

# OPEN

Compute Project

## Data Center v1.0

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## 1 Scope

This document describes the mechanical and electrical specifications used in the design of Facebook's innovative and energy-efficient data center.

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## 3 Overview

When data center design and hardware design move in concert, they can improve efficiency and reduce power consumption. To this end, the Open Compute Project is a set of technologies that reduces energy consumption and cost, increases reliability and choice in the marketplace, and simplifies operations and maintenance. One key objective is openness—the project is starting with the opening of the specifications and mechanical designs for the major components of a data center, and the efficiency results achieved at facilities using Open Compute technologies.

Two components of this project are the data center electrical and mechanical elements. Facebook's Prineville, Oregon, location is the first implementation of these elements in a data center.

The facility utilizes an electrical system with a 48VDC UPS system integrated with a 277VAC server power supply. The mechanical system uses 100% airside economization with an evaporative cooling system.

Facebook also deploys Open Compute Project servers at this facility, which use efficient and innovative motherboards, highly efficient (95%) power supplies, and 48VDC backup power. These technologies are discussed in separate specifications.

### 3.1 License

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## 4 Electrical Design

The electrical system uses 480/277VAC distribution with a 48VDC UPS system integrated with a server power supply.

### 4.1 Codes, Guidelines, and Standards

The systems are designed to meet or exceed these standards.

- NEC: National Electrical Code with Local Amendments
- NFPA: National Fire Protection Association
- ANSI: American National Standards Institute
- SFM: State and Local Fire Marshal
- IEEE: Institute of Electrical and Electronics Engineers
- NEMA: National Electrical Manufacturers Association
- UL: Underwriters' Laboratories, Inc. or equivalent testing lab
- IES: Illuminating Engineering Society
- Local and State Building Code

### 4.2 Featured Electrical Systems

In addition to standard data center electrical design elements (from grounding to transformers), the Prineville facility features these electrical and related systems:

- 115 kV substation
- Diesel backup generators
- Main switchboards (MSB)
- Battery monitoring
- 480/277VAC distribution switchboards
- Server battery backup
- Power busduct system
- Nitrogen-based fire sprinkler system eliminates pipe corrosion
- LED lighting systems
- Reactor power panels
- Cam lock connections

### 4.3 115 kV Substation

- A new transmission substation was constructed as the point of connection and power delivery from Pacific Power to the site at a transmission voltage level of 115kV.
- Incoming utility is aerial from adjacent utility looped transmission line and circuit breakers.
- The substation consists of incoming aerial dead end structures, Pacific Power metering equipment with KYZ pulse output, main disconnect switch or circuit switcher, and related 115kV distribution to three (3) transformer/distribution bays.
- Each bay contains a power transformer and related 115 kV circuit switcher or SF6 circuit breaker.
- The 115kV substation equipment, power transformers, circuit-switching devices, and 12.47kV medium voltage switchgear was installed in a secured fenced yard on site.
- Transmission metering is provided as per Pacific Power requirements.

- A main disconnect switch or circuit breaker was installed at the Pacific Power incoming 115kV dead end structure to provide a means to isolate equipment for preventative maintenance or to perform equipment repair.
- A circuit switcher was installed on the primary side of each power transformer. The circuit switchers are outdoor 3-pole operated devices with SF6 filled puffer-type interrupter, driven by a single, stored-energy mechanism. The circuit switcher is mounted on steel structures placing the interrupter at bus level. The mechanism cabinet is accessible at ground level.
- Two 115kV – 12.47kV, 15/20/25 MVA, OA/FA/FA 65°C oil-filled power transformers are provided. Voltage taps (LTC – load tap changer) are provided to allow for an adjustment of 5% above and below nominal voltage. The transformers are protected with lightning arresters, thermal relay, liquid pressure relay, and differential relays.
- Space is available for a future third power transformer.
- Grounding is provided to ensure the lowest practical resistance between circuit neutrals and true earth; it is also provided to ensure safe operation of the substation with low values of touch and step potential that conform to IEEE Standard 80.

