MODULE 14 · STUDY NOTES

Data Center Efficiency

How data center efficiency is measured, the PUE–DCiE relationship and airflow management, HVAC efficiency and effectiveness, and the portable and permanent instrumentation that monitors it all

A data center's job is to keep IT equipment running, but doing so draws enormous amounts of power — and every watt that does not reach the servers is overhead that costs money and generates heat. This module is about measuring and shrinking that overhead. It opens with the metrics that make efficiency visible — power usage effectiveness (PUE), its inverse DCiE, and companions such as CADE, CCF, LEED, ASHRAE, and PAR4 — then works through the PUE relationship in depth: what the numbers mean, the variables that drive them, how airflow management lowers PUE, and the benefits and limits of the metric. Because cooling is the single largest efficiency lever, the middle of the module dissects HVAC — what it is, how to calculate its efficiency, effectiveness, and airflow efficiency, the SEER/EER/HSPF ratings that monitor it, and twelve practical steps to make it energy-efficient. It closes with the instruments that keep all of this honest: the portable and permanent devices, and a strategy for putting them to work.

LEARNING OBJECTIVES

- Recognize the metrics used to measure data center efficiency
- Identify the variables in determining the PUE of a data center
- Identify ways to optimize PUE value, including the association between PUE and airflow management
- Recognize the meaning of HVAC
- Recognize the methods to calculate HVAC efficiency, HVAC effectiveness, and air efficiency
- Identify different ways to achieve power usage effectiveness in an HVAC system
- Identify the steps to achieve an energy-efficient HVAC
- Describe the use of portable and permanent instrumentation in monitoring the efficiency of a data center
- Identify the permanent instrumentation used for monitoring the efficiency of a data center

14.1 Measuring data center efficiency

Efficiency metrics give clear insight into what is happening inside data center operations. They ensure availability, help reduce overall energy consumption through smarter use of data center systems, pinpoint inefficient areas so you can fix, replace, or improve them, and let you recognize the most efficient data center — down to the efficiency of every individual part. In short, an efficiency metric measures a data center's ability to use its resources efficiently.

WHAT EFFICIENCY METRICS DO FOR YOU

- Ensure data center **availability**
- Reduce overall **energy consumption**
- Identify **inefficient areas** to fix, replace, or improve
- Recognize the **most efficient** data center — and the efficiency of each part

Seven widely used metrics recur throughout the field. **PUE** is considered one of the most exceptional metrics for data center energy efficiency: developed by **Green Grid** (a non-profit affiliated with the Information Technology Industry Council), it divides the power flowing into the data center by the power consumed by computer infrastructure — servers, storage units, and network devices. It is stated as a **ratio**, is **unit-less**, and is relatively stress-free to calculate. **DCiE** is its inverse — once called data center efficiency (DCE) — dividing IT-equipment power by the total power supplied to the data center.

TABLE 14.1 The seven data center efficiency metrics

METRIC	WHAT IT IS	DETAILS TO REMEMBER
PUE	Power usage effectiveness	Power into the data center ÷ power used by computer infrastructure; unit-less ratio; from Green Grid; lower is better
DCiE	Data center infrastructure efficiency	Inverse of PUE (IT power ÷ total power), as a percentage; formerly DCE
CADE	Corporate average data center efficiency	Facility efficiency (energy to IT ÷ total utility energy) × IT asset efficiency (average CPU utilization of all servers)
LEED	Leadership in Energy and Environmental Design	Green-building accreditation from the US Green Building Council; assesses materials, location, water use, indoor environmental quality, and energy
PAR4	Server power-consumption metric	Created by Power Assure; checks idle power, peak power, per-watt transactions, and total power; tested by UL to standard UL2640
ASHRAE	Society for heating, refrigerating & air-conditioning engineers	Worldwide society for human well-being; publishes efficiency standards and feasible operating ranges for IT temperature and humidity
CCF	Cooling capacity factor	Evaluates inefficiencies in cooling infrastructure and highlights future development opportunities

COMMON PITFALL

Don't blur the members of this list. CADE is a **product** (facility × IT asset efficiency), LEED is a **building accreditation**, ASHRAE is a **standards society**, and CCF targets **cooling** — only PUE and DCiE are the reciprocal power ratios.

