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MODELING MISSION CRITICAL FACILITIES FOR LEED: LESSONS LEARNED

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ABSTRACT

The critical facility market has grown exponentially in recent years with numerous new data centers being built worldwide. With its unique characteristics, special attention needs to be paid when modeling the performance of the data centers for design or Leadership in Energy and Environmental Design certification (LEED). This paper presents a technical overview of data centers, including a few components and unique characteristics; a description of various configurations such as hot aisle/cold aisle containment, economizing and virtualization; and an overview of the LEED modeling requirement for data center applications. It also provides techniques on properly simulating the energy use of data centers for design or LEED purpose.

INTRODUCTION

With the blooming of IT technology, our modern world increasingly relies on digital and cloud-based data. New mission critical facilities (data centers) are consistently being built throughout the world and existing data centers are expanding and upgrading to meet the future needs. The global data center construction market will grow from $14.59 billion in 2014 to $22.73 billion by 2019, at a compound annual growth rate of 9.3%. The market for data centers is thriving and expected to show significant growth rate with a consequent rapid growth in energy use and associated greenhouse gas emissions.

Amongst this growth, data center owners are embracing the rising awareness of green building design and their associated environmental responsibilities. They are seeking out sustainable design solutions that reduce the operating energy cost and enhance the performance of their facilities.

To this end, developed by U.S. Green Building Council, LEED (Leadership in Energy and Environmental Design) is a globally recognized and widely used green building rating system designed for all building types. Not surprisingly, less than 5% of the total datacenters in the U.S. today are currently LEED certified. This, however, is changing; within just our own firm, we have certified 19 data centers nationwide including Platinum certification.

To properly analyze and certify a data center, we must first appreciate that they are unique creatures. Typical buildings generally divide the building energy into three relatively equal parts: HVAC, lighting and plug load. In contrast, the energy use of a data center is dominated by the electrical demand of the IT servers, storage, and the supporting electrical infrastructure. In addition, there is little seasonal or geographical variation in thermal loads; the energy consumption of data centers is nearly flat throughout the year. Finally, the primary purpose of most buildings is to provide a comfortable indoor environment for human occupants. A data center’s sole purpose is to maintain a 24-hour uninterrupted runtime environment.

The electrical infrastructure of a critical facility consists of three (3) major components: the grid-provided utility power, the emergency standby generator and the uninterruptible power system (UPS). The data center equipment is supplied power through the UPS, which provides instantaneous protection from power interruptions and fluctuations. A UPS system consists of three (3) components: a rectifier, a battery and an inverter, which converts AC power into DC form and converts back to standard 60hz AC power for distribution. The efficiency of rectifiers and inverters have a great impact of the UPS efficiency. Finally, and the most importantly, the more efficient that the servers are, the less power is used, the less heat is produced and the less cooling is required.

Beyond the electrical infrastructure, the cooling system is the most critical element. Cooling is generally the second most intensive energy component, consuming between 15% and 25% of the total energy use. The cooling system is most commonly comprised of packaged direct expansion (DX) systems in smaller data centers and central system chilled water systems in larger ones. Though one-to-one standalone Computer Room Air Conditioning (CRAC) or Computer Room Air Handling (CRAH) units are flexible and provide excellent scalability for the capacity growth of the data center, they do not provide the same level of energy efficiency. Thus, the central hydronic chiller plant with chilled water delivered to individual CRAC/CRAH units are typical in large data centers. Beyond these common configurations, there are numerous alternatives within the market, including: evaporative cooling, in-row cooling, active cabinet cooling, and even water-cooled, submersible IT equipment!

LEED V4 FOR DATA CENTERS

The most current LEED rating system, version 4, begins to address Data Centers more specifically and provides distinct guidance in evaluating the performance of data centers.

