

Gaps in Modeling Data Center Energy

BY DONALD L. BEATY, P.E., FELLOW ASHRAE; DAVID QUIRK, P.E., MEMBER ASHRAE

The data center industry currently lacks appropriate, publicly available tools to holistically model data centers with confidence. Energy modeling tools are riddled with gaps in their capabilities to model the unique characteristics of data centers, particularly their internal loads.

Data center designers often use a combination of non-integrated tools (e.g., CFD analysis, spreadsheet calculations, and vendors' custom calculations and tools) for a given project. This is an error-prone method that lacks any form of consistency, co-simulation for proper convergence, unknown levels of accuracy and the inability for repeatability.

Further, the use of invalidated tools and methods makes it more difficult to obtain approval of the calculations by the authority having jurisdiction (AHJ). It also makes it more difficult to use the modeling programs as an effective tool for creating high-performance data centers where the sensitivities matter for optimization.

This column will explore the current gaps in data center energy modeling tools and what's currently being done to close those gaps.

Data Center Energy and Environmental Modeling

Data centers have unique characteristics (IT equipment, power conditioning equipment, different indoor environmental conditions, alternative cooling strategies, cooling equipment, minimal occupancy, and metrics) that traditional energy modeling software has not been designed to simulate. This vacuum often leaves designers and owners "at the mercy" of various claims and makes it difficult to assess the most energy-efficient system for a particular project.

To model a data center, the biggest parameters one needs to know are: the climate, the environmental

conditions, the load (mostly IT) and the Delta T across the IT equipment.

With the last two items in the list above, the airflow can be inferred. Knowledge of the building envelope is also needed for a detailed model, but since data centers have such large internal loads, and typically no windows, the envelope component is not that important.

The significant plug loads, mostly information technology equipment (ITE), also mean that the electrical losses (inefficiencies) must also be calculated. This is particularly true when seeking to calculate or project the power usage effectiveness (PUE), particularly when considering it on an annualized or energy basis.

The following looks at each of these parameters in some more detail.

Climate

Getting the climate right is probably the easiest part of the modeling equation, due to the wealth of data now available. For quick assessments, ASHRAE's Weather Data Viewer 5.0 has binned climate data on 6,643 locations worldwide. For hourly assessments, the third edition of typical meteorological year (TMY3) data is now available for 1,020 U.S. locations and their dependencies through the National Renewable Energy Laboratory (NREL).

Donald L. Beaty, P.E., is president and David Quirk, P.E., is vice president of DLB Associates Consulting Engineers, in Eatontown, N.J. Beaty is publications chair and Quirk is the chair of ASHRAE TC 9.9.

TABLE 1 Equipment environment specifications for air cooling. (Source: ASHRAE. 2011. *Thermal Guidelines for Data Processing Environments, Third Edition*, Table 2.3.)

CLASS	PRODUCT OPERATION					PRODUCT POWER OFF		
	DRY-BULB TEMPERATURE (°C)	HUMIDITY RANGE, NONCONDENSING	MAXIMUM DEW POINT (°C)	MAXIMUM ELEVATION (m)	MAXIMUM RATE OF CHANGE (°C/h)*	DRY-BULB TEMPERATURE (°C)	RH (%)	MAXIMUM DEW POINT (°C)
RECOMMENDED (SUITABLE FOR ALL FOUR CLASSES)								
A1 to A4	18 to 27	5.5°C DP to 60% RH and 15°C DP						
ALLOWABLE								
A1	15 to 32	20% to 80% RH	17	3,050	5/20	5 to 45	8 to 80	27
A2	10 to 35	20% to 80% RH	21	3,050	5/20	5 to 45	8 to 80	27
A3	5 to 40	-12°C DP and 8% RH to 85% RH	24	3,050	5/20	5 to 45	8 to 80	27
A4	5 to 45	-12°C DP and 8% RH to 90% RH	24	3,050	5/20	5 to 45	8 to 80	27
B	5 to 35	8% to 80% RH	28	3,050	N/A	5 to 45	8 to 80	29
C	5 to 40	8% to 80% RH	28	3,050	N/A	5 to 45	8 to 80	29

* 5°C/h for data centers employing tape drives and 20°C/h for data centers employing disk drives.

