



DOE Data Center Air-Management (AM) Tool: Data Collection Guide

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The Data Collection Guide and the Air Management Tool were developed jointly by Lawrence Berkeley National Laboratory (LBNL) and ANCIS Incorporated for the US Department of Energy (DOE)

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OVERVIEW

What does this Tool do?

Air management in data centers is essentially about keeping cold and hot air from mixing. Cold supply air from the air handler should enter the heat-generating IT-equipment without mixing with ambient air and the hot exhaust air should return to the air handler without mixing. Managing the cold and hot air streams in data centers is important for cooling infrastructure energy/capacity management and IT-equipment thermal management.

The DOE Data Center Air-Management Tool was developed to help accelerate the energy savings in data centers without affecting the thermal IT-equipment environment. Based on user input, the Tool provides air management recommendations and the potential for reducing the supply airflow rate and increasing the supply air temperature, both having an impact on energy use. Finally, the Tool estimates the % energy reduction, kWh reduction, and the associated \$ savings for supply fans and chillers.

The underlying assumption for this Tool is sufficiently stable environmental conditions, for example, the air handlers may well have variable air volume (VAV) fans but they are assumed operating at a stable constant reduced airflow. Since the majority of conventional data centers has raised-floor cooling with hot and cold equipment aisles, this Tool is intended mainly for such environments. Having some basic understanding of the physical data center environment makes this Tool easier to understand and use.

How is the Tool used?

First, the user fills in data and answers questions on four input Excel sheets (Steps 1-4). Each sheet includes basic guidance for entering the data correctly. The User's Manual (DOE 2014a) provides additional information. Second, based on this user input, numerical output and recommended actions are given on two result output Excel sheets (Steps 5 and 6). An Engineering Reference (DOE 2014b) and a Data Collection Guide (this document) complete the support documentation.

DOE Software Tool Suite

This Air Management Tool is part of the DOE Software Tool Suite (DOE 2014d) which also includes an online Profiling Tool (DC Pro) and an Excel-based Electrical Tool. These tools are not a substitute for a detailed "investment grade" audit. They provide estimates of savings for various measures, but actual savings may vary based on site-specific conditions that are not addressed in the tools.

Tool Download and Documentation

The Air Management Tool can be downloaded from the Center of Expertise for Energy Efficiency in Data Centers website: <http://datacenters.lbl.gov/data-center-air-management-tool> After downloading the Tool, there are three complementary documents on the same website for facilitating the use of the Tool:

- The *User's Manual* provides information on using the Tool
- The *Engineering Reference* provides detailed information on the calculations, equations, metrics, and limitations
- The *Data Collection Guide* (this document) provides information on collecting the input data.

Questions, comments, and/or suggestions on these documents can be directed to mherrlin@ancis.us

Data Collection Guide

This Data Collection Guide follows the layout of the Air-Management Tool with four input color coded Excel sheets (the remaining Steps do not require user input).

Step 1: AHU	User input: Air-handler unit (AHU) data for calculating the RTI metric
Step 2: Equip	User input: IT/electric equipment data for calculating the RTI metric
Step 3: RCI	User input: IT-equipment intake temperatures for calculating the RCI metric
Step 4: Main Input	User input: Main user input, including metrics from Steps 1-3

After briefly reviewing the importance of an up-to date equipment and AHU inventory, this Guide provides information on collecting the required input data. Poorly collected or measured data could introduce large errors in the energy savings estimates. Since this document parallels the layout of the User's Manual for input Steps 1-4, switching back and forth between the two documents should be straight forward. As mentioned above, the User's Manual provides information on using the Tool whereas the Engineering Reference provides information on the calculations, equations, metrics, and limitations.

EQUIPMENT AND AHU INVENTORY

The first step in planning the data collection for the Input Excel Sheets should be to compile a detailed and up-to-date inventory of the equipment placed on the data center floor, including electronic equipment such as server, storage, and network products and electrical equipment such as Power Distribution Units (PDU) and Uninterruptible Power Supplies (UPS). The AHU, permanent measurement, and metering gear should also be included in the survey. The equipment and AHU inventory serves as a map for organizing and simplifying the data collection. Please see Table 1 on page 13 for a summary of the required input data to collect.

