

CHAPTER 4 - RESULT AND DISCUSSIONS

4.1 Overview

This chapter presents the results and discussion of the research, focusing on the evaluation and implementation of sustainable data center cooling practices at Sinergy Data Center. The primary goal of this study is to investigate how advanced cooling technologies, supported by IT service management (ITSM) and governance frameworks such as ITIL 4 and COBIT 5, can enhance energy efficiency and contribute to environmental sustainability.

To support real-time monitoring, operational visibility, and performance analysis of cooling systems, the research employs the integration of a Data Center Infrastructure Management (DCIM) platform. Specifically, the DCIM software selected for this implementation is EKofa DCIM, which offers a unified dashboard for monitoring power usage, cooling metrics, environmental conditions, and IT asset health. EKofa DCIM is recognized for its scalability, interoperability with IoT sensors, and advanced analytics features, making it suitable for sustainability-focused data center operations.

The DCIM software is integrated with various hardware components, including:

1. IoT-based temperature and humidity sensors, strategically placed across cold and hot aisle zones
2. Power Distribution Units (PDUs) capable of real-time energy metering (kWh, amps, voltage)
3. Environmental monitoring nodes, linked to critical infrastructure points (e.g., CRAC units, chillers, UPS)
4. AI-based thermal controllers (proprietary machine-learning models), designed to adjust HVAC performance based on predictive thermal loads

These components enable continuous data collection, real-time visualization, and automated threshold alerts, which are essential for optimizing Power Usage Effectiveness (PUE) and maintaining ambient temperature stability. The integration of hardware and software is conducted via SNMP (Simple Network Management

Protocol) and API connectivity, allowing seamless data flow between devices and the central DCIM platform.

The monitoring system is configured to evaluate key performance indicators (KPIs) including:

1. PUE (Power Usage Effectiveness)
2. Cooling Efficiency Ratio (CER)
3. Total Energy Consumption (kWh/year)
4. Server Utilization Rate (% load)
5. HVAC System Response Time
6. Ambient Temperature Consistency (°C)

By leveraging this DCIM infrastructure, the research aims to validate the cooling policy through a static and dynamic testing approach. Static testing involves documentation review and configuration validation, while dynamic evaluation is performed through real-time monitoring and trend analysis enabled by the DCIM dashboard. This integrated monitoring strategy ensures a data-driven basis for assessing the effectiveness of cooling technologies, policy compliance, and governance alignment.

Furthermore, the insights obtained through DCIM integration support the Continual Service Improvement (CSI) phase of the ITIL 4 framework, as well as COBIT's MEA (Monitor, Evaluate, and Assess) domain, ensuring long-term performance tracking and regulatory compliance. The following sections of this chapter provide detailed analysis of survey results, expert appraisals, policy testing outcomes, and performance evaluation metrics.

4.2 ITIL 4

Showing in Table 4.1 outlines the structured implementation of the ITIL 4 Drive Stakeholder Value model in the context of cooling efficiency management at Sinergy Data Center. Each process stage Explore, Engage, Offer, Agree, Onboard, Co-Create, and Realize is evaluated through key items of review such as stakeholder analysis (ITIL001), cooling solution design (ITIL003), and continuous improvement of cooling

systems (ITIL007). For example, under ITIL004, the SLA and Compliance Policy includes a target PUE of ≤ 2.0 , while ITIL005 confirms that user training and onboarding protocols were completed. All stages passed their review goals, indicating a mature integration of ITSM principles into technical and operational layers. This structured implementation supports alignment between service governance, stakeholder engagement, and energy-efficient infrastructure management.

Table 4. 1. Implementation of ITIL 4

Test ID	Item Type	Item to Review	Review Goal	Status	Comments
ITIL001	Explore	Stakeholder Analysis	Identify key stakeholders and analyze their needs and influence	Pass	Stakeholder map created; includes operations, sustainability officers, and facility managers
ITIL002	Engage	Stakeholder Relationships	Build strong stakeholder relationships for project alignment	Pass	Engagement strategy includes monthly briefings and expectation management
ITIL003	Offer	Cooling Solution Design	Design sustainable and energy-efficient cooling solutions	Pass	Design for airflow within data centers
ITIL004	Agree	SLA and Compliance Policy	Establish clear service levels and compliance with energy regulations	Pass	SLAs include PUE ≤ 2.0 target
ITIL005	Onboard	Transition & Training	Ensure users are trained and the transition to new systems is managed smoothly	Pass	Training modules provided to operations team; onboarding