Additional notes for this table can be found in *Thermal Guidelines for Data Processing Environments, Third Edition*, Table 2.3.

Environmental Conditions

Key to modeling the energy use of a data center is the recommended and allowable environmental envelope in which the equipment can be operated. This envelope is defined for most IT equipment in ASHRAE's *Thermal Guidelines for Data Processing Environments*. The edition currently available is the third edition, published in 2012.

Based on recent ASHRAE research, however, TC 9.9 has recently voted out an expansion of the Recommended and Allowable Ranges to include lower humidity levels. The fourth edition, which will publish these expanded ranges, is expected to be available by ASHRAE's 2016 Winter Conference in Orlando, Fla.

To properly cool ITE, the data center's cooling infrastructure must deliver air and/or coolant (typically facility water) that meets the parameters of the chosen environmental classes. For a given zone in the data center, the modeler needs to be able to specify the recommended and allowable range for air delivered to the inlet of the ITE. At a minimum, this should include user-selectable options A1 through A4 as "classes" in *Table 1* for air-cooled applications and W1 through W5 for liquid-cooled "classes" as shown in *Table 2*.

IT Loads

IT equipment needs/demands are driven by software needs/demands and software is constantly

being updated, refreshed, optimized, etc. Therefore, IT loads are one of the most difficult parameters to project in the design of a data center. It is virtually guaranteed that the loads experienced on Day 1 will fluctuate and change throughout the lifespan of the data center.

In addition, a given data center customer's or client's needs are subject to change over time as a part of their business growth. This is rarely a linear growth but in terms of data center design, it is typical to consider Day 1 load vs. ultimate load where the ultimate load represents the projected future needs for the customer/client. The transition from Day 1 to ultimate is usually phased in some manner.

Some aspects of the design, such as utility power and site transformers, may be sized for the ultimate load to mitigate the disruption to ongoing operations when a future phase is constructed. Other aspects, such as the local cooling, may be designed in a physically segregated manner and installed in phases to align with IT loading over time.

The energy model typically needs to be able to accurately model both cases.

To accurately predict energy consumption, as well as to predict the thermal performance of a data center, accurate models of ITE are needed. Specifically, the knowledge of the ITE "black box" needs to include:

- Physical dimensions, including inlet and discharge opening locations.
- ITE fan curve, and pressure drop through the server as a function of airflow.
- Part- and full-load power input. This power curve will likely be a function of inlet temperature.
- Part- and full-load airflow, with airflow defined as the actual airflow at the inlet to the ITE. This airflow curve will likely be a function of inlet temperature.
- Part- and full-load Delta T . This Delta T will likely be a function of inlet temperature.
- Percentage of air cooled vs. liquid cooled heat release.

IT Delta T

In addition to IT loads, the Delta T across servers and other ITE is also quite important in modeling data centers. Ideally, the air-handling equipment in a data center should be designed to have close to the same average Delta T as the average Delta T across the servers and other ITE.

TC 9.9 is working on published information on Delta T ranges to expect for server design, with projections going out to 2020. This long-anticipated information will be contained in an upcoming ASHRAE book called, *Interaction Between IT Equipment and Data Centers with a Focus on Thermal Design*. This book is expected to be published in the first half of 2016.

The current draft of this book indicates that design IT Delta T s can be as high as 28°C (50.4°F) for products with a 25°C (77°F) inlet temperature, dropping to 22.5°C (40.5°F) for 35°C (95°F) server inlet temperature.

Airflow and Environmental Modeling

One of the biggest challenges in data center design, due to the high internal loads, is the elimination of hot spots or unacceptable conditions at the ITE intakes. All of the ITE in a data hall is important, and airflow modeling tools such as CFD may be needed to ensure that all of the equipment receives air with acceptable temperature and humidity conditions.

