

Optimizing the Existing Data Center Environment

Using the X-Factor Reliability Metric

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The x-factor analysis in ASHRAE's *Thermal Guidelines for Data Processing Environments*¹ is perhaps one of the most significant energy savings strategies still available in *all* data centers today, yet there's almost no application of it in practice, nor any mention of it in company environmental social and governance (ESG) reports. X-factor analysis can be incorporated into both existing operating data centers and new data center designs; however, both applications require a different set of strategies. Both are also subject to a different set of limitations. This column is a follow up to the March 2023 *ASHRAE Journal* column "*Thermal Guidelines' X-Factor IT Reliability Data: Data Center Energy and Capital Cost Considerations.*"² It is intended to encourage the industry to apply this energy savings both in practice and ESG reports.

Incorporation of x-factor analysis, in which a baseline failure rate—x-factor—of 1.0 reflects the average probability of failure under a constant ITE inlet temperature of 68°F (20°C) into data center design, is perhaps best suited to new construction because of the following:

- The computer room air handler (CRAH) airflows can be matched to server airflows (during design) at the upper end of the allowable class range;
- Servers can be selected to match the intended temperature excursions (ASHRAE Class A1–A4); and
- Service level agreements (SLAs) can be negotiated to include x-factors and higher temperature/humidity excursions.

For an existing facility, none of the above will typically be the case. However, with careful consideration of existing conditions, increased monitoring and

upgraded control strategies, it is possible to obtain energy savings in an existing facility through incorporation of x-factor principles without sacrificing server reliability. This column considers some additional constraints imposed by an existing facility and provides an example retrofit to compare x-factor, energy consumption and other parameters.

Alignment of CRAH Airflow to Server Airflow

One of the biggest challenges to working at temperatures higher than the ASHRAE Recommended Range is that server fans will speed up to keep the servers within internal temperature limits. This speed increase could be up to 2.5 times the minimum server

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fan speed, which is typically defined as the server airflow at 68°F (20°C) inlet temperature (*Figure 1*).

In a new data center, server specifications inclusive of airflow rates are typically known or can be specified, and CRAH capacities can be designed for the “worst case” airflow. For an existing data center, however, CRAH units may be undersized for operation at high temperatures, particularly on an airflow basis. But use of redundant HVAC equipment, knowledge of IT loads and improvements in containment can help alleviate this constraint.

Strategies to implement x-factor within existing data centers with CRAH airflow limitations could include:

- Making use of redundant and/or unused CRAH airflow. For instance, “N” CRAH units may be designed with sufficient airflow capacity to match server airflow with a 20°F (11°C) ΔT . If $N = 10$ units, and two additional units are installed (i.e., $N + 2$ redundancy), by operating all 12 units the CRAH airflow capacity exists to match a server ΔT of 16.7°F (9.3°C) at full IT load (servers operating at higher inlet temperatures have lower ΔT).
- Take advantage of the fact that data centers are rarely filled to capacity with IT equipment. This will allow for more CRAH airflow per cfm of server airflow.
- Add or improve hot/cold aisle containment.

Sealing of openings between supply and return air to the servers, and typically maintaining a slight negative pressure in the hot vs. the cold aisle, optimizes both data center airflow and temperature management.

- While the addition of containment is one of the most complementary improvements that can be made to align with x-factor control, fire protection must be considered (refer to NFPA 75/76/13). This is an issue that must be coordinated with the latest NFPA standards and applicable codes.

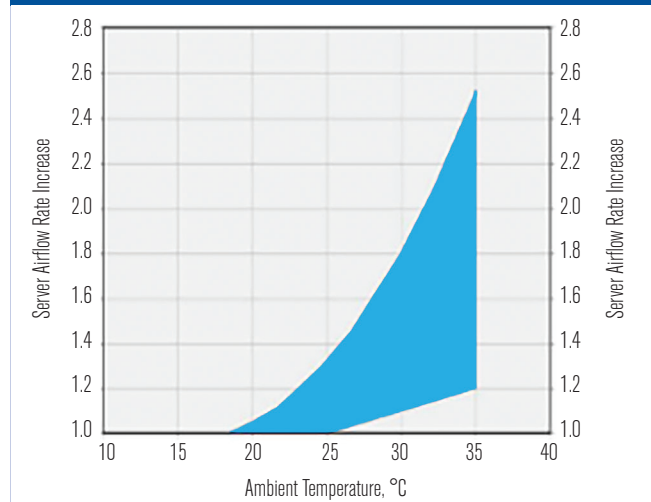
- Empirical data can be taken with an existing facility to better determine the potential constraint of CRAH airflow on x-factor implementation.