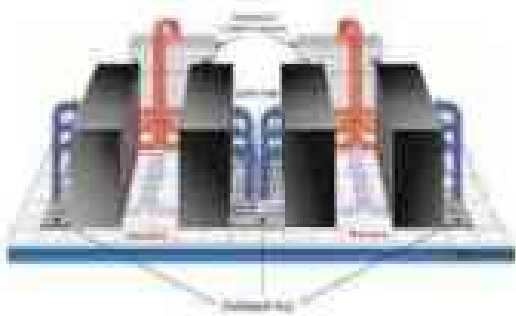
					checklist completed
ITIL006	Co-Create	Collaborative Implementation	Collaborate with stakeholders during implementation	Pass	Joint implementation with internal IT and external cooling vendors ensured alignment
ITIL007	Realize	Continuous Improvement	Drive value realization and continuous improvement of cooling system	Pass	Performance audits and CSI meetings scheduled bi-annually to track energy savings

To ensure the implementation of ITIL 4 is not only theoretical but practically verifiable, Table 4.2 presents evidence captured for each phase of the ITIL 4 stakeholder journey, from Explore to Realize. The evidence aligns with seven key ITIL stages: stakeholder analysis (ITIL001), engagement meetings (ITIL002), cooling solution design (ITIL003), SLA compliance (ITIL004), onboarding and training (ITIL005), collaborative implementation (ITIL006), and continuous improvement (ITIL007). These validations are supported through meeting minutes, photographs, system dashboards, technical drawings, and audit tables. For example, the performance audit summary in ITIL007 and the DCIM-based SLA monitoring in ITIL004 reflect governance maturity and real-time monitoring capabilities. This evidence-based approach ensures alignment between ITSM principles and operational excellence in managing data center cooling infrastructure.

Table 4. 2. Evidence Implementation of ITIL 4

Test ID	Item Type	Item to Review	Evidence Capture
ITIL001	Explore	Stakeholder Analysis	Creating MOM (Minute of Meeting) for every activity related with Data Centre. 

				
ITIL002	Engage	Stakeholder Relationships	Monthly meeting with management and internal staff.	

			
ITIL003	Offer	Cooling Solution Design	Cooling design 
ITIL004	Agree	SLA and Compliance Policy	SLA capturing parameter using DCIM 

ITIL005	Onboard	Transition & Training	Training Material ITIL® Data Centre Infrastructure Management Version 3.0.0 (2019) 1. Introduction to DCIM 1.1 Learning Objectives - Understand the information purpose of DCIM - Recognise the benefits and constraints of DCIM tools 1.2 Key Topics - What is DCIM? - Why DCIM matters, opportunities to capture - Common challenges in Infrastructure Management - DCIM is traditional monitoring 2. Core Functions of DCIM 2.1 Learning Objectives - Identify major functional areas covered by DCIM software 2.2 Key Modules - Asset Management (Active, Passive, PUE) - Power Monitoring and Capacity Planning - Thermal Modeling and Environmental Monitoring - Network Planning and Configuration - Workflows and Change Management - Reporting and Dashboards 3. DCIM Architecture and Data Flow 3.1 Learning Objectives - Understand system components and their interaction 3.2 Key Takeaways - DCIM is not an end product, it's a process (monitoring, modeling, power) - Integration with other DCIM applications - Data integration, storage and visualization - Why are interoperability with ITSM/ITIL tools 4. Implementation Roadmap 4.1 Learning Objectives - Understand the various stages of a DCIM implementation 4.2 Roadmap Phases - Requirements gathering & scope definition - Infrastructure audit and baseline assessment - Tool selection and vendor evaluation - Pilot testing and integration - Full deployment and training - Continuous improvement and validation 5. Hands-on DCIM System Training 5.1 Learning Objectives - Get a first-hand experience with the DCIM interface 5.2 Training Exercises - Logging into the DCIM dashboard - Viewing asset reports and alerts - Generating a power usage report (PUE) - Creating a temperature threshold alert - Creating a threshold breach (Alert) report 6. Best Practices for using DCIM 6.1 Learning Objectives - Identify the best practices for using DCIM 6.2 Key Practices - Monitor capacity and alert monitoring (PUE and CO2E) - Use DCIM for capacity forecasting - Integrate with other ITSM/ITIL processes - Define escalation paths for critical events - Perform regular audits and (PI) reviews 7. Case Study: Real World DCIM Implementation 7.1 Overview - Objective: Reduce power usage and optimize cooling
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ITIL006	Co-Create	Collaborative Implementation	Join implementation with internal IT and external IT cooling vendor vendor 
ITIL007	Realize	Continuous Improvement	Performance audit table. 