USGBC requires whole building energy modeling for all data center projects and requires the determination of the predicted power usage effectiveness (PUE). PUE is the standard metric for evaluating the overall building infrastructure efficiency; this is the ratio of the total data center energy consumption to the IT energy consumption. The lower PUE, the more efficient the infrastructure design, and the less costly to operate the facility. Depending on the geographic location and project design, we typically see PUEs in the range of 1.2 to 1.5, though extremes at both ends are possible. For LEED, the PUE must be calculated for two operating conditions: one assuming the initial startup IT equipment load at “Day 1”, and one assuming a fully fit-out data center with all anticipated IT equipment.

The simulation of the Proposed model is fairly straight forward, it is the development of the Baseline energy model that can get complicated. Like all projects, the Baseline is developed following the ASHRAE 90.1 PRM methodology, as defined by Appendix G. Based on the project criteria, the primary HVAC system type is usually a variable volume (VAV) system (System 5 through System 8). However, exceptions to G3.1.1 direct the data hall to be served by the constant volume systems System 3 PSZ-AC (packaged single zone – air conditioner) or System 4 PSZ-HP (packaged single zone-heat pump). These exceptions are applied to spaces that have occupancy, process loads, or schedules that differ significantly from the rest of the building. A typical data center includes minimal office space with the balance of the project split between high density white space (data hall) and mechanical/electrical support spaces. This results in the application of System 3 or 4 to the white space and mechanical support rooms, while the small office is served by the VAV system. It should be noted that ASHRAE 90.1-2013 has overhauled the Baseline system selections. Under this new version, all data halls are to use System 11 which is a single zone chilled water VAV unit with an integrated waterside economizer. Similar to the Proposed, the PUE must be calculated for Baseline model as well (with both start-up load and the full fit-out load).

Furthermore, the energy savings from the unregulated IT systems can be claimed through the Data Center Calculator provided by USGBC. It creates a representative IT energy baseline which evaluates the efficiency and utilization of both the computer servers as well as the electrical infrastructure. It produces the annual energy consumption saving values for the LEED exceptional calculation as well as the inputs for the energy model on calculating the corresponding cooling savings.

EXCEPTIONAL APPLICATIONS

Data centers present many unique and interesting applications for design, but even more interesting for simulation. Amongst many methods, configurations, technologies and workarounds, we have found the following 3 items especially pertinent in the energy analysis for data centers. This section describes the methodology for addressing the simulation input, independent of the energy modeling software.

Hot Aisle/Cold Aisle Containment

Overview

Over the past decade, containment has become a common design strategy within large data centers; this includes both cold aisle and hot aisle containment. All containment strategies are based on the simple premise that we isolate the airflows before and after the IT equipment. Without containment, the hot exhaust from the server racks mixes with the supply air prior to entering the intake of the server racks. It is this inlet temperature that is the critical controlled temperature in a data center. As such, the mixing of exhaust with supply air degrades the supply air temperature and requires colder supply air.

In 2004, the first edition of ASHRAE TC 9.9, the Standard that governs conditions in critical facilities, called for <u>room</u> temperatures to be in the 68°F-77°F (20°C-25°C) range. In 2008, the second edition of the Standard made two changes particular to containment. First, it noticeably expanded the conditioning to 65°F-80°F (18.3°C-26.7°C) and second, a more subtle change, it switched the governed temperature from the entire room to just the server inlet. It wasn't until 2011, the third edition, that we began to see a significant change in the industry.

In a containment strategy, each row of server racks is organized to face each other with the inlets served by the same aisle (the cold aisle) and the back sides or exhausts similarly organized around the same aisle (the hot aisle). Supply air is supplied to the cold aisle, while return air is pulled from the hot aisle. Once organized in this fashion, containment then refers to hard surfaces used to isolate either the cold or hot aisles from the balance of the data hall.