#### 4.4 Diesel Backup Generators

- A single engine generator is dedicated to a single main switchboard (MSB) in this block redundant scheme.
- The engine generators provide backup power to the MSBs, which distribute power to all facility loads:
  - Power distribution to server load.
  - HVAC equipment loads.
  - Interior and exterior lighting systems.
  - General purpose power.
- Generators are located in a secured exterior yard.
- Weather enclosure only; no sound attenuating enclosure.
- Generators are solidly grounded.
- 30-hour backup diesel fuel storage belly tank.
- The engine generators are diesel fueled with standby rating 3,000 kW/3750 kVA, Class H insulation and 125°C rise. Rated for higher elevation use.
- Equipment monitoring interface:
  - BMS Modbus interface for equipment monitoring.
  - Critical operating parameters.

#### 4.5 Main Switchboards (MSB)

MSB board main breakers are 4 pole breakers to isolate the neutral phase between utility power and generator power.

- Power bus configuration:
  - 480 volt, 3-phase 4-wire, 5000 amp primary bus switchboards (MSB).
  - Configuration is 6+1.
  - Each MSB equipped with electrically interlocked main breakers.
  - Normal source breaker: Incoming 480V from pad-mounted transformer.
  - Generator source breaker: Incoming circuit from bus generator.
  - Swing bus breaker: Connection to the [primary](#) or reserve bus.
  - Load bank breaker: Connection to Load Bank Switchboard (LBSB).

- Critical load bus: Segmented 1600A busses with interlocked circuit breakers.
- Protective device AIC rating is 65 kAIC with pad-mounted transformer impedance specified accordingly to limit the fault current.
- Automatic transfer:
  - The normal, generator, and swing bus source circuit breakers are controlled operated by an automatic transfer control circuit (AT) so that only one main breaker can be closed at a time.
  - The source breakers are configured for open transition in transfer of load. The transfer module automatically controls normal source and standby source circuit breakers. Programmable functions include time delay and abnormal power conditions (such as under voltage and under frequency).
- Infrared inspection windows in each section for thermal scanning each cable and bussing termination.
- MSB circuit breakers:
  - Electrically operated.
  - Draw-out type power circuit breaker UL 1066.
  - LSIG trip functions.
  - Ground fault trip with zone selective interlocking to the main circuit breaker.
- Power quality meter (PQM):
  - Transient /impulse waveform capture.
  - Incorporated into each MSB to monitor the normal and standby sources through separate CTs.
- Load terminations are 2-hole compression type.
- Surge Protection Devices (SPD) are incorporated into each switchboard. The SPD meets UL 1442 third edition category C3. Phase-to-phase and phase-to-ground protection is provided.
- Equipment monitoring interface:
  - BMS Modbus interface for equipment monitoring.
  - Load amps and power.
  - Circuit breaker position.
  - Power quality meter data.
  - SPD alarm.
  - AT -auto transfer module data.

#### 4.6 Battery Monitoring (Validation)

- Monitoring of each battery system is provided for status and alarm conditions.
- Monitoring of battery jar.
- Battery string voltage, battery discharge current, individual voltages, configured temperature, individual resistance, inter-cell connection resistance, and inter-tier resistances are monitored.
- The battery monitoring system communicates status and alarm conditions to the BMS via TCP/IP on the facility Ethernet backbone.

#### 4.7 Server Power

- L22-20: 3-phase 4-wire 20 amp.
- Overhead 480/277VAC busways.
- Rack power distribution: 480/277VAC, 48VDC

#### 4.8 Server Battery Backup

Open Compute Project servers in the data center are backed up by 48VDC battery backup cabinets. For information, read the *Open Compute Project Battery Cabinet Hardware v1.0* specification.