Currently, CFD programs are not designed for integration with energy modeling programs. Ideally, CFD and energy modeling tools would perform co-simulations, whereby iterative time-steps could be specified for

TABLE 2 Equipment environment specifications for liquid cooling. (Source: ASHRAE. 2011. *Thermal Guidelines for Data Processing Environments, Third Edition, Table 3.1.*)

TYPICAL INFRASTRUCTURE DESIGN			FACILITY SUPPLY WATER TEMPERATURE (°C)
CLASS	MAIN COOLING EQUIPMENT	SUPPLEMENTAL COOLING EQUIPMENT	
W1	Chiller/ Cooling Tower	Water-side Economizer	2 to 17
W2			2 to 27
W3	Cooling Tower	Chiller	2 to 32
W4	Water-side Economizer (With Dry- Cooler or Cooling Tower)	N/A	2 to 45
W5	Building Heating System	Cooling Tower	>45

the convergence of CFD outputs and energy modeling outputs.

Although it would certainly be nice to have “one stop shopping” (i.e., a program with sufficient computational bandwidth to determine the actual ITE intake conditions based on space geometry, air management strategies, HVAC vs. ITE airflow balance, and resulting equipment efficiencies and energy consumptions), realizing this vision remains a challenge.

Today, CFD results must be run independently, with outputs plugged into spreadsheets and energy modeling tools as non-converged assumptions without optimization of temperatures and airflow rates on ITE and HVAC.

Electrical Efficiency Modeling

The calculation of the PUE (refer to *ASHRAE Journal's* January 2013 column “Data Center Energy Metric” for a definition of PUE) is highly dependent upon accurate electrical efficiency calculations and modeling as well.

Data centers have categories of electrical conditioning equipment including uninterruptible power supplies (UPS), power distribution units (PDUs), and static transfer switches (STS) that are not typical in other commercial building types.

This equipment has part-load as well as full-load efficiency curves and is often cooled by the same central cooling plant as the ITE.

The redundancy strategy can also have a large impact on the electrical system operating energy use. Since the efficiency curves are nonlinear, and the load scheduling



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of the ITE and HVAC are variable, there are many degrees of freedom for the resulting energy calculations.

Mixtures of ITE Environmental Classes

To further complicate matters, many data centers have mixtures of ITE environmental classes, meaning the entire data center hall is not made up of the same hardware, same load profiles or schedules, the same cooling approach, or really anything that's the same.

Imagine for a moment a data center with a mixture of air-cooled and liquid-cooled environmental classes within the same zone. There is no single tool today that can model this situation, especially at the central plant where the heat rejection combines.

Scheduling of ITE Loads

ITE loads are variable. The difference between the idle loads and full loads can be significant, depending on the type of hardware, software running on it, and the power management strategy used by the ITE manufacturer.

Ideally, data center energy modeling software needs to be able to change the load schedules of the ITE, just like today's commercial building software can adjust plug loads or the occupancy loads of people.

Codes and Standards

Good energy modeling programs are essential for many reasons. One reason is that they are needed to demonstrate compliance with codes for buildings that use the performance path, rather than the prescriptive path.

The simulation of energy use in traditional buildings has a robust history, and there are currently very accurate programs for this purpose. ASHRAE has published a standard for the testing and analysis of these programs, Standard 140, *Standard Method of Test for the Evaluation of Building Energy Analysis Computer Programs*.

Unfortunately, the unique mechanical cooling and electrical distribution architectures found in data centers aren't easily modeled in most Standard 140-compliant software, leaving a gap that needs to be filled.

Financial Incentive Programs

Many states and utilities have financial incentive programs to encourage the use of energy-efficient cooling approaches to data centers, as well as incentives for

lighting and other energy-saving measures. The rebates for energy-efficient data center equipment are not typically prescriptive.