14.2 The PUE relationship

PUE compares the total power supplied to the data center with the power the IT equipment actually uses — servers, storage units, and network devices. DCiE measures the same two parameters but inverts the ratio. Formally, `PUE = total power supplied ÷ IT equipment power consumed` and `DCiE = IT equipment power consumed ÷ total power supplied`.

TABLE 14.2 Standard PUE and DCiE values and efficiency levels

PUE	DCIE	EFFICIENCY LEVEL
3.0	33%	Inefficient
2.5	40%	Moderately efficient
2.0	50%	Average
1.5	67%	Efficient
1.2	83%	Highly efficient

WORKED EXAMPLE – READING THE SCALE

Because DCiE is the inverse of PUE, `DCiE = 1 ÷ PUE`. Suppose a facility draws twice as much total power as its IT equipment consumes: PUE = 2.0, so `DCiE = 1 ÷ 2.0 = 50%` — the *average* level on the scale. Tighten operations until only 1.2 units of total power are drawn per unit of IT load and PUE falls to 1.2, lifting DCiE to about 83% — *highly efficient*. Every overhead watt you remove is an added expense eliminated, so cutting overhead power reduces total operating costs considerably.

VARIABLES THAT DETERMINE PUE

- **Data center design** — the maturity and design of the facility
- **Energy efficiency** — the energy efficiency of the IT devices
- **Power use** — the rate at which the data center uses power
- It is better for a data center to keep PUE **low**

HOW TO REDUCE THE PUE VALUE

- Reduce the supply power to the supporting infrastructure
- Reduce power-system losses
- Evaluate PUE at **regular intervals** — on different days and for different durations — to confirm that changes actually improved efficiency

COMMON PITFALL

Use the **precise IT load value** to calculate PUE, not the equipment's rated power capacity. The rated capacity overstates the real load and distorts the metric.

14.3 PUE and airflow management

Three airflow-management elements are associated with PUE, and when they work **in synchronization** with each other and allied factors they drive PUE **down**.

THE THREE AIRFLOW ELEMENTS

- Separating the returning **warm** air mass from the supplied **cold** air mass
- The **volume** of air inflow management
- The **temperature** of the air inflow

BENEFITS OF THE PUE-AIRFLOW ASSOCIATION	LIMITATIONS OF THE ASSOCIATION
why the association is worth managing ▪ Calculations span a considerable period, giving historical records of efficiency change ▪ Companies can share more information on efficient usage ▪ A low PUE can serve as a marketing tool and competitive edge ▪ Eco-friendliness — lower operating cost, less heat impact, greener operation, fewer carbon emissions	*what constrains the metric* ▪ An inadequate power-distribution network surges the data center's total energy intake ▪ The precise IT load value must be used — not the equipment's rated power capacity

14.4 HVAC overview

HVAC — heating, ventilation, and air conditioning — regulates indoor temperature, humidity, and air levels, and it is an integral part of every industrial, residential, and business facility. In a data center it matters for a specific reason: heat from IT equipment cannot easily escape, and excess heat causes **thermal stress** that can damage equipment and lead to downtime. HVAC provides the ventilation, temperature control, and cooling that keep IT equipment safe and operating over the long term.

TWO HVAC SYSTEM TYPES AND THEIR COMPONENTS

- Two system types: **central systems** and **self-contained packages**
- A **mechanical room** houses HVAC equipment — chillers, heat exchangers, and generators
- An **air handling unit (AHU)** humidifies, ventilates, filters, or dehumidifies (placed in a room, on a rooftop, or in an open area)
- A **dedicated room** for controlling the HVAC system

14.5 HVAC efficiency, effectiveness, and airflow efficiency

Data center cooling systems run **continuously** to expel hot air, which consumes a lot of electricity. To choose the best cooling solution, first calculate the total energy a data center produces annually, then compare options. Several calculations describe how well the system performs.