#### 4.9 Power Busduct System

- Indoor 5000A busduct is constructed to each MSB from the reserve bus and the LBSB. This interconnecting busduct provides for operation of the reserve bus in a backfeed operating mode or load bank testing of any one generator.
  - In the backfeed operating mode the reserve bus delivers power to any one of the 6 MSBs.
  - System interlocking allows for load bank testing of any one of the backup generators.
- Indoor 3200A busduct is constructed to each MSB critical load bus from the reserve bus switchboard. The busduct uses interlocked circuit breakers.

#### 4.10 Fire Alarm and Protection System

- Pre-action fire sprinkler system uses nitrogen gas in lieu of compressed air to eliminate pipe corrosion.
- Online nitrogen generator.
- A VESDA air sampling system is provided for early detection for fire/smoke detection.

#### 4.11 LED Lighting Systems

Energy-efficient LED lighting is used throughout the data center interior.

- Innovative power over Ethernet LED lighting system.
- Each fixture has an occupancy sensor with local manual override.
- Programmable alerts via flashing LEDs.

#### 4.12 Reactor Power Panel

- Line reactor reduces short circuit current < 10 kA.
- Corrects leading power factor towards unity.
- Reduces THD (total harmonic distortion) for improved electrical system performance.
- Line reactor power consumption 360W.

#### 4.13 Cam Lock Connections

The 480V distribution system is equipped with cam lock connections that allow for maintenance bypass of key components.

## 5 Mechanical Design

The goal of the mechanical design is a system with very low operating cost and a relatively low installed cost when compared to a conventional data center. Energy-intensive cooling systems are replaced with far simpler and lighter technologies that allow for a ductless overhead air distribution that can operate in an expanded temperature and humidity range beyond 2008 ASHRAE TC9.9 guidelines (see Figure 1).

We went beyond ASHRAE guidelines because we're using our own custom servers (see other Open Compute Project specifications) that we have tested, and are confident that they will operate within our dictated lifecycle.

### 5.1 Mechanical System Design Criteria

The data center was built with the following internal and external environmental conditions as guidelines.

#### 5.1.1 Data Center Conditions

- Cold aisle temperature controlled between 65°F and 85°F
- Dewpoint minimum 41.9°F
- 65% relative humidity (RH) maximum

#### 5.1.2 Outside Air Design Conditions

OA conditions at the Prineville site are ideal for using an evaporative cooling system.

- **Summer:** 110°FDB (dry bulb) maximum, 70.3°FWB (wet bulb) maximum (105.6°F is the 50 year extreme maximum and 70.3°F is the worst recorded WB temperature between 1972 and 2001 in Redmond, Oregon per ASHRAE)
- **Winter:** -30.8°FDB, 50%RH, 0.55 grains (50 year extreme minimum per ASHRAE)

**Note:** Design data is based on published data for Redmond, Oregon, which is the closest city to Prineville that has complete information available.

### 5.2 Outside Air Operating Conditions

The operating conditions of the different installed systems (economizer, direct evaporative cooling, and humidification) vary based on the outside air (OA) conditions. Figure 1 is a psychrometric chart indicating where these conditions occur. To better understand the sequence of operations, see section 6.



