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DOE Data Center Air-Management (AM) Tool:

User's Manual

Version 3.1 (July 25, 2023)

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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 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. It estimates the % energy reduction, kWh reduction, and the associated $ and carbon (CO_2) savings for supply fans and chillers. On-site water usage and simple payback periods are also provided. The Tool was validated with Computational Fluid Dynamics (CFD) modeling (PG&E, 2010).

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 most 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. This User's Manual 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 2023a) and a Data Collection Guide (DOE 2021) complete the support documentation.

DOE Software Tool Suite
This Air Management Tool is part of the DOE Software Tool Suite (DOE, 2023b) which also includes an online Profiling Tool (DC Pro) as well as Excel-based Electrical and IT Equipment Tools. 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 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/tools. There are three documents on the same website for facilitating the use of the Tool:

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

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

Tool Structure

The Air-Management Tool has seven color coded Excel sheets for input and output plus three hidden sheets (see Figure 1):

Overview	Provides an overview of the data flow through the Excel sheets
Step 1: AHU	User input: Air-handler unit (AHU) data for calculating the RTI metric
Step 2: Equip	User input: Electronic equipment data for calculating the RTI metric
Step 3: RCI	User input: Equipment intake temperatures for calculating the RCI metric
Step 4: Main Input	User input: Main user input, including metrics from Steps 1-3
Step 5: Main Results	Result output: Main results but excluding energy estimates
Step 6: Energy Results	Result output: Energy estimates for supply fans and chillers
Lookup	Lookup tables for internal use (hidden)
Action Rules	Rules for triggering actions or recommendations (hidden)
Export	Output for post-processing (hidden).

The Overview sheet allows the selection of either I-P (American) or SI (International) units. Please note that selecting I-P or SI units will not change the numerical values already entered by the user into the Tool. Therefore, the selection of units should be done before any data are entered on subsequent sheets. In addition, the computer must always use the US number format, i.e., decimal point (even when SI units are selected).
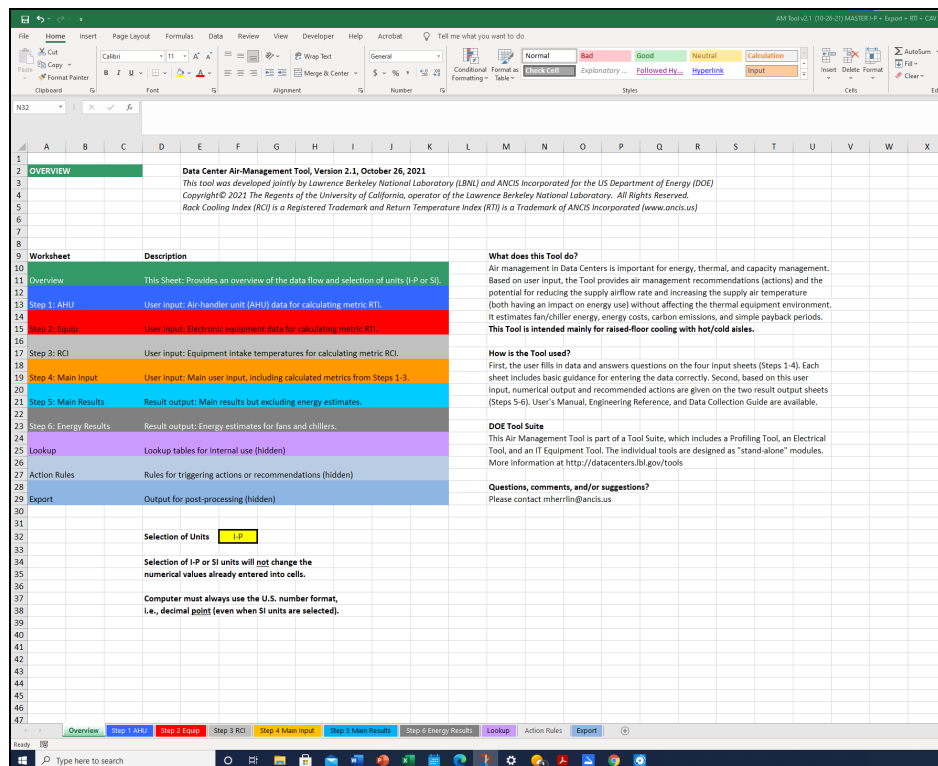
Figure 1: Overview sheet.

INPUT/OUTPUT SHEETS

This section describes the input and output sheets in the order they appear in the Excel Tool. This section can be read "from cover to cover" or as a reference manual for finding particular information on any of the sheets. General Information applicable to all four input sheets includes:

- Yellow cells indicate cells where to input data. All other cells are permanently locked.
- Dual units are shown next to each yellow input cell (e.g., °F or °C). The first unit represents I-P units, and the second unit represents SI units. I-P or SI units are selected on the Overview sheet.
- Colored cells (besides yellow) indicate data that are exported to or imported from other sheets. The cells are color coded per the receiving or originating sheet (tab) color.
- Grayed out data are for internal use only, generally showing intermediate calculation steps.
- All input cells have input-range checking to avoid data-entry errors. If an input is Out of Range, check the accuracy of the input.
- Some input cells accept typed data whereas other cells have fixed options selected from drop-down boxes. The drop-down boxes are activated by simply selecting the cell.
- Some input cells have Input guidance, which is activated by selecting the cell. You can temporarily drag the input guidance box to a different location on the worksheet to avoid interference with other input cells. All input guidance boxes on that worksheet will then appear in that location. Use the ESC key to close.
- The screen shots included in this User's Manual can be difficult to read at the conventional 100% zoom level. Use the zoom capability of your software to enlarge the figures. Note that the screen shots may differ slightly from the latest version of the Tool.
- The Tool comes preloaded with data for a simple case.

Step 1 AHU

"Step 1 AHU" is the first of four input sheets. It is imperative to enter (accurate) data on this sheet.

By entering the requested air-handling unit (AHU) data (yellow cells) 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 the data transfer to the Main Input sheet is to help 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 more information on RTI, please see section Step 4 Main Input.

Input data (yellow cells) (Figure 2):
- AHU Airflow [cfm or m^3/s]
- Supply Air Temperature [°F or °C]
- Return Air Temperature [°F or °C].

It is recommended to enter the AHU units from the top (AHU 1) down in the yellow input table. At least one AHU must be entered. An ERROR message will appear in column H if the supply temperature is greater or equal to the return temperature. Clear such an error before proceeding.

Higher supply air temperatures save energy at the chiller level but may slightly increase the energy usage at the server level. Generally, server fans speed up at intake temperatures above 77°F (25°C) to ensure adequate cooling. This effect and the CPU leakage current is not considered in the Tool. For guidance on determining (measuring) the input data, see the Data Collection Guide.

