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IT@Intel
Data Center Efficiency and Retrofit Best Practices

The use of best practices enables us to increase data center efficiency and capacity, optimize the return on invested capital, and decrease operating costs without negatively affecting data center customers.

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Executive Overview

Intel IT has developed best practices for increasing data center efficiency by retrofitting data center infrastructure. Our goal is to optimize capacity and the return on invested capital and decrease operating costs. We also focus on minimizing the impact to customers during the retrofit process.

Several factors have led Intel to perform increasing numbers of data center retrofit projects over the last few years:

- Data center consolidation
- Steady growth in demand for computing, network, and storage resources, which requires us to increase compute capacity while decreasing the data center footprint
- Refresh of low-density equipment to high-density equipment and upgrades to IT equipment that is approaching end of life
- The need to align capabilities for data center reliability with changing business needs

We use our data center lifecycle to guide our retrofit process, implementing best practices at every stage in the lifecycle—high-level requirements, feasibility study, design, construction, commissioning, and sustaining. This approach enables us to renovate a large data center or perform a targeted retrofit of a smaller facility as efficiently as possible.

Retrofitting data centers can cost less than new construction and can help extend the life of our data centers and adapt them to changing business needs.

Contents

Acronyms

CFD computational fluid dynamics

CRAC computer room air conditioning

PUE power usage effectiveness

UPS uninterruptible power supply

Background

Intel's data centers serve the computing needs of more than 100,000 employees worldwide. These data centers, which support the business needs of Intel's critical business functions—Design, Office, Manufacturing, Enterprise, and Services—are at the heart of everything Intel does. Data center managers are under pressure to increase data center efficiency (in terms of both facilities load and IT load), optimize capital investment, and decrease operating costs—all while maintaining service levels.

In an effort to operate our data centers as efficiently as possible, Intel has reduced its total data center square footage by 24 percent and consolidated a number of sites, reducing the number of data centers from 152 to 64 over a period of 8 years. During this time, Intel's data center managers have faced the same challenges that most data center managers face. These challenges include the following:

- Deciding whether to upgrade aging infrastructure
- Meeting a 35- to 40-percent year-over-year growth in computing and storage demand, raising the question of how to increase capacity without increasing the overall data center footprint
- Increasing the power density of IT equipment
- Matching a data center's redundancy capabilities to the business need and its continuity plan

A data center that has older technology or that is not providing adequate compute, network, or storage capacity does not necessarily need to be replaced. High construction costs, the lack of available land, and other factors may make it inappropriate to build a new data center. We have found that retrofitting a data center is often more cost effective and takes less time than building a new one, while providing the same benefits:

- Increased energy efficiency
- Ability to use higher-density equipment
- A higher return on invested capital
- Lower operating costs
- Ability to change the data center's tier level to enhance redundancy and reliability or right-sizing a facility by decreasing its redundancy characteristics

By retrofitting data centers instead of building new ones, we achieve significant cost avoidance on our capital investment. Our best practices for retrofitting, combined with deployment of the latest Intel® architecture-based technology, enable us to create efficient, high-density data centers.

Best Practices

Having supported numerous data center retrofit projects over the last several years, Intel IT has developed a set of best practices for retrofitting data centers. These best practices are tied to our data center lifecycle, described in Table 1. Essentially, we identify a retrofit opportunity, evaluate the options, develop and implement a plan, and then sustain the new facility.

We engage in a continuous process of evaluating our data centers, updating them, and then measuring results. This approach helps us focus on the business value of applying our data center design principles and our retrofit best practices.
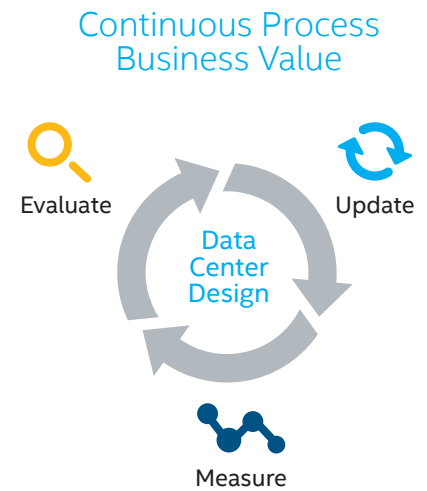
High-Level Requirements

In the first stage of our data center lifecycle—also the first step for a retrofit project—we document the business and technical requirements related to the planned project. The types of changes required for a data center retrofit depend on the business needs for that data center and the time available for the retrofit.

The following two sections explain the best practices we use as we evaluate ways to retrofit a data center to better meet business needs while increasing data center efficiency and decreasing operational costs. Following these best practices ensures that we engage all interested stakeholders and use key performance indicators.

Continuous Process Business Value

Evaluate

Update

Data Center Design

Measure

Table 1. Stages of a data center project lifecycle

Lifecyle Stage	Description	Duration	Best Practices
High-Level Requirements	Meet with end customers and key stakeholders.	Days or weeks	1. Engage stakeholders. 2. Define key performance indicators and establish a baseline.
Feasibility Study	Engage with external or internal design and engineering resources.	Weeks	3. Use appropriate tools to provide data and analytics. 4. Reevaluate redundancy levels. 5. Evaluate retrofit options.
Design	Engage internal design team or external architecture and engineering firm.	Weeks or months	6. Align retrofit activities with governmental and industry standards when appropriate. 7. Choose the appropriate retrofit options.
Construction	Work with the design team and trade contractors.	Months	8. Take advantage of existing redundancy. 9. Use a phased approach.
Commissioning	Conduct acceptance, functional, and integrated testing on all facility subsystem components.	Weeks	Best practices for this stage are out of the scope of this paper.
Sustaining	Strive for the best possible facility operation over the data center's lifetime.	Years	10. Measure results. 11. Conduct ongoing strategic optimization of cooling, power, and space.

Best Practices

HIGH-LEVEL REQUIREMENTS

1. Engage stakeholders.
2. Define key performance indicators and establish a baseline.

FEASIBILITY STUDY

3. Use appropriate tools to provide data and analytics.
4. Reevaluate redundancy levels.
5. Evaluate retrofit options.

DESIGN

6. Align retrofit activities with governmental and industry standards when appropriate.
7. Choose the appropriate retrofit options.