The visual documentation in Table 4.2 confirms that the ITIL 4 framework has been systematically implemented at Sinergy Data Center, with traceable proof for each phase. In ITIL001, the creation of MoMs (Minutes of Meeting) documents stakeholder mapping and decision processes. ITIL002 and ITIL006 are evidenced by collaborative meetings with internal teams and external vendors, demonstrating engagement and co-creation. Meanwhile, ITIL003 provides a schematic for airflow-based cooling design, and ITIL005 includes detailed training modules on DCIM system usage. ITIL004's SLA dashboard shows cooling metrics such as PUE and power load, while ITIL007 displays structured performance logs supporting the Continual Service Improvement (CSI) phase. This alignment between documentation and ITSM framework

demonstrates institutional readiness, procedural consistency, and commitment to sustainable cooling governance.

4.3 COBIT 5 Evaluation of Governance Readiness

This section evaluates the governance capability of Sinergy Data Center's sustainable cooling policies using the COBIT 5 framework, which provides a structured approach for aligning IT processes with enterprise objectives. COBIT 5's principles meeting stakeholder needs, covering the enterprise end-to-end, applying a single integrated framework, enabling a holistic approach, and separating governance from management were applied to interpret the findings of the ITSM static testing results (ITSM001–ITSM007), showing in Table 4.3.

The COBIT 5 domains relevant to this evaluation include:

1. EDM (Evaluate, Direct and Monitor)
2. APO (Align, Plan and Organize)
3. BAI (Build, Acquire and Implement)
4. DSS (Deliver, Service and Support)
5. MEA (Monitor, Evaluate and Assess)

Table 4. 3. COBIT 5 Evaluation of Governance Readiness

Test ID	Item Type	Item to Review	Review Goal	Status	Comments
COB001	Governance Alignment	Meet the Needs of the Stakeholder	Ensure cooling strategies address stakeholder performance, risk, and compliance	Pass	Stakeholder requirements gathered during FGD; SLAs tailored to business and energy goals
COB002	Governance Structure	Separate Governance from Management	Validate clear separation between decision-making (board) and	Pass	Sustainability board defines policy; operational team executes with oversight

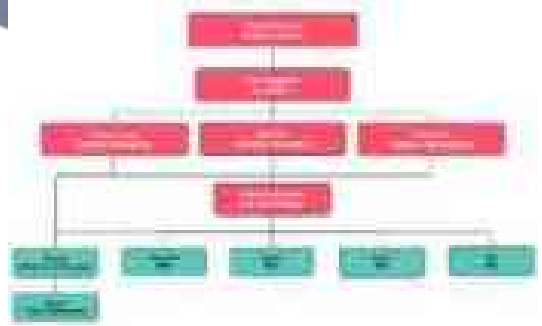
			execution (ops)		
COB003	Governance Scope	Covers the Enterprise End-to-End	Confirm cooling policy is integrated across facilities, procurement, and IT	Pass	Cooling policy applies across datacenter assets, DCIM, and environmental compliance teams
COB004	Governance Approach	Enable Holistic Approach	Ensure all enablers (processes, people, tech, culture) support cooling strategy	Pass	Roles and Responsibilities, Monitoring and Reporting, also training and awareness.
COB005	Governance Framework	Apply Single Integrated Framework	Validate integration with existing ITIL, and energy compliance frameworks	Pass	Uses ITIL 4 for service design/delivery; COBIT 5 for oversight.

To ensure the governance of cooling infrastructure complies with enterprise-level standards, this section evaluates the implementation of COBIT 5 principles. Table 4.4 presents evidence related to five core governance components: stakeholder alignment (COB001), structural independence (COB002), enterprise scope (COB003), holistic approach (COB004), and integrated governance framework (COB005). Each principle is supported by visual documentation, including stakeholder meeting minutes, organizational charts, and DCIM dashboard outputs. For example, COB003 demonstrates that the data center strategy covers all departments through a cooling roadmap, while COB005 shows how cooling lifecycle activities align with COBIT domains such as BAI09 (asset management) and MEA01 (performance assessment).

