Calculating Total Cooling Requirements for Data Centers

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Executive Summary

This document describes how to estimate heat output from Information Technology equipment and other devices in a data center such as UPS, for purposes of sizing air conditioning systems. A number of common conversion factors and design guideline values are also included.

Introduction

All electrical equipment produces heat, which must be removed to prevent the equipment temperature from rising to an unacceptable level. Most Information Technology equipment and other equipment found in a data center or network room is air-cooled. Sizing a cooling system requires an understanding of the amount of heat produced by the equipment contained in the enclosed space, along with the heat produced by the other heat sources typically encountered.

Measuring Heat Output

Heat is energy and is commonly expressed in Joules, BTU, Tons, or Calories. Common measures of heat output rate for equipment are BTU per hour, Tons per day, and Joules per second (Joules per second is equal to Watts). There is no compelling reason why all of these different measures are used to express the same commodities, yet any and all of them might be used to express power or cooling capacities. The mixed use of these measures causes a great deal of senseless confusion for users and specifiers. Fortunately, there is a worldwide trend among standard-setting organizations to move all power and cooling capacity measurements to a common standard, the Watt. The archaic terms of BTU and Tons will be phased out over time[1]. For this reason, this paper will discuss cooling and power capacities in Watts. The use of the Watt as the common standard is fortuitous, because it simplifies the work associated with data center design as will be explained later.

In North America, specifications for power and cooling capability are still often provided in the legacy BTU and Tons terms. For this reason, the following conversions are provided to assist the reader:

Given a value in	Multiply by	To Get
BTU per Hour	0.293	Watts
Watts	3.41	BTU per Hour
Tons	3,530	Watts
Watts	0.000283	Tons

The power transmitted by computing or other information technology equipment through the data lines is negligible. Therefore, the power consumed from the AC power mains is essentially all converted to heat. This fact allows the thermal output of IT equipment in Watts to simply equal its power consumption in

[1] The term "Tons" refers to the cooling capacity of ice and is a relic of the period from 1870-1930 when refrigeration and air conditioning capacity were provided by the daily delivery of ice blocks.

Watts. BTU per hour, as is sometimes provided in datasheets, is not necessary in determining the thermal output of equipment. The thermal output is simply the same as the power input[2].

Determining heat output of a complete system

The total heat output of a system is the sum of the heat outputs of the components. The complete system includes the IT equipment, plus other items such as UPS, Power Distribution, Air Conditioning Units, Lighting, and People. Fortunately, the heat output rates of these items can be easily determined via simple and standardized rules.

The heat output of UPS and Power Distribution systems consists of a fixed loss and a loss proportional to operating power. These losses are sufficiently consistent across equipment brands and models and so they can be approximated without significant error. Lighting and people can also be readily estimated using standard values. The only information needed to determine the cooling load for the complete system are a few readily available values, such as the floor area in square feet, and the rated electrical system power.

Air conditioning units create a significant amount of heat from fans and compressors. This heat is exhausted to the outside and does not create a thermal load inside the data center. It does, however, detract from the efficiency of the air conditioning system and is normally accounted for when the air conditioner is sized.

A detailed thermal analysis using thermal output data for every item in the data center is possible, but a quick estimate using simple rules gives results that are within the typical margin of error of the more complicated analysis. The quick estimate also has the advantage that it can be performed by anyone without specialized knowledge or training.

A worksheet that allows the rapid calculation of the heat load is provided in **Table 1**. Using the worksheet, it is possible to determine the total heat output of a data center quickly and reliably. The use of the worksheet is described in the procedure below **Table 1**.

[2] Note: the one exception to this rule is Voice Over IP (VOIP) Routers; in these devices up to 30% of the power consumed by the device may be transmitted to remote terminals, so their heat load may be lower than the electrical power they consume. Assuming that the entire electrical power is dissipated locally as is assumed in this paper will give a small overstatement of heat output for VOIP routers, an insignificant error in most cases.

