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Intel IT: Extremely Energy-Efficient, High-Density Data Centers

Our new data centers are achieving the following results:

- 1.06 PUE
- Up to 43 kW per rack
- Lowest \$/kW construction cost
- Environmental sustainability
- 51% higher compute performance

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Executive Overview

As part of our effort to strategically transform data centers to achieve significant business results, Intel IT used design best practices to convert two vacant silicon-wafer-fabrication building modules into extremely energy-efficient, high-density, 5+ MW data centers, each with its own unique design and cooling technologies. These data centers operate at the lowest cost per kilowatt (kW) and are designed to be environmentally sustainable through creative use of unused building space and prevailing site environmental conditions.

The latest data center module uses a close-coupled evaporative cooling technique with the first 5.5 MW IT load power in production, which is designed to operate within 1.07 power usage effectiveness (PUE) annually. The previous data center module uses an outside free-air cooling technique with 5 MW IT load power within 5,000 square feet; over two years of operation it has delivered 1.06 PUE.

These innovatively designed data centers are achieving the following results:

- A rack power density (up to 43 kW per rack) that is 1.5 times greater than what we have delivered in the past for high-density computing
- A 1,100 W/square-foot cooling density and a 1,300 W/square-foot electrical density (10 times the industry average)
- Data center space A uses only evaporative cooling-tower water to condition the data center space at up to 95°F supply air and densities >1,000 W/square foot
- Data center space B uses only free-air cooling except for 39 hours or less per year and runs our servers at an air intake temperature of up to 95°F (35°C)
- Both our close-coupled evaporative cooled and free-air-cooled data center spaces are designed for 1.07 PUE, but are achieving 1.06 PUE

Our newly designed water-cooled data center has a total power capacity of all the existing high-density and Intel® legacy data centers. The 60,000 Intel® Xeon® processor-based servers installed in these facilities offer

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Acronyms

- kW** kilowatt
- PUE** power usage effectiveness

51 percent higher performance per core than previous models,¹ which enables us to significantly increase compute density. The higher cooling and electrical densities will enable us to support the large growth in compute demand associated with electronic design automation tools, while delivering high performance for application needs. This growth is a result of an increase in chip design complexity and the workload required for comprehensive silicon design and testing.

Business Challenge

Increasingly complex silicon chip designs are driving more than 30 percent annual growth in compute demand at Intel—more than 45 million compute-intensive design workloads run every week. There is also increasing pressure industry-wide to reduce data center operating costs and increase data center energy efficiency. To address these challenges, we have been exploring ways to increase data center efficiency and capacity without increasing the cost of operation.²

We considered the following possibilities:

- Build new data centers.
- Repurpose existing vacant spaces
- Retrofit existing data centers.
- Purchase a container-type data center solution.
- Use external hosting providers.

After evaluating the available options, we decided to repurpose existing vacant silicon-wafer-fabrication spaces.

Solution

The building space we chose to convert to data centers has several characteristics that made it a logical choice:

- We have underutilized site resources available for utility power, water, and floor space.
- The modules are located near a global design computing hub, which provides access to network infrastructure and optimizes support activities.
- Module A had the cooling-tower capacity and electrical substation capacity that was stranded when the fab facility was decommissioned. The multistory building provides space below and above for power and water piping infrastructure. The old fab floor provided clear space for efficient rack deployment.
- Module B is a multistory building with high ceilings and available plenums. The upper floor provides access to outside walls that have a favorable exposure for exhaust-air venting.

¹ Internal Intel IT tests, June 2014.

² To learn more about our design best practices for high-density data centers, read the Intel IT white paper "Facilities Design for High-density Data Centers."

Due to our use of commodity IT equipment, we were able to use only evaporative cooling even though the building is located in a climate with an average high temperature of 85°F (29°C).³

The resulting data centers are classified as batch high-performance computing facilities. They don't contain storage servers and don't have any requirements for high-tier reliability. As shown in Figure 1,⁴ our newly designed water-cooled data center has a total power capacity greater than of all Intel high-density and legacy data centers' current loads.