A baseline needs to be established (typically code where available), and then the annual energy savings calculated. One baseline document, created for California but also used for other entities, is *Energy Efficiency Baselines for Data Centers*. Currently, most calculations submitted for these rebate programs are "custom calculations," because the current programs do a poor job of modeling the data center equipment.

Data Center Modeling Tools

A data center modeling tool would have to have all the features of today's commercial modeling tools meeting Standard 140, plus the list in the sidebar.

Still to Come

ASHRAE TC 9.9 is working to bridge the energy and flow modeling gap with a number of initiatives.

One is Work Statement WS-1739, *Development of Improved and Integrated Energy Modeling Software for Data Centers*. Progress on this work statement needs to be coordinated with the more short-term needs of Standard 90.4P, *Energy Standard for Data Centers*, now currently in its second public review, as well as with upcoming modeling initiatives in other ASHRAE TCs.

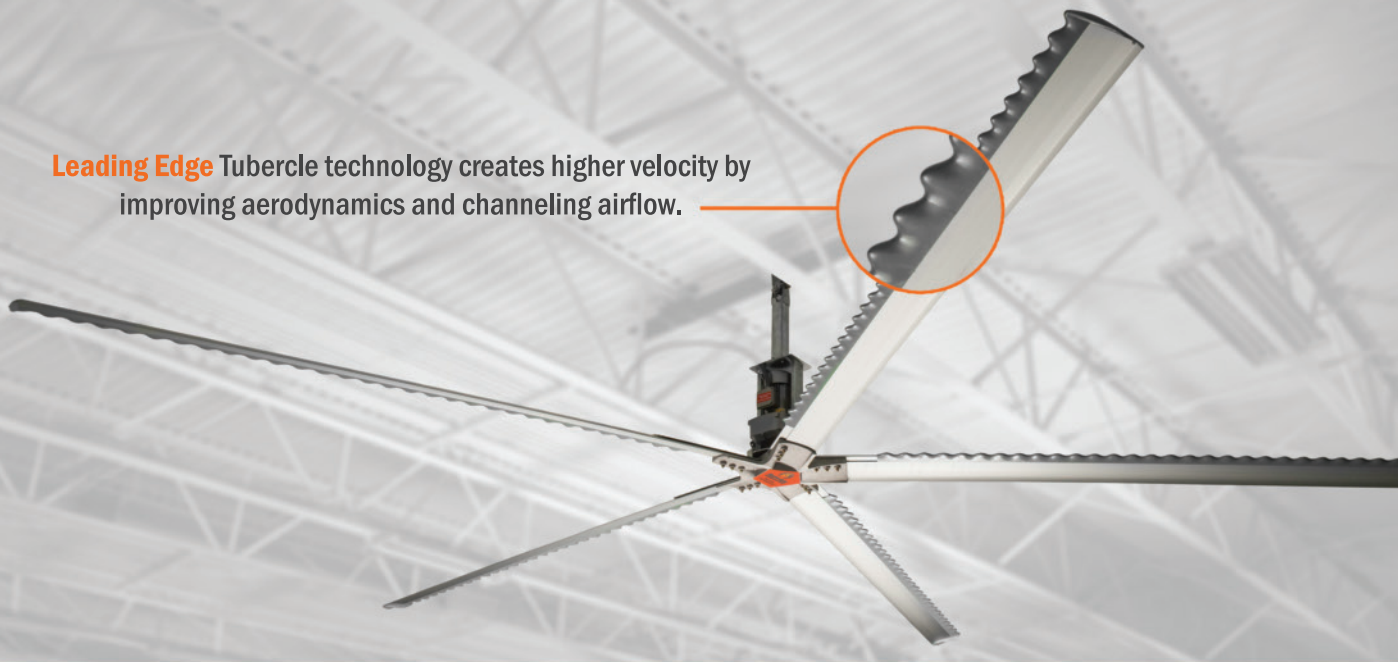
The intent of this research is to fill in the gaps of data center modeling so that existing computational programs can be made as relevant to data centers as they are for most other building types.

