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Thermal Guidelines' X-Factor IT Reliability Data

Data Center Energy And Capital Cost Considerations

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An underused portion of ASHRAE's *Thermal Guidelines for Data Processing Environments, 5th Edition*,¹ is the analysis of server reliability data and the impact this can have on both the energy consumption and the capital cost of a data center. This reliability analysis is called x-factor and is the focus of Section 2.4.3, Server Reliability Trend Versus Ambient Temperature, of the *Thermal Guidelines'* 5th edition.

What exactly is the x-factor reliability metric? It first appeared in the 3rd edition of *Thermal Guidelines*.² As stated in the document, "Since there are so many different variables and scenarios to consider, the approach taken by TC 9.9 was to initially establish a baseline failure rate (x-factor) of 1.0 that reflected the average probability of failure under a constant ITE inlet temperature of 20°C (68°F)." Using manufacturer's data, a table was then created to show the relative failure rate (with lower, average and upper bounds) at other information technology equipment (ITE) inlet temperatures. This table has been previously reproduced in *ASHRAE Journal*³ but is shown in *Table 1* as a refresher.

The purpose of this column is to reexamine x-factor with an eye toward the potential energy and capital cost savings.

Alignment of Data Center Cooling System With Local Climate

While designing with x-factor considerations can yield significant capital and energy cost advantages, it is important to understand that the intent of operating without mechanical refrigeration does not mean that one should operate outside of the allowable operating range of the IT equipment. This means that mechanical cooling (and possibly also humidification and/or dehumidification) will be required in certain climates to stay within the Allowable (A2, A3 or A4 as applicable) range at all times. It may be that partial cooling can be accomplished via integrated economizer even during the worst-case design

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TABLE 1 Relative ITE failure rate x-factor as a function of constant ITE air inlet temperature.¹

DRY-BULB TEMP, °F	FAILURE RATE X-FACTOR		
	LOWER BOUND	AVERAGE BOUND	UPPER BOUND
59.0	0.72	0.72	0.72
63.5	0.80	0.87	0.95
68.0	0.88	1.00	1.14
72.5	0.96	1.13	1.31
77.0	1.04	1.24	1.43
81.5	1.12	1.34	1.54
86.0	1.19	1.42	1.63
90.5	1.27	1.48	1.69
95.0	1.35	1.55	1.74
99.5	1.43	1.61	1.78
104.0	1.51	1.66	1.81
108.5	1.59	1.71	1.83
113.0	1.67	1.76	1.84

Relative hardware failure rate x-factor for volume servers is shown as a function of continuous operation.

condition. In this instance, the cooling system can be designed for only a portion of the full IT load and associated reduction in capital costs and energy consumption.

Impact on Data Center Equipment Sizing and Capital Costs

The x-factor was originally developed to exploit the concept of reducing or even eliminating mechanical cooling for data centers. The primary capital cost savings associated with implementing variable supply temperature control based on x-factor is the reduced cost of the cooling system. For this column, we examine the trade-offs for a chilled water system, though similar analyses could be performed for direct or indirect outside air cooling or other systems.

Chilled water systems using cooling towers have an aggregate approach temperature (temperature difference between cold aisle supply temperature and ambient wet-bulb temperature) in the range of 15°F to 25°F (8.3°C to 13.9°C). The aggregated approach temperature is typically lowest near the design condition due to the higher efficiency of cooling towers at high wet-bulb temperatures.

The capital cost of a system with chillers vs. a system without chillers depends on two main parameters:

- Cost savings associated with eliminating the chillers (mechanical cooling); and
- Cost penalty associated with increased airflow requirements in a warm data center due to server fan speed increases.

The overall capital cost savings associated with the elimination of the chillers can be normalized at \$1,300/ton (\$370/kW), but a significant range in CapEx is possible depending on the equipment type, physical location, system topology and labor availability. For a 1,000 kW (1 MW) data center with two 350 ton (1231 kW) chillers and $N + 1$ redundancy, the capacity and CapEx of installed chillers would be 350 tons $\times$ 2 chillers = 700 tons $\times$ \$1,300/ton = \$910,000.