CONSTRUCTION

8. Take advantage of existing redundancy.
9. Use a phased approach.

SUSTAINING

10. Measure results.
11. Conduct ongoing strategic optimization of cooling, power, and space.

Best Practice #1: Engage Stakeholders

To safeguard customer interests and ensure project success, we engage with the people who will be involved with and affected by the changes to the data center. For most of our data centers these people include facilities personnel who manage the facility and personnel in the business units who rely on the IT equipment. Other stakeholders can include manufacturers and suppliers of equipment and utility consultants.

During the planning process, we communicate closely with these groups to identify their needs and concerns. The data center project lifecycle we implemented (see Table 1) helps ensure that we build and deploy a facility that meets critical customer requirements and is fully supportable over the lifetime of the facility.

Best Practice #2: Define Key Performance Indicators and Establish a Baseline

To manage something, one has to measure it, including establishing a baseline. Without a baseline, it is impossible to tell whether any changes help achieve a certain goal or hinder its achievement. Therefore, whenever we decide to retrofit a data center, we measure current performance and identify business needs. We also document data center costs and compare them to our model of record.[1] This information helps us justify retrofit activities.

Measuring what it costs to run a data center and how much energy it uses involves numerous key performance indicators. While these indicators vary across data centers, they generally include those shown in Figure 1.

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[1] For more information about our model of record and our overall data center strategy, see the IT@Intel white paper "Intel IT's Data Center Strategy for Business Transformation."

Key Performance Indicators for Data Centers

POWER
- Electrical density (watts/sq ft)
- Power density (kW per rack)
- Stranded power capacity
- Facility load
- IT load

SPACE
- Rack density (sq ft/rack)
- Number of servers/sq ft
- Stranded rack capacity

COOLING
- Cooling density (watts/sq ft)
- Return and supply air temperature range
- Humidity
- Differential pressure (if air segregation is used)
- Stranded cooling capacity

OTHER
- Percentage of uptime
- Percentage of service-level-agreement achievement
- Power usage effectiveness
- Server usage effectiveness

Figure 1. Common key performance indicators that play a role whenever measuring the cost of running a data center and energy usage.

Feasibility Study

The second stage of a retrofit project is to conduct a feasibility study. During this stage, we develop various options and determine whether they satisfy the project requirements. Generally, high-level cost estimates and trade-offs with different designs are considered part of the feasibility study. At the end of this stage, we select a preferred option and submit a capital funding request for approval. Our best practices for feasibility studies include using appropriate tools to gather data, reevaluating the data center's redundancy level, and evaluating possible retrofit options.

Best Practice #3: Use Appropriate Tools to Provide Data and Analytics

Many tools are available that can help data center managers assess the efficiency and operational costs of a data center. Some of the tools we use include the following:

- **Data center infrastructure management tools.** A data center infrastructure management solution can create a holistic model of the data center by establishing new relationships and dependencies between data elements from disparate systems of record in different knowledge domains. These relationships and dependencies can illustrate how IT-controlled assets are related to facilities-controlled assets.[2] We use such tools to determine a data center's capacity and calculate the opportunity for efficiency improvements. We can also model the expected future demand and calculate when we will reach constraint thresholds that would necessitate further retrofits.

- **Intel® Datacenter Manager (Intel® DCM).** Intel DCM is a standalone power management solution for the data center. We use Intel DCM to establish and monitor baseline server workloads. Intel DCM also helps us monitor the power and thermal operating trending data within the data center.

- **Capacity planning.** We use our predictive data center capacity planning process[3] to help us accurately forecast demand on our data center facilities and proactively identify capacity shortfalls years in advance. By predicting data center capacity issues over a 3-year planning horizon, we can plan to accommodate evolving business needs and market changes.

- **Computational fluid dynamics (CFD).** We use CFD analysis to better understand the thermal attributes of Intel's data centers. A CFD tool enables us to model a data center's airflow (including temperatures and pressures) and perform failure analysis of CRAC (computer room air conditioning). The model enables us to predict how changes, such as potential equipment installations and layout modifications, could improve airflow and thereby improve thermal management and cooling efficiency.

- **Metering, monitoring, and alerting.** To improve the energy efficiency of our data centers, we have adopted manufacturing clean room management technology that uses real-time data to supply the appropriate temperature and volume of air for the data center load at any time.[4] Types of wireless sensors include those that measure environmental conditions such as temperature, humidity, and differential pressure. Others monitor power, physical security, and equipment failure. We have also replaced single-speed, direct-drive fan motors in the air handling systems with variable frequency drives. These drives take readings from the pressure and return air temperature sensors to allow the throttling of cold air during fluctuations in server load and heat generation.

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[2] In 2012–2013, we conducted a proof of concept that investigated a data center infrastructure management solution. See the IT@Intel white paper "Exploring DCIM for Intel's Data Centers."

[3] See the IT@Intel white paper "Improving Business Continuity with Data Center Capacity Planning."

[4] See the IT@Intel white paper "Facilities Design for High-density Data Centers."

When analyzing our data centers, we have often found that rooms with an N+1 configuration have greater cooling capacity than the actual capacity required.

Best Practice #4: Reevaluate Redundancy Levels

Adding redundancy when it is not required leads to unnecessary financial investments. So when considering facilities upgrades, it is important to understand the redundancy requirements of the room to make appropriate investment decisions. Understanding the customer needs is a critical part of this process, and at Intel we track application-level criticality so that we can match data center tier levels to customer needs. This process can be complex in a mixed-use data center because different application criticalities and therefore different tier-level requirements often coexist. In these cases it may be possible to provide localized redundancy options for critical systems.

We often consider a multitenant, multitier facility design. For example, we consolidate racks with a higher level of redundancy to a smaller portion of the facility rather than spread them over the entire facility. Then if needed we can move lower-tier applications to a lower level of electrical redundancy and redirect that capacity to higher density racks.

We also realign electrical redundancy so that the facility has an A-B server redundancy at circuit levels but doesn't extend back to the level of the uninterruptible power supply (UPS). This approach, which we use for lower-tier applications, minimizes the risk of failure without consuming critical capacity of the UPS.

Finally we focus on optimizing cooling, in which we adjust redundant or overprovisioned CRAC units. A quality CFD and airflow analysis can help to determine both inefficiencies and unneeded CRAC units. When analyzing our data centers, we have often found that rooms with an N+1 configuration have greater cooling capacity than the actual capacity required. By optimizing the data center's cooling, we can harvest this excess electrical energy and make it available to increase rack-level power density.