Calculated data exported to the Main Input sheet (orange cells) (Figure 3):
- Total AHU Airflow [cfm or m^3/s] and AHU Count [-]
- Max-Min AHU supply temperature [°F or °C]
- Typical (airflow weighted) AHU supply air temperature [°F or °C]
- Typical (airflow weighted) AHU temperature drop [°F or °C].

Other calculated data (white cells):
- AHU kW Cooling
- AHU Ton Cooling

Resulting AHU kW cooling and AHU Ton Cooling (the heat extraction from the room by mechanical means and/or by free cooling) are calculated based on Total AHU Airflow and Typical (airflow weighted) AHU temperature drop. Note that AHU data are considered more robust than Equipment data (Step 2); Equipment Power (heat) is set equal to Resulting AHU Cooling (heat balance in room).

If there is a separate air-side economizer (one that provides cooling and airflow in addition to the AHUs) it could be specified as another "AHU". The Other Calculated Data listed above will then include the associated cooling effect. However, disregard separate fresh-air systems that generally have limited airflows. For built-in economizers, no additional entries are necessary.

For calculation details, see the *Engineering Reference*.

Figure 2: Step 1 AHU sheet, upper part.

Figure 3: Step 1 AHU sheet, lower part.

Step 2 Equipment

"Step 2 Equipment" is the second of four input sheets.

By inserting the requested equipment data (yellow cells), this spreadsheet will calculate two pieces of data (orange boxes) and export them to the Main Input (Step 4) sheet. "Equipment" includes heat-generating electronic equipment (IT) as well as electric equipment such as PDU and UPS.

The principal purpose of the data transfer is to help 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 more information on RTI, please see section Step 4 Main Input.

Since determining the equipment input data may be a challenging task, three options are available through the "Select Class Option" cell in the upper left corner of the spreadsheet. Select the cell to activate the drop-down box. Selection will display relevant table headings and yellow input cells. The option to select depends on which data are available and the quality of the data.

Depending on the selection, group the equipment into Classes with similar temperature rise (DT) or airflow rates (V) and fill in the remaining yellow input cells. Note that a "Class" can be on server, rack, or any spatial level defined by the user. Unique inputs for every piece of equipment, rather than consolidation into equipment Classes, are not allowed. Furthermore, only one Class Option can be selected for all input.

One of the following Class Options can be selected:

- Similar DT: "Class" refers here to equipment with similar Measured Temperature Rise (DT); used with corresponding fair estimates of Airflow (V). The manufacturers' published thermal reports or their online thermal calculators can also be used for estimating the equipment airflow and temperature rise.

  Input data (yellow cells):
  o Measured Temperature Rise arranged in Classes (DT) [°F or °C]
  o Estimated (low quality) Airflow per Class (V) [cfm or m^3/s].

- Similar V: "Class" refers here to equipment with similar Estimated Airflow (V); used with corresponding Number of Units (U). Use the manufacturers' published thermal reports or their online thermal calculators for estimating the equipment airflow.

  Input data (yellow cells):
  o Estimated (high quality) Airflow (V) [cfm or m^3/s]
  o Number of Units (U) [-].

- Similar DT(P): "Class" refers here to equipment with similar Measured Temperature Rise (DT); used with corresponding Measured Power (P) (Figure 4). Do not use nameplate power as a replacement for lack of measured power data. Instead, use the manufacturers' published

thermal reports or their online thermal calculators for estimating the equipment power and temperature rise.

The Measured Power (P) can be imported from either the IT Equipment Tool or the Electrical Power Chain Tool (DOE, 2023b). The latter option includes IT power chain losses and result in more accurate heat release values. These import options also open up an opportunity to capture design and operational changes to the IT equipment and the IT equipment power chain in the Air Management Tool.

Input data (yellow cells):
o   Measured Temperature Rise (DT) [°F or °C]
o   Measured Power (P) [W].

Although not required, it is recommended to enter the Classes from the top (Class 1) down in the yellow input tables. For more guidance on determining the input data for all three options, see the *Data Collection Guide*.

If no data are available, select "Similar DT" and fill in one row only. Estimate DT (table below may help) and set Airflow to any positive number. The trend is towards higher temperature rise across the electronic equipment.

Table 1: Typical temperature rise across IT equipment.

Equipment Mix	ΔT [°F]	ΔT [°C]
Mainly traditional equipment	10 to 20	6 to 11
Mainly modern equipment	20 to 30	11 to 17
Mainly blade equipment	30 to 50	17 to 28

Calculated data exported to the Main Input sheet (orange cells):
•   Typical (airflow weighted) equipment temperature rise [°F or °C]
    o   "Similar DT": Based on yellow cells
    o   "Similar V" or "Similar DT(P)": Based on Total Equipment Airflow and AHU data.
•   Total Equipment Airflow
    o   "Similar V" or "Similar DT(P)": Based on yellow cells
    o   "Similar DT": Based on Typical (airflow weighted) equipment temperature rise and AHU data.

Other calculated data (white cells):
•   Equipment Power (= AHU cooling) [kW].
Compare with UPS readings—if available. If the UPS equipment is located outside the data center room, use the delivered UPS power. If poor agreement, revisit Steps 1 and 2, looking for potential errors. Note that the AHU data (Step 1) are considered more robust than the Equipment data; Equipment Power (heat) is set equal to Resulting AHU Cooling (heat balance in room).

- Total Measured Power (Similar DT(P) option only) [kW] and Power Imbalance [%].

Compare with Equipment Power. If poor agreement (>10% difference), revisit Steps 1 and 2 to avoid large errors in the Total Equipment Airflow and Typical (airflow weighted) Equipment Temperature Rise. Poor agreement will not affect the Equipment Power (white box).