The following design components helped us meet the requirements for high-density computing in the most cost-efficient way (these design components are also described in more detail in the following sections):

- **Custom rack design.** We used a custom design, instead of an off-the-shelf design, which enabled us to better optimize space and power density. Our design provides 70 percent more rack U space in the same floor footprint.
- **State-of-the-art electrical density and distribution system.** We used 800-amp 415/240-VAC rack power distribution and achieved a single-path rack power density of 25 to 43 kW per rack. With custom high-efficiency transformers that produce losses at only 1 percent.
- **100-percent evaporative cooling in data center space A.** We are using cooling-tower water only with close-coupled cooling heat rejection. We used and extended innovations for high-density air-cooling designs that we had perfected in past facility projects and retrofits. Examples of such innovations include flooded supply air and hot-aisle enclosures for air segregation management.
- **100-percent free-air cooling in data center space B.** We used and extended innovations for high-density air-cooling designs that we had perfected in past facility projects and retrofits. Examples of such innovations include flooded supply air, hot-aisle enclosures for air segregation management, and direct hot-air exhaust to the building's exterior.

³ For more information about how we choose where to locate Intel data centers, read the Intel IT white paper "Selecting a Data Center Site: Intel's Approach."

⁴ The net square footage of the data centers' production area is 4,545 and the remaining space out of the total 5,000 square feet comprises access areas.

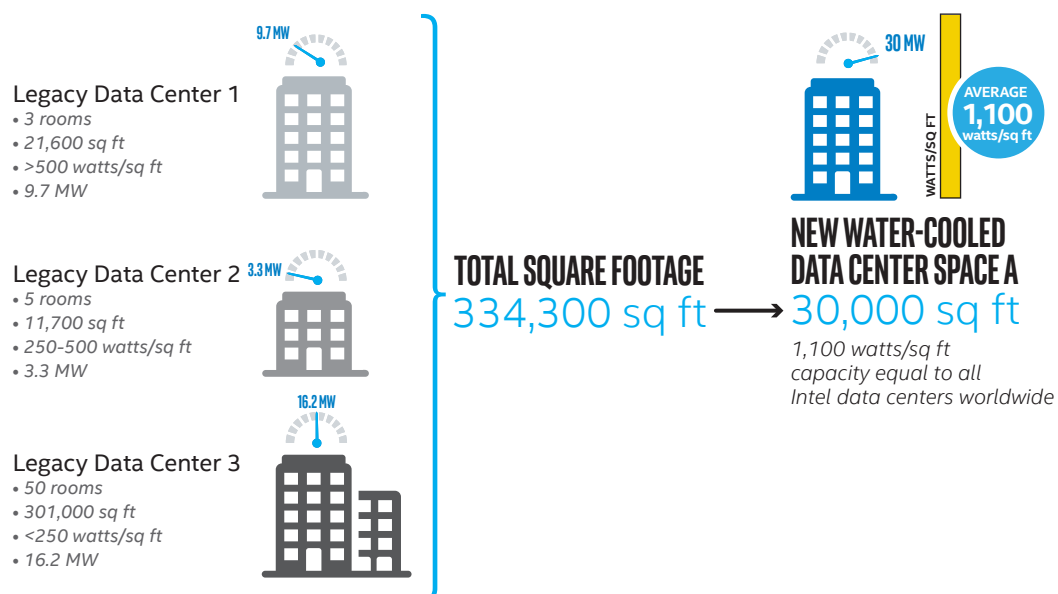


Figure 1. When construction is complete, the close-coupled evaporative cooling solution data center will exceed the combined power capacity of all current Intel® data centers. Economies of density work similar to Moore's Law: the cost per kW goes down as more kW are added to each square foot of production area.

Because the regional operating utility substation has high-quality power, we determined that the use of utility power was not a significant risk. However, we did provide for easy tie-in of an uninterruptible power supply or generator in the future should a business need or power qualities necessitate this change.