- Energizing an existing chiller system for a limited number of the hottest days of the year can significantly decrease the maximum server airflow by limiting server inlet temperatures. The maximum temperature can be tailored to the existing CRAH airflow limitations, server and/or SLA temperature limits.

Limits of Existing Server and SLA Maximum Temperatures

The concept of x-factor was created by ASHRAE

FIGURE 1 Typical range of server airflow as a function of inlet air temperature.²



TC 9.9 to align with the design of “chillerless data centers” with Class A3 and/or Class A4 servers. The concept of “chillerless” simply refers to the elimination of the vapor-compression cycle for cooling a data center. A Class A3 server has a maximum allowable inlet temperature of 104°F (40°C), which should be satisfied with a chillerless data center with water-cooled heat rejection in almost all ASHRAE climate zones. Similarly, a Class A4 data center, which has a maximum allowable inlet temperature of 113°F (45°C), should be satisfied with a chillerless data center with direct airside economizer in almost all ASHRAE climate zones.

An existing data center, however, may have Class A1 or A2 servers, with maximum allowable inlet temperatures of 89.6°F (32°C) and 95°F (35°C), respectively. In this case, or in the case of a non-negotiable SLA upper temperature limit, an existing facility could operate as a chillerless facility for most of the year but switch to chiller operation as needed to maintain a specified maximum server inlet temperature. The example calculation presented in this column provides examples of such an operating strategy.

Increased monitoring of server inlet temperatures will be a critical part of the transition and ongoing operation at higher temperatures. Many industry solutions are now available for achieving this via wireless and wired monitoring at a granular level, as desired.

Practical Example

To illustrate the use of x-factor optimization in an existing facility, TMY3 weather data from the city of

TABLE 1 Properties of all liquids used in the experiment.

CASE	ANNUAL COOLING PLANT ENERGY, kWh/ RELATIVE PLANT ENERGY USE	ANNUAL SERVER ENERGY, kWh/ RELATIVE SERVER ENERGY USE	ANNUAL FACILITY ENERGY, kWh/ RELATIVE ENERGY USE ² /PUE	MAXIMUM SERVER AIRFLOW, cfm/ RELATIVE MAX. AIRFLOW	ANNUALIZED X-FACTOR/EXPECTED ANNUAL SERVER FAILURE RATE ³	AVERAGE RACK INLET TEMP/MAX RACK INLET TEMP ⁴ /WB THRESHOLD
(1) Baseline 60°F CHWS, No Economizer, No Containment	1,626,025	8,891,027	11,850,706	120,353	1.14	73.0°F
	100%	100.0%	100%	100%	4.6%	73.0°F
			1.33			N/A
(2) Baseline w/ Integrated Economizer, No Containment	1,043,390	8,891,027	11,268,072	120,353	1.14	73.0°F
	64%	100.0%	95%	100%	4.6%	73.0°F
			1.27			66°F-46°F WB
(3) X-Factor with No Containment; Excursions to 85°F	887,193	8,915,825	11,140,382	156,381	1.08	71.2°F
	55%	100.3%	94%	130%	4.3%	84.6°F
			1.25			62°F WB
(4) X-Factor with Containment; Excursions to 83°F	761,597	8,864,217	10,955,447	150,480	1	69.3°F
	47%	99.7%	92%	125%	4.0%	82.7°F
			1.24			66°F WB
(5) X-Factor with Excursions to 94°F, No Chiller	561,303	8,983,545	10,892,379	185,638	1.07	71.6°F
	35%	101.0%	91%	154%	4.3%	94.0°F
			1.21			N/A

¹ Annual server energy does not include UPS or electrical distribution losses (i.e., “pure” IT energy).

² Facility energy consumption is defined as the sum of the chiller plant energy + annual server energy with 15% electrical overhead added to account for UPS and distribution losses.

³ Server failure rates assume that an x-factor of 1.0 corresponds to an individual server failure rate of 4.0% per year. Annual server failure rate is proportional to annualized x-factor.

⁴ Server inlet temperatures assume a 7.0°F (4°C) approach temperature for CRAH units or equivalent cooling coils, and either a 1°F (0.6°C) average temperature rise between the CRAH discharge and the server inlet for cases with containment, or 6°F (3°C) average temperature rise between the CRAH and the server inlet for cases without containment. The “max rack inlet temp” as presented here is the maximum average server inlet temp on the “worst case” hour of the year using TMY3 wet-bulb data. Individual server temps may be higher or lower depending on containment level and position in the rack. The “WB threshold” refers to the ambient wet-bulb temperature at which waterside economizer operation occurs. In the case of integrated economizer (Case 2), the first value denotes the start of economizer operation and the last value denotes entry into full economizer mode.

