 0.05 in of static pressure [12]. To avoid infiltrations from untreated air, the room must be kept with a positive air pressure. This can be accomplished by adjusting the opening of the dampers. In the case of the floor plenum, the airflow panels will regulate the pressure.

TOTAL COST OF OWNERSHIP

Data Centers are design for 10-15 years. Server's life is between 3-5 years [13]. Based on an analysis were the average cost per server is $1,300 and the number of servers is 384, we can determined the total capital cost of servers in the data center to be $499,200. By replacing the equipment every 3 years during the design life of 10 years, the total expenses on servers will be $1,664,000. On the other hand, replacing the equipment every 5 years during the design life of 10 years will cost $998,400. This will give us savings of $665,600 over the design period. Consequently, by reducing the mixture of air in the data center, the life of the equipment can be extended.

CONCLUSION

Airflow management is essential to preserve the lifespan of the IT equipment and prevent failure due to increasing temperatures and the formation of hot spots. As a result, a series of guidelines were developed to offer insight into increasing the efficiency of data centers. This was accomplished by redesigning the air conditioning system infrastructure, developing a strategic layout arrangement, and controlling the rack density to lower the energy consumption.

A Chilled Water System was used as the heat removal method, where the air distribution was based on a combination of targeted and containment approaches. To make this possible, good practices, such as cold and hot aisle separation, management of the racks internal airflow, integration of the air conditioning system, and containment of the hot aisle, were implemented.

Since the path of hot airflow can become highly unpredictable, as the demand for IT equipment and power increases, the techniques mention before were developed to help achieve a maximum return temperature. As a result, the heat exchange inside the cooling units can be more efficient. A larger ΔT results in a more effective removal of energy and lower operational costs. Consequently, the amount of airflow (cfm) to the room was reduced, and the efficiency of the data center was increased.

REFERENCES

[1] N. R. Laboratory, “Best Practices Guide for Energy Efficient Data Center Design”. *US Department of Energy*, 2011.

[2] T. Evans, “Fundamental Principles of Air Conditioners Information Technology White Paper 57”, *Massachusetts: Schneider Electric*, 2011.

[3] T. Evans, “The Different Types of Air Conditioning Equipment for IT Environments White Paper 59”, *Massachusetts: American Power Conversion Corporation*, 2004.

[4] N. Rasmussen, “The Different Types of Air Distribution for IT Environments White Paper 55”, *Massachusetts: American Power Conversion Corporation*, 2012.

[5] C. Koplin, “Optimization Facility Operation in High Density Data Center Environments”, *Hewlett Packard Development Company*, 2007.

[6] K. Dunlap, “Choosing Between Room, Row, and Rack-based Cooling for Data Centers White Paper 130”, *Massachusetts: American Power Conversion Corporation*, 2012.

[7] P. Lin, *et al.*, “Implementing Hot and Cold Air Containment in Existing Data Centers White Paper 153”. *Massachusetss: American Power Conversion Corporation*, 2013.

[8] S. Hambruch, “Improving Data Center Efficiency and Capacity with Aisle Containment”, *Data Center Resources*, 2015.

[9] N. Rasmussen, “Power and Cooling for Ultra High Density Racks and Blade Servers White Paper 46”, *Massachusetts: American Power Conversion Corporation*, 2005.

[10] P. Bemis and L. Marshall, “Improving Data Center PUE Through Airflow Management White Paper 103”, *Applied Math Modeling Inc*, 2010.

[11] R. Grundy, “Recommended Data Center Temperature & Humidity”. *AVTECH News*, 2005.

[12] C. Opherson, “Rules of Thumb for Troubleshooting”, *California: The News Magazine*, 2001.

[13] M. Patterson, “Data center TCO; a comparison of high-density and low-density spaces” *Santa Fe: Intel Corporation*, 2007.