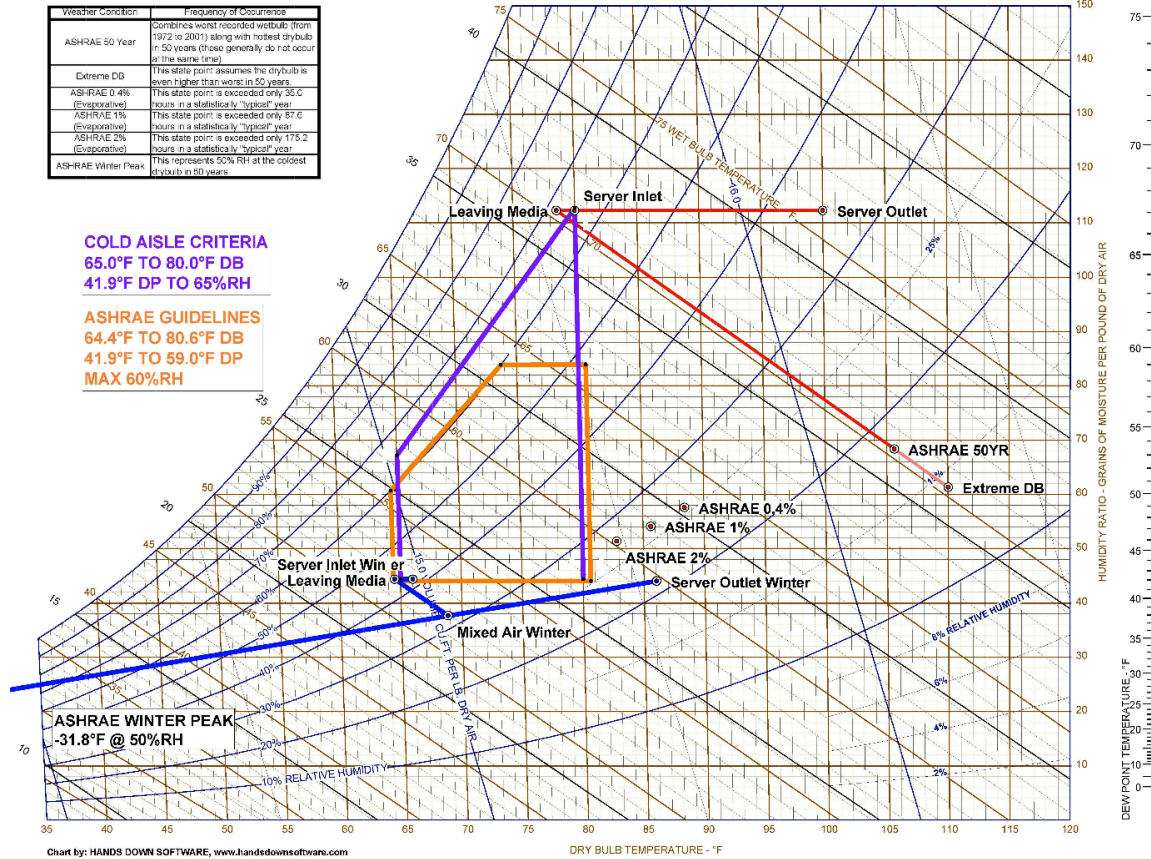


Figure 1 Design Psychrometric Chart

## 5.3 Mechanical System Concept

The mechanical system basis of design utilizes a direct evaporative cooling concept where no chillers or compressors are needed for cooling the IT load.

The design utilizes a built-up system where the mechanical airside functions are located in a field-constructed penthouse.

### 5.3.1 Built-Up System Advantages and Disadvantages

A built-up system (penthouse design) has advantages with construction and operational serviceability.

#### Construction Advantages

- Reduced footprint of mechanical room.
- No field ductwork required; air is distributed with plenums.
- Lower potential for roof leakage that can penetrate into the data center compared to roof-mounted AHUs.
- No exposed piping on the roof that can cause access, potential leaks, and reproofing issues.
- Less required equipment redundancy, which can result in a lower construction cost.