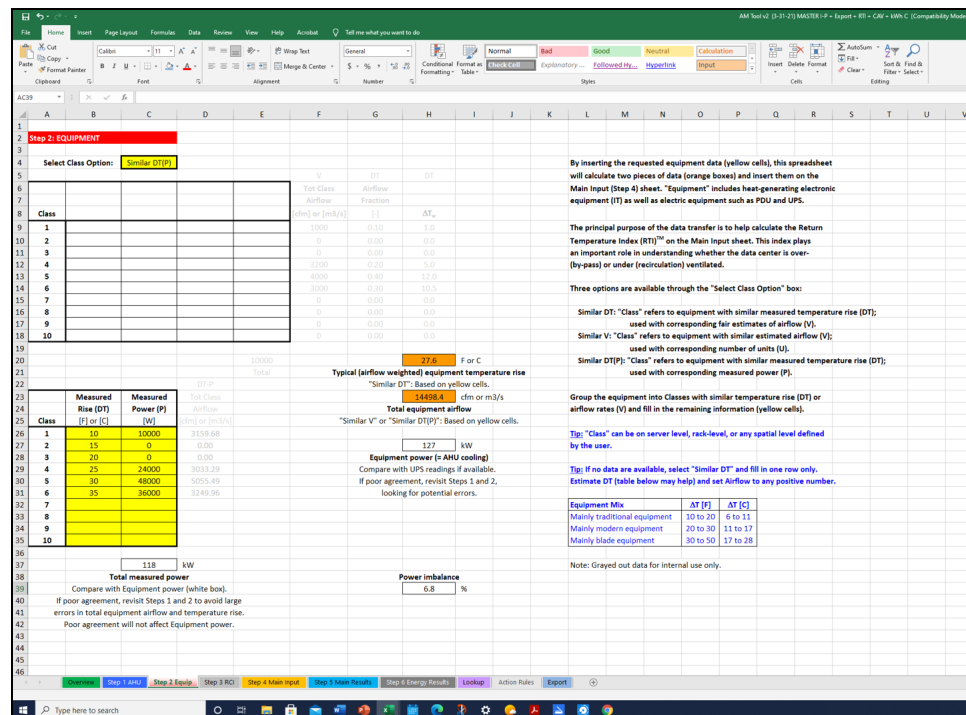For calculation details, see the *Engineering Reference*.

Figure 4: Step 2 Equipment sheet
(Class Option DT(P) is selected in this screen shot).

Step 3 RCI

"Step 3 RCI" is the third of four input sheets.

The Rack Cooling Index (RCI)$^{®}$ plays an important role in understanding whether the data center is complying with the recommended and allowable intake temperature ranges (Herrlin 2005). These ranges are specified in Step 4 Main Input under "Current" for Questions 1 and 2 in Table B. The selected ranges are echoed next to the Intake Temperature plot.

The RCI is a performance metric explicitly designed to gauge compliance with the thermal guidelines of ASHRAE (2021) and NEBS for a given data center. The RCI is often used to make sure that no degradation of the thermal environment occurs when air-management measures are introduced for the purpose of saving energy. This index compresses the equipment intake temperatures into two numbers: RCI_{HI} and RCI_{LO}. The RCI is a measure of how effectively equipment racks are cooled within a given thermal guideline, both at the high end and at the low end of the temperature range.

Specifically, the RCI_{HI} is a measure of the absence of over-temperatures, and 100% means no over-temperatures. Over-temperature conditions exist once one or more intake temperatures exceed the maximum recommended temperature. The lower the percentage, the greater probability (risk) that equipment experiences temperatures above the max allowable temperature. Indication of such potentially harmful thermal conditions is provided by a warning flag "*" appended to the index, generally indicating localized overheating. A value below 90% is often characterized as "poor". An analogous index is defined for temperature conditions at the low end of the temperature range. An RCI_{LO} of 100% mean no under-temperatures. Both RCI numbers at 100% mean that all intake temperatures are within the recommended temperature range; i.e., absolute compliance.

Input data (yellow cells):
- Intake Temperature [°F or °C].
  A maximum of 999 intake temperatures is allowed (Figure 6). The data must be inserted from the top down. If no data are available, leave all yellow input cells blank.

Calculated data exported to the Main Input sheet (orange cells):
- RCI_{HI} [%]   ("*" appended to the index means at least one intake > max allowable)
- RCI_{LO} [%]   ("*" appended to the index means at least one intake < min allowable)
  The spreadsheet will calculate the Rack Cooling Index (RCI) and export RCI_{HI} and RCI_{LO} (orange cells) to the Main Input (Step 4) sheet. If either value is below 90%, a warning will be shown in red.

Other calculated data (white cells):
- Intake Temperature Plot (Figure 5).
  The Intake Temperature plot shows a graphical representation of the entered intake temperatures. The plot will dynamically update and scale with changes made to the intake temperatures and number of intake temperatures, respectively. The corresponding RCI values are shown immediately to the right of the plot in the orange boxes.

For RCI definitions, equations, and calculations, see the *Engineering Reference*. For guidance on determining the intake temperatures, see the *Data Collection Guide*.
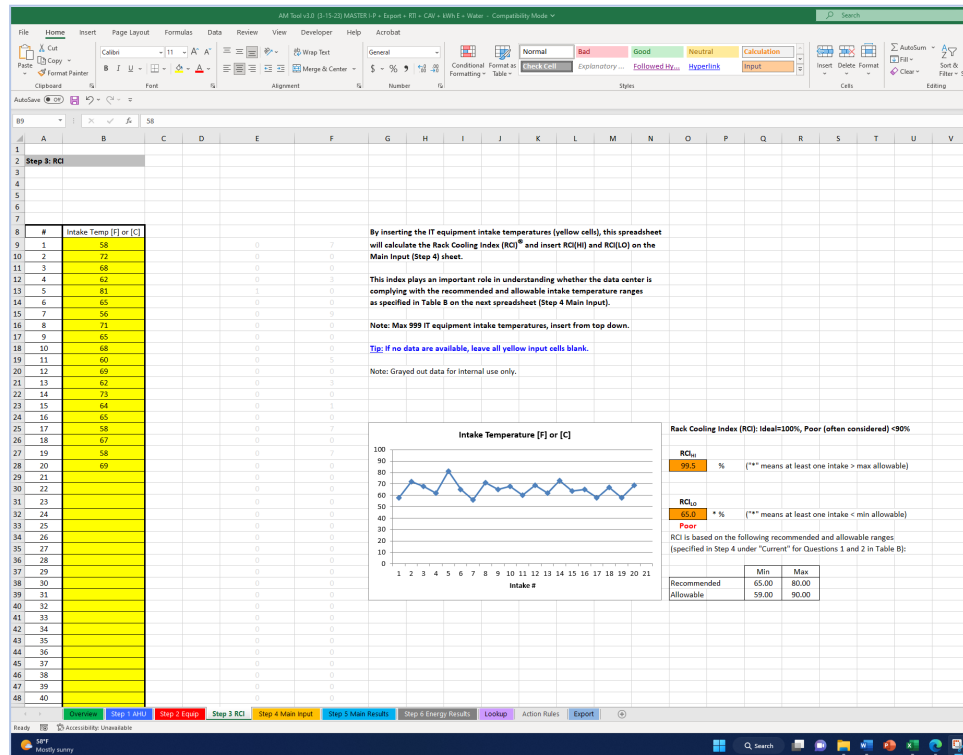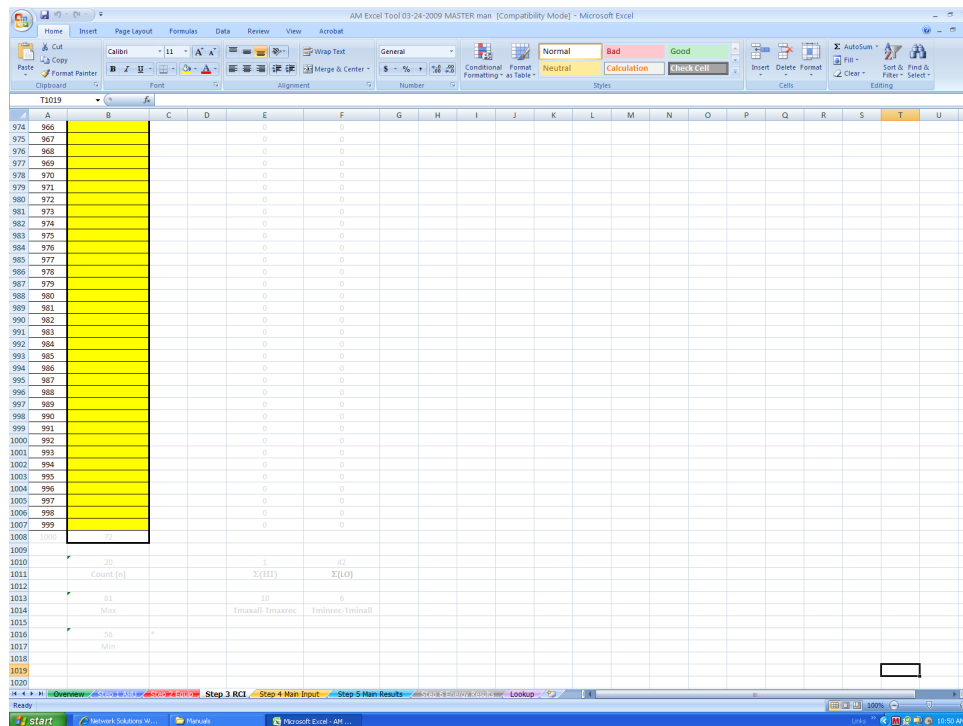
Figure 5: Step 3 RCI sheet, upper part.

