

Strategies for IECC 2021 Compliance in Hot Climates With Air-Cooled Chillers

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Design and operations of data center cooling systems are vital components to ensuring the reliable operation of information technology equipment (ITE). Cooling systems for data centers also need to be energy efficient and comply with applicable energy codes. Data centers were exempt from all energy codes as a “process industry” until the 2010 edition of ASHRAE/IES Standard 90.1. Shortly thereafter, ASHRAE created the SPC Standard 90.4 committee to create an energy standard dedicated to data centers. This standard was first released in 2016 as Standard 90.4-2016.

While it is not the intent of this column to go into depth on the process of standards becoming codes, the process has a fairly lengthy time line. The first adoption of Standard 90.4-2016 by a building code was the International Energy Conservation Code, IECC 2021. Rather than adopt Standard 90.4-2016 as written, however, the IECC committee inserted their own table of values for the mechanical load component (MLC). These values were much more stringent than the Standard 90.4 values (*Table 1*). As of this writing, the IECC 2021 Commercial Code has been adopted in several states, so it is worth reviewing to what extent a popular equipment choice for cooling data centers, the air-cooled chiller, can comply with IECC 2021 in a challenging climate.

Table 1 shows a comparison between the maximum annualized MLC for ASHRAE Standard 90.4-2016¹ vs.

IECC 2021.² MLC is calculated for the aggregate of 100% and 50% of the ITE (based on ASHRAE Standard 90.4-2016), with all units in kWh:

Annualized MLC 50% and 100% ITE =
(Cooling Energy + Pump Energy + Heat Rejection + Air Handler Fan Energy)/Data Center ITE Energy

First, why should we look at air-cooled instead of water-cooled chillers? Water-cooled chillers typically take advantage of the adiabatic temperature depression of ambient air that comes with evaporation, and the lower refrigerant condensing temperature improves thermodynamic efficiency. But water-cooled data

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TABLE 1 Comparison between the max allowed MLC values in ASHRAE Standard 90.4-2016 and IECC 2021 for various climate zones.

CLIMATE ZONE	ANNUALIZED MLC VALUES	
	STANDARD 90.4-2016	IECC 2021
0A	0.37	0.19
0B	0.40	0.20
1A	0.36	0.18
2A	0.35	0.19
3A	0.33	0.18
4A	0.33	0.17
5A	0.33	0.17
6A	0.32	0.17
1B	0.38	0.16
2B	0.36	0.18
3B	0.35	0.18
4B	0.35	0.18
5B	0.33	0.16
6B	0.34	0.17
3C	0.32	0.16
4C	0.32	0.16
5C	0.32	0.16
7	0.32	0.16
8	0.32	0.16

centers use significant amounts of water, a scarce resource in many parts of the country. And a chillerless data center using direct outdoor air is typically confined to cool climates.

This column looks at IECC 2021 compliance in

Phoenix, Ariz., in ASHRAE Climate Zone 2B. *Table 2* provides basic information on this climate zone. As a baseline, we will look at an air-cooled chiller (ACC) without any economizer, then an air-cooled chiller with an integrated closed-loop water economizer. Finally, we will look at scenarios that make use of a direct airside economizer. The annualized server failure rate, as characterized by x-factor, is also tracked to make sure code-compliant energy solutions do not result in an increase in server failure rates.

Scenario Assumptions

In this column, operational scenarios

for a sample ACC are examined, each designed to assess compliance with ASHRAE Standard 90.4-2016 and the IECC 2021 code while operating in a high-temperature climate like Phoenix. These scenarios (*Table 3*) include variations in chilled water supply (CHWS) temperatures and different types of economizers, including direct free cooling with outdoor air. More detailed descriptions of the cases are below.

Scenario 1 (Baseline): ACC, no economization (chiller year-round, CHWS temperature of 68°F [20°C]). This scenario serves as a baseline, representing typical operating conditions for ACCs without the implementation of economization strategies. By maintaining a constant CHWS of 68°F (20°C) (corresponding to a 76°F [24°C] cold aisle or server inlet temperature) throughout the year, the chiller operates solely based on mechanical cooling.