#### Operational and Maintenance Advantages

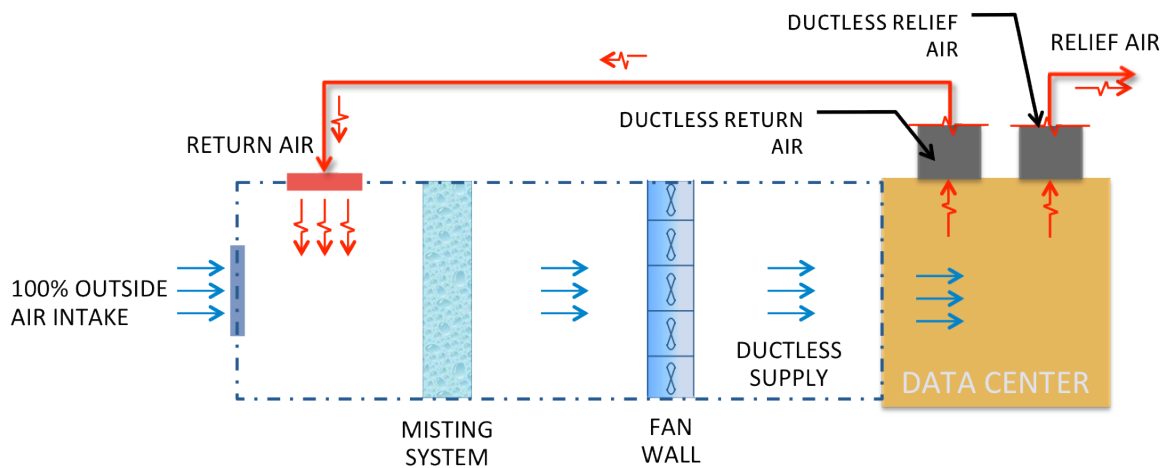
- Enclosed interior space makes service and maintenance better than being exposed to exterior elements (cold winters and hot summers).

- Less likelihood of mixing relief/exhaust air with outside intake air.
- Longer life expectancy than AHU casing based on the AHU's exposure to outside elements.
- Less maintenance cost (door seals, control cabinets, etc. exposed to weather).
- Easier access to service and maintenance of damper actuators, fans, starters, VFDs, humidifiers, and controls.

### Built-up System Disadvantages

- More reliance on mechanical contractor capabilities to field assemble and install a quality system.
- Drains required for direct evaporation/humidification will most likely need to be located below the roof and thus will require double containment and leak detection.
- Scaling is limited, as unit count must increase to match built-up system capacity and redundancy.

### 5.3.2 Airflow Overview



**Figure 2 Airflow Overview**

1. Outside air (OA) enters through vertical drainable louvers in the penthouse.
2. The air proceeds into the OA intake corridor.
3. OA mixes in with data center return air and passes through the filter bank in the filter room.
4. Air enters the evaporative cooling/humidification room and may get sprayed by the misting system.
5. The air passes through mist eliminators to prevent water carryover.
6. The air enters the supply fan room, and gets pushed down the supply air openings to the data center cold aisles.
7. The air enters the front of the server cabinets, passes through to the contained hot aisles, which then enters the return air plenum. The air then is returned back to the filter room or exhausted out of the building by natural pressure and/or relief fans.

### 5.3.3 System Functions and Features

The system is designed to provide the following functions and features:

#### Full Airside Economizer System

- Can obtain free cooling whenever outside air conditions are favorable.

- Provides very significant operating cost savings, especially in the high desert climate.
- Dampers are situated so that there is good mixing and to avoid moisture issues when the cold outside air mixes with the relatively moist return air in the winter condition.

#### **Filters**

- MERV 13 (ASHRAE 85%) cartridge filters with low initial pressure drop and high dust loading capability will be provided. The filter system has space for 2" pleated 30% prefilters. The filters can be upgraded to MERV 14 (95% ASHRAE). However, the pressure drop increases from 0.27"SP at 500 FPM to 0.36"SP.

#### **High Pressure Atomization**

- High pressure pumps and atomizing heads provide both evaporative cooling and humidification.
- System is fully modulating.
- Redundant softener and reverse osmosis (RO) systems with distribution pumps and piping to each built-up AHU system.
- The softener and RO systems require maintenance; the atomizing heads require replacement after approximately 10 years.