This evidentiary approach validates the governance maturity and operational compliance of Sinergy Data Center's cooling policy with COBIT 5.

Table 4. 4. COBIT 5 Evaluation of Governance Readiness

Test ID	Item Type	Item to Review	Evidence Capture
COB001	Governance Alignment	Meet the Needs of the Stakeholder	Creating MOM (Minute of Meeting) for every activity related with Data Centre. 

			
COB002	Governance Structure	Separate Governance from Management	Organization Chart 
COB003	Governance Scope	Covers the Enterprise End-to-End	Supporting evidence for COB003 indicates that governance is around the entire data center and is consistent with COBIT 5's

			view on the enterprise. It involves cooling techniques, airflow zoning, surveillance, and role-based responsibilities. These holistic practices further reveal that Corporate Governance is reflected within the technical, operational, and sustainability domains, thus ensuring that the IT functions are aligned with the objectives of the corporation.
COB004	Governance Approach	Enable Holistic Approach	 In the case of COB004 there is, in addition, evidence of an integrated governance based on the clearly defined roles, continuous monitoring, and ongoing training. Duties range from facilities management, through technical operations, sustainability and alignment with IT. Weekly logging, monthly reporting and bi-annual auditing, enforce accountability, while mandatory employee training serves to achieve continuous improvement, policy compliance and both green cooling and emergency response readiness.
COB005	Governance Framework	Apply Single Integrated Framework	Related with ITIL4 • Design & Transition → Cooling system design • Obtain/Build → Technology procurement • Deliver & Support → Real-time monitoring • Improve → PUE & CER audit cycle

Design Proposal for Data Centre Layout

Real Layout after construction

Related with COBIT 5
Manage Assets (BAI09)

Inventaris Data Center LT.3 PT. Inti Pusat Data Nusantara						
No.	Nama Barang	Jumlah	Tahun Perolehan	Harga	Lokasi	Foto
1.	PAC	3	2025		LT.3	
2.	Monitor	1	2025		LT.3	
3.	Rack WallMount	1	2025		LT.3	
4.	Lemari Besi	1	2025		LT.3	
5.	UPS	2	2025		LT.3	
6.	Rack Panel PDU	4	2025		LT.3	
7.	Tabung FM	3	2025		LT.3	
8.	Open Rack MMIR	3	2025		LT.3	
9.	Rack Full 46U	24	2025		LT.3	

Manage Operational (DSS01)

		 Monitor, Evaluate, Assess Performance and Conformance (MEA01) 
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The evidence shown in Table 4.4 confirms that Sinergy Data Center effectively integrates COBIT 5 practices into its cooling system governance. COB001 and COB002 demonstrate how stakeholder involvement is mapped and separated from executive management functions. COB004 is supported by clearly defined roles, such as facility managers and sustainability officers, enabling a holistic governance model. Furthermore, COB005 illustrates process alignment with ITIL 4 phases from cooling system design and procurement to monitoring and improvement underscoring a single integrated governance framework. Asset inventory sheets, cooling layout proposals, and performance dashboards serve as proof that operational decisions are governed and monitored systematically. Collectively, this evaluation confirms alignment with COBIT’s strategic, tactical, and operational domains.

4.4 Organizational Role Alignment Analysis (RACI Comparison)

In the pursuit of implementing sustainable cooling practices within Sinergy Data Center, it is essential to delineate the roles and responsibilities of all stakeholders involved. A clearly structured RACI matrix which designates who is Responsible (R), Accountable (A), Consulted (C), and Informed (I) for specific activities ensures accountability, minimizes role ambiguity, and improves operational efficiency. This becomes particularly critical in data center environments where cross-functional

collaboration between IT, engineering, and sustainability teams is required to achieve performance targets like PUE reduction, thermal stability, and regulatory compliance.

The following RACI matrix, showing in Table 4.5 was constructed to map the functional distribution of roles for key monitoring and evaluation activities related to cooling performance under the MEA01 (Monitoring, Evaluation, and Analysis) framework. This customized model reflects the proposed governance approach in this research, aligned with both sustainability goals and IT governance principles such as those outlined in COBIT 5 (specifically APO and MEA domains).