DATA COLLECTION SOURCES

When the equipment and AHU inventory has been completed, the next step is to decide the most appropriate sources for collecting the data. Examples of data sources for both manual and automatic methods are briefly reviewed below. A more detailed discussion is included under each Input Sheet, starting on the next page. Please note that each data collection source may yield useless data if the personnel involved have inadequate knowledge and/or experience.

- IT-Equipment Real-Time Data
The Energy Star Partnership Agreement (Energy Star, 2008) is requiring from January 1, 2009 that Energy Star qualified computer servers must have the ability to provide real time data on power draw and intake air temperature. When implemented by the industry, this may be the best option for collecting accurate power and intake temperature data for servers.
- Measurements
Some data must be measured, most notably various air temperatures. Measurements also have the capacity to produce the most accurate IT-equipment power (heat release) data. However, it requires well-trained staff and it may be time consuming. Meters should be calibrated to avoid inaccurate readings, which can have a large impact on results. IT-equipment airflow is not easily measured; the options listed below are more practical approaches.

- Manufacturers Online Calculation Tools
IT-manufacturers' online calculation tools can generally be found on their websites. These tools are often very flexible allowing detailed analysis of equipment operating conditions such as airflow and power (heat release). AHU manufacturers have their own look-up tools.
- IT-Manufacturers Thermal Reports
As of yet, IT-manufacturers' thermal reports per ASHRAE (2011) are not common. If the report is available, however, it provides an effective way of estimating key operating data such as equipment airflow and power (heat release).
- Nameplate Data
Nameplate data can be found on the equipment/gear and in its documentation. Since operating data often differ from nominal data, this option is not recommended. This is especially true for IT-equipment power (heat release). The nameplate rating is for the purpose of electric safety, not as an indicator of actual power draw during normal operation. Depending on many factors, the power draw can be 50% or less than the nameplate rating.

INPUT SHEETS

This section describes the four Input Sheets in the order they appear in the Excel Tool. This section is best read as a reference manual for finding particular information on the data collection process on any of the sheets. Note that the yellow cells on the input sheets indicate cells where to input data. Complete screen shots are included in the User's Guide.

Step 1 AHU

"Step 1 AHU" is the first of the four input sheets. It is imperative to enter accurate data on this sheet. By entering the requested Air-Handling Unit (AHU) data for up to 40 operating units, this sheet will calculate five pieces of data (orange boxes) and export them to the Main Input (Step 4) sheet.

The principal purpose of this data transfer is to calculate the Return Temperature Index (RTI)TM, which plays an important role in understanding whether the data center is over-ventilated (by-pass air) or under-ventilated (recirculation air) (Herrlin 2008). For additional information on RTI, please see the Engineering Reference (DOE 2014b).

The input data include the following:

- AHU Airflow [cfm or m³/s]
- Supply Air Temperature [°F or °C]
- Return Air Temperature [°F or °C].

The AHU's cooling effect can be calculated by using these data. However, obtaining accurate AHU airflow and supply/return air temperatures are sometimes challenging. For example, the manufacturers' airflow catalog data typically differ from those of an installed system. An error sensitivity analysis may be needed to determine the potential impact of errors.

The most common air conditioning and air handling gear in data centers is known as Computer Room Air Conditioners (CRAC) with direct expansion (DX) and Computer Room Air Handlers (CRAH) with chilled water, respectively. One quality of the CRAH units is that they lend themselves to Variable Frequency Drive (VFD) implementation. Typically the CRAC/H is placed on a raised floor and discharges conditioned air into the floor plenum (see Figure 1).

