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Analysis of the Role of DCIM in Energy Optimization for Data Centers in Indonesia

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ABSTRACT

The global digital transformation, accelerated by the COVID-19 pandemic and the massive adoption of generative artificial intelligence (AI) architectures, has triggered an exponential surge in the construction of hyperscale data center infrastructure, positioning data centers among the most energy-intensive industrial facilities in the world. This research presents a comprehensive analysis of the role of Data Center Infrastructure Management (DCIM) as an instrument to diagnose, orchestrate, and improve energy efficiency, quantified specifically through the reduction of the Power Usage Effectiveness (PUE) metric. Using a framework of systematic review and empirical multi-case analysis, this research explores the operational thermodynamic dynamics that cause inefficiencies, such as zombie servers and over-provisioning of HVAC systems. Quantitative analysis demonstrates that DCIM intelligence features can help reduce PUE, with several institutional facilities successfully lowering baseline PUE from 1.83 to 1.51 while cutting cooling loads by up to 48%. In Indonesia, DCIM integration supports the fulfillment of the mandates of SNI 8799:2020 and SPBE guidelines and helps mitigate peak load resilience risks for PT PLN (Persero).

1. INTRODUCTION

Cloud computing, big data analytics, and artificial intelligence (AI) now underpin nearly every commercial and governmental activity. The COVID-19 pandemic compressed a digital transformation expected to unfold over years into a matter of months, and the clearest physical trace of that shift is the worldwide expansion of data center facilities. Behind the abstraction of "the cloud" sits a concrete thermodynamic reality: a data center is an industrial-scale information factory with exceptionally high energy intensity [1][2].

Indonesia illustrates the pressure this creates. GDP grew 5.05% in 2023, driven substantially by the telecommunications and digital sectors, while final energy demand rose 6.29% to 1,220 million barrels of oil equivalent (BOE). PT PLN (Persero) reported total electricity production of 343,891.75 GWh in 2024, with national peak load reaching 61,287.80 MW — 5.15% above the previous year. The Java–Bali interconnection system, where most hyperscale data center clusters operate, carried a peak load of 42,635.66 MW. Because these facilities draw a constant base load, and because power density per rack continues climbing under AI hardware requirements, the data center industry has become a critical entity for national grid stability [3][4].

This research examines the operational significance of Data Center Infrastructure Management (DCIM) in restructuring data center energy efficiency. It addresses three questions: how DCIM bridges the operational silos separating facility and IT teams, how it exposes latent energy leakage such as zombie servers, and how it aids in re-engineering thermal flow profiles. The study then presents a multi-case review comparing PUE before and after the implementation of thermal management systems, situating the findings within the governance parameters of SNI 8799 to inform policymakers and digital infrastructure architects in Indonesia [5][6][7].

2. LITERATURE REVIEW

2.1 Efficiency Metrics, Regulation, and the DCIM Platform

In response to this extreme consumption profile, the global data center industry established Power Usage Effectiveness (PUE) as the de facto efficiency metric, initiated by The Green Grid consortium. PUE quantifies the ratio of total facility electrical power to the energy consumed by IT equipment. A PUE of 1.0 represents perfect theoretical equilibrium, while traditional facilities that have not been optimised generally sit in the range of 1.8 to above 2.0 [8][9].

The pressure to re-engineer energy efficiency is no longer motivated solely by the desire to reduce operating expenditure (OPEX); it has evolved into a regulatory imperative. The EnEfG Act in Germany requires an annual PUE of ≤ 1.2 for data centers operating after July 2026. Singapore requires design compliance with a PUE below 1.3. Domestically, SNI 8799:2020 and the SPBE framework increasingly underline the urgency of operational efficiency in national data centers [5][10].

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To resolve the dilemma between computational reliability and thermal efficiency, the infrastructure engineering industry has turned to Data Center Infrastructure Management (DCIM) platforms. DCIM is a convergent software ecosystem that bridges the historical separation between building facility management teams and IT management teams. Through real-time intelligent sensor-based monitoring, prescriptive analytics, and digital twin modelling, DCIM delivers granular visibility that was previously difficult to obtain [11].