TABLE 14.3 Calculating HVAC performance

CALCULATION	EQUATION	WHAT IT TELLS YOU
Coefficient of performance (COP)	output cooling energy (kW) ÷ input electrical energy (kW)	Efficiency of heating/cooling machines; allows continuous improvement — react quickly if COP deteriorates
HVAC efficiency (common method)	aggregate cooling-system power (kW) ÷ aggregate cooling load (tons)	The most common way to calculate efficiency
HVAC effectiveness	IT-equipment energy (kWh/year) ÷ HVAC energy (kWh/year)	Ideal range 0.6–3.5; low effectiveness suggests the IT equipment is far more optimized than the installed HVAC
Airflow efficiency	gross fan power (W) ÷ gross fan airflow (cfm)	Effective airflow needs low fan power per unit at low-pressure drops; airflow is crucial to removing thermal stress

For **effectiveness**, the data center's energy input is segregated into two parts — IT-equipment energy and HVAC energy, both measured in **kWh per year** — and the ratio of the two parts gauges the HVAC system. When effectiveness is low, there is a chance the IT equipment is highly optimized compared with the HVAC system currently installed.

14.6 Monitoring HVAC for PUE

With data center demand rising, the amount of IT equipment — and the heat it produces — keeps escalating. The HVAC installed to handle it **also consumes power, accounting for almost 40% of the center's total power consumption**, so operating HVAC efficiently is essential. Three ratings monitor an HVAC system for its PUE.

TABLE 14.4 SEER, EER, and HSPF

RATING	DEFINITION	SCOPE
SEER	Season energy efficiency ratio — output cooling energy (BTU) ÷ electrical input energy (Wh) over a season	Seasonal regions with varying outdoor temperature; higher SEER = higher efficiency
EER	Energy efficient ratio — output cooling energy (BTU) ÷ electrical input energy (Wh)	Built for residential HVAC; ignores seasonal conditions and reflects only machinery-created conditions
HSPF	Heating seasonal performance factor — same units as SEER (BTU/h ÷ Wh)	Measures the heating mode; heat pumps or reversible units only; HSPF × 0.0293 = COP; higher = more efficient heat pump

COMMON PITFALL

SEER, EER, and HSPF look similar but are not interchangeable: **SEER** captures a full varying season, **EER** captures machinery-only conditions, and **HSPF** rates **heating** performance — so HSPF never applies to a cooling-only unit.

14.7 Achieving an energy-efficient HVAC

An energy-efficient HVAC unit can save a data center a great deal of energy. The module lists **twelve steps** for getting there, spanning equipment reuse, airflow management, maintenance, and placement.

TABLE 14.5 Twelve steps to an energy-efficient HVAC

STEP	HOW IT SAVES ENERGY
Backfit an old system	Reuse a good-condition old system as an economizer by replacing parts such as the condenser fan and compressor
Insulate the space	A well-insulated duct lets less cold air escape, avoiding an overhead on the cooling unit
Automate temperature control	A programmable control system adjusts indoor temperature to the outdoor temperature to save power
Regulate airflow	Clear dust, tangled cables, dirt, and debris that block airflow and cause inefficient cooling
Perform regular maintenance	Overlooked maintenance is a common cause of efficiency loss; regular upkeep keeps systems in good condition
Change the air filters	Filters clogged with dirt and dust force the HVAC system to use more power
Install fans	In low-temperature areas fans remove thermal stress and assist the HVAC by regulating airflow, cutting its power use
Place the unit in shade	A shaded unit works less to cool hot air than one exposed to the sun
Allow airway into the plenum	Organize cables in the raised-floor plenum; a stuffed plenum hinders airflow and makes cooling work harder
Stop hot/cold aisle recirculation	Remove obstructions — empty rack spaces, tangled cables — so expelled hot air is not recirculated to IT equipment
Use a CRAC unit	Place the computer room air conditioning unit perpendicular to the rows to work with hot/cold aisles and avoid hot-air recirculation
Use efficient equipment	Install equipment optimized for performance and design; consider the star rating before investing

14.8 Portable and permanent instrumentation

In large industrial and commercial establishments, actual power consumption often exceeds the actual power requirement — older systems draw more power than newer ones. To determine efficiency in power utilization, you must **monitor the power consumption of all equipment and devices**. Data centers run numerous circuits and consume large amounts of power, so calculating efficiency in that complex environment calls for either **permanent instrumentation** or **portable instrumentation used at regular intervals**.