Scenario 2-A: ACC with integrated economizer (chiller on year-round, but at reduced or no load as a function of outdoor air dry-bulb temperature, CHWS of 68°F [20°C]). This scenario introduces integrated economization, whereby the return water from the computer room air handler (CRAH) unit is passed through a coil to reduce its return temperature prior to reaching the evaporator. The water coil is only active when the outdoor dry-bulb temperature is below the return temperature of the water. It is placed in series with the chiller's refrigerant condenser coil, so the condenser fan requires more energy to force airflow through both coils. To maximize economization hours,

TABLE 2 Details of Phoenix, Ariz., climate conditions.

CLIMATE ZONE	DESCRIPTION	DETAILS			
		REPRESENTATIVE CITY	WEATHER LOCATION	ANNUAL COOLING DESIGN CONDITIONS, DB (0.4%)	MCWB
2B	Hot Dry	Phoenix	Phoenix Sky Harbor International Airport	110.3°F	69.5°F

TABLE 3 Details of scenarios evaluated.

SCENARIO	SCENARIO DESCRIPTION	CHILLER OPERATING DESCRIPTION	DETAILS
			CHW SUPPLY
1 (Baseline)	Air-Cooled Chiller, No Econ	Year-Round	68°F
2-A	Air-Cooled Chiller w/Integrated Economizer	Year-Round	68°F
2-B	Air-Cooled Chiller w/Integrated Economizer	Year-Round	68°F if OA > 65°F 60°F if OA < 65°F
3-A	Air-Cooled Chiller, No Econ & Airside Free Cooling (Min Server Inlet Maintained at 64.4°F)	If OA > 80.6°F	68°F
3-B	Air-Cooled Chiller, No Econ & Airside Free Cooling (Min Server Inlet Maintained at 59°F)	If OA > 80.6°F	68°F

TABLE 4 Summary of results comparing various ACC operating strategies. See Table 3 to be reminded of the scenario description and chiller operating description.

SCENARIO	DETAILS									
	CHW SUPPLY (°F)	AVG. SERVER INLET TEMP MAX SERVER INLET TEMP MIN SERVER INLET TEMP	NET X-FACTOR	ANNUAL COOLING PLANT ENERGY USE AT 100% ITE (kWh)	ANNUAL CRAH ENERGY USE AT 100% ITE (kWh)	TOTAL ANNUAL ENERGY USE (kWh)	CRAH REDUNDANCY TYPOLOGY NEEDED	90.4-2016 METHOD CALCULATED MLC	COMPLIES WITH 90.4- 2016?	COMPLIES WITH 2021 IECC?
1 (Baseline)	68°F	Avg., Max & Min: 76°F	1.22	1,879,867	606,331	2,486,198	N + 2	0.26	Yes	No
2-A	68°F	Avg., Max & Min: 76°F	1.22	1,447,401	606,331	2,053,732	N + 2	0.21	Yes	No
2-B	68°F if OA > 65°F 60°F if OA < 65°F	Avg. 73°F Max 76°F Min 68°F	1.15	1,606,858	524,671	2,131,529	N + 2	0.22	Yes	No
3-A	68°F	Avg. 71°F Max 80°F Min 64.4°F	1.09	880,847	547,170	1,428,017	N + 4	0.15	Yes	Yes
3-B	68°F	Avg. 69°F Max 80°F Min 59°F	1.05	880,847	547,170	1,428,017	N + 4	0.15	No	No

the outdoor air enters the economizer coil first and then the condenser coil. The cold aisle temperature is constant and the same as in Scenario 1.

Scenario 2-B: ACC with integrated economizer (chiller on year-round, but at reduced or no load as a function of outdoor air dry-bulb temperature, CHWS reset ability). This scenario is similar to Scenario 2-A except that the chilled water supply setpoint resets to 60°F (16°C) when ambient temperature is below 64.4°F (18°C). The reason for modeling this alternative scenario is to see the dual impacts that this control change has both on x-factor (server reliability) and energy consumption.

Scenario 3-A: ACC and airside free cooling (FC): (chiller on if OA > 80.6°F [27°C], CHWS: 68°F [20°C], 64.4°F [18°C] minimum cold aisle temperature during FC operation). This scenario combines the baseline chiller examined in Scenario 1 with direct airside FC. Airside FC allows the data hall to bypass mechanical cooling and instead use ambient air as a coolant when outdoor air temperatures are below the top end of the ASHRAE Recommended Range (80.6°F [27°C] dry-bulb).