Custom Rack Design

We are maximizing our investment by increasing the density rather than scaling out, and we have more than doubled our previous server capacity per row and are providing >70 percent more capacity per rack floor space than standard industry designs (see Table 1). The off-the-shelf Intel Xeon processor-based servers installed in this facility offer significant advantages over previous server models: 51 percent higher performance per core and advanced small form-factor design for extremely high rack capacity. The combination of higher performance per core and high server rack density enables us to increase the capacity without increasing the data center footprint.

We increased the rack height to 60U and decreased the rack width to less than 20 inches. This design resulted in an overall cooling density of 1,100 W/square foot and a rack power density of up to 43 kW/rack—1.5 times what we have delivered for high-density computing in the past.

Table 1. Capacity per 50LF Data Center Row

	RACK DESIGN	
	Intel	Standard
Racks	30/60U	25/42U
Rack Width	20 in	24 in
Space	1800U	1050U
Number of 3U Servers	600	350

Intel has 71% more capacity per rack floor space than standard industry designs

Close-Coupled Cooling: Data Center Space A

Our current cooling design provides a cooling solution that maximizes the wet-side economizer concept and pushes the limits of evaporative cooling for the climate zone combined with a cooling coil placement in close proximity to the data center heat load (see Figure 2).

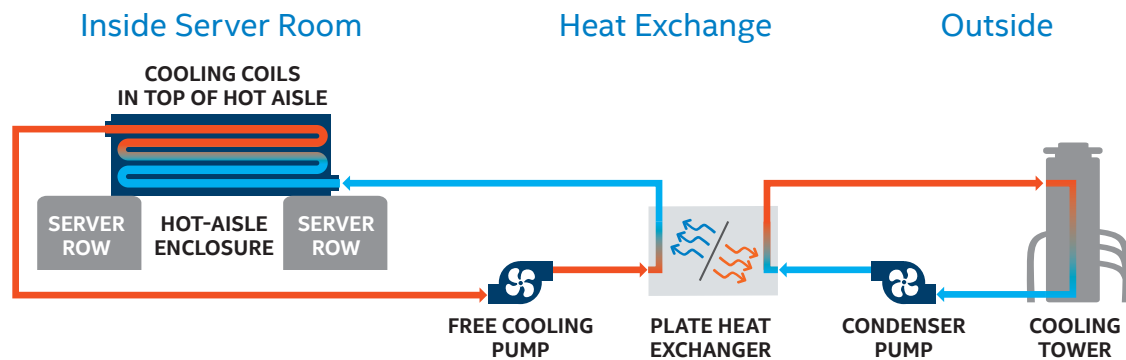


Figure 2. Data center space A uses a close-coupled cooling design. The wet-side economizer concept uses water-cooled coils to transfer heat away from the data center.

Newer server platforms allow for a wider range of thermal operating conditions—from 32°F (0°C) to 104°F (40°C). The specific equipment we are using is designed to operate with a supply-air temperature between 41°F (5°C) and 95°F (35°C). Our cooling-tower design will produce 79°F supply water in the summer and provide 90°F supply air to the servers through the overhead water-cooled coil. Taking into account our testing and the manufacturer's published operating conditions, we have found that we can now run servers at higher temperatures.

Two more design components—static pressure relief fans and in-room sensors—make our close-coupled cooling design more efficient.

- **Static pressure relief fans.** We installed fans in the hot aisle as a precaution in our first generation in the event the static pressure (ΔP) difference across the cooling coil exceeds the design calculations. We are currently operating our environment without any auxiliary fans.
- **In-data-center space sensor array.** Data center space A is a closed-loop air-distribution design using only pressure sensors in the hot aisle and temperature sensors on the return and supply airstream of the cooling coils.