Best Practice #5: Evaluate Retrofit Options

As part of the data center lifecycle process, we first identify the key business drivers for the retrofit, and then we choose the retrofit options that match those needs within our available timeline and budget. For example, not all retrofits are motivated by increased efficiency, although we strive for as much efficiency as possible. Other reasons for a retrofit include increasing redundancy, or upgrading and refreshing equipment that is approaching end of life.

Our retrofit strategy often includes electrical upgrades. For example, for some projects we have switched from in-room branch circuit power distribution delivered by traditional panels, trays, gutters, and whips to an overhead high-amperage busway with branch circuit distribution at the rack

and equipment locations. A properly designed and specified system allows the addition or change of circuits without an electrical shutdown. In the Americas, we use 415/240 Vac rack power distribution when we need to upgrade power or increase capacity. This type of rack power distribution is highly efficient, allowing for higher voltages and greater rack power density. It also enables us to use the same electrical distribution components worldwide because the voltage ranges now match those used in Europe and Asia.

A data center retrofit can improve space utilization and enable the consolidation of data centers while at the same time enabling us to accommodate next-generation technologies. Figure 2 shows the results of one of our major retrofit projects (spanning 7 years). Before the retrofit, we had five data centers (a total of 16,500 square feet), which consumed 2 MW. After the retrofit, we were able to supply the same server capacity using only 1.65 MW and two data centers with a total of 9,000 square feet.

Two important retrofit options to consider relate to rapidly changing technology:

• **Server refresh.** New Intel architecture-based server form factors offer an opportunity to significantly increase data center power density.[5] See Case Study 2: Alleviate a Severely Constrained Data Center section describes how deploying new IT infrastructure avoided investment in a data center facilities upgrade.

• **Network updates.** Higher-speed network fabrics can decrease total cost of ownership and improve performance and productivity.[6]

As shown in Figure 3, a four-year server refresh helps accommodate growth in computing demand without increasing the number of servers or the data center footprint. As the graph indicates, the EDA-MIPS demand grows by an average of 60 percent year over year, while the number of servers remains at about 3,200.

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[5] Visit the Intel IT Server Sizing Tool at http://estimator.intel.com/serversizing to evaluate which servers best fit your particular workloads. Also see the IT@Intel white paper "Intel IT Redefines the High-Density Data Center: 1,100 Watts/Sq Ft."

[6] See the IT@Intel white paper "Preparing Intel's Data Center Network Architecture for the Future."

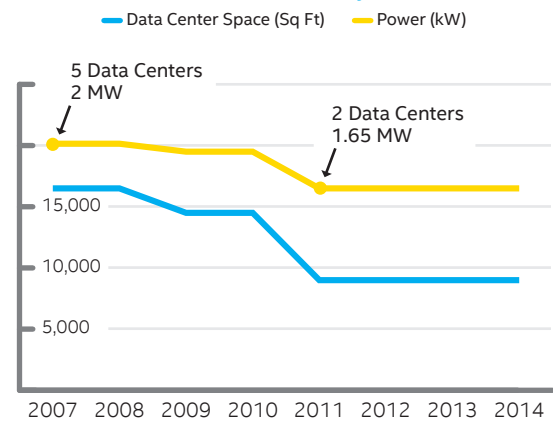## Retrofit Efficiency Gains

Figure 2. We found that the efficiencies gained by retrofitting data centers, over a seven-year span, can lead to better power density and use of space.
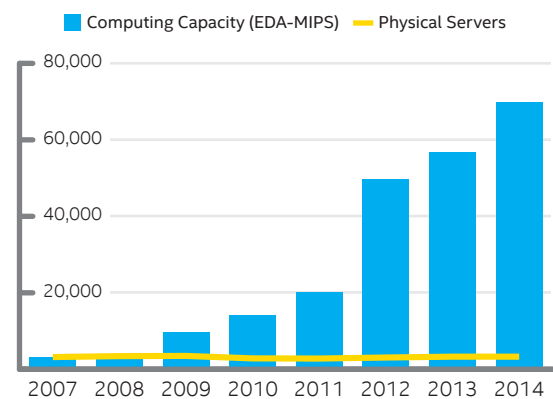

Refresh Capacity Gains

Figure 3. Refreshing the servers in our data centers every four years significantly increases compute capacity without increasing the number of servers or the data center footprints.

Design

Once the feasibility study is complete, we finalize the project design and engineering, the construction schedule, and a detailed project budget. Typically design milestones are managed at increments of 30, 60, and 90 percent complete to provide predictable and timely reviews. These reviews help ensure that the design progression is consistent with the documented business and technical requirements. When finalizing the design, we choose the appropriate retrofit options and align retrofit activities with governmental and industry standards when appropriate.
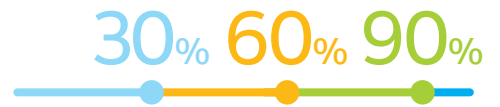
Best Practice #6: Align Retrofit Activities with Governmental and Industry Standards When Appropriate

When we undertake a data center retrofit project, we often turn to various industry bodies and standards for guidance (see Table 2). While we do not necessarily use standards exclusively or strictly in all cases, our master design specifications are adapted from these standards and applied to specific Intel use case and design requirements.

Best Practice #7: Choose the Appropriate Retrofit Options

In general, we can complete retrofit options in time periods that are short term (less than 6 months), mid term (6 to 12 months), or long term (1 to 3 years). We may initially choose a short-term solution, and then implement an incremental solution later (such as with air segregation). Longer-term retrofit activities—those that can take 1 to 3 years to complete—are discussed in the Sustaining section.

Short-Term Retrofit Options

Sometimes we can identify problems that can be fixed almost immediately. For example, simply walking through a data center with a temperature sensor can identify areas that have too much cooling. The fix requires a simple adjustment on the CRAC unit. Potentially idle servers are also easy to find during a walkthrough. For a more complex issue we may do a temporary fix, with the goal of applying a better, permanent solution later.

The upper portion of Table 3, on the next page, lists some short-term data center retrofit options that we consider.

Mid-Term Retrofit Options

While a temporary quick fix is sometimes possible, most permanent solutions fall into the mid-term range, taking 6 to 12 months. Some of the mid-term data center options in use at Intel are listed in the lower portion of Table 3.