PORTABLE INSTRUMENTATION	PERMANENT INSTRUMENTATION
temporary and periodic ▪ Temporarily installed to measure efficiency, then removed after the work is done ▪ Installed by qualified professionals familiar with the devices ▪ A cost-effective, periodic audit — ideal where permanent installation is impractical, such as older data centers ▪ Measures actual power consumption and demand; troubleshoots input issues (harmonics, surge, fluctuation); can capture and record efficiency precisely	*fixed and continuous* ▪ Installed and fixed for permanent use, continuously monitoring live power circuits ▪ Produces real-time efficiency data with no human involvement, removing human-error miscalculations ▪ Higher initial cost, but ideal for new data centers because it reduces risk ▪ Built-in monitors (in UPS, cooling systems, and other equipment) generate reports retrieved by computerized management software

Portable instruments may not suffice where **continuous** monitoring of power usage is required; there, permanent instrumentation is advised. Permanent monitoring is more effective in the long term because the collected data feeds continuous improvement and, ultimately, a more sustainable data center.

14.9 Permanent instrumentation devices, benefits, and strategy

Four common types of permanent instrumentation devices appear in data centers, and meters can also be embedded into other equipment to protect it or improve its efficiency.

TABLE 14.6 Four permanent instrumentation devices

DEVICE	MONITORS	ROLE
Power quality meter	Harmonics, sags, surge, fluctuations, voltage, power, wavelength, frequency at the main input (generators, UPS)	Energy management, maintenance support, and verifying electricity bills, circuit loading, and balancing
Digital relay embedded meter	Current, energy, power fluctuations, and frequency across the whole electrical layout	Stand-alone; raises a notification or interrupts the circuit on any anomaly; suits medium-voltage needs
Power meter	Voltage, frequency, power, current, and energy	Inspects mechanical loads, IT busway and panel boards, PDUs, and branch circuits; efficient at raising alarms in critical times
UPS meter	Frequency, voltage, power, and current of the main supply	Provides critical alarm support and helps analyze main power and calculate overall loss

METERS EMBEDDED IN OTHER EQUIPMENT

- **Trip unit** — protective equipment that cuts off power on overload or short circuit; the embedded meter monitors current flow and initiates the trip (common in low-voltage circuit breakers)
- **PDU** — embedded meters avoid power overloads, improve calculations, and serve critical alarms
- **Rack PDU** — embedded meters calculate power quality for an individual rack for better, optimized power-consumption calculations

BENEFITS OF PERMANENTLY INSTALLED METERING SYSTEMS

- PUE reporting
- Decreased downtime and quicker downtime recovery
- A more effective data center maintenance process
- Maximum resource utilization
- Reduced power bills

Instrumentation alone cannot guarantee effective efficiency monitoring — it needs a strategy. Build one in four steps.

TABLE 14.7 A four-step efficiency-monitoring strategy

STEP	ACTION
Select device	Choose between permanent and portable efficiency-assessment devices
Determine points	Determine the measurement and monitoring points
Implement system	Implement a planned system to track and save efficiency data
Explore options	Explore other instrumentation options