Hot-Aisle Enclosures

As shown in Figure 3, the facility uses hot aisles (exhaust air) and cold aisles (supply air). Airtight doors at the end of each hot aisle and sheet metal air segregation enclose the server racks. The hot aisles' air temperature ranges from 110°F (44°C) to 130°F (54°C) depending on server workload. The supply-air temperature ranges from 80°F (27°C) to 95°F (35°C). Each enclosure is 1.1 to 3.3 MW depending on length.

Direct Hot-Air Cooling

In our design we installed water-cooled coils as part of the ceiling structure of the module; each 12-rack module can cool 330 kW of heat. Since the heat exchange takes place within an average of 20 airstream feet of server supply (front) and exhaust (back), very little energy is wasted moving air (see Figure 4).

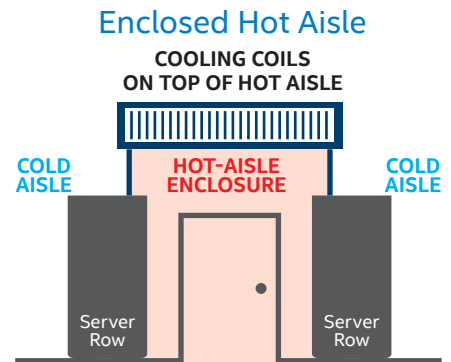


Figure 3. Hot aisles use airtight doors at the end of aisles to separate hot air from the supply air in the cold aisles.

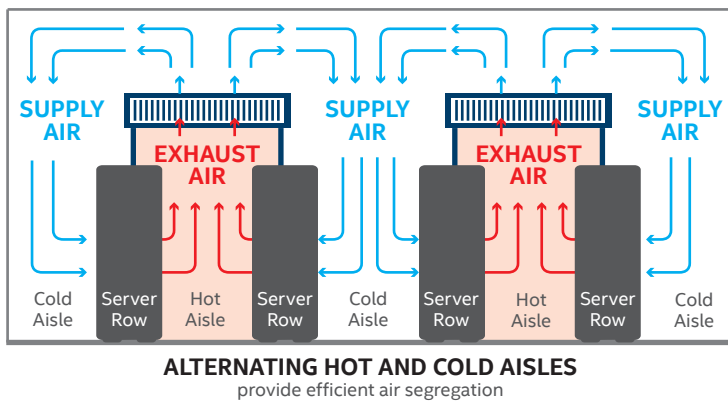


Figure 4. Water-cooled coils are built into the ceiling structure of the module.

Free-Air Cooling: Data Center Space B

We chose a flooded-air design for data center space B that provides supply air to the cold aisles by flooding the room with air at a slightly positive pressure. This design allows any amount of air required by any server to be available. The building was already equipped with rooftop air handlers. These repurposed units provide the air-flow filtering and supplemental cooling. The supply-air demand for the room is 542,324 cubic feet per minute. The facility more than meets this demand, providing 572,000 cubic feet per minute. We also reconfigured the existing rooftop supply-air plenums to connect to the room's overhead supply-air plenum, which is large enough to accommodate two school buses parked side by side (see Figure 5).

Newer server platforms allow for a wider range of thermal operating conditions—from 32°F (0°C) to 104°F (40°C). The specific equipment we are using is designed to operate between 41°F (5°C) and 95°F (35°C). In the data center, the supply-air temperature averages 60°F (16°C) in the winter and 90°F (32°C) in the summer. Taking into account our testing and the manufacturer's published operating conditions, we have found that we can now run servers at higher temperatures—no cooling is necessary unless the outside air is hotter than 95°F (35°C). Except for an estimated 39 hours per year, free-air cooling completely cools the facility.

If the outside temperature exceeds 90°F (32°C), we begin to augment free-air cooling using the available chilled water supply. Doing so ramps up the supplemental cooling before it is actually needed, for example, when the outside temperature reaches 95°F (35°C).

Two more design components—mixing fans and in-room sensors—make our free-air cooling design more efficient.