Design Milestone Reviews

30% 60% 90%

Table 2. Sample list of data center-related industry bodies and relevant standards

Industry Body	Industry Standard (if applicable)
ASHRAE (American Society of Heating, Refrigeration and Air Conditioning Engineers)	ASHRAE TC9.9 Guidelines for Mission Critical Facilities
Building Industry Consulting Services International	ANSI/BICSI 002 – Data Center Design and Implementation Best Practices
European Commission	Code of Conduct for Data Centres
Telecommunications Industry Association	ANSI/TIA 942 – Infrastructure Standard for Data Centers
Association for Computer Operations Management	
The Green Grid	
United States Department of Energy	
United States Environmental Protection Agency	
Uptime Institute	

Table 3. Short-term (less than 6 months) and mid-term (6 to 12 months) retrofit options

SHORT-TERM (less than 6 months)	
COOLING	**EXPECTED BENEFIT**
Perform CFD analysis	May identify easily fixed problems, such as two competing CRAC units.
Install blanking panels on server cabinets	May aid air segregation.
Seal underfloor cable cutouts	May aid air segregation.
Adjust temperature set point and humidity range	Improves cooling efficiency by creating an increase in the difference in temperature (also known as *higher ΔT*) and the optimal humidity range.
Align racks into hot and cold aisles	May result in more efficient cooling by removing areas where exhaust heat from one rack is affecting the inlet of another rack.
Deploy quick-fix air segregation	May improve cooling efficiency through the use of temporary chimney cabinets, hot-aisle enclosures, and cold-aisle containment.
POWER	
Perform non-instrumented power capping	May increase effective utilization of power by turning off and officially decommissioning idle servers.
Consolidate servers	May yield more compute power with less electrical consumption, by refreshing existing IT infrastructure with the latest Intel® architecture-based servers.
SPACE	
Upgrade to Intel architecture-based blade servers	May help increase rack density and reduce lower thermal and power footprint per compute capacity.
Infill existing equipment racks	Harvests stranded rack capacity by using all the vacated spaces.
Replace existing 24-inch (60-centimeter) equipment racks with narrower and/or taller racks	May increase space utilization by 10 to 30 percent, depending on rack selection.
Remove network patch panels and/or horizontal power strips from racks	May increase space utilization by 2U to 6U per rack, depending on the type of patch panel or power strip.
Eliminate passive network racks	Increases the rack space available for computing by incorporating the patch panel into the back side of the network switch rack or using a direct-pull topology from the switch port to the server.
Extend the equipment rows into aisles	By infilling center aisles not required for equipment movement, we can add 2 to 4 rack positions per row.

MID-TERM (6 to 12 months)	
COOLING	
Install variable fan drives in CRAC units	Increases the efficiency of operation because the fans automatically adjust to dynamic IT equipment load to provide the required cubic feet per minute. The efficiency gain, which depends on loading, may range from 10 to 40 percent (sometimes even higher).
Install permanent air segregation solutions	May result in an increase in cooling efficiency that ranges from 5 to 15 percent, by reducing air mixing through air segregation and returning hotter air. This process increases the ΔT across the cooling coils, which allows the cooling equipment to work more efficiently.
Use a false ceiling as a return air plenum	Provides dedicated hot air return to CRAC units for increased efficiency. Gains may range from 5 to 20 percent.
Use proximity cooling	May increase cooling efficiency through the use of water-cooled cabinets and rear-door heat exchangers.
Consolidate servers or reallocate server load	May help balance cooling needs resulting in about a 10- to 30-percent efficiency gain.
Employ a flooded supply air design	Increases return air temperatures and cooling coil efficiencies, provides higher rack density installations, and removes stranded cooling capacity caused by the raised metal floor supply plenum or perforated tile size.#
POWER	
Install metering on IT and facility loads	Enables data center to achieve at least The Green Grid Category 1 through PUE monitoring and reporting.
Use a busway power distribution	May release stranded electrical capacity and provide more support for different IT equipment.
Increase power density supplied to IT cabinets	Helps prepare for additional IT equipment in the future.
Change equipment power distribution voltage	Increases the available kW per electrical path 2x per single phase by changing 480/208/120 Vac to 480/415/240 Vac in 60-Hz countries.
SPACE	
Refit with high-density racks	May double physical capacity in the same footprint with the use of 60 RU and narrower racks.

See the IT@Intel white paper "Facilities Design for High-density Data Centers."

Construction

After the retrofit design plan is complete, the construction stage begins. Typically milestones are managed in increments of 30, 60, and 90 percent complete to provide predictable and timely reviews, with ample time to verify that the work is progressing as expected.

We define a successful retrofit project as one that accomplishes the necessary infrastructure improvements without interrupting services provided to data center customers. The use of two best practices—taking advantage of existing redundancy and performing the work in phases—enables us to successfully complete a retrofit project.

Best Practice #8: Take Advantage of Existing Redundancy

The more redundancy is already built into a data center, the more we can take advantage of it during a retrofit project. For example, if a data center has one or more redundant CRAC units, we can take one or two offline at a time and upgrade them without negatively affecting data center operations, such as causing server slowdown or unavailability, or data center shutdown. Similarly, the following redundancy features all contribute to our ability to retrofit a mature data center without affecting the level of service: modular UPS, short-duration switches to utility power, and multiple power supplies for servers.

Redundancy also helps protect Intel employees performing the retrofit: they never need to perform energized electrical work, but at the same time they can accomplish the necessary upgrades to electrical equipment.

Best Practice #9: Use a Phased Approach

We use a phased approach for the construction stage that enables us to complete the work without shutting down the data center or impacting server performance. For example, if the goal is to change the data center over to free-air cooling, we can divide the project into phases, converting one portion of the data center at a time. Or if we are implementing hot- and cold-aisle enclosures, we can do much of the framing and curtain installation without touching the IT equipment. After we complete the aisle enclosures, we can work on a few racks at a time, adding finishing touches such as blanking panels and consolidating servers or reallocating the server load.

Commissioning

While the commissioning stage is important, it is beyond the scope of this paper. During this stage, we validate that the delivered facility works as designed, and we test critical maintenance procedures and documentation. We revise these procedures and documentation as required to help ensure that the facility can be supported over its expected lifecycle.

SUCCESSFUL RETROFIT

A project that accomplishes the necessary infrastructure improvements without interrupting services provided to data center customers.

Power Usage Effectiveness

Power usage effectiveness (PUE) is a measure of how efficiently a computer data center uses energy. It is defined as follows:

$$\frac{\text{Total Facility Power}}{\text{IT Equipment Power}} = \text{PUE}$$

We consider PUE to be just one of many useful data points. When calculating PUE, some companies make trade-offs based on the monitoring capabilities they have and adjust for local considerations. This approach results in a number that may be inaccurate or at least misleading.