Table 4. 5. RACI Matrix table for MEA01

Activity	Project Lead / Researcher	Data Center Manager	IT Operations Team	Facility Engineering	Sustainability Analyst
Define KPIs (PUE, energy savings, thermal stability, etc.)	B	A	C	C	R
Collect and validate cooling system performance data	A	R	C	R	I
Evaluate performance against sustainability benchmarks	R	C	I	C	A
Conduct periodic compliance audits on HVAC and cooling controls	I	A	C	R	C
Report and recommend improvements based on analysis	A	C	I	C	R

This RACI model reveals several improvements over the existing operational role structure observed at Sinergy Data Center. Most notably, the Sustainability Analyst is explicitly positioned as accountable in evaluating performance against benchmarks and contributing directly to final improvement reports roles often underrepresented in traditional setups. In contrast, the Data Center Manager assumes accountability for operational data validation and compliance auditing, consistent with their governance role.

The Project Lead / Researcher, although not operationally embedded, plays a key role in defining metrics and overseeing performance evaluation, thus contributing to continuous improvement efforts. Facility Engineering and IT Operations are both consulted or responsible for tasks requiring technical input, ensuring cross-functional integration. This role-based clarification is expected to enhance data transparency, promote sustainability-centric thinking, and support more strategic decision-making.

Overall, the proposed RACI structure serves as a governance improvement recommendation that supports better alignment between sustainability objectives and operational practices in data center cooling management. It also fulfills COBIT BAI09 (“Manage the configuration”) and MEA01 (“Monitor, Evaluate and Assess Performance and Conformance”) practices, enabling clearer accountability for critical infrastructure performance.

In line with the COBIT 5 governance and management objectives particularly BAI09 (Manage Assets), showing in Table 4.6, it is crucial to ensure that the management of cooling-related assets in Sinergy Data Center follows a well-structured framework of responsibilities. BAI09 emphasizes the full lifecycle management of IT and infrastructure assets to optimize value, reduce risk, and align with strategic business objectives. Within the context of sustainable data center operations, this involves not only the identification and acquisition of cooling equipment but also continuous assessment of their performance and contribution to energy efficiency.

The RACI matrix below outlines the distribution of roles across stakeholders for key asset management activities. It assigns who is Responsible (R) for executing tasks, who is Accountable (A) for ensuring completion, and who should be Consulted (C) or Informed (I) in the decision-making process. This model was tailored for the BAI09 domain and reflects an enhanced coordination strategy proposed by this research.

Table 4. 6. RACI Matrix table for BAI09 (Manage Assets)

Activity	Project Lead / Researcher	Data Center Manager	IT Operations Team	Facility Engineering	Sustainability Analyst
Identify critical cooling assets and inventory	R	A	C	C	I
Assess asset lifecycle cost (e.g., cooling units, CRACs, chillers)	A	R	C	C	I
Evaluate efficiency of cooling technology (PUE, WUE metrics)	A	R	C	C	I
Ensure sustainability goals in asset acquisition	C	A	I	C	R
Maintain and update asset performance data	C	A	A	R	I

This RACI mapping offers a strategic improvement over traditional asset management roles within Sinergy Data Center by integrating sustainability analysis and cross-

functional collaboration. The Data Center Manager remains the central accountable figure for operational and financial aspects of asset management, including lifecycle costing and performance tracking. However, the inclusion of the Sustainability Analyst in both consultative and responsible roles ensures that environmental performance metrics (e.g., PUE, WUE) are consistently monitored and considered in asset acquisition decisions.

Meanwhile, Facility Engineering contributes technical insights, and IT Operations supports real-time performance data collection, emphasizing the importance of interdisciplinary collaboration. The Project Lead / Researcher is positioned to initiate assessments and bridge research insights with practical execution, fostering continuous innovation.

This role clarity strengthens organizational alignment, improves asset value realization, and supports the broader thesis objective of enhancing cooling efficiency through governance and operational refinement aligned with BAI09's principles in the COBIT 5 framework.

As part of the implementation assessment of sustainable cooling practices, a RACI (Responsible, Accountable, Consulted, Informed) matrix was developed to clarify the functional roles of key stakeholders involved in the data center cooling initiative. The proposed RACI structure, illustrated in Table 4.5 and Table 4.6 (Proposed RACI for Cooling Efficiency Project), was compared against the existing operational role chart within the Sinergy Data Center organization show in Figure 4.1.