The reason airflow requirements need to increase in a data center without chillers is that the data hall will be operating near the top of the allowable range for a significant number of hours per year. *Figure 1* shows that the airflow requirement for servers can increase significantly with higher inlet temperatures, to as much as 250% of the baseline value corresponding to 65°F to 68°F (18°C to 20°C). This higher airflow will result in the need for more CRAH units or other forms of terminal air distribution. If we assume that the airflow rate increase requirement is 180%, 1.8 times as many CRAH units would be needed. The CapEx of additional airflow is assumed to be about \$4.50/cfm (\$9.54/L·s). For the example provided in this column, an increase in airflow of 104,820 cfm (49 470 L/s) is needed, corresponding to a cost of \$471,690. Adding these two values together yields

FIGURE 1 Server flow rate increase vs. server inlet temperature.¹

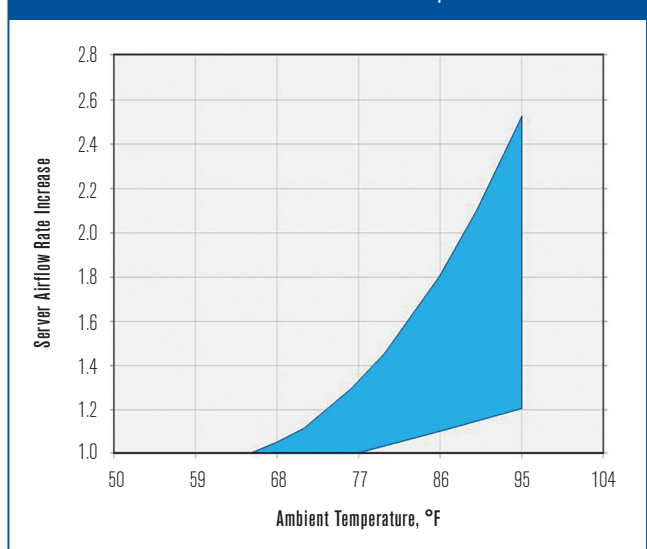


TABLE 2 Potential reduction in capital and energy costs related to a chillerless data center with 1 MW ITE load in various climates.

CLIMATE ZONE	DETAILS						
	REPRESENTATIVE CITY	MAX ANNUALIZED MLC (ITE >300 kW)	MLC SCENARIO 1	MLC SCENARIO 2	NET X-FACTOR	ANNUAL ENERGY COST SAVINGS (75% ITE)	CAPITAL COST SAVINGS (\$/MW)
1A	Miami	0.26	0.21	0.08	1.41	\$94,242	\$438,310
2A	Tampa, Fla.	0.23	0.20	0.07	1.34	\$90,488	\$438,310
2B	Tucson	0.17	0.17	0.06	1.14	\$82,093	\$438,310
3A	Atlanta	0.21	0.17	0.06	1.17	\$76,976	\$438,310
3B	El Paso, Texas	0.17	0.15	0.06	1.08	\$72,035	\$438,310
3C	San Francisco	0.14	0.18	0.06	1.13	\$87,275	\$438,310
4A	New York	0.18	0.15	0.06	1.11	\$65,641	\$438,310
4B	Albuquerque, N.M.	0.14	0.13	0.05	0.97	\$56,914	\$438,310
4C	Seattle	0.14	0.15	0.05	1.04	\$73,577	\$438,310
5A	Buffalo, N.Y.	0.16	0.13	0.05	1.03	\$56,959	\$438,310
5B	Denver	0.15	0.12	0.05	0.94	\$51,154	\$438,310
5C	Port Angeles, Wash.	0.14	0.15	0.05	1.00	\$68,904	\$438,310
6A	Rochester, Minn.	0.16	0.12	0.05	1.02	\$50,531	\$438,310
6B	Great Falls, Mont.	0.14	0.11	0.05	0.90	\$45,722	\$438,310
7	International Falls, Minn.	0.14	0.11	0.05	0.97	\$43,747	\$438,310
8	Fairbanks, Alaska	0.13	0.09	0.05	0.86	\$34,217	\$438,310

a net CapEx savings of \$438,310 for a data center with a 1 MW ITE design load.

Impact on Data Center Energy Consumption

For a chilled water system, the energy savings would accrue from the reduction (or elimination) of chiller energy during the course of a year. Parasitic energy to be included in the analysis includes: (a) the increase in cooling tower fan energy to provide 100% economizer cooling for the entire year, and (b) increased fan energy required to operate CRAH units at higher airflow rates when server fans ramp up. It should be noted that in the case of (b), the chillerless data center is assumed to be equipped with more CRAH units than the baseline design, and these CRAH units can operate at low fan speeds except during the hours of the year when the cold aisle supply temperature is significantly above the baseline x-factor temperature of 68°F (20°C). As such, the annualized cooling air distribution fan energy of a chillerless design will typically be less than the fan energy associated with a standard chiller

plant design with fewer CRAH units. The exact trade-off depends on the ambient wet-bulb distribution of the site in question.

