The electric power consumed to manage our digital dependency is growing, and so is the resulting by-product: heat. HVAC engineers are tasked with selecting mechanical systems that strike a balance between high reliability and low life-cycle cost. This article explores a cooling/heat rejection strategy that is gaining acceptance and achieves a balance of reliability and energy efficiency.

**Indirect Air-Side Economizer (IASE)**

The indirect air-side economizer (IASE) cycle uses outdoor air to reject heat, but the outdoor air never enters the process or space. The IASE uses an air-to-air heat exchanger (HX) to transfer data center heat to a separate outdoor airstream ("scavenger air"). Figure 1 illustrates one type of IASE system that uses a plate-type air-to-air HX.

In Figure 1 scavenger outdoor air enters the unit and flows through one side of an air-to-air HX (enters from lower right). Warm air from the data center hot aisles enters from the other side (upper left) of the unit and flows through the opposite side of the air-to-air HX, completely separated from the scavenger air by sealed HX plates. As the hot-aisle air flows through the HX, it transfers heat to the cooler scavenger outdoor air. The scavenger air may be used untempered, or the scavenger air may be evaporatively cooled prior to entering the HX. Evaporative precooling significantly enhances heat rejection potential when a wet-bulb depression (difference between the dry-bulb and wet-bulb temperature) exists of 10°F (5.6°C) or more.

**Why Indirect?**

Intuition suggests it’s more efficient to use a direct air-side economizer and introduce outdoor air directly into the data hall. The IASE provides some key advantages that may not be readily apparent. Refer to the IASE system in Figure 2 as you read the following list of benefits.

**Benefits of the IASE**

Because the data hall air is recirculated and cooled with IASE systems, and no outdoor air is introduced into the data center by the heat rejection units, filters may be eliminated from some or all of the heat rejection air-handling units (AHUs). Particulate removal may be accomplished by using a side-stream filtration unit, or filters may be included in some of the IASE units, such that the room air is filtered at a rate of perhaps 6 to 10 air changes per hour (ach). This approach results in reduced filter maintenance, and fan power costs compared to installing filters on all of the heat rejection units.

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which often have air turnover rates in excess of 100 ach. Since outdoor air is not introduced into the space by the heat rejection units, there is reduced risk of outdoor air pollutants adversely affecting the information and communication technologies (ICT) equipment. Also, space humidity and pressure are not impacted, resulting in the potential to lower humidification costs and maintain more stable moisture levels in the data hall. Single, or multiple makeup air units, with MERV 8 and MERV 13 filters, equipped with dehumidification and humidification capability as required by the local climate, provide the recommended ventilation (0.25 ach has been recommended as the minimum) and humidity control. Humidification may be accomplished using direct evaporative media with heat from the return air. The IASE units are laser focused on one objective: heat rejection.

Unlike water-side and wet-bulb economizer systems, IASE systems may operate dry during cooler ambient conditions, resulting in lower annual water consumption and elimination of freeze concerns. IASE systems are able to achieve 100% heat rejection operating dry when outdoor air temperature is below 48.5°F (9.2°C) using HXs that are 50% effective, or 66.2°F (19°C), using HXs that are 75% effective based on a hot aisle temperature of 101.5°F (38.6°C) cooling to 75°F (23.9°C). Modular mixed air dampers and relief fans/dampers are not required as part of the heat rejection cycle. IASE systems achieve supply temperature control by varying scavenger fan flow and staging/modulating DX or modulating chilled water valves.