3. RESEARH METHODS

This study was orchestrated using a mixed-methods systematic evaluation framework combining qualitative and quantitative analysis, functioning as a multi-case industry review. The methodology relied on a structured literature search process across academic databases, standardisation body publications, and multinational operator telemetry (such as OCP and ASHRAE frameworks). Case studies were selected based on a strict criterion: the availability of explicit, quantifiable Power Usage Effectiveness (PUE) metrics both before and after the implementation of facility efficiency interventions.

Data collection was partitioned into two structured aggregate segments:

- **Segment 1 — Extraction of quantitative DCIM performance metrics:** Data center efficiency performance ratios were obtained by identifying baseline statistical indicators prior to infrastructure interventions and post-implementation indicators. The quantitative sample was drawn from real operational facilities recorded in empirical literature published by international institutions. The analytical procedure isolated the comparative PUE ratio values and the percentage modification of heat dissipation in cooling systems.
- **Segment 2 — Qualitative mapping of the national macroeconomic energy ecosystem:** Macro secondary data were compiled from the official PT PLN (Persero) Statistics 2024, the Handbook of Energy and Economic Statistics of Indonesia 2023 (Ministry of Energy and Mineral Resources), and the OJK legislative landscape. This contextualised the technical DCIM findings within local grid reliability and Indonesian regulatory governance.

The operational analysis procedure executed comparative integration. Macro grid electrical load data were juxtaposed against projected escalation in AI rack load density. The study critically reviewed the functional significance of DCIM platforms, deliberately distinguishing software-driven diagnostics from physical cooling interventions, while also evaluating the limitations of the PUE formula.

4. RESULT AND DISCUSSIONS

4.1 National Electricity Capacity Profile of Indonesia

Based on the extraction of current-year energy supply parameters, the structural pressure on domestic power sources requires close monitoring. The 2025 edition of PT PLN (Persero) Statistics shows that the electricity infrastructure configuration during the 2024 accounting year produced a cumulative total power supply of 343,891.75 GWh. Total installed generation capacity across the archipelago has reached 75,936.46 MW. Load consumption from the industrial cluster, which houses data center facilities, reached 92,195.69 GWh, or 30.11% of national grid supply [4].

The imbalance in electrical load distribution between regions reveals a latent challenge for the IT industry. The Java–Bali interconnection grid carried a peak load of 42,635.66 MW at the close of 2024. By contrast, renewable energy penetration within the Java portion of the network has not yet grown to a dominant share. Data centers in the Cikarang industrial estate and the Jakarta corridor remain supported largely by coal-fired steam power plants (PLTU), which account for more than 27% of the primary capacity mix [3]. This indicates that every decimal unit of PUE inefficiency left unsaved contributes to increased emissions [12].

Table 1. Macroeconomic electricity supply profile of Indonesia (2023–2024)

Electricity Infrastructure Indicator	Quantitative Realization	Implication for Data Centers
Total PT PLN (Persero) system production (2024)	343,891.75 GWh	Covers total energy supply for commercial compute-intensive industry.
Java–Bali system peak load (2024)	42,635.66 MW	Centre of gravity for large data center siting; vulnerable to grid supply deficits.
Energy delivered to industrial customer class (2024)	92,195.69 GWh (30.11%)	PUE savings through facility intelligence tools would reduce this industrial share.
Total renewable energy supply (2023)	13,155 MW	Green integration constrained by regulation and availability; internal efficiency optimisation is urgent.

Source: PLN Statistics 2024 [4] & Handbook of Energy and Economic Statistics of Indonesia 2023 [3]

4.2 Empirical Comparison of Energy Efficiency Performance

Quantitative extraction from field interventions yields statistical metrics that speak to the capability of monitoring software instruments in guiding concrete power-reduction programmes. It is critical to distinguish between physical mechanical interventions (such as containment) and the diagnostic intelligence of DCIM. DCIM acts as the analytical layer that makes physical interventions measurable and dynamically adjustable [13].