The PUE is also not always the correct measure of efficiency. For example, it is possible to decrease the overall energy consumption of a data center while making the PUE worse. Suppose that a significant number of unused servers are decommissioned. In this case, the IT load decreases, but the facility load stays the same, which might cause the PUE to actually increase (if the facilities cooling system does not have the ability to ramp down to match the decreased IT load).

To avoid these problems, we monitor the PUE of most of Intel's data centers, but we advocate investing in efficiencies directly—such as server refresh or air segregation improvements—instead of investing in instrumenting the facility for advanced PUE tracking.

Sustaining

After the construction and commissioning stages are completed, the facility is turned over to the operations team and is ready to host production IT equipment. Over the facility's lifetime, the team maintains critical facility subcomponents according to each one's lifecycle. Facility upgrades, depending on size and duration, may be done as part of this phase, or a new project that begins with high-level requirements may be initiated.

Best Practice #10: Measure Results

We document the business value of the changes made during a data center retrofit. As discussed earlier, it is critical to establish key performance indicators and a baseline measurement for each—as well as a return-on-investment analysis for the project—before the project starts. Otherwise, measurements made afterward will be meaningless.

After the project is complete, we gather data to determine whether our initial analysis was correct according to the initial retrofit business drivers. For example, we may analyze whether operating costs have been reduced, PUE has improved, or server density has increased. Providing such data to management can help build support for further retrofit activities.

Measuring the results of a retrofit is part of the sustaining stage of the data center lifecycle. Thus it can take one or more years to gather enough data to fully understand its benefits.

Best Practice #11: Conduct Strategic Ongoing Optimization of Cooling, Power, and Space

We focus on four areas of strategic optimization: continue with the optimal server refresh cycle, create a multitier data center, review redundancy, and consolidate data centers. Table 4 lists the long-term retrofit options that we consider.

Table 4. Long-term (1 to 3 years) retrofit options

LONG-TERM (1 to 3 years)	
COOLING	**EXPECTED BENEFIT**
Employ misting or fog-based cooling	Allows for up to a 10°F (5.5°C) temperature reduction of supply air at low power consumption when added to an air-side economizer solution.
Modify existing air cooled chillers	Increases cooling capacity on outside pad equipment by installing an evaporative cooling package.
Install dual-fluid CRAC units	Saves floor space because one unit provides two cooling solutions (redundancy).
Use a flooded supply air design	Provides higher rack density installations and removes stranded cooling capacity caused by the supply air plenum or perforated tile size. The increased return air temperatures may result in a 10 percent or greater savings on fan energy to move air in the room compared to using a raised metal floor.
Install a fan wall	May eliminate ductwork if outside walls and room shape are the correctly proportioned (a variation of an air-side economizer).
POWER	
Replace the UPS	May help increase the data center's energy efficiency and reliability, which is especially important if the existing UPS is approaching its end of life.
Implement fuel cell technology	Enables the fuel cell to be used as the uninterruptible power supply and generator in the case of an unstable electrical utility supplier but a stable fuel supply.
Deploy instrumented power capping using Intel® Datacenter Manager	May help identify peaks and valleys in power usage and may contribute to increasing the data center's power efficiency.# When configured as a response to a negative power or cooling event, the tool can allocate power utilization of the designed N+1 capacity during normal operations and then reduce the total allocated power to match the lost capacity.
Upgrade room power distribution wherever possible	May eliminate energized electrical work by upgrading the power distribution to higher amperage electrical branch circuit paths and a higher voltage distribution bus-type system (400-amp minimum; 800 amp preferred). Upgrading step-down transformers supporting the bus to 415/240 Vac in 60-Hz countries may provide significant upfront capital cost savings by eliminating some electrical transformers. Estimate: for a 3-MW facility the yearly electrical savings on a 2-percent loss reduction may be in excess of USD 52,000.
Use fully rated electrical components	Used when building code requires the de-rating of standard components; eliminates the stranded 20-percent capacity on the power distribution and branch circuit paths. Each material in the path including conductors must be reviewed.

For more information, see the IT@Intel white paper "Exploring DCIM for Intel's Data Centers."

Best Practices in Action: Two Case Studies

The following two case studies are tangible examples of how to apply our best practices for retrofitting, whether the retrofit is a complete modernization of a large mature data center or a targeted retrofit of a smaller facility.

Case Study 1: Modernize a Mature Data Center

This data center was supporting critical manufacturing and office IT services. While still serving its stated purpose, it was not considered highly efficient by today's data center standards. Much of the data center's supporting facilities infrastructure was aging, and upgrade decisions relating to efficiency and redundancy were needed. With this in mind, we formed a project team and conducted a major review of the data center.

We based the project on an iterative approach. First we studied the data center, gathering the correct trending data, reviewing changes with customers, and securing a budget to execute a transparent, zero-downtime solution. Based on the data, we developed a plan to implement a broad range of efficiency, redundancy, and manageability improvements. We implemented these improvements using a phased approach in which we reviewed and reevaluated the results of each implementation before moving on to the next phase. We made changes to everything except the walls. When our retrofit was complete, we had in essence a new data center.

Problem

Constructed 12 years previously, this 7,000 square foot, Tier 2 data center was designed using the data center perimeter CRAC unit topology on a single-source chilled water path, which meant a lack of cooling redundancy, resulting in a lower tier rating. Other problems included the following:

- Cooling costs were high and airflow was not managed. The lack of air segregation caused the room to be overcooled. Excessive amounts of supply air were being provided without any reference to actual demand, resulting in a best-case PUE estimation of 2.2 to 2.4.

- Metering for PUE did not exist, and no incentives were in place to better manage energy. During the study we relied on point-in-time readings and engineering estimates for cooling costs.

- Intel's documented best-known methods were not strictly adhered to. Problem areas included inconsistent use of blanking panels, air segregation, raised floor perforated tile management, and supply air temperature set points. Few IT controls for removal of end-of-life equipment were in place.

- There was little coordination between IT and facilities staff. The data center was part of a much larger facility and did not have any direct facilities engineering staff. Much of the data center's facilities infrastructure, such as the UPS, chilled water system, and CRAC units, was aging.