Newark, N.J., was used, and an IT facility and cooling system very similar to that analyzed in the March 2023 *ASHRAE Journal* column (nominal 1,000 kW IT load, water-cooled chillers with waterside economizer) was chosen for simulation. Five different operating scenarios (Cases 1 to 5) were examined:

1. For the baseline (Case 1), a “legacy chilled water plant” with 60°F (15.6°C) chilled water and no economizer, with cooling tower temperature controlled to 75°F (23.9°C) off the tower whenever possible, and towers operating at 100% fan speed when wet-bulb temperatures are too high to realize this design value. The facility has a hot/cold aisle IT equipment arrangement but does not have significant containment between the two aisles;
2. Case 2 is identical to Case 1, except that an integrated waterside economizer has been added. This could be an expensive retrofit, but is included to allow for an energy comparison with x-factor Cases 3, 4 and 5;
3. Case 3 is similar to Case 1 (no containment, no

integrated economizer), but a parallel economizer operation is allowed with the constraint that the maximum average rack inlet temperature (during the highest ambient wet-bulb condition) is limited to 85°F (29.4°C).

4. Case 4 is similar to Case 3, except that aisle containment has been added, and the maximum average rack inlet temperature (during the highest ambient wet-bulb condition) is limited to 83°F (28.3°C).
5. Case 5 is similar to Case 4, except that no chiller operation is allowed.

Highlights from *Table 1* include the following:

- For Case 1, note that the baseline x-factor is 1.14.

This is because even though the average discharge temperature from the CRAHs is 67°F (19.4°C), the lack of aisle containment results in an average server inlet temperature of 73°F (22.8°C) (above the 68°F [20°C] that would align with an x-factor of 1.00).

- For Case 2, note that relative to the baseline, an integrated economizer drops annual cooling plant

energy by 36%, and annual facility energy (which includes IT energy) by about 5%.

- Case 3 is the first “x-factor optimization” option. Note that cooling plant energy drops by 45% compared to the baseline, facility energy use by 6% (better than Case 2) and annualized x-factor is also reduced even though there are rack inlet excursions above the recommended range (to 84.6°F [29.2°C]).

- Case 4 is the second “x-factor optimization” option. Note that with containment added in addition to using x-factor excursions, Case 4 provides better results than Case 3 in all pertinent areas: cooling plant energy drops by 53% (vs. 45%) compared to the baseline, facility energy use drops by 8% rather than 6%, annualized x-factor drops to 1.00 rather than 1.08, and maximum server inlet temperature drops from 84.6°F to 82.7°F (29.2°C to 28.2°C). The complementary nature of implementing aisle containment at the same time as x-factor optimization is clearly apparent in this comparison.

- Case 5 (year-round chillerless operation) has the lowest energy consumption, but only by about 1% relative to Case 4. It also has the highest maximum average server inlet temperature (94.0°F vs. 82.7°F [34.4°C vs. 28.1°C] for Case 4), and a higher annualized x-factor (1.07 vs. 1.00 for Case 4). Case 5 would not be compatible with existing ASHRAE Class 1 IT equipment (which has a maximum allowable inlet temperature of 89°F [28.3°C]), whereas Case 4 would be.

Parametric Analysis of Cases 4 and 5

Cases 4 and 5 are similar in most respects. The exception is that Case 4 initiates chiller operation at a specific ambient wet-bulb temperature (66°F [18.9°C]), while in Case 5 the chiller is never turned on. Of interest in this section is the impact of the economizer wet-bulb temperature threshold on pertinent variables. For this part of the analysis, the wet-bulb temperature for onset of chiller operation was varied from 62°F (16.7°C) all the way up to chillerless operation, in 2°F (1°C) increments. The results are shown in *Table 2* and *Figure 2*.

Highlights from *Table 2* and *Figure 2* include:

- Annualized server energy is remarkably constant over all these solutions, within 1% of the baseline (99.2% to 101%). It is indicative of that fact that the excursions in energy associated with limited operation at high temperatures are reasonably counterbalanced by

extended operation at low temperatures during winter.