- **National Information Technology Center (NITC):** Initially, this operations centre lacked precision heat distribution profiles, leading to excessively low supply air temperature settings. The installation of a layered diagnostic computing architecture with precision sensors enabled technicians to detect safe zones and raise air-conditioning supply parameters. This software-driven insight reduced cooling compressor load by 48%, total facility power draw by roughly 17%, and brought PUE down from 1.83 to 1.51 [14].
- **San Diego Supercomputer Center (SDSC):** Covering approximately 19,000 square feet, this facility implemented physical mechanical airflow partitioning through hot aisle containment systems. While the physical containment structure actively eliminated thermal turbulence, supporting monitoring and validation were required to confirm the boundaries, contributing to a stable PUE reduction from 1.8 to 1.5.
- **Climate-based air-side economizer optimisation:** A simulation study comparing nine air-side economizer cycles against conventional cooling across 23 locations in Australia found that economizer cooling reduced annual cooling energy by up to 84% and lowered average PUE from approximately 1.42 to 1.22, with the largest savings in cooler climates [15].

Table 2. Summary of DCIM intervention outcomes — comparative case studies

Computing Facility	DCIM & Physical Interventions	Baseline PUE	Post-Intervention Outcome
NITC [14]	Detection of temperature anomalies; re-engineering of cooling load.	1.83	PUE 1.51; cooling load reduced by 48%.
SDSC	Physical hot aisle containment structure with sensor validation.	1.80	PUE 1.50.
Enterprise Datacenter [6]	Automated predictive modelling of AI load response.	Persistent downtime	30% reduction in power billing load on the night cycle.
Air-side economizer simulation [15]	Nine air-side economizer cycles compared with conventional cooling (23 climate locations).	Conventional cooling (avg. 1.42)	Average PUE ~1.22; cooling energy savings up to 84%.

Source: Mahdavi & Tschudi (2012) [14]; Brady et al. (2013) [6]; Habibi Khalaj et al. (2016) [15]

4.3 Algorithmic Correlation Between Software Architecture and Thermal Dynamics

DCIM does not alter the fundamental physical laws of heat rejection; rather, it weaves together fragmented facility telemetry into a coherent whole. It converts the informational darkness of the electrical room into decision visibility, enabling technicians and mechanical automation actuators to reduce defensive overcooling practices in server rooms.

In conservative architectural designs lacking micro-level thermal sensor instrumentation, infrastructure staff often set thermostats far below rational parameters — typically at 18°C–20°C — out of concern for unseen hot spots. This setting, with fans and compressors operating at a 100% duty cycle, constitutes an energy loss that can drive PUE beyond 2.0. When the DCIM digital twin panel is rendered, the system identifies layered thermodynamic zones. This directs designers to realign compressor speed with Variable Frequency Drive (VFD) converter systems to the precise level required, a primary factor behind the cooling demand reductions observed at NITC.

4.4 Eradicating Phantom Assets: Executing Zombie Servers

Beyond thermal engineering, DCIM possesses specialisation in identifying zombie servers — machines that are fully energised yet produce minimal computational value. Layered physical connectivity tracing algorithms and individual rack PDU ping sensors observe the voltage traffic profile. Correlating network silence with the utility status of ownerless chassis allows technicians to unplug legacy machines, which instantly shaves off phantom power load and severs useless thermal chains. Industry estimates often suggest conventional corporate data centers may operate at server capability utilisations as low as 7%–10% [16], indicating that the savings potential realisable through this mechanism is substantial.

4.5 Unveiling the Mathematical Paradox in PUE Interpretation

Responsible governance requires an exposition of the potential optical illusion inherent in the single-metric interpretation of PUE figures following server rationalisation. When virtualisation or the decommissioning of low-performing servers is carried out, the IT load figure acting as the PUE denominator shrinks drastically. If stationary cooling instruments are left to operate at static mechanical capacity without automatic speed calibration, the mathematical equation will reproduce a worsening quotient — a PUE of 1.5, for instance, may mathematically degrade to 2.0 even though the absolute monthly electricity bill has declined.

The PUE metric must therefore be viewed not merely as a measure of operational electricity savings, but as a metric of synchronisation between environmental conditioning facilities and IT performance. Modern DCIM platforms mitigate this anomaly through intelligently synchronised variable dynamic cooling.