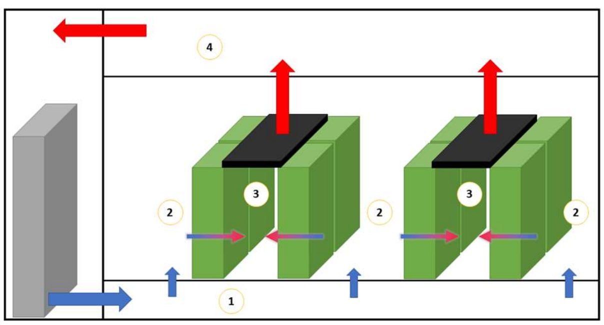

Figure 1 – Hot Aisle Containment

Simulation

In setting up containment within the simulation it is first important to understand how the data center operations differ from a typical energy model expectation. In general, an energy model expects a thermostat to reflect the net energy input or output of a "well-mixed" space. However, a data center with containment not only is not a well-mixed zone, but it is not controlled to a specific "room" temperature.

To best understand the energy model configuration, it is important to first understand 4 distinct points in the airflow path of a data center, see Figure 1.

1. Supply Air – The air leaving the AHU; this is generally not the same as the air entering the data hall.
2. Server Inlet Air – Air entering the server racks; this includes temperature degradation from supply distribution, mixing with room air, and a portion of the server load itself. This is the critical point of control and the temperature that is governed by ASHRAE TC 9.9.

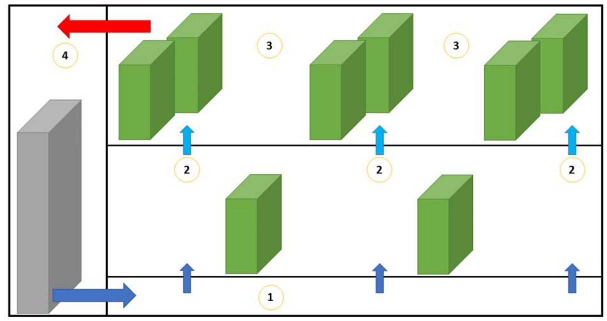

Figure 2 – Representation of Containment in Simulation

3. Server Outlet Air – Air exiting the server racks; generally, airflows are designed around a 20°F (11.1°C) delta T across the rack. It should be noted that the delta T across the cooling coil is greater than that across the rack.
4. Return Air – Air returning to the AHU; this accounts for any mixing of server outlet air with supply air.

To account for containment within the energy simulation, we create a plenum and apply a portion of the data load to this plenum. The split of the load between the "occupied" space and the "plenum" space defines the level of containment simulated. In this way, the energy simulation sees the cold aisle as the well-mixed, conditioned zone. As shown in Figure 2, the supply air enters the zone, the energy causing thermal degradation is added to the zone, and the consequent "return air" leaving the conditioned zone represents the server inlet air. The balance of the data load is then added in the plenum, essentially simulating the load across the server rack and results in a temperature rise across the unconditioned plenum.

For an example, imagine a 1 MW data hall – a 3,412,000 Btu/h cooling load (ignoring all other loads) that employs a 75°F (23.9°C) inlet server temperature. In one application, we have ideal containment and in another application, we only have partial containment. Table 1 shows the expected operational parameters, while Table 2 shows the consequent split in the IT load input into the energy model.

Table 1 – Example - Operational Parameters

OPERATIONAL PARAMETERS	IDEAL	PARTIAL
IT Load, kBtu/h	3412	
% of load met by airflow	95%	
Rack Load, kBtu/h	3241	
Airflow (@20F dT), cfm	150,000	
Server inlet temperature	75°F (23.9°C)	

Thermal degradation	4°F (-15.6°C)	12°F (11.1°C)
Supply air temp	71°F (-21.7°C)	63°F (17.2°C)
Return air temp (21F dT)	92°F (33.3°C)	84°F (28.9°C)

SIMULATION INPUT	IDEAL	PARTIAL
IT load applied to zone, kBtu/h	648	1944
IT load applied to plenum, kBtu/h	2764	1468
% of load to zone/plenum	19%/81%	57%/43%

Table 2 – Example - Simulation Input

Some of the benefits of this simulation strategy include:

- Accurately simulates the increased air temperatures across the cooling coils to properly account for compressor savings due to economizer and higher operating temperatures.
- Allows for the modeled "Space Temperature" to reflect the Server Inlet temperature, making the energy performance comparison of containment significantly more straightforward.
- Allows for the self-sizing routines to properly size airflows.