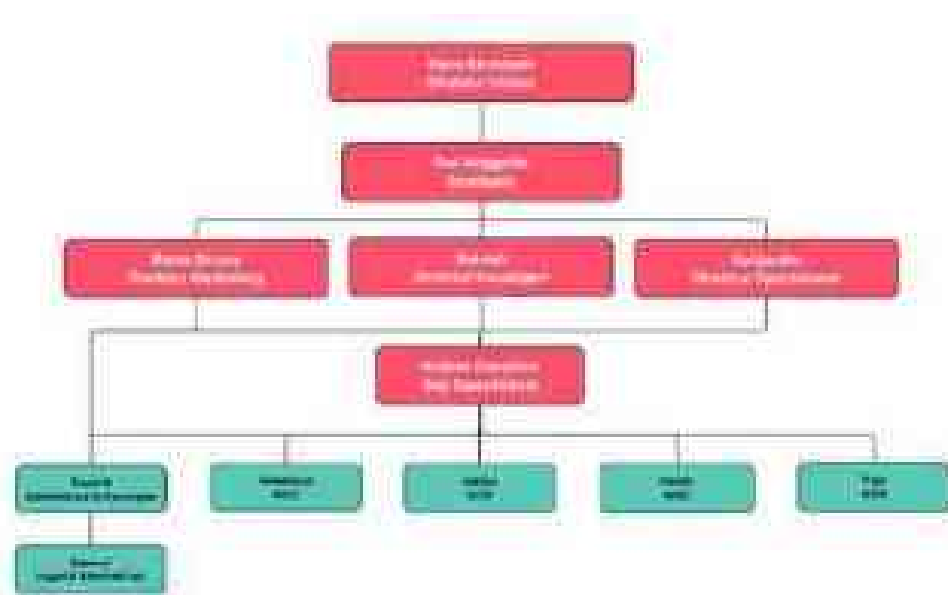


Figure 4.1. Organization chart of Sinergy Data Center

The comparison reveals key gaps and misalignments. In the proposed matrix, the Sustainability Analyst plays an accountable role in monitoring environmental metrics such as PUE and carbon footprint, which was not explicitly defined in the existing RACI. Similarly, the Project Lead/Researcher assumes a central role in coordinating cross-departmental efforts, while current practice at Sinergy assigns this to operational or engineering leads, potentially diffusing strategic alignment with sustainability goals.

Furthermore, the proposed RACI includes clearly delineated responsibilities for IT Operations and Facility Engineering in data collection, reporting, and system feedback, whereas the current organizational structure often overlaps these roles without distinct accountability. The absence of a unified documentation and communication pathway was also noted, particularly in SLA reporting and compliance processes.

Aligning the RACI model with best practices from IT governance frameworks (e.g., COBIT 5 APO & BAI domains) and sustainability standards ensures that decision-making authority, operational control, and compliance monitoring are well-distributed. Therefore, Sinergy Data Center is recommended to revise its internal RACI chart to

enhance transparency, optimize role clarity, and ensure holistic engagement in sustainability driven infrastructure optimization.

4.5 Policy Development and Testing

The development and validation of policies related to sustainable cooling in data centers must adhere to structured IT governance and service management frameworks. This research integrates policy evaluation through static testing, a key process in validating the completeness, coherence, and alignment of documentation prior to implementation. The aim is to assess whether the cooling policy developed for Sinergy Data Center conforms to ITIL 4 and COBIT 5 governance principles while also meeting sustainability objectives such as energy efficiency, risk mitigation, and regulatory compliance.

Static testing involves the review of documentation and process flows by stakeholders including policy makers and quality control (QC) teams, ensuring that the policies are comprehensive, clear, and technically sound. Unlike dynamic testing, which relies on live implementation, static testing is used to detect flaws, gaps, and non-compliance before execution. This proactive approach enhances the reliability of policies and minimizes implementation risks (Al-Nasrawi et al., 2020).

4.5.1 Static Testing – (Policy Maker, QC)

The static testing phase for Sinergy Data Center’s cooling policy involved seven critical checkpoints aligned with ITSM domains, covering strategic planning, service design, operations, and compliance. The process utilized expert review by both internal stakeholders (policy owners and risk managers) and external QC representatives, ensuring objectivity and comprehensiveness. Table 4.5. outlines the results of this evaluation.