- To make the appropriate upgrade decisions, we needed to develop an understanding of efficiency and redundancy considerations. In fact, at the beginning of the project, the project team learned that the operational costs for the data center were not being tracked. Therefore, gathering the relevant data was the first step to developing a cost-effective plan that would deliver the required efficiency results and meet the future needs of the data center and its customers.

Solution

We applied many of the best practices documented in this paper to successfully retrofit this data center and solve these problems. Here are some examples of how we put our best practices to use, to meet our goals of zero negative impact to data center customers, enhanced redundancy, and improved efficiencies.

1.3 PUE GOAL

Stakeholder Engagement (Best Practice #1)

To help ensure alignment across a broad range of stakeholders, we included equipment manufacturers, suppliers, Intel facilities personnel, utilities consultants, and our data center customers (Intel business units) in the early stages of the project. We chose to assemble a large group of stakeholders because of the complexity of the project and the impact that the project activities could have on an active data center. This level of engagement helped us determine customer needs and concerns and led us to develop a plan that mitigated the risks and concerns expressed by the stakeholders.

Key Performance Indicators (Best Practice #2)

We established PUE as the key metric for the project, using The Green Grid Category 2 protocol, with a PUE target of 1.3. We measured the IT load at the room's power distribution unit output and total annual energy through meters and periodic measurements if meters were not available at the energy consumption points.

Tools (Best Practice #3)

A key part of the overall data center retrofit program was taking advantage of preexisting data points and new meters. Increased and improved levels of data furthered our understanding of the data center's operating cost and will enhance future decision making.

- In phase 1 of the project (2010), we used a combination of Lean Six Sigma* and Systematic Innovation for Teams to pinpoint opportunities for significant, measurable energy reductions in the server load and cooling load areas.[7]

- In later phases of the project, we deployed Intel DCM[8] and an integrated facilities management system that featured an easy-to-understand dashboard. This dashboard graphically illustrates the energy usage of the facility. Having real-time information from Intel DCM also helped to make additional improvements to data center operations.

- We also installed a radio-frequency identification scanning system, integrated with our automated service tools and processes to enhance asset management, procurement auditing, and loss prevention. The radio-frequency identification system also helps ensure timely removal of servers that have reached end of life.

Informed Choice of Retrofit Options (Best Practices #5 and #7)

Gathering this data helped ensure stakeholder and managerial support for the project, particularly when having to justify capital investment. Having performed the data analysis, engaged with stakeholders, and researched potential solutions, we developed a retrofit plan that focused on cooling, power, and increasing the use of data gathering tools (see Figure 4).

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[7] For more information, see the IT@Intel white paper "Using Lean Six Sigma* and Systemic Innovation in Mature Data Centers."

[8] See the IT@Intel white paper "Exploring DCIM for Intel's Data Centers."

Power
- CRAC monitoring
- Distribution board monitoring
- UPS upgrade

Cooling
- Hot-aisle enclosure
- CRAC replacement
- Chiller upgrade
- Free-air cooling

Tools
- Integrated facilities management system and energy dashboard
- Radio-frequency identification scanning system
- Intel® Datacenter Manager

INCREASED ENERGY EFFICIENCY   **IMPROVED REDUNDANCY**   **ENHANCED OVERALL MANAGEABILITY**
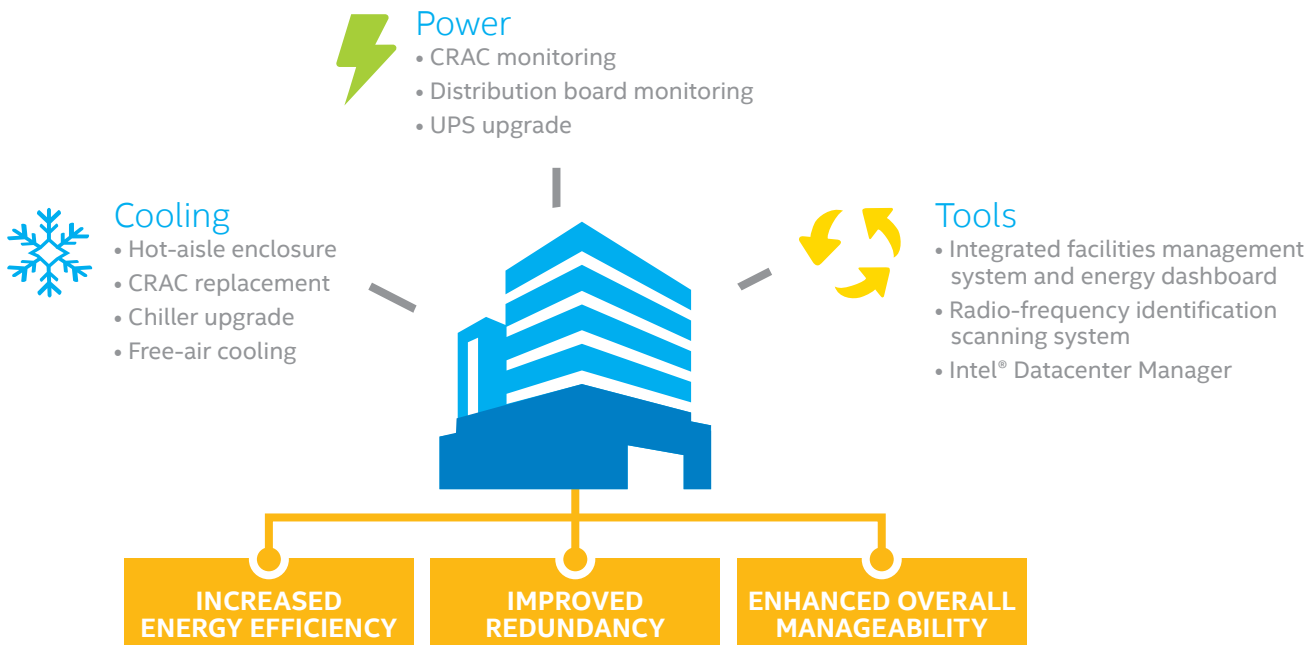
Figure 4. Our retrofit of a mature data center involved upgrades to cooling and power equipment and the deployment of new tools to gather and analyze operational data.

- **Cooling.** We installed hot-aisle enclosures and replaced and reoriented 11 CRAC units with more efficient ones containing variable speed drives. Installing this new equipment resulted in a gain of 300 kW of stranded cooling capacity. Installing the hot-aisle enclosures alone led to significant efficiency gains because air is now supplied at the temperature the data center requires rather than overcooling it to compensate for the mixing of the room's hot air and cold air.