Figure 6: Step 3 RCI sheet, lower part.

Step 4 Main Input

"Step 4 Main Input" is the last of four input sheets (although some data can be entered on "Step 6").

Table A shows air-management metrics (Figure 7):
- Yellow cells: Enter data
- Remaining metrics: Calculated or echoed from the AHU, Equip, and RCI sheets (color coded).

The Return Temperature Index (RTI)^{TM} is a high-level measure for by-pass air and recirculation air (Herrlin 2008). For the RTI definitions, equations, and calculations, see the *Engineering Reference*. However, the interpretation is straight forward:

- Balanced airflows (total equipment airflow = total air-handler airflow); RTI=100%
- Net by-pass air (air bypasses the equipment and not contributing to cooling); RTI<100%
- RTI<90% indicate an over-ventilated space (A warning will be shown in red)
- Net recirculation air (air re-circulates from equipment exhaust to equipment intake); RTI>100%
- RTI>110% indicate an under-ventilated space (A warning will be shown in red).

If no data or insufficient data were entered in Step 1 (AHU) and Step 2 (Equip), multiple cells in Table A will be empty. If this happens, more likely than not, no energy estimates will be calculated in Step 6. Therefore, it is imperative that data are entered in both Step 1 and Step 2.

Rack Cooling Index (RCI)$^{®}$ is a measure of absence of over- and under-temperatures (Herrlin 2005). For the RCI definitions, equations, and calculations, see the *Engineering Reference*. However, the interpretation is again straight forward:

- Ideal (max): 100%
- Poor: <90% (A warning will be shown in red).

If no data was entered in Step 3 (RCI), the two RCI metric 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 immediately below (Alt. 2). Note that Alt. 1 has priority over Alt. 2 should all four cells have values.

Table B lists air-management questions (Figure 8):
- Yellow cells: Enter data for Current and Target conditions.

The table has two columns:

- "Current" refers to existing data center architecture/controls.

- "Target" refers to realistic target data center architecture/controls. For Questions 3-10, this column is valid for raised-floor cooling only (Question 18 = Floor Plenum).

The table has three sections:

- Primary Input (impact on Energy estimates, Table 1 on Step 5 Main Results—if raised-floor cooling—and recommended Actions, Table 2 on Step 5 Main Results).

  - Questions 1 and 2: Recommended IT-equipment intake temperature range (this is a statement of equipment reliability) and Allowable IT-equipment intake temperature range (this is a statement of equipment functionality). The Current ranges will impact the numerical value of the RCI values calculated in Step 3 RCI. The drop-down boxes with the fixed options are activated by simply selecting the cells. The standard ASHRAE (2021) recommended range (65°-80°F) and the ASHRAE allowable A1 (59°-90°F) and A2 (50°-95°F) ranges are included. Two additional recommended ranges are provided: Wide and Narrow. They provide added flexibility in specifying a wider range (60°-85°F) and a narrower range (70°-75°F), respectively.

  - Questions 3-10 are considered the key factors for air management. These questions have three options: LOW, MID, and HIGH quality/implementation of the measure. (Question 15 has two options only: LOW and HIGH.) The drop-down boxes with the fixed options are activated by simply selecting the cells. A brief guidance on each option is also included. Note that only air-management measures can be rated for Current and Target conditions. For example, air-side economizers are not part of these measures.

  - Note that there is no input for the location of the temperature sensors for the control system. The AM-Tool assumes the preferred location; namely, at the electronic equipment intakes. The commonly used location at the air return is less accurate and the level of accuracy depends on the calibration with the intake temperatures. Return Air Temperature (RAT) sensing may require post-processing.

- Secondary Input (impact on recommended Actions only, Table 2 on Step 5 Main Results).

  - Questions 11-28 are mostly about physical characteristics of the data center. Most of the questions have drop-down boxes with fixed options. Activate the drop-down boxes simply by selecting the cells. Depending on the answers, downstream questions may appear or disappear. Question 15 imports data from Step 1.

- Management Practices Input (impact on recommended Management Actions only, Table 2 on Step 5 Main Results, Actions 38-44).

  - Questions 29-35 covers management practices with Yes or No answers. The drop-down boxes are activated by simply selecting the cells.

Figure 7: Step 4 Main Input sheet, upper part.

Figure 8: Step 4 Main Input sheet, lower part.