LEED

The Baseline model for LEED assumes no containment. Therefore, the entire IT load is entered the occupied space and no load occurs in the stratified space. If the server inlet temperature in the Proposed model is 75°F (23.9°C), then the room temperature in the Baseline model is set at 75°F (23.9°C) as well, this leads to a supply air temperature of 55°F (12.8°C).

Economizing

Overview

It was less than 10 years ago that not only standard practice, but recommended practice, controlled the room temperature of entire data halls to the ~68°F (20°C) range. To accomplish this, typical supply air in the ~55°F (12.8°C) range was employed. Under these design and operating parameters, economizing, or the "free" cooling stemming from compressorless systems, was simply seen as more trouble than it was worth. However, based on research showing that current IT equipment could operate and survive at more extreme conditions coupled with the subsequent focus on inlet temperature rather than room temperature, economizing has become an essential element of nearly every data center design.

First, economizing encompasses a number of different technologies and strategies. Given that there is no consistent terminology in the industry, we have classified them into the following 4 categories.

- Airside
  This is the traditional approach of using outside air instead of return air to cool the data hall. In a containment strategy where the return air is likely ~90-95°F (32.2°C-35°C) (~30 Btu/lb, more accurately), the system will often operate at 100% outside air during all but the most extreme days and then ramp down during cold weather to avoid over cooling the space. This is certainly the simplest approach, but will require massive outside air intakes and relief air exhausts, not to say anything about additional filtration and air quality issues.
- Waterside-Precooling
  This approach adds a precooling coil in each AHU and generally uses condenser water from the cooling towers to precool the return air prior to the primary cooling coil. In a containment configuration, the precooling coil sees ~90-95°F (32.2°C-35°C) return air that is precooled with ~65-80°F (18.3°C-26.7°C) condenser water. This strategy keeps the data hall air isolated, but requires water for all cooling; though similar approaches have used air to air heat exchangers in place of the precooling coil.
- Waterside-Plant
  This is the traditional approach where cooling towers are allowed to deliver chilled water "directly" to the air handling units. Though parallel configurations have been more traditional in the past, this setup only allows economizing when the cooling towers can provide the entirety of the chilled water load. The series configuration is more common and allows for operation under both partial or full economizing loads. The cooling towers precool the return chilled water leaving the chillers to provide the unmet load. Given the same containment system, chilled water temperatures are generally in the ~54 supply /~70 return range. This offers significant opportunities for water only cooling.
- Refrigerant
  New to the market, in both air-cooled chiller and packaged DX formats, we are now seeing economizing equipment that can bypass the compressors converting the refrigeration loop

into a run around heat exchanger between the outdoor condensers and the evaporators. Though not as energy efficient on the surface, it uses no water and maintains the isolation of the data hall air.

Simulation

Airside economizing is fundamental to all energy simulation programs, however, correctly addressing humidification in combination with airside economizers can be tricky.

- Humidity is the primary concern in both realty and in simulation. ASHRAE TC 9.9 recommends a humidity no less than a 42°F (5.6°C) dewpoint, or as industry seems to have settled on a number, 40% RH. With the use of airside economizer and no internal sources of moisture, there is the potential for significant humidification. From a simulation perspective, it is critical to understand how the software address space humidity. Some programs like IES-VE (Integrated Environmental Solutions-Virtual Environment) can control humidification based on individual space or return conditions, while other programs like eQUEST control humidification on return air only. The significance can be seen in the following example. Given a containment configuration, a 40% RH at a server inlet temperature of 70°F (21.1°C) has a dewpoint of 45 °F (7.2°C), while the same 40% RH of the return air temperature of 95°F (35°C) has a dewpoint of 67°F (19.4°C). In this scenario, you would want to humidify to a return air RH of roughly 20% to maintain a room RH of 40%.

Again, waterside economizers are fundamental in most energy simulation packages. There are a few unique workarounds in various platforms that we have used in simulating data centers.