- Maximum server airflow is higher than baseline for all x-factor cases, but there is a wide variation, dependent on the maximum average server inlet temperature. The maximum airflow is 117% of baseline with a maximum server inlet temperature of 79.6°F (26.4°C) (Case 4A), rising to 154% of baseline with a maximum server inlet temperature of 94°F (34.4°C) (Case 5). A facility constrained by CRAH airflow would thus be better off with a Case 4 option (especially Case 4A) than with chillerless operation (Case 5).

- Since the maximum average rack inlet temperature of Case 4A falls within the recommended range of ASHRAE’s *Thermal Guidelines* (64.4°F to 80.6°F [18°C to 27°C]), unmet hours from the standpoint of ASHRAE 90.4-2022³ would be zero except for the fact that there are about 3,000 hours/year of operating hours in the cooler temperature range of 59°F to 64.4°F (15°C to 18°C). For Case 4A to fully align with Standard 90.4’s unmet hours requirement, the minimum rack inlet temperature of 59°F (15°C) would have to be raised to 64.4°F (18°C). The energy impact of this change would be minimum, but the x-factor would increase from about 0.96 to 1.02 (i.e., about a 6% increase in the server failure rate would be expected).

Other Considerations

There are several other items consider as part of the x-factor optimization process with an existing facility:

- In simulating the various options, it is noted that different cooling tower control strategies were examined and used for different cases. Strategies examined included: a) constant cooling tower setpoint (such as 75°F [23.9°C] condenser water supply temperature) year-round, b) cooling tower approach varies as a function of wet-bulb temperature, c) cooling tower approach varies as a function of both wet-bulb temperature and IT load and d) cooling tower fans operate at 100% speed except as needed to prevent overcooling. We found that strategy b) was close to optimal when not in economizer mode and that approach d) was close to optimal when in economizer or chillerless mode. An optimization calculation provides the best results, as the optimal strategy can also change with different wet-bulb temperatures and IT loads.
- Both chilled water and condenser water pump flow rates were assumed to be proportional to cooling load

TABLE 2 Properties of all liquids used in the experiment.

CASE	DETAILS									
	THRESHOLD FOR SWITCH TO 100% ECONOMIZER, WB (°F)	CHILLER PLANT ENERGY, % OF BASELINE	SERVER ENERGY, % OF BASELINE	FACILITY ENERGY, % OF BASELINE	MAXIMUM SERVER AIRFLOW, % OF BASELINE	ANNUALIZED X-FACTOR ¹	MAX AVG RACK INLET TEMP, °F	AVG RACK INLET TEMP, °F	HIGH UNMET HOURS AT FULL LOAD, H/YR AVG RACK INLET >80.4°F	LOW UNMET HOURS AT FULL LOAD H/YR AVG RACK INLET <64.4°F
Case 1 (Baseline, No Containment)	N/A	100.0	100.0	100.0	100	1.140	73.00	73.00	0	0
Case 2 (Baseline w/ Integrated Economizer, No Containment)	66/46	64.0	100.0	95.0	100	1.140	73.00	73.00	0	0
Case 4A (w/ Containment)	62	53.4	99.2	93.0	117	0.965	79.60	67.05	0	2,995
Case 4B	64	50.8	99.4	92.7	121	0.979	81.14	67.63	388	2,995
Case 4C (Case 4 in Table 1)	66	46.8	99.7	92.4	125	0.998	82.70	68.43	867	2,995
Case 4D	68	43.3	100	92.2	129	1.017	84.27	69.23	1,296	2,995
Case 4E	70	40.6	100.3	92.1	133	1.031	85.86	69.86	1,604	2,995
Case 4F	72	38.6	100.5	91.9	137	1.043	87.46	70.38	1,839	2,995
Case 4G	74	36.5	100.8	91.9	141	1.056	89.08	70.96	2,081	2,995
Case 4H	76	35.1	101	91.9	146	1.065	90.71	71.38	2,241	2,995
Case 4I	78	34.7	101	91.9	150	1.068	92.36	71.51	2,289	2,995
Case 5 (Chillerless)	N/A	34.5	101	91.9	154	1.068	94.02	71.56	2,304	2,995

¹ Values assume that Cases 4A–4I and Case 5 can operate with rack inlet temperatures as low as 59°F (15°C). The x-factor penalty for a minimum inlet temp of 64.4°F (18°C) is about +0.06.

for all cases in this example analysis, but could also be further optimized.