Step 5 Main Results

"Step 5 Main Results" is the first of two output sheets.

Table 1 lists numerical output based on user input (Figure 9).

There are four columns:
- Measured: Measured data (Step 4, Table A) with Current architecture/controls (Step 4, Table B, Questions #1-10)
- Commissioned: Achievable through commissioning with Current architecture/controls (Step 4, Table B, Questions #1 and 3-10) and Intake Air Temperature (IAT) sensing
- Retrofitted: Achievable through retrofit with Target architecture/controls (Step 4, Table B, Questions #1 and 3-10) and Intake Air Temperature (IAT) sensing
- State-of-the-Art: Achievable with State-of-the-Art architecture/controls (SAT based on Target recommended range).

The "Commissioned" and "Retrofitted" columns are valid for raised-floor cooling only (Step 4, Table B, Question 18 = Floor Plenum). Multiple cells may be empty if insufficient data have been provided in Steps 1-3.

There are six rows:
- 100/RTI = Total AHU Airflow/Total Equipment Airflow (V_{AHU}/V_{Equip}) [-]
- SAT = Typical (airflow weighted) AHU Supply Air Temperature [°F or °C]
- RAT = Typical (airflow weighted) AHU Return Air Temperature [°F or °C]
- 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
- V_{AHU} = Total Air-Handler Unit Airflow [cfm or m^3/s].

By reading across the columns for the three first rows, the achievable improvements for three levels of air-management measures can quickly be evaluated. If CAV fans were selected on Step 4 Main Input (Question 8), see the Engineering Reference. The data are used for estimating the percentage savings for fan energy and chiller energy in Step 6 Energy Results. Since the Tool is using discrete look-up tables for calculating the numerical output, the results may not change if the input is only marginally changed.

Table 2 lists recommended Actions based on user input (figure 10).

The table has three sections:

- Actions for realizing Commissioned conditions in Table 1 (Actions 1-10)
- Actions for realizing Retrofitted or State-of-the-Art conditions in Table 1 (Actions 11-37)
- Management Practices (Actions 38-44).

Not applicable Actions are indicated by "N/A". By implementing recommended Actions (by revisiting user data input and/or question responses) further Actions may be provided.
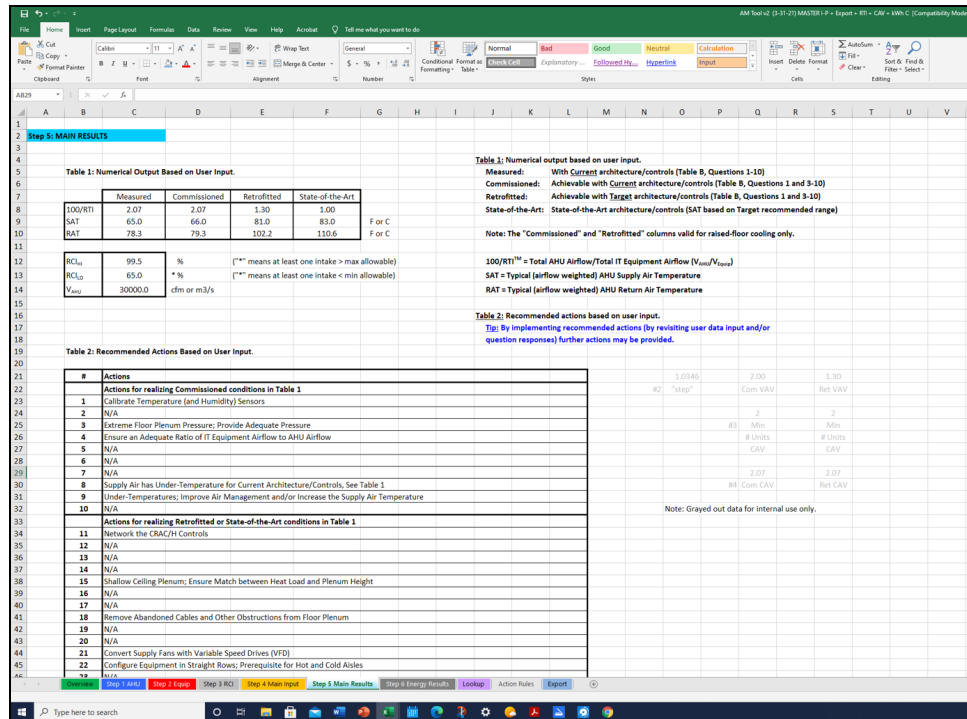
Step 5: MAIN RESULTS

Table 1: Numerical Output Based on User Input.

	Measured	Commissioned	Retrofitted	State-of-the-Art	
100/RTI	2.07	2.07	1.30	1.00	
SAT	65.0	66.0	81.0	83.0	F or C
RAT	78.3	79.3	102.2	110.6	F or C

RCI$_{HI}$	99.5	%	("*" means at least one intake > max allowable)
RCI$_{LO}$	65.0	* %	("*" means at least one intake < min allowable)
V$_{AHU}$	30000.0	cfm or m3/s	

Table 1: Numerical output based on user input.

Measured: With Current architecture/controls (Table B, Questions 1-10)
Commissioned: Achievable with Current architecture/controls (Table B, Questions 1 and 3-10)
Retrofitted: Achievable with Target architecture/controls (Table B, Questions 1 and 3-10)
State-of-the-Art: State-of-the-Art architecture/controls (SAT based on Target recommended range)

Note: The "Commissioned" and "Retrofitted" columns valid for raised-floor cooling only.

100/RTI^{TM} = Total AHU Airflow/Total IT Equipment Airflow (V$_{AHU}$/V$_{Equip}$)
SAT = Typical (airflow weighted) AHU Supply Air Temperature
RAT = Typical (airflow weighted) AHU Return Air Temperature

Table 2: Recommended actions based on user input.
Tip: By implementing recommended actions (by revisiting user data input and/or question responses) further actions may be provided.

Table 2: Recommended Actions Based on User Input.

#	Actions
	Actions for realizing Commissioned conditions in Table 1
1	Calibrate Temperature (and Humidity) Sensors
2	N/A
3	Extreme Floor Plenum Pressure; Provide Adequate Pressure
4	Ensure an Adequate Ratio of IT Equipment Airflow to AHU Airflow
5	N/A
6	N/A
7	N/A
8	Supply Air has Under-Temperature for Current Architecture/Controls, See Table 1
9	Under-Temperatures; Improve Air Management and/or Increase the Supply Air Temperature
10	N/A
	Actions for realizing Retrofitted or State-of-the-Art conditions in Table 1
11	Network the CRAC/H Controls
12	N/A
13	N/A
14	N/A
15	Shallow Ceiling Plenum; Ensure Match between Heat Load and Plenum Height
16	N/A
17	N/A
18	Remove Abandoned Cables and Other Obstructions from Floor Plenum
19	N/A
20	N/A
21	Convert Supply Fans with Variable Speed Drives (VFD)
22	Configure Equipment in Straight Rows; Prerequisite for Hot and Cold Aisles
23	N/A

Note: Grayed out data for internal use only.