4.6 Strategic Implications for Financing and National Standards Governance

Energy saved as the fruit of thermal diagnostics produces layered effects in the governance of capital returns and operational continuity. Compressing the consumption profile below a validated PUE of 1.5 frees kilowatts of reserve load previously locked within redundant power supply protection systems. This recovered capacity provides reserve electrical ammunition for server rack expansion without the need to construct costly new PDU transmission substations.

In terms of business continuity, studies affirm that every minute of server outage imposes significant financial losses, estimated up to USD 9,000 [17]. Given that a vast majority of infrastructure incidents may be triggered by failures in equipment lifespan prediction or manual calibration errors [18], DCIM helps lower the technical disaster figure through the integration of predictive maintenance alerting systems.

This governance adjustment intersects with the Indonesian digital ecosystem. SPBE couples certification standardisation requirements with SNI 8799:2020 [5], [19], which mandates containment architecture systems (hot and cold aisle separation) to suppress PUE. Furthermore, corporate bank investment management boards increasingly insert OJK Green Taxonomy clauses into financing agreements. Data centers that fail to build a culture of cooling facility synchronisation may face challenges in qualifying for OJK green portfolio classification

4.7 Extreme AI Computing and Future Multidimensional Metrics

The future of data center governance points toward exponential power density driven by generative artificial intelligence GPUs. While conventional server racks operate at 5–10 kW, emerging projections indicate that the latest AI-specialised racks may demand energy flows of 40–100 kW per individual chassis unit [1], [20]. The thermal capacity of conventional air-based cooling will likely reach its limit, making the transition toward direct-to-chip liquid cooling loops and two-phase immersion tanks a fundamental shift in design.

DCIM aggregation platforms wrapped in artificial intelligence (AI DCIM) will assume central control, orchestrating thermal fluid network pumps in synchrony with AI workload spikes. This evolution targets not only a PUE below 1.2, but the construction of a holistic governance architecture encompassing WUE (Water Usage Effectiveness) and CUE (Carbon Usage Effectiveness). Viewed from a service perspective, this transition constitutes a disruptive innovation that requires a service-oriented framework to align new technological capabilities with stakeholder needs and regulatory expectations [21].

4.8 Metrics Integrating ITSM for Cooling Operation Management

Beyond traditional mechanical enhancements, ensuring zero downtime and minimizing risks requires IT Service Management (ITSM) implementation. When infrastructure anomalies or thermal incidents occur, an ITIL V3 Service Operation framework uses an incident management flow to swiftly group problems by priority and dispatch technicians for immediate resolution. Adopting problem management ensures that these root causes are captured and minimized. This guarantees that service operations maintain the expected PUE targets seamlessly without disrupting server access [22]. More broadly, the success of enterprise-scale platforms such as DCIM depends on critical success factors captured by the information system success model, including system quality, information quality, and user satisfaction [23].

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5. CONCLUSSION

An analytical review across engineering literature and multi-case studies affirms that the adoption of Data Center Infrastructure Management (DCIM) systems constitutes a backbone for optimizing operational electricity consumption in global data center environments. DCIM platforms map heat flow corridors, tame the energy-wasting load of zombie servers, and command automatic reductions in cooling machine speed. This execution delivers thermodynamic savings that culminate in a reduced PUE ratio, demonstrating that a PUE target of 1.5 is realistically attainable in optimised scenarios.

Within the Indonesian national ecosystem, the implementation of DCIM diagnostic parameters has become crucial for supporting the resilience of the Java–Bali electricity grid. Meeting green computing power efficiency parameters will aid Indonesia's data center industry in passing compliance audits under the SNI 8799:2020 mandate while aligning with OJK Green Taxonomy financing schemes.

Study Limitations: It is important to acknowledge the limitations of this study. The available evidence is based primarily on secondary case data and macro-level reporting, which may be subject to specific operational contexts and reporting biases. Furthermore, isolating the exact quantitative impact of DCIM software independently from physical supporting interventions—such as hot-aisle containment and economizer installations—remains challenging. Future empirical assessments should cautiously separate software-driven diagnostics from mechanical facility upgrades to accurately trace individual performance attributions.

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