- **Mixing fans.** We use these fans to return hot air if we want to increase the supply temperature to eliminate extremely cold air or manage the temperature dew point.
- **In-data-center space sensor array.** Data center space B outside free-air design uses pressure sensors and temperature sensors to adjust the volume of air required to meet the servers' needs through the adjustment of automated supply-air louvers. This maintains the positive pressure in the cold aisle that our flooded-air design requires.

Hot-Aisle Enclosures

As shown in Figure 6, the facility uses alternating hot aisles (exhaust air) and cold aisles (supply air). Airtight doors at the end of each hot aisle and the translucent air segregation enclosure materials above the server racks are made of a material similar to that used for heavy-duty greenhouse roofs and walls.

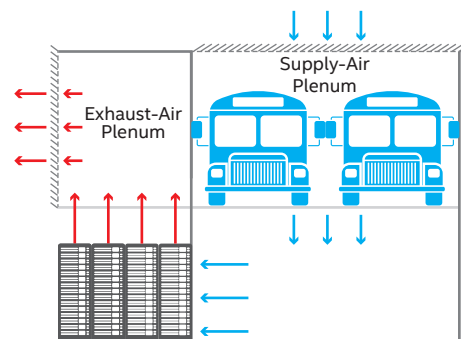


Figure 5. The overhead supply-air plenum is large enough to accommodate two school buses parked side by side.

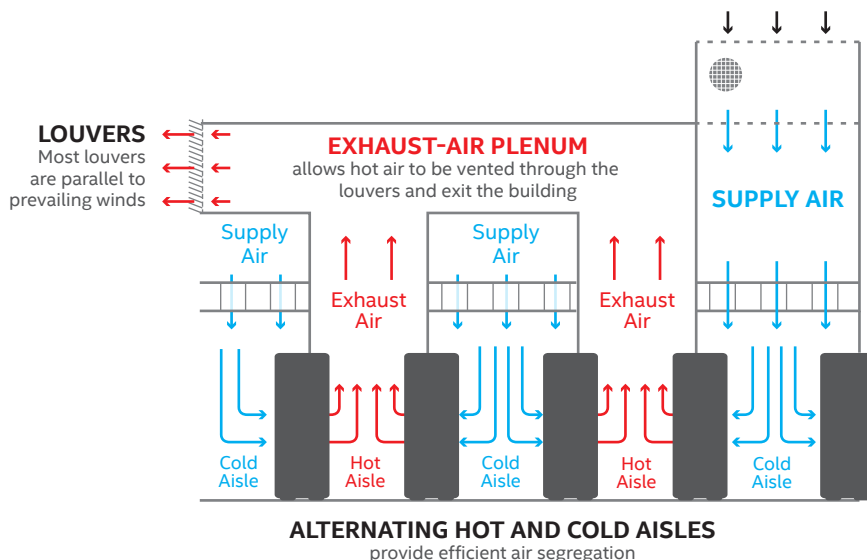


Figure 6. Alternating hot aisles (exhaust air) and cold aisles (supply air) provide efficient air segregation, and the exhaust-air plenum allows hot air to easily exit the building. The louvers are positioned parallel to prevailing winds so that the exhaust air can easily exit the building.

Hot aisles average 110°F (43°C) in the winter and 125°F (52°C) in the summer. The range of temperatures for the supply and exhaust air in the room makes the environmental conditions acceptable for the few staff that work occasionally in the room.

Direct Hot-Air Exhaust

As part of the building conversion, we added 1,100 square feet of louvers along a long wall of the building. As shown in Figure 6, after the supply air enters the cold aisles and passes through the servers, the exhaust air from the hot aisles enters the exhaust-air plenum and is vented through the louvers. We positioned these louvers parallel to prevailing winds so that the exhaust air can easily exit the building. To accommodate the occasional significant change in wind direction, we added 300 square feet of exhaust-air vent louvers perpendicular to the prevailing winds.