Table 2 compares the potential reduction in CapEx costs and the potential reduction in energy (OpEx) costs while using x-factor variable supply temperature control. For reference, ASHRAE Standard 90.4-2019⁴ mechanical load component (MLC) factors are also shown, as well as the MLCs calculated for both the baseline (chiller) and the x-factor (chillerless) designs.*

Table 2 provides general information on the variation in energy use of Scenario 1 (the water-cooled chilled water baseline) and Scenario 2 (water-cooled chillerless data center) for representative cities in each of the U.S.-based ASHRAE Climate Zones. To make sure the baseline system is reasonably aligned with standard designs, MLC values are compared to the MLC targets contained in Standard 90.4-2019. There was reasonable alignment in this regard, with the baseline system slightly above Standard 90.4-2019 in only three climate zones, and slightly below in all others.

*ASHRAE Standard 90.4-2022 was not available as a reference for this column, but will be published in 2023.

TABLE 3 Summary of advantages and disadvantages of data center design using x-factor reliability.

CRITERIA	MECHANICAL COOLING (BASELINE)	CHILLERLESS COOLING (X-FACTOR)
Data Center Design Options	Flexible Deployment Topology	Aisle Containment Required
Capital Cost	Higher	Lower (Except Possibly With Peak Server Fan Speeds at 2.5x Baseline Values)
Energy Cost	Baseline	Lower: Average MLC Reduction ± 0.09 for Stated Conditions
Maintenance Costs	Higher (More Complex Systems)	Lower (Less Complex Systems)
Mechanical Cooling (Chillers)	Required	Not Required
Cooling Air Distribution (CRAH or Similar)	Baseline (1.0x cfm)	Higher (1.2 to 2.5x Higher cfm vs. Baseline)
Global Warming Impact	Baseline	No GWP Refrigerant Concerns (Energy GWP Savings Also Accrue)
90.4-2019 MLC Compliance	Challenging	Readily Achievable
Cooling System Reliability	Baseline	More Reliable (Less Complex Systems, No Chillers, No Economizer Functionality, etc.)
X-Factor Server Reliability	Baseline	Range Between 0.9 to 1.6, Climate Zone and System Dependent
Capability to Host ASHRAE H1, A1 Server Classes	Capable	Not Capable (Without Separate Cooling System)

The chillerless system had an MLC that averaged 0.09 less than the baseline system MLC. Energy costs examined the climate impacts on cooling tower, chiller and air distribution energy. An average annual U.S. retail energy cost of \$0.115/kWh was assumed for all sites. Note that the potential energy savings is highest in Climate Zones 1A and 2A because the baseline chillers rarely operate in economizer mode and the (Scenario 1) MLC is thus higher.

Table 3 provides a summary of the advantages and disadvantages of a chillerless data center when compared to a “standard” chilled water system with mechanical cooling. As can be seen, there are many factors to be considered, and a design without mechanical cooling is probably not the best choice in all cases. However, in instances in which server specifications and failure rates are known, several advantages exist to the chillerless design. These include lower capital cost, lower energy cost, lower maintenance cost, a less complex and more reliable cooling system and no global warming potential (GWP) refrigerant issues.

Alignment With Project and IT Equipment Specifications

The x-factor values provided in *Thermal Guidelines* are based on ITE aligned with Classes A2, A3 and A4. If equipment corresponding to high performance Class A1 and/or the new Class H1 is being installed, consideration should be given to the addition of mechanical cooling even if it is not needed for the A2/A3/A4 ITE based on the x-factor analysis.

Segregation of Class A1/H1 equipment (and also Class A2 depending on Climate Zone and cooling system design) should still allow for significant capital and operating cost savings by using x-factor floating temperature control when most of the IT equipment falls into the A3 and/or A4 classes.

Summary

The x-factor reliability data has been part of ASHRAE's *Thermal Guidelines for Data Processing Environments* for 10 years. Greater implementation of floating supply air temperature control to align with x-factor reliability data should result in lower construction and operating costs for new data centers with only minor impact on ITE reliability for most climate zones. The exact impact on capital cost, energy use and annualized x-factor reliability depends on many variables. It is important to look at climate zone, IT equipment specs, energy use and capital cost impact to determine whether x-factor is a good match for your data center. This is the first of two columns on the reliability data on data center design and operation. The second column will focus on optimization and the potential use of x-factor analysis in design modifications to existing facilities.

References

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3. Beaty, D. 2014. “X-Factor explained.” *ASHRAE Journal* (11).
4. ASHRAE Standard 90.4-2019, *Energy Standard for Data Centers*. ■