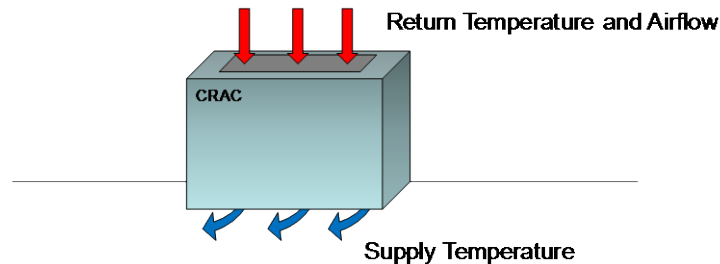


Figure 1: Airflow and temperatures for a down-flow CRAC (or CRAH) unit

Data Collection of AHU Airflow

- The Pitot tube is a relatively inexpensive way of measuring airflow in the field. A more sophisticated device such as a hot-wire anemometer can be used when better accuracy is required. Since the air velocity across the return opening (or duct) varies over the cross section, it is difficult to rely on information from a single probe location.
- For a permanent installation, the installation of an airflow monitoring station is an approach for measuring the average air velocity, airflow, and temperature. The station is permanently installed in a duct and uses probes that are arranged in a grid to measure the average velocity.
- For temporary measurements, the airflow through an AHU can be accurately measured by using anemometers and the log-linear velocity traverse method across the return opening (or duct) (ASHRAE, 2011). It measures the velocity in several different locations. By establishing a calibration curve, the average velocity can be calculated from a single center point probe.
- Catalog airflow can be found in the AHU documentation. There is also a correlation between airflow and frequency for VFD fans. Since actual airflow may differ from nominal data, this is not the best option. However, it may be the most practical option and sometimes the only option.

Data Collection of Supply and Return Air Temperatures

Measuring the supply temperature from AHUs is generally an easy task with a calibrated, high quality sensor. For raised-floor applications with down-flow CRAC/H units, placing a thermocouple probe in the airstream coming out of the CRAC unit under the raised floor should present few challenges. Thermocouples are easy to use and have the advantage of having relatively low cost and being reliable, stable, and durable. Thermistors provide high accuracy but are generally more costly. Resistance Temperature Detectors are among the most accurate sensors; the drawback is an even higher cost.

Measuring the return temperature of AHUs is not as easy. For down-flow CRAC/H units, the temperature distribution across the return opening cannot be assumed to be uniform. Further complicating the matter is that the airflow cannot be assumed to be uniform either. If the log-linear traverse method is used for determining the airflow, the average temperature can be calculated by measuring the temperature in the same locations. Before trying this, estimate the temperature variation across the opening by manual sampling. If the variation is small, use the center-point temperature.

Step 2 Equipment

“Step 2 Equipment” is the second of four the input sheets. By inserting the requested equipment data, this spreadsheet will calculate two pieces of data (orange boxes) and export them to the Main Input (Step 4) sheet.

The principal purpose of the data transfer is to calculate the Return Temperature Index (RTI)TM on the Main Input sheet. This index plays an important role in understanding whether the data center is over-ventilated (by-pass air) or under-ventilated (recirculation air) (Herrlin 2008). For additional information on RTI, please see the Engineering Reference (DOE 2014b).

The ultimate goal of the probe count and location is to produce the same RTI (and RCI) value had every piece of equipment been included. Since determining the equipment data may be a challenging task, three options are available. Depending on the selection, the equipment should be grouped into Classes with similar temperature rise (DT) or airflow rates (V). The input options are as follows:

- Similar DT: Equipment with similar Measured Temperature Rise (DT); used with corresponding fair Estimated Airflow (V).
- Similar V: Equipment with similar Estimated Airflow (V); used with corresponding Number of Units (U).
- Similar DT(P): Equipment with similar Measured Temperature Rise (DT); used with corresponding Measured Power (P).