- In IES-VE, we have the options of for precooling, as well as both parallel and series plant configurations built in. However, with IES-VE, the condenser water pumps are required to be constant volume. In many applications, the condenser water pumps are actually operated at a variable flow. In these instances, an effective W/gpm must be calculated outside the program.
- Though rumors abound for the existence of a version of eQUEST that includes a waterside economizer in series, for the time being this is still a rumor. With the implementation of containment in data centers, the performance

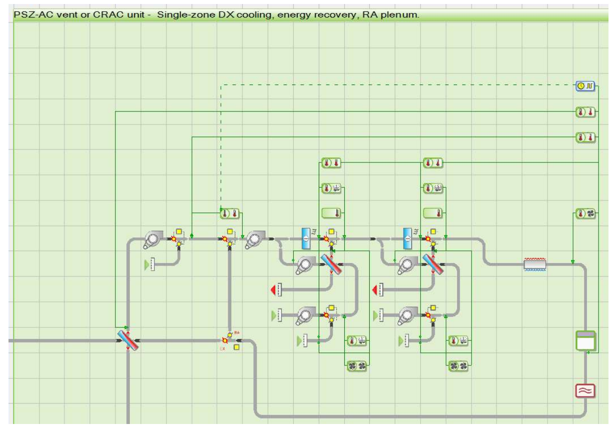

Figure 3 – IES-VE ApacheHVAC – Refrigerant Economizer

difference between the parallel configuration that we can simulate and the series that we cannot is massive. As a workaround, we have been able to simulate pipe loss on the chilled water return leg to emulate the precooling that the waterside economizer would provide. It is a fairly ugly process, but with the pipe located in the ambient conditions, the UA on the pipe loss can be calibrated to match the precooling expected at a variety of outdoor temperatures and offer the effective performance of the economizer

Unlike the other economizers, refrigeration economizers are new and needed a custom approach to set them up in the energy model.

- Most recently, we were able to use IES-VE to explicitly simulate the operations of adding a refrigerant economizer to an air-cooled packaged DX CRAC. The real-life CRAC has 2 separate refrigeration loops in series and each can operate with either a refrigerant pump to transfer heat from evaporator to condenser or a compressor that powers the refrigeration cycle. Within the energy model schematic in Figure 3,

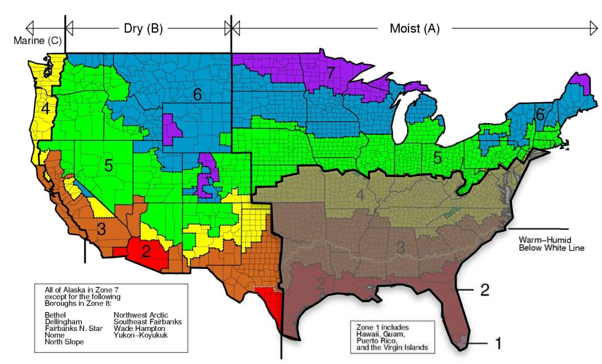

Figure 4 – ASHRAE 90.1 Climate Zones

we first mimicked the cooling coils in series, each providing a 12°F (6.7°C) delta T to achieve the combined 24°F (13.3°C) delta T. Each circuit includes a branch prior to the cooling coil. The airflow down each path is dictated by outdoor air conditions. Within the proper temperature ranges, the full flow of supply air bypasses the cooling coil and passes through an air to air heat exchanger (HX) with outside air. This HX mimics the run around HX functionality of the refrigerant. Finally, the energy used by the refrigerant pumps and condenser fans were simulated using the fans on the supply air side stream and outdoor air stream, respectively. This configuration allows for 3 operating modes: full economizing, partial economizing (bypass first cooling coil), or no economizing.

LEED

The original concerns for introducing large volumes of outside air into the critical environment have mostly been abandoned. The Baseline model requires airside economizers for all data centers, except in climate zones 1a, 1b, 2a, 3a, & 4a. As can be seen in the map in Figure 4, the majority of the country requires an airside economizer. Interestingly, ASHRAE 90.1 does acknowledge this lingering concern in the industry and exempts all Tier IV data centers. Technically, this is part of the prescriptive compliance path, but we have carried this intent over to the PRM methodology.