Table 1 – Data center or network room heat output calculation worksheet

Item	Data required	Heat output calculation	Heat output subtotal
IT Equipment	Total IT load power in Watts	Same as total IT load power in watts	____________ Watts
UPS with Battery	Power system rated power in Watts	(0.04 x Power system rating) + (0.05 x Total IT load power)	____________ Watts
Power Distribution	Power system rated power in Watts	(0.01 x Power system rating) + (0.02 x Total IT load power)	____________ Watts
Lighting	Floor area in square feet, or Floor area in square meters	2.0 x floor area (sq ft), or 21.53 x floor area (sq m)	____________ Watts
People	Max # of personnel in data center	100 x Max # of personnel	____________ Watts
Total	Subtotals from above	Sum of heat output subtotals	____________ Watts

Procedure

Obtain the information required in the "Data required" column. Consult the data definitions below in case of questions. Perform the heat output calculations and put the results in the subtotal column. Add the subtotals to obtain the total heat output.

Data Definitions

Total IT load power in Watts - The sum of the power inputs of all the IT equipment.

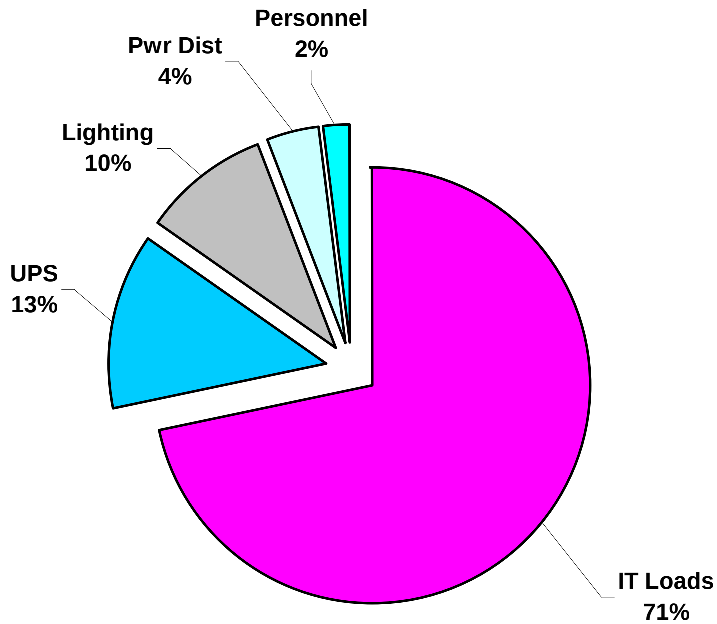
Power System Rated Power - The power rating of the UPS system. If a redundant system is used, do not include the capacity of the redundant UPS.

Example of a typical system

The thermal output of a typical system is described. A 5,000 ft^2, (465 m^2) 250 kW rated data center with 150 racks and a maximum staff of 20 is used as an example. In the example, it is assumed that the data center is loaded to 30% of capacity, which is typical. For a discussion of typical utilization, see APC White Paper #37, "Avoiding Costs From Oversizing Data Center and Network Room Infrastructure". The total IT load of the data center in this case would be 30% of 250 kW, or 75 kW. Under this condition, the total data center thermal output is105 kW, or approximately 50% more than the IT load.

In the typical example, the relative contribution of the various types of items in the data center to the total thermal output is shown in **Figure 1**.

Figure 1 – Relative contributions to the total thermal output of a typical data center



Note that the contributions to the thermal output of the UPS and the Power Distribution are amplified by the fact that the system is operating at only 30% of capacity. If the system was operating at 100% of capacity, the efficiency of the power systems would increase and their relative contributions to the thermal output of the system would decrease. The significant loss of efficiency is a real cost of oversizing a system.