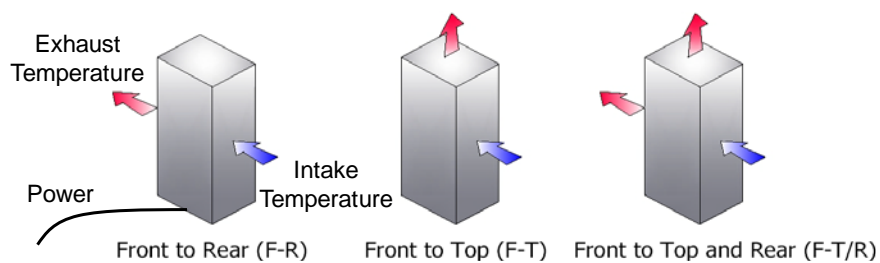


Figure 2: Power and temperatures for equipment racks

Data Collection of Measured Rise (DT)

Measuring the temperature rise includes measuring the intake and exhaust temperatures. However, there is no industry standard on the methods, locations, etc. for performing temperature measurements at the intakes and exhausts of equipment. The following should be considered as a guideline only.

- The probe location must coincide (geometric center) with the actual equipment air intake or exhaust opening. Also, placing the temperature probe inches in front of the actual IT-equipment intake opening rather than flush with the opening may well render an erroneous result in the presence of recirculation of hot exhaust air *inside* the rack.
- The optimal quantity and elevation of the temperature probes depend strongly on the content of the IT-rack. A rack often has multiple pieces of IT-equipment each with its own intake and exhaust openings. Also, the temperature profiles along the front of the racks generally vary with elevation due to recirculation *above* the equipment racks.
- It is not necessary to collect data for every IT-rack. Measuring every other or third rack is often adequate; even less on the exhaust side if the racks have similar design and function. The racks at the end of the lineups should be included since they may be exposed to higher temperatures due to recirculation *around* the equipment racks. Some racks can often be disregarded because of marginal criticality and/or heat dissipation.
- For IT-racks with many (20-40) evenly distributed intake or exhaust openings, six sensors per rack (three on the intake side and three on the exhaust side) is a reasonable compromise between accuracy and cost especially when the ventilation openings have similar airflow and heat dissipation. Placing the sensors at three elevations (high, mid, and low) is usually adequate.
- For IT-racks with multiple (4-10) intake or exhaust openings, six sensors per rack are again a sensible compromise. If a few openings dominate with regard to airflow and heat dissipation, place the sensors at those openings. If not, placing the sensors at three elevations (high, mid, and low) is usually adequate.
- For IT-racks with ≤ 3 discrete intake or exhaust openings, place the sensors at the geometric center of the actual intake and exhaust openings (flush to the openings). This is often the case for UPS gear.

Data Collection of Estimated Airflow (V)

Measuring the airflow through IT-equipment is complicated—if not impossible. The options listed below provide more practical approaches.

- Airflow can easily be calculated if the power draw (see below) and the temperature difference between intake and exhaust (see above) are known.
- IT-manufacturers online calculators can generally be found on the manufacturers' websites. These tools are often very flexible allowing detailed analysis of equipment airflow.

- IT-manufacturers thermal reports per ASHRAE Thermal Guidelines are not common. If the report is available, however, it provides a quick way of estimating equipment airflow.
- Nominal airflow can be found in the equipment documentation. Since actual airflow can differ from nominal airflow, this is not the best choice. However, it may be the most practical option.

Data Collection of Number of Units (U)

Count the number of equipment units with similar Estimated Airflow (V).

Data Collection of Measured Power (P)

Besides the guidelines provided below, ASHRAE (2009) provides an overview of Real-Time Energy Consumption Measurements in Data Centers. It is imperative that the person that conducts the power measurements understands the data collection techniques and the criticality of data centers.