- The addition of CRAH units may be possible and recommended in some cases if the use of redundant units still results in a shortfall of airflow at high temperatures, especially if a facility has the desire to convert to chillerless operation. Upfront measurements could be made to better determine the increase in airflow for a specific data center mix of IT equipment.
- As the results of Case 3, 4A–4I and 5 demonstrate, a wide range of temperature control strategies can be considered on a case-by-case basis. One advantage of chiller operation in Case 3 and 4 relative to integrated economizer operation is that the chillers do not have to operate at low condenser water temperatures, which can be an issue with older chillers.
- Cases 3 and 4 could result in a step function change in cold aisle temperatures when the chillers are either turned on or off. Methodology to soften this sudden rate-of-change is required to avoid IT reliability issues.

Summary

By using x-factor analysis and targeted use of existing cooling plant equipment, one can likely achieve a

“win-win” situation, saving energy *and* increasing server reliability (lowering annualized x-factor) in existing data centers as well as in new ones.

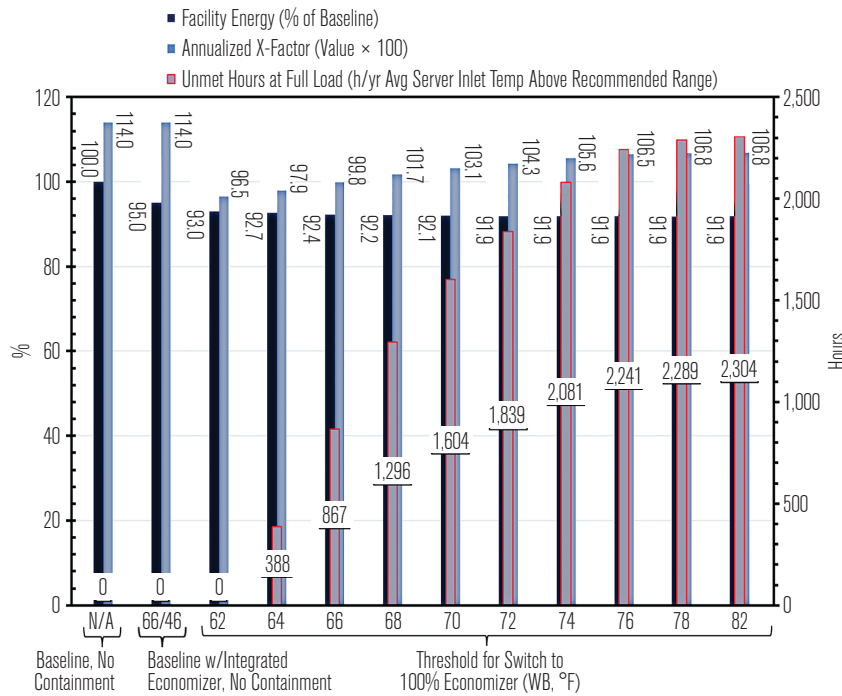
In an existing facility, incorporating hot/cold aisle containment is a complementary measure, able to improve both energy efficiency and server reliability relative to the “status quo,” or operating x-factor analysis by itself.

As part of the x-factor optimization process, improvements in measurement, analysis and control systems would typically also be recommended.

A change to either the Recommended Range of ASHRAE’s *Thermal Guidelines* or to Standard 90.4-2022’s³ definition of “unmet hours” to allow rack inlet temperatures in the temperature range of 59°F to 64.4°F (15°C to 18°C) to be counted as acceptable, rather than as unmet hours, is recommended by the authors. The cooler winter operation is desirable to counteract warmer summer conditions and keep annualized server failure rates low.

In summary, x-factor optimization can be a central strategy for improving a site power usage effectiveness/mechanical load component (PUE/MLC), reducing energy consumption, improving

FIGURE 2 Parametric study of energy use, x-factor and unmet hours for existing chiller operation above various wet-bulb temperatures.



server reliability and demonstrating further action in corporate ESG reporting.

A future column will discuss the challenge of achieving the MLC compliance values listed in the 2021 IECC with air-cooled chillers (the 2021 IECC is more stringent than ASHRAE Standard 90.4-2019 in many climate zones), along with strategies for achieving compliance using x-factor techniques.

References

1. Quirk, D., Y. Yassaghi, T. Davidson. 2023. "Thermal Guidelines' X-Factor IT Reliability Data: Data Center Energy and Capital Cost Considerations." *ASHRAE Journal* 65(3):20-24.
2. ASHRAE. 2020. *Thermal Guidelines for Data Processing Environments*, 5th Edition. Atlanta: ASHRAE.
3. ASHRAE Standard 90.4-2022, *Energy Standard for Data Centers*. ■