Figure 9: Step 5 Main Results sheet, upper part.

#	
	Actions for realizing Commissioned conditions in Table 1
1	Calibrate Temperature (and Humidity) Sensors
2	N/A
3	Extreme Floor Plenum Pressure; Provide Adequate Pressure
4	Ensure an Adequate Ratio of IT Equipment Airflow to AHU Airflow
5	N/A
6	N/A
7	N/A
8	Supply Air has Under-Temperature for Current Architecture/Controls, See Table 1
9	Under-Temperatures; Improve Air Management and/or Increase the Supply Air Temperature
10	N/A
	Actions for realizing Retrofitted or State-of-the-Art conditions in Table 1
11	Network the CRAC/H Controls
12	N/A
13	N/A
14	N/A
15	Shallow Ceiling Plenum; Ensure Match between Heat Load and Plenum Height
16	N/A
17	N/A
18	Remove Abandoned Cables and Other Obstructions from Floor Plenum
19	N/A
20	N/A
21	Convert Supply Fans with Variable Speed Drives (VFD)
22	Configure Equipment in Straight Rows; Prerequisite for Hot and Cold Aisles
23	N/A
24	N/A
25	N/A
26	N/A
27	N/A
28	Use Supplemental Cooling for High-Density Areas
29	Improve CRAC/H Floor Layout
30	N/A
31	Use IT Equipment with Front-to-Rear or Front-to-Top Cooling Airflow (EC-Class)
32	Remove Cosmetic Doors from Equipment Racks or...
33	...Provide Adequate Free Area for Air Movement
34	N/A
35	Implement Equipment Intake Air Temperature Control (program default)
36	N/A
37	N/A
	Management Practices
38	Implement a Sensor Calibration Program
39	Implement a Raised-Floor Cable Mining Program
40	Implement a Tile/Diffuser-Placement Program
41	Implement a Plenum-Tightness Program
42	Implement a Rack- and Row-Tightness Program
43	Implement an Air-Balancing Program
44	N/A

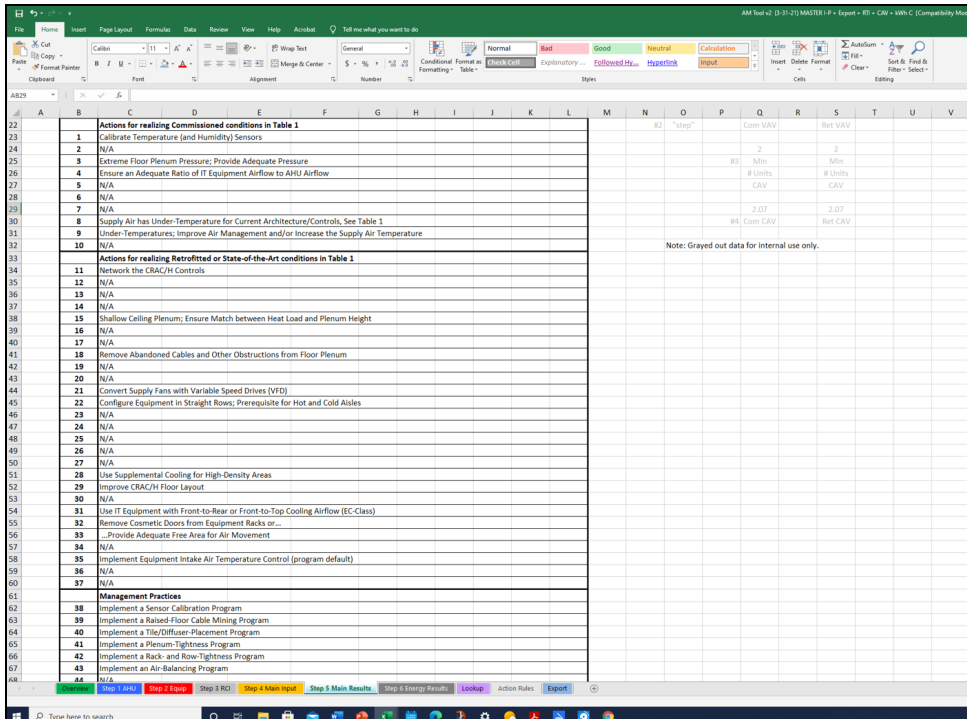Note: Grayed out data for internal use only.

Figure 10: Step 5 Main Results sheet, lower part.

Step 6 Energy Results

"Step 6 Energy Results" is the second of two output sheets.

This sheet contains % energy reduction, kWh reduction, and associated $ and carbon (CO_2) savings for supply fans and chillers. Simple payback periods are also provided based on entered implementation costs. Finally, an estimate of on-site water consumption is provided. All other results can be found in Step 5.

The two bar charts shown here are based on Table 1 in Step 5 Main Results. Since the Tool is using discrete look-up tables for calculating the numerical output, the percentage savings may not change if the input is only marginally changed.

The "Measured" bars are the reference (100%) and values above 100% for the other bars will not be displayed. Obviously, this is a situation that should be avoided—the goal is to decrease the energy demand, not increase it. The "Commissioned" and "Retrofitted" bars are valid for raised-floor cooling only (Step 4, Table B, Question 18 = Floor Plenum).