Electrical Distribution

For data center spaces A and B, our new electrical bus distribution designs provide 575 kW on a single bus supporting 440 square feet of data center compared to a standard 575-kW bus distribution path that typically provides electrical distribution for 4,400 square feet. The electrical density of the new facilities is 10 times greater than the industry average.

To achieve outstanding rack power distribution, we used a power strip designed by Intel and built by a third-party OEM. This 3-phase 60-amp 415/240-VAC power strip has the highest capacity in the industry, providing 12 individual sub-circuits with a total capacity of 43 kW at a delivered cost of less than USD 1,300 each. The strip design itself provides for phase balancing of the load. The power strip, in conjunction with the busway plug-in unit, reduced our installation cost by 75 percent compared to previous solutions.

The electrical design of the data centers has three other noteworthy aspects:

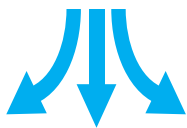
- **Ease of use.** The design is flexible and allows for easy configuration and connectivity for attaching server power and configuring the layout of equipment in the racks. As equipment footprints change, we can easily adjust and scale the racks and connectivity solution.
- **Flexibility.** The busway and power strip design enables us to support not only the current generation of IT equipment but also legacy, lower-amperage equipment without having to rewire branch circuits.
- **Reliability.** Based on our business requirements and the power quality of the current utility provider, we are using utility power to operate our data center. The electrical distribution equipment was designed with the capability to easily switch the power source to an uninterruptible power supply or, if necessary, generator support in the future. We can make this tie-in in less than one day per single bus without impacting any other electrical distribution in the room.



RACK POWER DENSITY

up to **43 kW**

per rack using state-of-the-art Intel® architecture-based servers



10X industry average

1,100 w/sq ft cooling density and 1,300 w/sq ft electrical density

Results

Using the basic design principles described above, we achieved the following results with our close-coupled cooling in the data center supported by the evaporative heat rejection through cooling towers.

- A rack power density of up to 43 kW/rack, which is the same as we delivered in our free-air cooling design density for high-density computing
- The ability to rely on a cost-effective 100-percent wet-side economizer
- A cooling density of 1,100 W/square foot, which is 10 times greater than the industry average—a density that the industry has referred to as “impossible” and “remarkable” for an air-cooled facility

We anticipate that after we gather the operating data over the next 12 months, our design will result in a PUE that is sub 1.07. We also expect the capital cost avoidance and operation cost savings to be significant due to the reduced amount of mechanical cooling capacity required (and therefore reduced electricity requirements), a small footprint, and the ability to reuse an existing building shell and cooling-tower infrastructure.

Next Steps

We have brought two 5 MW data center modules into production and support more than 60,000 high-performance Intel Xeon processor-based servers today. We have installed power monitoring according to The Green Grid Category 3 requirements, which will help enable us to gather data about the PUE of the facilities for any further energy optimization and key learning for future data center designs. We have started the next phase of adding another 15 MW of data center capacity using close-coupled evaporative cooling technology.

Conclusion

By converting two vacant silicon-wafer-fabrication buildings into data centers instead of building new facilities, we achieved significant capital investment cost avoidance. Through careful design and the use of the latest Intel Xeon processor-based technology, we established high-density compute data centers that include the following characteristics:

- A small footprint
- Best-in-class cost and operational efficiency
- Low construction and sustaining cost per kW
- Two years of realized extreme energy efficiency of 1.06 PUE in operation

The design components include the following:

- Custom rack design using Intel Xeon processor-based servers, which have 51 percent higher performance than previous models
- Low-cost wet-side economizer cooling (including hot-aisle enclosures and direct close-coupled cooling)
- State-of-the-art electrical system

These design components have enabled us to increase the maximum supply air intake temperature to 95°F (35°C) and achieve a cooling density of 1,100 W/sq. ft., a 1,300 W/sq. ft. electrical density (10 times the industry average), and a rack power density of up to 43 kW/rack.

For more information on Intel IT best practices, visit www.intel.com/IT.

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Our goal is simple: improve efficiency throughout the organization and enhance the business value of IT investments.

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