Module summary

- Efficiency metrics reveal what is happening inside a data center — ensuring availability, cutting energy use, exposing inefficient areas, and ranking the most efficient facilities. The seven to know: PUE, DCiE, CADE, CCF, LEED, ASHRAE, and PAR4.
- PUE = total power supplied ÷ IT-equipment power; a unit-less ratio from Green Grid where lower is better. DCiE is its inverse (IT ÷ total power) shown as a percentage where higher is better.
- On the standard scale, PUE 3.0 / DCiE 33% is inefficient and PUE 1.2 / DCiE 83% is highly efficient; every overhead watt removed cuts operating cost.
- PUE is driven by data center design, IT-device energy efficiency, and rate of power use; reduce it by cutting supply power to supporting infrastructure and power-system losses, and by evaluating PUE at regular intervals.
- Three airflow elements lower PUE in synchronization: separating returning warm air from supplied cold air, the volume of air inflow, and the temperature of air inflow. Always calculate PUE from the precise IT load, not rated capacity.
- HVAC regulates temperature, humidity, and air levels to prevent thermal stress; it comes as central systems or self-contained packages and can consume nearly 40% of total power.
- Measure HVAC with COP and the common cooling-power-to-cooling-load ratio; effectiveness is IT energy ÷ HVAC energy (ideal 0.6–3.5); airflow efficiency is fan power ÷ fan airflow.
- Monitor HVAC PUE with SEER (seasonal), EER (machinery-only, residential), and HSPF (heating mode, heat pumps only); twelve practical steps — from insulating the space to using a CRAC unit — make HVAC energy-efficient.
- Portable instruments give cost-effective periodic audits by professionals; permanent instruments (power quality, digital relay, power, and UPS meters, plus embedded meters) give continuous real-time data — and a four-step strategy selects the device, sets the points, implements the system, and explores options.

Review questions

1. **State the PUE and DCiE formulas and say which direction is 'better' for each.**

   Answer: PUE = total power supplied to the data center ÷ IT-equipment power consumed — lower is better. DCiE = IT-equipment power ÷ total power supplied (the inverse of PUE), expressed as a percentage — higher is better.

2. **A data center's PUE is 2.0. What is its DCiE and efficiency level, and how did you get there?**

   Answer: DCiE = 1 ÷ PUE = 1 ÷ 2.0 = 50%, the 'average' level — twice as much total power is drawn as the IT equipment consumes.

3. **Which three variables determine a data center's PUE, and what two methods reduce it?**

   Answer: Variables: data center design and maturity, the energy efficiency of the IT devices, and the rate of power use. Reduce PUE by lowering supply power to supporting infrastructure and by reducing power-system losses.

4. **List the three airflow-management elements associated with PUE, and state the one rule about which power value to use.**

   Answer: Separating the returning warm air mass from the supplied cold air mass, the volume of air inflow, and the temperature of air inflow. Always use the precise IT load value, not the equipment's rated power capacity.

5. **What does HVAC stand for, what two system types exist, and roughly what share of total power does it consume?**

   Answer: Heating, ventilation, and air conditioning; central systems and self-contained packages; almost 40% of total power.

6. **Give the equations for HVAC efficiency (common method), HVAC effectiveness, and airflow efficiency, plus the ideal effectiveness range.**

   Answer: HVAC efficiency = aggregate cooling-system power (kW) ÷ aggregate cooling load (tons); HVAC effectiveness = IT-equipment energy (kWh/yr) ÷ HVAC energy (kWh/yr), ideal 0.6–3.5; airflow efficiency = gross fan power (W) ÷ gross fan airflow (cfm).

7. **Distinguish SEER, EER, and HSPF.**

   Answer: SEER measures output cooling ÷ electrical input over a varying season; EER uses the same ratio but ignores seasonal conditions (machinery-only, residential); HSPF uses SEER's units but rates the heating mode and applies only to heat pumps or reversible units (HSPF × 0.0293 = COP).

8. **Contrast portable and permanent instrumentation, and name the four common permanent devices.**

   Answer: Portable instruments are temporarily installed by qualified professionals for cost-effective periodic audits (good for older data centers); permanent instruments are fixed for continuous real-time monitoring and automatic reporting (ideal for new data centers). The four common permanent devices are the power quality meter, digital relay embedded meter, power meter, and UPS meter.