#### **Supply Fan Systems**

- Low operating cost, direct-drive plug (plenum) fans.
- Fan array fed by three electrical busses at N+1 redundancy.
- Fans are controlled with VFDs to minimize the operating cost, as the load and fan pressure requirements vary.
- Fan array minimizes penthouse area.

#### **Complete Hot Aisle Containment**

- Center and end aisles are considered to be cold aisles to keep as much of the area as comfortable as possible.

#### **Relief Fans**

- Fan array fed by three electrical busses at N+1 redundancy.
- Fans are controlled with VFDs to minimize the operating cost as the load and fan pressure requirements vary.
- The fans discharge through hooded automatic dampers to minimize the possibility of moisture penetrating into the space.

#### **Building Management System (BMS)**

- Distributed system provides redundancy in case of failure.
- Direct Digital Control (DDC) based. Provides all control, data logging, monitoring, and alarming functions required for the mechanical systems.
- Interfaced to the electrical components and provides monitoring and alarming of critical points.
- Interfaced to the fuel systems, VESDA, and fire alarm to provide monitoring and alarming of critical points.
- Does not monitor data center power use at the server level.

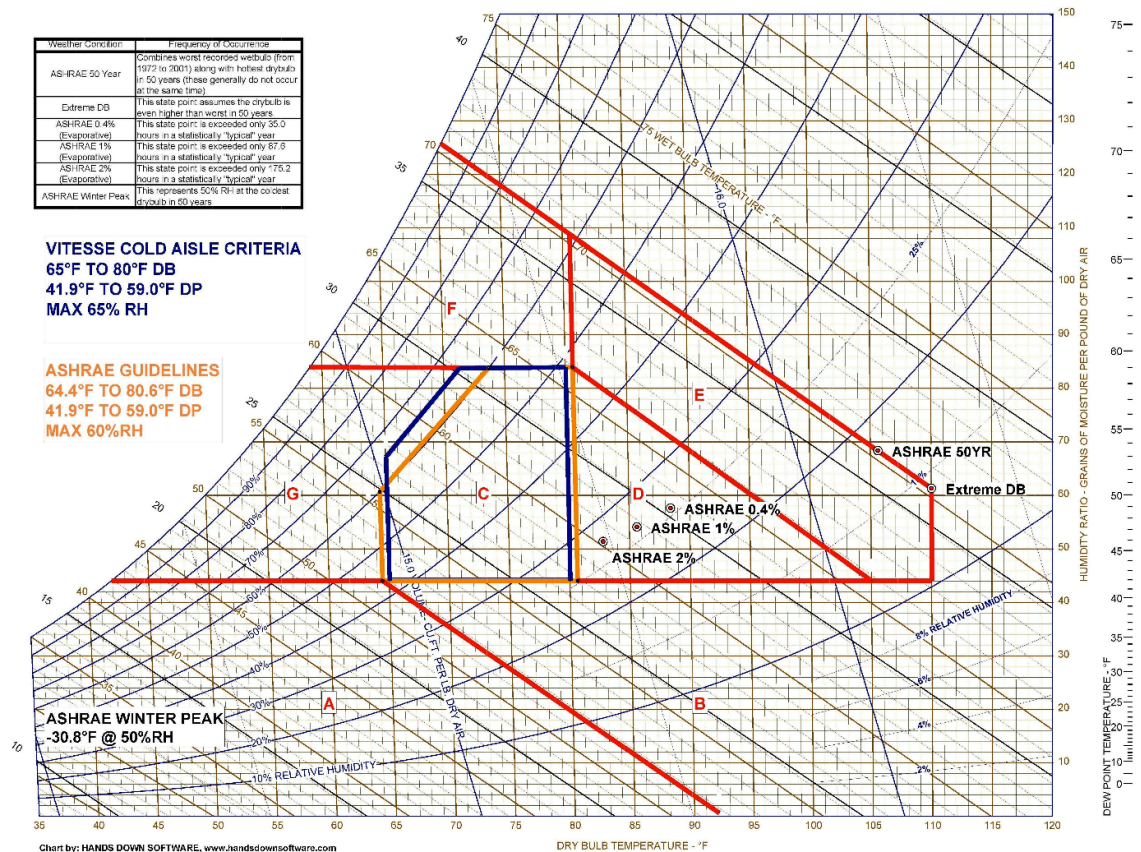
#### **Other Items**

- Major equipment is controlled with VFDs to minimize operating cost and to allow the systems to accurately match the load.