  We also upgraded the CRAC units to a dual-fluid model and upgraded the chilled water system, leading to improved chilled water efficiency and overall cooling redundancy. (The chilled water pipework was no longer a single point of failure because the CRAC units could fail over to a direct expansion system if necessary.)

  The final phase of our cooling upgrade was to implement a direct free-air cooling system (see Figure 5). This system can use outside air to cool the data center for most of the year and can mix outside air and return air to achieve the desired temperature set point. The implementation of the direct free-air cooling module was particularly significant in terms of delivering the substantial energy savings illustrated in Figure 6 on the next page.

  The installation of this solution was potentially disruptive to the day-to-day operations within the data center. Data center personnel encountered construction activity, structural scaffolding, and construction personnel and equipment. This project phase, while leveraging a supplier-based solution, required significant adjustment and an innovative approach to the design and ongoing control of the system.

  To minimize physical disruption to the facilities infrastructure that supported the room, both outside and within the data center itself, we planned each phase of the implementation to help ensure flawless execution to safety and quality standards. We conducted post-implementation reviews to help ensure that we achieved the expected results before moving on to subsequent phases.

- **Power.** We implemented electrical monitoring of the CRAC units and the electrical distribution boards. These improvements could deliver real-time data about our power consumption. Replacing the UPS that supported the data center was a major part of the electrical work. This involved significant planning to ensure that the various efforts required to transfer the data center from the old UPS to the new one did not affect any of the IT systems. Having a significant amount of built-in redundancy helped in this regard, and the dual power supply model employed in the data center made it possible for us to transition to the new UPS with zero downtime in the data center. These changes increased the data center's redundancy and enabled us to increase the data center's tier level from Tier 2 to Tier 3.

Free-Air Cooling System
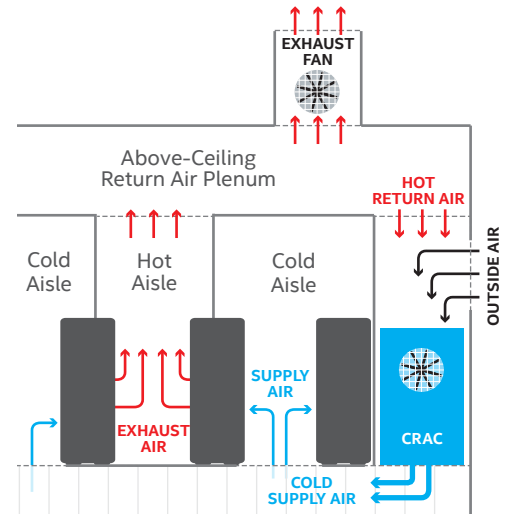Partial economizer mode mixes outside and return air

Figure 5. Direct free-air cooling augments the CRAC units, decreasing cooling costs. Mixing outside air and return air can achieve the desired temperature in the data center.

Government and Industry Standards (Best Practice #6)

Increasing data center efficiency and decreasing operating costs were high-priority goals. But we also felt strongly that Intel should adhere to the European Commissions' Code of Conduct for Data Centers. Other guiding standards for this project included the local sustainable energy authority and ASHRAE (American Society of Heating, Refrigeration and Air Conditioning Engineers). This specific design was developed around ASHRAE category A1 supply air (about 80°F (27°C)) with a future expectation to move toward category A2 supply air (95°F (35°C)) with 100-percent free-air cooling.

Use of Redundancy Features (Best Practice #8)

During this project, we managed critical environments using the already built-in redundancy features of the data center. Through CFD modeling and analysis we determined which CRAC units were doing little or no work in the existing environment. We moved or replaced those units first with no impact to the room. We performed a new CFD model with the interim equipment configuration, and then verified in practice the model's results. When satisfied with the outcome, we moved to the next set of CRAC units and repeated the process until the job was complete. Because the UPS was designed in an N+1 configuration, we were able to move the protected loads through the failover modes of the switch gear and isolate the group of components that needed modification or replacement.

Phased Implementation (Best Practice #9)

At times, more than 40 construction personnel were working in the active data center at any given time. We used a phased approach to manage and coordinate these construction efforts. For example, when installing hot-aisle enclosures, we worked on one section of the data center at a time. When doing electrical upgrades we worked on one power path at a time so we always knew which critical load was being transferred. Wherever possible we prebuilt and pretested our electrical panels and components. Whenever practical and where space was available, we landed new electrical components instead of upgrading existing ones, thereby reducing the time required to tie in between the old and new systems.

Measurement (Best Practice #10)

Intel DCM and other monitoring tools enabled us to quantify what sort of improvements we achieved over the baseline measurement.

Results

Figure 6 illustrates the savings in kW—a 60-percent decrease in facilities load, which reduced the PUE from 2.2 to 1.3.

This case study shows that a data center can be entirely retrofitted without impacting customers. The best practices we applied delivered efficiency and redundancy improvements comparable to building a new data center.

Guiding Industry Standards

- European Commissions' Code of Conduct for Data Centers
- ASHRAE
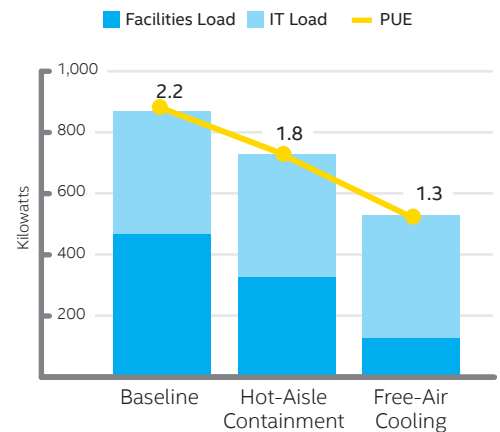- Local sustainable energy authority

Data Center Retrofit

Figure 6. The data center retrofit significantly reduced the facilities load, thereby improving the data center's power usage effectiveness (PUE).

60% DECREASE

Facility Load (kW)

Improved PUE

1.97	Before
1.71	Now
1.4	Expected

Case Study 2:
Alleviate a Severely Constrained Data Center

In 2003, Intel built a data center in Asia. At that time we did not use air segregation practices, and the local engineering teams did not anticipate the requirements of high-density blade server platforms. In a cost savings move the project team chose direct expansion cooling over the higher initial cost of chilled water. In 2010 we performed a retrofit on this data center. Our retrofit goal was to improve the data center's efficiency while alleviating the problems of limited space and power.