- The inventory (see Page 6) of the equipment in the data center should include an estimate of the equipment power profile over time so that corrections can be made. Another important factor that needs to be understood is redundant power feeds (both must be measured).
- Measurements of IT-rack power (heat release) have the capacity to produce most accurate results. The power input to the rack can be measured via voltage and current or using a Watt (power) meter, but it requires well-trained staff and it may be time consuming.
- Clamp-on Current Transformers (CT) can be applied without breaking the electric circuit by placing the conductor to be measured through the CT. Current can be a standalone measurement or be combined with voltage (generally known) to compute power. Portable power meters are generally used for short-term measurements.
- Measurement of rack power may become tedious and time consuming due to the sheer number of IT-equipment in many data centers. Based on the inventory, however, power measurements can be performed on one representative of many similar IT-equipment.
- If there is a remote power management system with rack Power Distribution Units (rPDUs), the task of determining rack power may be straight forward. The inventory should provide enough information for accurate mapping the IT-equipment with the rPDUs.
- In data centers, the IT-equipment is generally powered from several/many PDUs, which often have meters for power draw. If this level of metering is sufficient, this may be the best option. The PDU meter accuracy is generally better than that of the rPDU.
- Some servers are able to measure and report power (Energy Star 2008). Long term, users may wish to collect power data directly from the servers rather than from the rPDUs or PDUs.
- IT-manufacturers' on-line calculation tools can generally be found on their websites. These tools are often very flexible allowing detailed analysis of equipment power (heat release).

- IT-manufacturers thermal reports per ASHRAE (2011) are currently not common. If the report is available, however, it provides a quick way of estimating the power draw (heat release).
- Nameplate power rating can be found on the IT-equipment and in the product documentation. However, the nameplate rating is for the purpose of electrical safety, not as an indicator of actual power draw. Depending on a number of factors, actual power draw can be 50% or less than the nameplate rating. Using nameplate power rating is strongly discouraged.
- For an UPS, the power dissipated as heat can be calculated by subtracting the OUT power from the IN power. Both entities are generally accessible on the unit.

Step 3 RCI

“Step 3 RCI” is the third of the four input sheets. The Rack Cooling Index (RCI)[®] provides an unbiased and objective way of quantifying the quality of an air-management design from a thermal perspective. Specifically, the index is a performance metric explicitly designed to gauge compliance with the thermal guidelines of ASHRAE (2011) and NEBS (Telcordia 2001, 2012) for a given data center. The index is included in the ASHRAE thermal guidelines for purposes of showing compliance.

For details on the RCI, please see Herrlin (2005) and the Engineering Reference. The required input data to be measured is limited to the IT-equipment air intake temperatures. The intake temperatures should comply with the ASHRAE/NEBS specifications through the use of the RCI metric.

Data Collection of Intake Temperature

See Step 2 Equipment under Data Collection of Measured Rise (DT) for guidance on measuring the IT-equipment air intake temperatures. Note again that the goal of the temperature probe count and location is to produce the same RCI value had every intake been measured.

Step 4 Main Input

“Step 4” Main Input is the last of the four input sheets (although some data can be entered on “Step 6”). Table A on the Main Input sheet shows air-management metrics either entered or calculated/echoed from the AHU, Equipment, and RCI sheets (color coded). If no data or insufficient data are entered in Step 1 AHU and Step 2 Equipment, multiple cells in Table A will be empty.

Specifically, if no data are entered in Step 3 RCI, the two RCI cells in Table A will be empty (Alt. 1). Typical (not extreme) maximum and minimum IT-equipment intake temperatures can then be entered in the yellow cells (Alt. 2). Alt. 1 has priority over Alt. 2 should all four cells have values. Since the RCI metric is well defined, the quality of the RCI data is higher.

Data Collection of IAT max and IAT min

See Step 2 Equipment under Data Collection of Measured Rise (DT) for guidance on measuring the IT-equipment air intake temperatures. Please note again that these temperatures (IAT max and IAT min) are not the two extreme temperatures but rather typical maximum and minimum intake temperatures, taking a larger number of intake temperatures into consideration.

Finally, no non-trivial data collection is associated with Table B on the Step 4 Main Input sheet. For a general discussion on Table B, please see the User’s Manual (DOE 2014a).