IASEs, using scavenger air evaporative cooling, require about one-third of the water flow rate of conventional water-side economizer systems, and operate with less pump head, resulting in annual pump power savings. IASE systems, using wetted HXs (described later in the article), require a maximum recirculating water flow rate of 2 gpm (0.13 L/s) per 1,000 cfm (471.9 L/s) of supply air and require a pump head of 30 ft (9.1 m). IASE systems using dry HXs with direct evaporative cooling, taking a water-side temperature rise of 10°F fan static efficiency of 75% and motor efficiency of 95%). Since conventional air-side economizer units must use filtration (ASHRAE recommends MERV 8 or MERV 11 or MERV 13 filters), the recirculating air IASE heat rejection units typically consume less supply fan power than direct air-side economizer units because the total internal static pressure within the polymer-tube IASE units (including the HX and supplemental coil) is typically less than 1 in. w.c. (24.1 Pa). The filters used in the recirculating airstream of an IASE system also load more slowly than those installed in direct air-side economizers, and there are far fewer to change, leading to savings in the annual cost of replacement filters and the labor to change them.

Conclusion
The merits of the IASE strategy presented here are applicable to data centers in almost any locale and are not limited for use in areas perceived to be cold or dry climates. The IASE strategy may be used even when cooler cold-aisle conditions are desired. The 100°F (37.8°C) hot-aisle and 75°F (23.9°C) cold-aisle conditions were used in this article solely as a point of reference, since modern data centers are designed to similar or more aggressive conditions. Clearly, the maximum benefit of the IASE strategy is derived when implemented with hot or cold-aisle containment, with warmer hot-aisle and warmer cold-aisle temperatures.

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References
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evaporated is 132.3 gph (500.8 L/h) per unit, which equates to 2.06 gph (7.8 L/h) per ton of heat rejected by the indirect evaporative coolers.

After leaving the HX, the process air enters the cooling coil, where an additional 49 tons (172.3 kW) of sensible heat rejection per unit must occur to cool the supply air to 75°F (23.9°C). Sizing the refrigeration component based on this conservative Chicago ambient design condition results in a comfortable margin of safety. Note that in the environments of 63°F (17.2°C), IASE units have a rapid restart after power outage with little delay reaching full heat rejection potential.

Dry HX IASE System

Referring back to Figure 1, when a HX with an effectiveness of 80% is selected and a 95% efficient direct evaporative pre-cooler is used, most of the ICT load from a data center may be rejected to ambient air through the HX, even during a hot and humid ambient condition as indicated on the figure. Given a 100°F (37.8°C) hot-aisle temperature and 75°F (23.9°C) target cold-aisle temperature, when the outdoor dry bulb temperature is 68.4°F (20.2°C) or lower, the IASE cycle can reject 100% of data center heat (assumes 1.5°F [0.83°C] rise across supply fan). Similarly, when a 95% efficient scavenger air evaporative pre-cooler is included, 100% of data center heat may be rejected by the IASE cycle if the ambient wet-bulb temperature is 65°F (18.3°C) or lower, regardless of how hot the corresponding ambient dry-bulb temperature may be.

Table 1 shows how the counterflow plate-type HX IASE system performs at various ambient conditions. Note that the required scavenger airflow falls rapidly with decreasing ambient dry-bulb entering temperature. At an ambient dry-bulb temperature of only 50°F (10°C), the scavenger flow has dropped by more than 50% of its design flow, and corresponding scavenger-fan motor power is reduced to less than one-eighth of the power consumed at design condition.

Table 2 shows the annual hours in a typical year (as defined by TMY2 weather data) where an 80% efficient HX augmented with a 95% efficient scavenger air evaporative pre-cooler can cool hot-aisle air from 101.5°F (38.6°C), including supply fan heat, to 75°F (23.9°C). Note that the IASE cycle rejects 100% of data center heat for almost 80% of annual hours in Atlanta. In Salt Lake City, the IASE cycle rejects 100% of data center heat for 99.9% of annual hours. If server inlet temperatures are allowed to occasionally rise to the upper end of the recommended range, refrigeration management systems using IASE heat rejection with the addition of SSF , filtering the data center air at a proposed rate of 6

TMY2 summer days in which 95% of the full design flow, and corresponding scavenger-fan motor power is reduced to less than one-eighth of the power consumed at design condition.