Table 4. 7. Static Testing – (Policy Maker, QC)

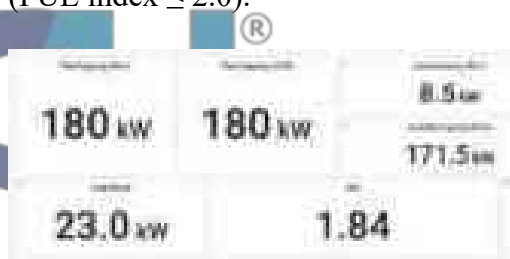
Test ID	Item Type	Item to Review	Review Goal	Status	Comments
ST001	Service Strategy	Alignment with sustainability strategy	Ensure the policy reflects long-term energy efficiency	Pass	Cooling policy aligned with Corporate Environmental Strategy

ST002	Service Design	Cooling system architecture and airflow control	Validate infrastructure design supports energy-efficient cooling practices	Pass	Includes hot/cold aisle containment.
ST003	Service Transition	Change management for cooling upgrades	Confirm structured change enablement for cooling system transitions	Pass	Rollback procedure
ST004	Service Operation	Real-time thermal monitoring and automation	Assess operational control using DCIM	Pass	Real-time alerts, logs showing temperature and humidity alerts
ST005	Continual Service Improvement	Performance metrics and trend analysis	Ensure measurable improvements via PUE benchmarking	Pass [®]	Reports showing energy efficiency gains
ST006	Risk Management	Risk identification and mitigation for cooling failures	Validate the presence of risk controls for system failure and downtime scenarios	Pass	Identification and Mitigation Plan
ST007	Compliance Management	Adherence to national and international regulations	Ensure compliance with ISO, ASHRAE, and Indonesian energy conservation laws	Pass	Regulatory Compliance Document

To ensure the governance of cooling infrastructure complies with enterprise-level standards, this section evaluates the implementation of COBIT 5 principles. Table 4.4 presents evidence related to five core governance components: stakeholder alignment

(COB001), structural independence (COB002), enterprise scope (COB003), holistic approach (COB004), and integrated governance framework (COB005). Each principle is supported by visual documentation, including stakeholder meeting minutes, organizational charts, and DCIM dashboard outputs. For example, COB003 demonstrates that the data center strategy covers all departments through a cooling roadmap, while COB005 shows how cooling lifecycle activities align with COBIT domains such as BAI09 (asset management) and MEA01 (performance assessment). This evidentiary approach validates the governance maturity and operational compliance of Sinergy Data Center's cooling policy with COBIT 5.

Table 4. 8. Evidence Static Testing

Test ID	Item Type	Item to Review	Evidence Capture
ST001	Service Strategy	Alignment with sustainability strategy	Sustainability KPI table (PUE goals) (PUE index ≤ 2.0). 
ST002	Service Design	Cooling system architecture and airflow control	Data Center layout diagram showing hot/cold aisle 

													
ST003	Service Transition	Change management for cooling upgrades	Rollback procedure document Rollback Procedure for Cooling System Changes Document Title: Rollback Procedure for Cooling System Changes Version: 1.0 Author: [Name] Approved Date: [Date] Reviewed Date: [Date] Approved By: [Name] Reviewed By: [Name] 1. Purpose The purpose of this document is to provide a clear and concise guide for the rollback procedure for cooling system changes. This document is intended for use by the IT department and the operations team. 2. Scope This document applies to all cooling system changes, including: • Cooling system upgrades • Cooling system replacements • Cooling system repairs • Cooling system maintenance • Cooling system testing 3. Roles and Responsibilities <table><tr><th>Role</th><th>Responsibilities</th></tr><tr><td>IT Manager</td><td>Approve and sign off on the rollback procedure.</td></tr><tr><td>IT Technician</td><td>Perform the rollback procedure.</td></tr><tr><td>Operations Manager</td><td>Approve and sign off on the rollback procedure.</td></tr><tr><td>Operations Technician</td><td>Perform the rollback procedure.</td></tr></table> 4. Rollback Procedure When a rollback is required, the following steps should be followed: 1. Notify the IT Manager and the Operations Manager of the rollback. 2. Stop the cooling system. 3. Remove the cooling system components. 4. Reinstall the original cooling system components. 5. Test the cooling system. 6. Restart the cooling system.	Role	Responsibilities	IT Manager	Approve and sign off on the rollback procedure.	IT Technician	Perform the rollback procedure.	Operations Manager	Approve and sign off on the rollback procedure.	Operations Technician	Perform the rollback procedure.
Role	Responsibilities												
IT Manager	Approve and sign off on the rollback procedure.												
IT Technician	Perform the rollback procedure.												
Operations Manager	Approve and sign off on the rollback procedure.												
Operations Technician	Perform the rollback procedure.												