Problems

This particular data center, while not large (6,500 square feet), had significant problems with cooling, power, and space since its construction:

- Insufficient segregation of hot and cold air
- Hot-spot issues, which created further inefficiency
- High cost of cooling due to inefficiency (1.97 PUE)
- Capacity constraint—a 2N UPS design reduced the available UPS capacity
- Cabinet and electrical circuit breaker design that was only 4 or 5 kW per cabinet, precluding the installation of blade servers

Solution

To solve these challenges, we applied a subset of the best practices discussed earlier:

Stakeholder Engagement (Best Practice #1)
Early engagement of internal stakeholders, such as data center customers, facilities personnel, and design engineers, helped us successfully execute this project over several months of planning and customer coordination. Doing business globally can add significant complexity and cost, and extend project timelines. The long lead times associated with ordering and delivering the UPS and CRAC units made it difficult at first to notify customers of when construction would occur. As the orders entered production at the equipment manufacturer's facilities, we were able to identify actual start work dates and duration based on previous construction projects.
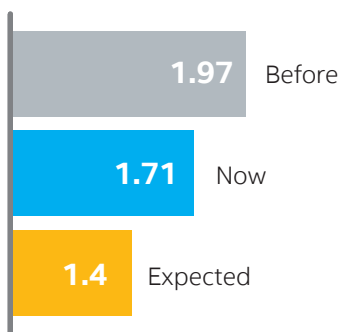
Key Performance Indicators (Best Practice #2)
The key performance indicators we chose were PUE, cubic feet per minute per kW, and higher ΔT across the CRAC cooling coil.

Tools (Best Practice #3)
We used CFD modeling and an air-flow calculator that we developed in-house.

Informed Choice of Retrofit Options (Best Practices #5 and #7)

The room was designed with a 2N UPS power distribution. Based on current business need, we added one UPS module and reconfigured the UPS electrical distribution to an N+1 parallel redundant topology. The additional UPS capacity was distributed through new 1200-amp panel boards fitted with 400-amp breakers to provide greater branch circuit capacity at the row and cabinet levels.

We opened the return path directly to the CRAC unit from the ceiling return air plenum, which allowed for more efficient airflow. We replaced four 20-ton direct expansion CRAC units with six 33-ton chilled water units featuring state-of-the-art controls, electronically commutated fans, supply air temperature controls, and a higher ΔT coil design. These units provide additional cooling capacity and a higher ΔT across the CRAC cooling coil, higher return water temperatures to the chiller, and improved PUE and lower kW/ton operation cost.

To improve the overall cooling efficiency of the room, we added hot-aisle enclosures and changed the perforated floor tiles from 25-percent open grates to 53-percent open grates. This change provided a flooded air design and reduced the underfloor airflow obstructions and the need to maintain greater pressure differential. To override the temperature rise if a grid failure occurs, we added a thermal storage system that is designed to maintain the cooling for 12 minutes (the length of time it takes for the diesel generator to start and the chilled water temperature to stabilize). The CRAC units' fans and pump are powered through the UPS.

Government and Industry Standards (Best Practice #6)

We maintain the same corporate minimum construction and efficiency standards worldwide for our data centers.

Use of Redundancy Features (Best Practice #8)

We were able to implement the project because of the redundant capacity that existed in the UPS and cooling designs. The UPS was expanded, with the remaining modules carrying the room-critical electrical load as each UPS was moved from the old panel board's distribution to the adjacent new boards. We also took advantage of open space inside the electrical rooms to place the new electrical components nearby, add the new UPS module that became the parallel redundant unit, and transfer the original UPS modules one at a time.

112% ↑

INCREASE IN PERFORATED FLOOR TILES

We used similar processes to replace and upgrade the existing data center CRAC units. We performed a CFD analysis to determine which units were underutilized. Next we replaced or modified the units in an ascending order from the most underutilized to the most utilized. By the time we had finished replacing the most heavily utilized units, the loss of the excess capacity had no impact on the room because we were already rebalanced as an N+1 configuration.

Phased Implementation (Best Practice #9)

We upgraded the switchgear taking advantage of N+1 in a production data center during the first phase. The second phase—upgrading the main electrical and chilled water branch—was conducted during the site's annual maintenance shutdown, because working space inside the data center was tight, and the CRAC replacement and ductwork changes required significant floor space for equipment staging. The last phase was adding the hot-aisle enclosures, while the data center was in production.

Measurement (Best Practice #10)

Monitoring tools enabled us to quantify how our key performance indicators were affected by our efforts.

Results

The changes we made enabled this data center to meet the business demand for compute capacity. We also achieved the following results:

- Improved the PUE from 1.97 to 1.71. Currently the room is at only 70 percent of maximum IT load; we expect to achieve 1.4 PUE when the room's IT load reaches the electrical design capacity.

- Reduced the airflow cubic feet per minute per kW by 67 percent, from 320 CFM/kW to 106 CFM/kW.

- Increased the ΔT across the cooling coil from 16°F (9°C) to a ΔT of 32°F (18°C). This higher temperature provides additional cooling capacity and makes the actual chiller more efficient.

- Reduced bypass air from 60 to 20 percent.

- Added 68 percent more total UPS capacity for a cost of USD 2,500/kW.

- Increased rack-level density by 64 percent.

- Decreased operational cost related to electricity by 20 percent.

We completed this retrofit project in only 12 weeks compared to the 42 weeks it would have taken to build a modular data center or a new, from-the-ground-up data center.

64%

INCREASE IN RACK-LEVEL DENSITY
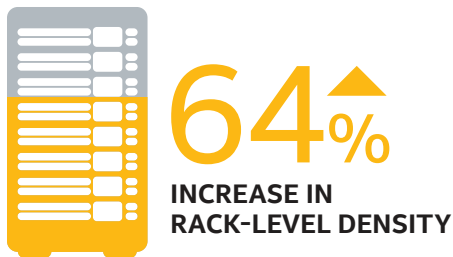
Conclusion

Intel must extend the life of its data centers by increasing data center efficiency and adapting data centers to changing business needs. We have developed retrofit best practices for each stage of the data center lifecycle, helping us achieve our efficiency and redundancy goals.

Whether the project entails a complete modernization of a mature data center or is less extensive, our best practices for developing high-level requirements, performing a feasibility study, designing the project, constructing and commissioning the project, and sustaining the data center over time enable us to retrofit a data center without negatively impacting data center customers during the process.

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

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