With adequate air management, the reduction in fan energy is often very large due to the fact that the fan energy varies close to the cube of the airflow. It is not uncommon to be in the 70-80% range.
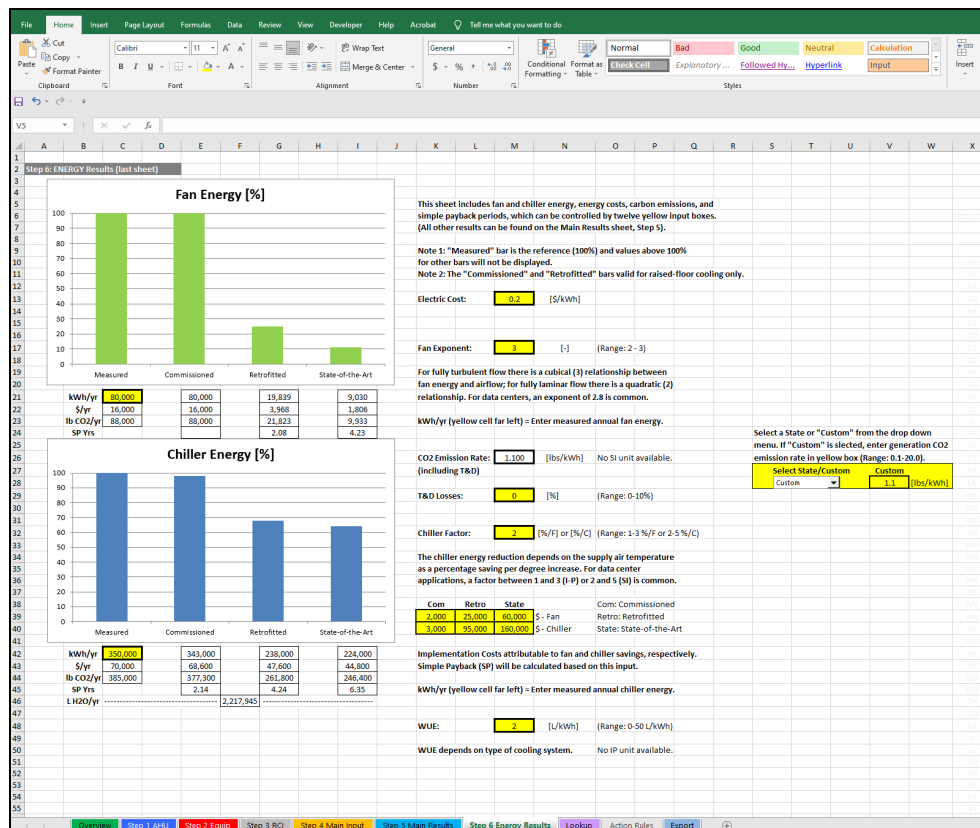

Figure 11: Step 6 Energy Results sheet

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<u>Input data (yellow cells):</u>

The calculations of fan and chiller energy, energy cost, carbon emissions, and simple payback periods can be controlled by fourteen yellow input boxes. Placing these input boxes directly on the result screen allows for quick parameter changes with instant result feedback to the user.

- Measured Annual Fan Energy [kWh/year].
  Enter the measured annual fan energy in kWh/year. This entry together with chart values will be used to calculate the fan energy for the Commissioned, Retrofitted, and State-of-the-Art scenarios (displayed under the fan chart).

- Measured Annual Chiller Energy [kWh/year].
  Enter the measured annual chiller energy in kWh/year. This entry together with chart values will be used to calculate the chiller energy for the Commissioned, Retrofitted, and State-of-the-Art scenarios (displayed under the chiller chart).

  This input can be manually calculated based on sheet Step 1: AHU, Cell G58 ("AHU kW Cooling") and an assumed Coefficient of Performance (COP). For the preloaded example, the "AHU kW Cooling" is 127kW. Assuming a COP of 3.18 results in 40kW chiller power. Lastly, converting to kWh/year by multiplying with 8,760 hours results in roughly 350,000 kWh/year chiller energy.

- Electric Cost [$/kWh].
  Enter the electric cost in $/kWh. This entry together with kWh/year will be used to calculate the associated dollar costs for each scenario: Measured, Commissioned, Retrofitted, and State-of-the-Art (displayed under both charts).

- Fan Exponent [-].
  For fully turbulent airflow, there is a cubical (^3) relationship between fan energy and airflow whereas for fully laminar airflow there is a quadratic (^2) relationship. For data centers, the majority of the flow resistance is turbulent. Therefore, an exponent of 2.8 can often be used.

- CO_2 Emission Rate [lbs/kWh].
  The annual carbon emissions are calculated by multiplying the fan and chiller energy (kWh/year) for each scenario by the CO_2 Emission Rate (lbs/kWh). To limit the information on the Step 6 screen, we adjust the CO_2 Emission Rate for line losses (see T&D Losses below) rather than adjusting the site energy consumption.

  Select a state from the drop-down list and the average emission rate per eGRID (2021) for that state will be shown in the white Emission Rate box. Note that these are CO_2 emission rates and not CO_2e (equivalent) emission rates. The latter includes CH_4 and N_2O emissions, which generally adds less than 1% to the CO_2e numbers. Alternatively, you can specify any emission rate by selecting Custom from the same drop-down list (first item) and then input the custom emission rate in the yellow Custom box.

  The Emissions & Generation Resource Integrated Database (eGRID) is a comprehensive source of data on the environmental characteristics of almost all electric power generated in the United States. The map below (Figure 12) from eGRID (2023) provides an overview of the CO_2 emission

rates across the United States in 2021 (latest available numbers). These numbers do not include T&D Losses, but they will be added under T&D Losses below. Please note that the map uses lbs/MWh whereas the input on the Energy Results screen requires lbs/kWh.

The correlation with type of generation fuel is strong. States with a high percentage of coal are generally colored dark blue or >1,200 lbs. CO_2/MWh electric generation (e.g., West Virginia and Wyoming), and states with a high percentage of clean power are colored light blue or <500 lbs. CO_2/MWh. If more current and/or detailed information is needed for a specific location, please contact your energy provider.

Please note that individual power stations can have much higher emission rates than the state averages shown in Figure 12.
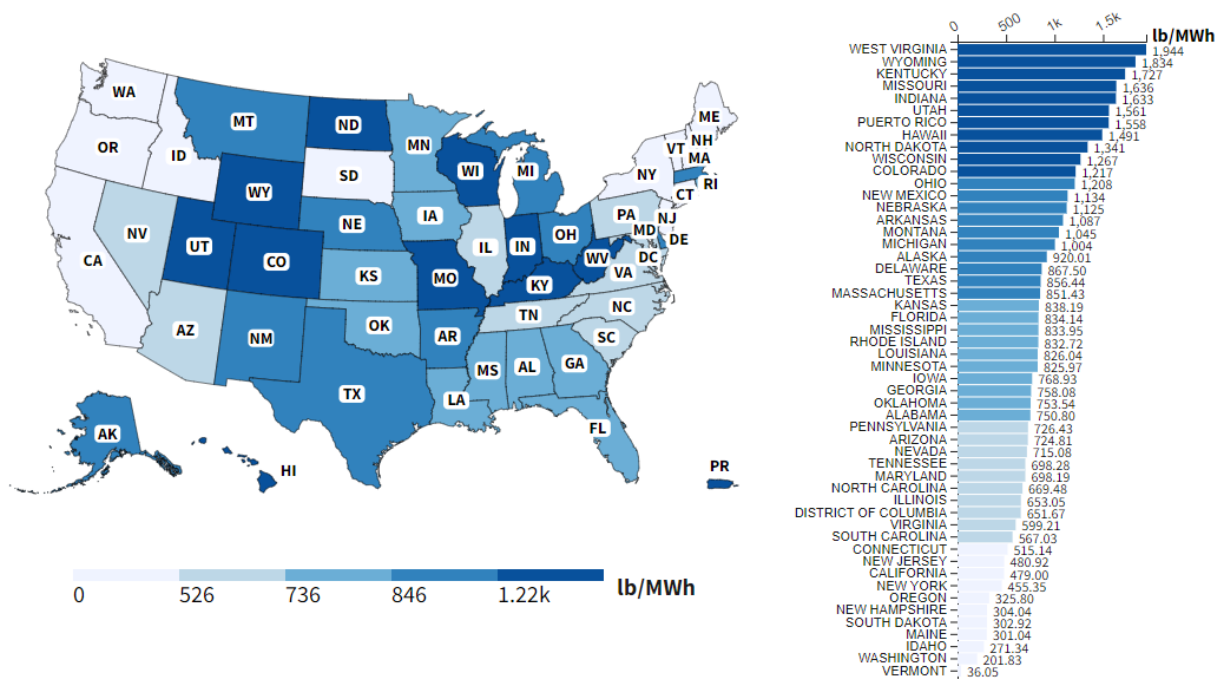
Figure 12. 2021 CO_2 emission rates (lbs/MWh) (eGRID, 2023)