As noted earlier, the 2013 version of ASHRAE 90.1 has overhauled the baseline system selection for data centers. These changes, in terms of economizers, require an integrated waterside economizer to be applied to all data centers in all climate zones.

Virtualization

Overview

There is no single bigger opportunity for energy savings than attacking the IT load itself. As discussed previously, our typical PUEs in the range of 1.20 to 1.50 convert to IT equipment that is responsible for 67% to 83% of the total building energy. Virtualization is just such a strategy that uses less equipment and less power to provide the same workload. Technically, virtualization replaces the old *1 box – 1 application* concept with a *1-box – multiple application* approach. Simplistically, the energy savings does not come from more efficiently producing the workload, we actually assume the energy per process is the same between the two configurations. Rather the savings is realized by dramatically reducing the massive standby losses. Virtualization can reduce IT energy by up to 70%!

All of this is amazing, but what is interesting is if you look at a data center from a total energy or a PUE perspective, the virtualized data center rarely outperforms the non-virtualized. Essentially, a 5 MW virtualized data center will always consume more energy than a 5 MW non-virtualized datacenter…it is actually the production or output of the virtualized data center that is dramatically increased. The virtualized data center performs significantly higher on a metric such as "Workload/W."

Simulation

The simulation of a virtualized data center is quite simple…it really comes down to a single input of wattage for the data hall. Whether virtualized or not, the connected load of a data center is always a known quantity, one of the primary parameters of the project. The difficulty in the simulation is defining what you are comparing against. Theoretically, we would determine the annual energy consumption of a non-virtualized data center producing the equivalent workload, or maybe more appropriately a data center that was only 20% virtualized.

Though a few years back, this is where we would begin to make assumptions about virtualization rates and utilization rates to put together a reasonable estimate to compare against. Today this is where we turn to the virtualization tool (Data Center Calculator) put out by the US Green Building Council (USGBC) for just this purpose. Within the spreadsheet, you enter the connected load of the design, expected utilization rates, virtualization rates, even the anticipated server performance data. The result of the tool is the calculation for the annual kWh for both the design and for the "equivalent" baseline. The last step is to simply convert annual consumption to a demand by dividing by the full

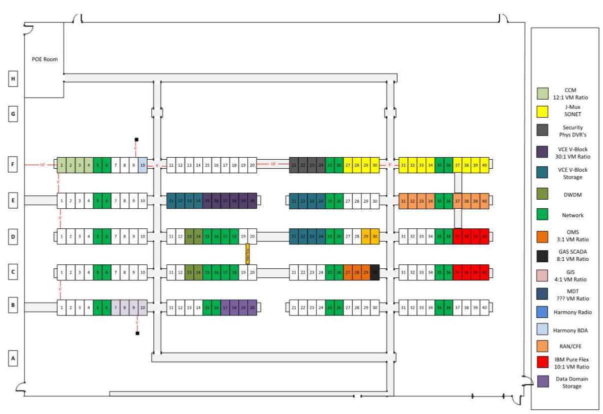

Figure 5 – Virtualized Data Center Layout

load hours of the applied schedule.

This tool is great for comparing against a generic industry standard baseline, but is a bit more complicated to apply to a client specific baseline. In these instances, posing the question to the IT designers will always be the best route forward.

LEED

The LEED process for Virtualization is entirely founded on the use of the USGBC virtualization tool. The most important aspect is the approach; USGBC is very clear that they require the same process and plug loads. For virtualization, we must think and justify it as providing the same amount of work, but at different efficiencies.

The real trick, however, is that they ask for supporting documentation to defend the virtualization rates used in the tool. Different industries and server functions all have varying potential for virtualization. Banks and forward-facing servers often use no virtualization while backward facing and telecom often use high virtualization rates. We have had our greatest success when the IT designer has provided a layout of the data center like in Figure 5 where each grouping of server racks is identified with their own virtualization rate. From this data, a data hall average virtualization rate is fairly straightforward.

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