Within the past few years, some developments have occurred. With funding from the U.S. DOE, several enhancements have been made to the EnergyPlus program. Included are features for a new data center IT equipment model, and a new data center HVAC simulation model.

In terms of airflow modeling within a data center, this fall ASHRAE will release for bid 1675-TRP, *Guidance for CFD Modeling of Data Centers*. The outcome of this research will be improved knowledge of what parameters are most important in data center modeling.

Ultimately, a goal for the industry will be to merge the energy modeling and the CFD, or at least to get the two programs talking to each other so that a data center modeler has a more complete knowledge not just of the

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Filling the Gaps

Features needed for a data center modeling tool (in addition to those meeting Standard 140):

- Equipment tested and rated per ASHRAE Standard 127, *Method of Testing for Rating Computer and Data Processing Room Unitary Air Conditioners* and AHRI 1360, *Performance Rating of Computer and Data Processing Room Air Conditioners*, such as:
 - CRAC units with integral compressors and heat rejection to remote condensers;
 - CRAC units with integral compressors and heat rejection to a condenser water loop; and
 - CRAH units (chilled water or chilled glycol).
- Close-coupled cooling solutions (rear doors, row-based, etc.).
- Various forms of airflow containment (e.g., hot aisle containment, cold aisle containment, cabinet exhaust ducts).
- Systems using pumped refrigerant.
- Different interior design conditions: range of data center environments.
- Mixtures of ITE environmental classes.
- Scheduling of ITE loads and use of redundant cooling equipment.
- Electrical power distribution and conditioning equipment.
- Modeling of ITE, including impact on inlet temperature on power and airflow:
 - Detailed part-load airflow and power curves for all standard types of ITE, especially incorporating the impact of inlet temperature on airflow and power.
- Redundancy classifications (active redundant operations, impact of redundant paths on system efficiency, etc.) per ANSI/TIA Standard 942, *Telecommunications Infrastructure Standard for Data Centers*.

- Detailed part-load equipment curves for all cooling equipment.
- Airflow delivery by raised floors, overhead, and various close-coupled cooling systems.
- Data center equipment density models.
- Liquid cooling models.
- Standard cooling system component models suitable for the data center environment.
- Makeup air systems for pressurization, humidification, and dehumidification.
 - Different types of economizer modeling.
- Mixed use facilities and combined cooling and electrical plants.
- Waste heat recovery systems.
- Direct and indirect adiabatic cooling solutions.
- Economizer models that enable lockout at specified relative humidity, dewpoint or temperature conditions.
- Control algorithms for:
 - Different fan speed control strategies based on return air, supply air, cold aisle, or underfloor static pressure setpoints;
 - Chilled water valve control based on return air, supply air, or cold aisle temperatures; and
 - Variable equipment control strategies such as active redundant where all units are run at part-load.
- New chiller models, capable of accepting part-load curves for a range of supply water temperatures that are a function of both condenser water (or condenser air) temperature and the percentage of chiller part load. This is important because data centers have significantly different annual load profiles than most other facilities. And, the value of industry standard seasonal performance metrics, such as IPLV, typically will not provide an accurate annualized chiller energy use model for data centers.

equipment, but also the environment that the equipment resides in.

Final Thoughts

Today's data center designers need to recognize that there still exists a large gap between the modeling tools capabilities and the requirements for accurate data center energy modeling. Reliance on information from today's modeling tools is very limited and should not be solely relied upon for energy standard compliance, optimizations, or utility use projections.

The gaps are significant and will take significant time for the industry to close. Data center designers need to

be mindful of these limitations when using Standard 140-compliant software packages.

In the meantime, ASHRAE TC 9.9 has sponsored and cosponsored research intended to help close the modeling gaps. These research projects are long-term efforts typically lasting 3 years from start to finish.

Data center designers and owners alike need to carefully assess the approaches used for the energy modeling of their data centers. Not all approaches, tools, and modelers are alike. For now the industry is dependent upon selecting good modelers who understand these limitations, can make the appropriate assumptions, and combine a portfolio of tools to solve the right problems. ■



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