- T&D Losses [%].
  The CO_2 Emission Rate shown on the Step 6 screen includes an adjustment for electrical line losses, mainly transmission and distribution (T&D) losses, as entered by the user. Transmission is high-voltage transmission from the plant to a substation whereas distribution is over lower-voltage power lines to the end users. The T&D losses are around 5% and not very dependent on geographic region.

- Chiller Factor [%/°F or %/°C].
  The chiller energy reduction depends on the supply air temperature as a percentage saving per degree increase. For data center applications, a Chiller Factor between 1 and 3 (I-P) or 2 and 5 (SI) is common.

- Implementation Costs [$]
  Enter the implementation costs attributable to fan and chiller savings, respectively, for each of the three scenarios (Commissioned, Retrofitted, and State-of-the-Art). Simple Payback periods will be calculated based on this input for the three scenarios (displayed under the charts).

- WUE [L/kWh$_{IT}$]
  The Water Usage Effectiveness (WUE) [L/kWh$_{IT}$] is defined as the annual *on-site* water usage in liters divided by the annual IT equipment energy usage in kWh. WUE depends on the data center cooling system. Systems using dry-coolers have no water usage whereas cooling towers often have significant water usage especially for high cooling loads. The average data center WUE in the United States is around 2 liter (0.53 gallons) of water per kWh. However, the corresponding water usage at the electrical power plant is generally many times higher than the on-site usage (LBNL, 2016).

  The on-site water consumption will be calculated based on the entered WUE and the Measured Power as entered on Step 2 for the IT equipment. Including the power losses associated with the IT power chain in the entered Measured Power will result in more accurate heat release but the water consumption will be overestimated. Only one water consumption value is shown under the Chiller Energy bar chart. This value should be applied to the scenario represented by the entered WUE.

Note finally that the following input data are applicable to all four scenarios in Figure 11: Electric Cost, Fan Exponent, Generation CO_2 Emission Rate, T&D Losses, and Chiller Factor.

Clearly, a large amount of data needs to be collected for a thorough air management analysis. The DOE Data Center Air-Management (AM) Tool: Data Collection Guide (DOE, 2021) provides information on collecting the required input data. However, there may be times when a simpler approach is preferred.

The Guide for Quickly Estimating Air Management Energy Savings in Small Data Centers: Air Management Look-up Tables (LBNL, 2020) may then prove useful. The purpose of this document is to provide a quick way of estimating the potential energy savings with air management in data centers by using look-up tables, which are included in the document. There is no software involved.

Lookup

This sheet is initially a hidden since there are no user inputs or user outputs. If the sheet is made visible, please do not enter or change data. The screen shot below has been included for completeness only.

For calculation details and the significance of the lookup tables, see the *Engineering Reference*.

Figure 13: Lookup sheet.

Action Rules

This sheet is initially hidden since it does not contain any user inputs or user outputs. No screen shot is included for this sheet. Instead, please open the Tool and then select tab Action Rules (after making it visible) for viewing the sheet.

The Action Rules are rule-sets for triggering certain Actions or recommendations in Step 5 Main Results, Table 2 based on user input, mainly Table B in Step 4 Main Input, and the rather self-explanatory rule-sets on this sheet. Across the top of the spreadsheet, the Questions from Step 4 Main Input are listed as table columns. The rows in the table represent the resulting Actions or recommendations. In the body of the table are the actual rules or the conditions that trigger Actions.

See also the *Engineering Reference*.

Export

This last sheet is also initially hidden. The purpose of this sheet is to summarize output that may be used for post-processing, for example in whole-building simulation packages. The table cells are color coded per the originating sheet (tab) color.

Figure 14: Export sheet.

SUMMARY OF REQUIRED NUMERICAL INPUT DATA

This table provides a quick reference for Tool input data. For details, see the associated Program Step(s) in this User's Manual.

Table 2: 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} 2) UPS Heat Release: P_{in}-P_{out}	W W	Step 2 Equip
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/Chiller Energy	kWh/year	Step 6 Energy Results
Energy Cost	$/kWh	Step 6 Energy Results
CO_2 Emission Rate	lbs/kWh	Step 6 Energy Results

ABBREVIATIONS AND ACRONYMS

ΔT_{AHU}	Typical (airflow weighted) AHU temperature drop [°F or °C]
ΔT_{Equip}	Typical (airflow weighted) equipment temperature rise [°F or °C]
AHU	Air-Handler Unit
AM	Air Management
By-pass	Cool air that by passes the electronic 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 [°F or °C]
Equip	Equipment (IT and Electrical)
HVAC	Heating, Ventilating, and Air-Conditioning
IAT max	Typical (not extreme) maximum IT-equipment intake temperature [°F or °C]
IAT min	Typical (not extreme) minimum IT-equipment intake temperature [°F or °C]
Measured	Measured data with Current architecture/controls
P	Power [W] or [kW]
RAT	Return air temperature [°F or °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 equipment exhaust re-circulated back to the equipment intakes
Retrofitted	Achievable with Target architecture/controls

RTI   Return Temperature Index (RTI)^{TM} [%]; $\Delta T_{AHU}/\Delta T_{Equip} = V_{Equip}/V_{AHU}$

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]

WUE   Water Usage Effectiveness [L/kWh$_{IT}$]

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