Table 2: Annual hours where an IASE using an 80% efficient dry HX with a 95% efficient DEC scavenger air pre-cooler rejects 100% of data center heat.

Note: Calculated from TMY2 weather data. 101.5°F (allows for 1.5°F of fan heat) hot aisle cooling to 75°F cold aisle.
Polymer-Tube Indirect Air-Side Economizer

Another type of horizontal polymer-tube heat exchanger (Figure 3). With this design, outside scavenger air is drawn across the exterior of elliptical tubes, which are wetted by a recirculation water pump. The elliptical shape of the heat exchanger tubes maximizes the allowable surface area for heat rejection and is sufficiently elastic such that its subtle expansion and contractions, resulting from normal operation, aid in the shedding of residual solids that are by-product of evaporation. With scavenger air flowing over the wet exterior tube surfaces, evaporative heat transfer efficiently cools the data center hot aisle air flowing through the inside of the tubes.

Although only 45% to 51% effective when operating dry, when the outside of the polymer-tube HX (Figure 3) is wetted, the HX is able to provide 70% to 80% of wet-bulb depression effectiveness (WBDE), as an indirect evaporative cooler. When using the optimum configuration, the HBDE is 75°F (23.9°C) dry bulb at 55°F (12.8°C) dew point and target cold-aisle temperature of 75°F (23.9°C).

Figure 4 shows the scavenger-side pressure drop and WBDE as a function of the HX’s rated flow for the condition of recirculation air entering at 101.5°F (38.6°C) dry bulb at 55°F (12.8°C) dew point. The HX is predicted to be just over 52.5%. Because the WBDE declines slowly as scavenger flow is reduced, the scavenger fan flow and corresponding power consumption rapidly drop as the ambient temperature increases, with N+1 units operable, the SEER increases resulting from the redundant and essential units run in tandem. In addition to the electrical power, water consumption including evaporation, bleed, and periodic flush cycles must all be taken into account.

Figure 5 shows how the scavenger fan flow for an IASE system using polymer-tube HX is predicted to vary with the ambient wet-bulb temperature for a 1,500 kW data center operating in Chicago. The hot-aisle temperature applicable to this figure is 101.5°F (38.6°C) after fan heat, and the target cold-aisle temperature is 75°F (23.9°C).

Having discussed polymer-tube IASE system operating in Chicago, with a hot-aisle condition of 75°F (23.9°C) dry bulb at 55°F (12.8°C) dew point, and with a target cold-aisle delivery of 75°F (23.9°C) cooling to a target cold-aisle temperature of 75°F (23.9°C).

Figure 6 shows the supply fan motors are the largest single contributor to the total power consumed in rejecting the data center heat. The total system power for the supply fans on this example is 2.59 in. (664.5 Pa), which is the sum of the WBDE pressure drop (0.74 in. w.c. [184 Pa]), the cooling coil (0.15 in. w.c. [37 Pa]), AHU system losses (0.2 in. w.c. [50 Pa]), and the external static pressure resulting from the return and supply connected ductwork (1.5 in. w.c. [374 Pa]). Filter pressure drop is not included here for reasons already explained. The supply fan static efficiency is 74% in this example, and the supply fan motors operate at 93% efficiency.

Figure 7 shows the design performance of the polymer-tube IASE system operating to reject an IAT load of 1,500 kW in Chicago. Five units total are selected for the duty, operating in an N+1 configuration. The system design is based on N units active, for this example equals four. 5127 acfm (24 188 L/s) of hot returns air at 100°F (37.8°C) dry bulb at 55°F (12.8°C) dew point enters each of the four IASE units. The hot aisle air enters the supply fan, resulting in a 1.5°F (0.83°C) rise in the supply temperature. The AHU then cools the air to 86.5°F (30.3°C), rejecting 64.3 tons of load per unit. This heat is transport-