- Redundancy is provided for major equipment so that on loss of any single electrical bus or a mechanical failure, the full design capability is still available.
- The direct evaporative system is supplied primarily by an on-site well and secondarily by the normal city water distribution system. Both sources feed into a storage tank. The storage tank provides 48 hours of water in the event well water and city water sources are unavailable. The water storage tank is not insulated, and there is no bubbler to keep it from freezing.
- Piping outdoors is insulated and heat traced to protect it from freezing. Systems that will be drained down during the winter would not require freeze protection.

## 6 Appendix A: Psychrometric Sequence of Operations

The following is a detailed psychrometric chart describing outside air conditions at the Prineville, OR, site.



### OUTSIDE AIR OPERATING CONDITIONS

Figure 3 Psychrometric Chart, Outside Air Operating Conditions

#### Condition A: <52°FDB and <41.9°FDP

- Economizer mixes OA/RA (return air) to control to 65°F SA (supply air) to cold aisles.
- Direct evaporation system provides required humidification by staging/modulating the evaporative cooling/humidification system.
- The supply air and thus the cold aisle control to maintain 54°FDB and 42°FDP minimum.

#### Condition B: >52°FDB and <41.9°FDP

- Economizer at 100% OA.
- Direct evaporation system provides required humidification and/or cooling by staging/modulating the evaporative cooling/humidification system.
- The supply air and thus the cold aisle control to maintain 80°FDB maximum, 65°FDB minimum and 43°FDP.

#### Condition C: > 65°FDB (-fan heat) & > 41.9°FDP & < 80°FDB (-fan heat) & < 59.0°FDP & < 65%RH

- Economizer at 100% OA.



- Direct evaporation system is off. No evaporative cooling or humidification is required.
- The room supply air is within the envelope defined by the conditions above.

**Condition D: > 80°FDB (-fan heat) & > 41.9°FDP & < 65.76°FWB**

- Economizer at 100% OA.
- Direct evaporation system provides required cooling by staging/modulating the evaporative cooling/humidification system.
- The supply air temperature and thus the cold aisle are controlled at 80°FDB and the dewpoint is allowed to float between 42 and 59°FDP.

**Condition E: > 80°FDB (-fan heat) & > 41.9°FDP & > 65.76°FWB**

- Economizer at 100% OA.
- Direct evaporation system provides required additional cooling, if necessary, by staging/modulating the evaporative cooling/humidification system.
- The supply air temperature and thus the cold aisle are controlled at 80°FDB and the dewpoint is above 59°FDP.

**Condition F: < 80°FDB (-fan heat) & > 59.0°FDP & > 70.3°FWB**

- Economizer mixes OA/RA to increase cold aisle temperature as necessary to reduce cold aisle RH to 65%RH maximum. The RH overrides the temperature control to maintain 65%RH maximum. The supply air and thus the cold aisle temperature are controlled to 65°FDB minimum and 80°FDB maximum.
- In this condition, room dewpoint (DP) is >59.0°FDP.
- Direct evaporation system is bypassed. No evaporative cooling or humidification is required.

**Condition G: > 65°FDB (-fan heat) & < 59.0°FDP & > 65%RH or < 65°FDB & > 41.9°FDP & < 59°FDP**

- Economizer mixes OA/RA as necessary to meet 65°FDB minimum or 65%RH maximum in the cold aisle.
- In this condition, room DP will be <59.0°FDP.
- Direct evaporation system is bypassed. No evaporative cooling or humidification is required.