Scenario 3-B: ACC and airside FC: (chiller on if OA > 80.6°F [27°C], CHWS: 68°F [20°C], 59.0°F [15°C] minimum cold aisle temperature during FC operation). This scenario is similar to Scenario 3-A except that it is assumed that ambient air mixes with hot return air to maintain server inlet temperatures at a minimum of 59.0°F [15°C] instead of 64.4°F [18°C]. During cooler ambient conditions, the expectation is

that this option will lower x-factor (i.e., improve server reliability) relative to Scenario 3-A, but have little impact on MLC since the drop in the minimum temperature doesn't involve more chiller operation, but rather only a change in the mixing ratio of outdoor and return airstreams.

In all cases, CRAH energy was tracked in addition to chiller energy. The modeling assumes that CRAH airflow is equal to server airflow. Since server airflow typically increases once server inlet temperatures exceed 68°F (20°C), and all these options assume some operational time with cold aisle temperatures above 68°F (20°C) and as high as 80.6°F (27°C), the impact of CRAH energy on MLC cannot be ignored.

Results

Energy consumption metrics, including annual cooling plant energy use and CRAH energy use, varied across different operational scenarios, as did server reliability (x-factor) and ASHRAE Standard 90.4-2016 vs. IECC 2021 compliance.

As expected, scenarios incorporating economization strategies exhibited lower energy consumption than Scenario 1 (Baseline), which relied solely on mechanical cooling. Table 4 offers a summary comparison of the various ACC operating scenarios. A more detailed explanation of the results is provided below.

Energy Use

Scenario 1 (Baseline). In this scenario, the ACC operates with no economization with a chilled water

supply temperature of 68°F (20°C) CHWS. *Table 4* shows that Scenario 1 has a relatively high x-factor of 1.22 (higher than 1.00 because the cold aisle temperature is above the x-factor baseline of 68°F [20°C]). It also has a relatively high mechanical cooling energy use (annualized MLC = 0.26). This complies with Standard 90.4-2016 for Climate Zone 2B (MLC ≤ 0.36), but is not close to IECC 2021 (MLC ≤ 0.18). Not all chiller efficiency curves are the same, but this result indicates that ACCs operating without economizers with a CHWS of 68°F (20°C) will likely struggle to meet IECC 2021.

Scenarios 2-A and 2-B. Here, the ACC benefits from an integrated closed-loop water economizer, with lower annualized chiller energy use compared to Scenario 1 (Baseline). The MLC drops in both scenarios compared to the baseline, but not sufficiently to comply with the IECC 2021 MLC.

Note that in Scenario 2-B, which allows chilled water reset to 60°F (16°C) at lower ambient dry-bulb temperatures, the x-factor is reduced by 0.07 compared to Scenario 2-A. The total energy use, however,

increases, as the chiller is not as efficient operating at the lower CHWS, even though the ambient air is relatively cold when the transition to 60°F (16°C) CHWS setpoint is used.

Scenarios 2-A and 2-B represent a different set of priorities. Scenario 2-A aims to reduce energy consumption as much as possible, while 2-B aims to improve server reliability by reducing cold aisle temperatures for much of the year.

Scenarios 3-A and 3-B. These scenarios incorporate the ACC from Scenario 1, but replace the chiller's integrated economizers (Scenario 2-A) with direct airside free cooling. Both Scenarios 3-A and 3-B were able to comfortably meet the IECC 2021 MLC levels with an MLC of 0.15. Scenario 3-A represents the code-compliant case, as cold aisle temperatures are always within ASHRAE's recommended temperature range of 64.4°F–80.6°F (18°C–27°C).³ Scenario 3-B was included because it shows that in this instance, a significant increase in server reliability as defined by x-factor can be obtained by dropping the minimum cold aisle

temperature from 64.4°F (18°C) to 59°F (15°C), without a negative impact on energy consumption. The x-factor dropped from 1.09 to 1.05, while energy use stayed constant. Note that both values have significantly better x-factor than the baseline scenario of 1.22, as the cold aisle operates on average at a colder temperature.

Ancillary Considerations

When designing a data center to operate over a range of temperatures, there are more considerations than energy code compliance and server reliability. Some additional considerations are described below.

CRAH Redundancy

CRAH redundancy varied in the above scenarios. Scenarios incorporating economization strategies that allowed operation up to the high end of the ASHRAE Recommended Range need more CRAH units than options that maintain the cold aisle temperature at a lower constant value. This could create a challenge to existing facilities currently at full load that are not designed with sufficient CRAH redundancy. However, for facilities currently operating at part-load ITE this may be achievable.