Other heat sources

The prior analysis ignores sources of environmental heat such as sunlight through windows and heat conducted in from outside walls. Many small data centers and network rooms do not have walls or windows to the outside, so there is no error resulting from this assumption. However, for large data centers with walls or a roof exposed to the outdoors, additional heat enters the data center which must be removed by the air conditioning system.

If the data room is located within the confines of an air-conditioned facility, the other heat sources may be ignored. If the data center has significant wall or ceiling exposure to the outside, then a HVAC consultant will need to assess the maximum thermal load and it must be added to the thermal requirement of the complete system determined in the previous section.

Humidification

In addition to removing heat, an air conditioner system for a data center is designed to control humidity. Ideally, when the desired humidity is attained, the system would operate with a constant amount of water in the air and there would be no need for ongoing humidification. Unfortunately, in most air conditioning systems the air-cooling function of the air conditioning system causes significant condensation of water vapor and consequent humidity loss. Therefore, supplemental humidification is required to maintain the desired humidity level.

Supplemental humidification creates an additional heat load on the CRAC unit, effectively decreasing the cooling capacity of the unit and consequently requiring oversizing.

For small data rooms or large wiring closets, an air conditioning system which isolates the bulk return air from the bulk supply air by using ducting can result in a situation where no condensation occurs and therefore no continuous supplemental humidification is needed. This allows 100% of the rated air conditioning capacity to be utilized and maximizes efficiency.

For large data centers with high amounts of air mixing, the CRAC unit must deliver air at low temperatures to overcome the recirculation effects of the higher temperature equipment exhaust air. This results in substantial dehumidification of the air and creates the need for supplemental humidification. This causes a significant decrease in the performance and capacity of the air conditioning system. The result is that the CRAC system must be oversized up to 30%

The required oversizing for a CRAC unit therefore ranges from 0% for a small system with ducted exhaust air return, to 30% for a system with high levels of mixing within the room. For more information on humidification see APC White Paper #58, “Humidification Strategies for Data Centers and Network Rooms”.

Sizing air conditioning

Once the cooling requirements are determined, it is possible to size an air conditioning system. The following factors, which were described earlier in this paper, must be considered:

The size of the cooling load of the equipment (including power equipment)
The size of the cooling load of the building
Oversizing to account for humidification effects
Oversizing to create redundancy
Oversizing for future requirements

The Watt loads of each of these factors can be summed to determine the total thermal load.

Conclusion

The determination of cooling requirements for IT systems can be reduced to a simple process that can be done by anyone without special training. Expressing all measures of power and cooling in Watts simplifies the process. A general rule is that a CRAC system rating must be 1.3 times the anticipated IT load rating plus any capacity added for redundancy. This approach works well with smaller network rooms of under 4,000 ft^2 (372 m^2).

For larger data centers, the cooling requirements alone are typically not sufficient to select an air conditioner. Typically, the effects of other heat sources such as walls and roof, along with recirculation, are significant and must be examined for a particular installation.

The design of the air handling ductwork or raised floor has a significant effect on the overall system performance, and also greatly affects the uniformity of temperature within the data center. The adoption of a simple, standardized, and modular air distribution system architecture, combined with the simple heat load estimation method described, could significantly reduce the engineering requirements for data center design.

About the Author:

Neil Rasmussen is a founder and the Chief Technical Officer of American Power Conversion. At APC, Neil directs the world's largest R&D budget devoted to Power, Cooling, and Rack infrastructure for critical networks, with principal product development centers in Massachusetts, Missouri, Denmark, Rhode Island, Taiwan, and Ireland. Neil is currently leading the effort at APC to develop modular scalable data center solutions.

Prior to founding APC in 1981, Neil received his Bachelors and Masters degrees from MIT in electrical engineering where he did his thesis on the analysis of a 200MW power supply for a Tokamak Fusion reactor. From 1979 to 1981 he worked at MIT Lincoln Laboratories on flywheel energy storage systems and solar electric power systems.