**Condition H: Unacceptable OA Conditions (Smoke or Dust)**

- Economizer at minimum OA (recirculation mode). We acknowledge that this is a condition that can cause potential shutdown. We already have filtration installed and will run evaporative cooling at full capacity to reduce smoke and particulates in the event of a fire or contamination. Then, depending on intensity, we can utilize time for orderly shutdown, or else run for a prolonged period of time at minimum OA. We have a provision for a closed-loop system that uses indirect cooling; see section 7.
- Direct evaporation system provides required additional cooling or humidification, if necessary, by modulating the atomizing system.

**Note:** The fan heat will vary depending on the position of the bypass dampers around the indirect coil and the direct evaporation systems as well as the conditions of the filters. With clean filters and direct systems in bypass, the fan heat should be about 0.62°F (AHU system with all units on). With no bypass and dirty filters, the fan heat should be about 1.46°F (with one bus failed and thus some AHUs off).

## 7 Appendix B: Indirect Cooling

One option considered but not implemented at Facebook's Prineville site was to use indirect cooling, which uses cooling coils that are piped to open cooling towers with condenser water pumps.

An indirect system can provide sensible cooling to bring data center recirculated air from 100°F down to 78.5°F (80°F cold aisle -1.5F fan heat) when the outside wet bulb temperature is 66.0°F or lower.

**Note:** 66.0°F WB was chosen as this allows the system to control to 80°F cold aisle while supplying 72°F water to the coil, which makes the cooling tower selection a reasonable 6°F approach and keeps the coil air side pressure drop to approximately 0.65"SP; basically optimizing the cooling tower and coil. 66.0°F WB is 2.7°F above the ASHRAE 0.4% WB design of 63.3°F WB, indicating that there is a good safety factor to allow the overall system to maintain conditions within the ASHRAE guideline envelope of better than 99.6% or 8725 hours of an average year.

This capability would therefore allow the system to operate in the non-economizer mode if there is an outside atmospheric problem such as smoke or dust.

The indirect system would allow the overall cooling system to stay within the ASHRAE data center guidelines of 60%RH and 59.0°F DP (dew point) maximum up to the ASHRAE extreme maximum of 70.3°F WB with a coincident of 110°F DB (this high a DB has never been coincident with the 70.3°F WB).

Bypass dampers could be installed at the cooling coils so that when the conditions are such that they are not required, they will open and the supply fans can then work at a lower pressure drop, thus saving significant energy during the year.

The cooling towers could have VFDs on the fan motors, sweeper piping in the basin with filtering system, and a non-chemical water treatment system. Due to the freezing climate they would need to be drained in the winter.

The system can use an N+1 redundancy for the cooling towers and the condenser water pumps, but not for the water distribution piping systems. It seems very unlikely that the space conditions would be compromised if there were a leak with a possibility of a high RH condition for perhaps a few hours. The likelihood of a leak that could not be repaired within a reasonable time is very low and this system would only be used to avoid high humidity problems and to handle unusual dust or smoke conditions, which are infrequent. There would be one tower and pump for each electrical bus.

In order to minimize piping runs, the cooling towers can be located on a roof, particularly if a built-up outside air system is selected; however they could be located on the ground, if desired. For sites implementing rooftop air handling units, the towers would have to be located on the ground because of space limitations.

The indirect coil would be fully active in the following outside air conditions (as per section 6):

- Condition E: >80°FDB (-fan heat) and >41.9°FDP and >65.76°FWB
- Condition H: Unacceptable OA conditions (smoke or dust)

In these situations, the cooling towers and pumps would be on. Condenser water temperature would be controlled (cycle on towers and control tower fan speed with VFD and stage pumps, and control pump speed with VFD) to maintain 80°F (-fan heat) cold aisle temperature.