SUMMARY OF REQUIRED INPUT DATA

This table provides a quick reference for Tool input data. For details on the data collection, see the associated Step(s) in this Data Collection Guide.

Table 1: Required Numerical Input Data

	Unit	Program Step
AHU Airflow	cfm or m ³ /s	Step 1 AHU
AHU Supply Air Temperature	°F or °C	Step 1 AHU
AHU Return Air Temperature	°F or °C	Step 1 AHU
Equipment Temperature Rise	°F or °C	Step 2 Equip
Equipment Airflow	cfm or m ³ /s	Step 2 Equip
Number of Equipment Units	-	Step 2 Equip
1) IT-Equipment Heat Release: P _{in}	W	Step 2 Equip
2) UPS Heat Release: P _{in} -P _{out}	W	
IT-Equipment Intake Temperature	°F or °C	Step 3 RCI
Typical Max IT-Equipment Intake Temperature	°F or °C	Step 4 Main Input
Typical Min IT-Equipment Intake Temperature	°F or °C	Step 4 Main Input
Recommended IT-Equipment Intake Temperature Range	°F or °C	Step 4 Main Input
Allowable IT-Equipment Intake Temperature Range	°F or °C	Step 4 Main Input
Measured Annual Fan and Chiller Energy	kWh/year	Step 6 Energy Results
Energy Cost	\$/kWh	Step 6 Energy Results

ABBREVIATIONS AND ACRONYMS

ΔT_{AHU}	Typical (airflow weighted) AHU temperature drop [$^{\circ}\text{F}$ or $^{\circ}\text{C}$]
ΔT_{Equip}	Typical (airflow weighted) equipment temperature rise [$^{\circ}\text{F}$ or $^{\circ}\text{C}$]
AHU	Air-Handler Unit
AM	Air Management
By-pass	Cool air that by passes the IT-equipment
Commissioned	Achievable with Current architecture/controls
CRAC	Computer Room Air Conditioner
CRAH	Computer Room Air Handlers
Current	Current architecture/controls in data center
DC Pro	DOE Data Center Profiling Tool
DOE	U.S. Department of Energy
DT	Temperature differential across Equipment [$^{\circ}\text{F}$ or $^{\circ}\text{C}$]
Equip(ment)	Equipment (IT and Electrical)
HVAC	Heating, Ventilating, and Air-Conditioning
IAT max	Typical (not extreme) maximum IT-equipment intake temperature [$^{\circ}\text{F}$ or $^{\circ}\text{C}$]
IAT min	Typical (not extreme) minimum IT-equipment intake temperature [$^{\circ}\text{F}$ or $^{\circ}\text{C}$]
Measured	Measured data with Current architecture/controls
P	Power [W] or [kW]
RAT	Return air temperature [$^{\circ}\text{F}$ or $^{\circ}\text{C}$]
RCI	Rack Cooling Index (RCI) [®] [%]
RCI _{HI}	Rack Cooling Index (RCI) [®] “HI” [%]; Measure of absence of over-temperatures
RCI _{LO}	Rack Cooling Index (RCI) [®] “LO” [%]; Measure of absence of under-temperatures
Recirculation	Hot IT-equipment exhaust re-circulates back to the equipment intakes
Retrofitted	Achievable with Target architecture/controls

RTI	Return Temperature Index (RTI) TM [%]; $\Delta T_{AHU}/\Delta T_{Equip} = V_{Equip}/V_{AHU}$ (x100)
SAT	Typical (airflow weighted) AHU supply air temperature [°F or °C]
ΔSAT	Maximum difference between AHU supply air temperatures [°F or °C]
State-of-the-Art	State-of-the-Art architecture/controls
Target	Realistic target architecture/controls for raised-floor cooling
Ton	Ton Cooling = 3.52 kW
U	Number of Equipment Units [-]
V_{AHU}	Total Air-Handler Unit airflow [cfm or m ³ /s]
V_{Equip}	Total equipment airflow [cfm or m ³ /s]
VAV	Variable Air Volume
VFD	Variable Frequency Drive

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