Server Temperature Limitations

Servers are limited to operating within a certain range, which may or may not correspond to ASHRAE's Recommended and/or Allowable ranges. Our results indicate that operating economizers while mindful of server operating ranges and the x-factor can in some cases result in a win-win situation (i.e., improved x-factor and lower or equal energy use); in other cases improved annual server reliability comes at the cost of increased energy consumption.

Airside Free Cooling Limitations Due to Outdoor Pollution

Airside free cooling leverages outdoor air for cooling during favorable conditions. However, outdoor pollutants (e.g., dust, smoke, salty air, gaseous pollutants) can pose challenges. Air filters and regular maintenance become critical but could be costly. A less-efficient option would be an indirect economizer. Consider local environment and air quality.

ITE Humidity Limitations

ITE equipment is typically limited to a range of

humidity levels, both for relative humidity and dew-point temperature. Designers should assess ITE requirements. It may be necessary to pull out of direct airside economization when outdoor humidity levels are not appropriate for the indoor data center environment.

Temperature and Humidity Limits Per Service Level Agreements (SLAs)

Compliance with SLAs is often nonnegotiable and may result in limited design considerations and approaches.

Rate of Change Control

In practice, a user interested in lower x-factor will likely want to provide a gradual reduction in CHWS as a function of outdoor temperature to avoid step-function changes in cold aisle temperature that could adversely impact server reliability. For example, Scenario 2B, which has chilled water temperatures of 60°F (16°C) or 68°F (20°C), is a simplification of what should be a more gradual transition.

Other Air-Cooled Heat Rejection Options

While this column focuses on air-cooled solutions without any use of on-site water evaporation, within this subset there are options that this column does not touch on. A more comprehensive list of air-cooled heat rejection solutions would include:

1. Some air-cooled chillers have very high efficiency at low condensing temperatures (typically using oil-free magnetic bearing technology), and may therefore not be much different than having a chiller with an economizer. This column used data from a "standard" air-cooled chiller, not an oil-free one.
2. Scenarios 3-A and 3-B assume direct airside free cooling use once ambient conditions drop below the upper bound of ASHRAE's Recommended Range. Indirect airside free cooling is another option, though not as efficient.
3. Data centers are starting to use liquid cooling. Depending on processor power density and other factors, year-round cooling of a liquid cooling loop may be possible with a dry cooler or heat recovery, even in Arizona. At a minimum, the loop should be able to reject heat at a higher temperature than air cooling, increasing economizer hours and lowering MLC.
4. While not covered in this column, there are also many hybrid air-cooled/evaporative-cooled solutions that typically use up to 80% less water than cooling

towers, often with only a small increase in annual energy consumption. Some require water evaporation during extreme conditions, while others may allow for air-cooling (with the associated energy penalty) year-round, but with a preference for evaporative cooling if available during peak ambient dry-bulb conditions.

Summary

This column examined several air-cooled chiller systems and their ability to comply with the MLC of the IECC 2021 in a hot climate. We found that a “standard” ACC system, without economizers, will likely not comply, even though the same system would comply with Standard 90.4-2016, which is referenced by the same code except for the MLC tables.

We then looked at several alternatives, including an integrated closed-loop water economizer, and the incorporation of direct airside free cooling at temperatures at or below the high end of ASHRAE’s Recommended Range for ITE classes A1 to A4. We found that IECC 2021 compliance would be challenging with

just the integrated closed-loop water economizer, while the combination of ACCs for cooling and direct airside free cooling for temperatures at or below the recommended range would be compliant.

Direct airside free cooling is the type of use envisioned by x-factor creators, as it allows cold aisle temperatures to float within a certain range and for the higher failure rate of relatively higher cold aisle temperatures to be more than offset by the colder temperatures available in the winter. In this column, all economizer/free cooling scenarios studied had a lower x-factor (and thus higher server availability) as well as reduced energy consumption when compared to the constant-temperature mechanically cooled baseline.

References

1. ANSI/ASHRAE Standard 90.4-2016, *Energy Standard for Data Centers*.
2. International Code Council. 2021. *2021 International Energy Conservation Code*.
3. ASHRAE. 2021. *Thermal Guidelines for Data Processing Environments, 5th Edition*. Atlanta: ASHRAE. ■