			 As for ST003, evidence points to a "rollback procedure" document on cooling upgrades and change management. It has clear roles, roll-back preconditions, risk triggers, and step-by-step recovery steps. That way if a failed or flaky upgrade happens, we've got a safe path to rollback and continue running. It also requires configuration snapshots and approval processes to reduce the change for operational disruption.
ST004	Service Operation	Real-time thermal monitoring and automation	Logs showing temperature and humidity alerts 

ST005	Continual Service Improvement	Performance metrics and trend analysis	Reports showing energy efficiency gains
ST006	Risk Management	Risk identification and mitigation for cooling failures	Identification and Mitigation Plan Document

			3. Risk Mitigation Plan <table><tr><th>Risk ID</th><th>Prevention Measures</th><th>Response Actions</th></tr><tr><td>R001</td><td>Regular inspection of PUE, air and humidity and DRP plan update</td><td>Coordinate with TSC, Hazard Incident, and log to HCSM system</td></tr><tr><td>R002</td><td>Quarterly, off-site emergency drills, and DRP exercises (e.g. fire drill or power off outage)</td><td>Coordinate with TSC, Hazard Incident, and log to HCSM system</td></tr><tr><td>R003</td><td>Quarterly, off-site emergency drills, and DRP exercises (e.g. fire drill or power off outage)</td><td>Coordinate with TSC, Hazard Incident, and log to HCSM system</td></tr><tr><td>R004</td><td>Quarterly, off-site emergency drills, and DRP exercises (e.g. fire drill or power off outage)</td><td>Coordinate with TSC, Hazard Incident, and log to HCSM system</td></tr><tr><td>R005</td><td>Quarterly, off-site emergency drills, and DRP exercises (e.g. fire drill or power off outage)</td><td>Coordinate with TSC, Hazard Incident, and log to HCSM system</td></tr><tr><td>R006</td><td>Quarterly, off-site emergency drills, and DRP exercises (e.g. fire drill or power off outage)</td><td>Coordinate with TSC, Hazard Incident, and log to HCSM system</td></tr><tr><td>R007</td><td>Quarterly, off-site emergency drills, and DRP exercises (e.g. fire drill or power off outage)</td><td>Coordinate with TSC, Hazard Incident, and log to HCSM system</td></tr><tr><td>R008</td><td>Quarterly, off-site emergency drills, and DRP exercises (e.g. fire drill or power off outage)</td><td>Coordinate with TSC, Hazard Incident, and log to HCSM system</td></tr><tr><td>R009</td><td>Quarterly, off-site emergency drills, and DRP exercises (e.g. fire drill or power off outage)</td><td>Coordinate with TSC, Hazard Incident, and log to HCSM system</td></tr><tr><td>R010</td><td>Quarterly, off-site emergency drills, and DRP exercises (e.g. fire drill or power off outage)</td><td>Coordinate with TSC, Hazard Incident, and log to HCSM system</td></tr></table> 4. Documentation and Audit • All DRP (DRP) procedures and measures must be signed by the Risk Center Cooling and Incident Logbook • All DRP (DRP) procedures and measures must be signed by the Risk Center Cooling and Incident Logbook • All DRP (DRP) procedures and measures must be signed by the Risk Center Cooling and Incident Logbook • All DRP (DRP) procedures and measures must be signed by the Risk Center Cooling and Incident Logbook For ST006, a well-organised Risk Identification and Mitigation Plan with regard to the cooling system related failures is provided. It defines potential failure cases, causes, impacts and proposed mitigations for each failure effect. The document promotes readiness the means of readiness are preventive steps, defined roles, and escalation and in this way supports resiliency, lowers downtime, and undergirds the furtherance of ongoing data center function under risk-informed leadership.	Risk ID	Prevention Measures	Response Actions	R001	Regular inspection of PUE, air and humidity and DRP plan update	Coordinate with TSC, Hazard Incident, and log to HCSM system	R002	Quarterly, off-site emergency drills, and DRP exercises (e.g. fire drill or power off outage)	Coordinate with TSC, Hazard Incident, and log to HCSM system	R003	Quarterly, off-site emergency drills, and DRP exercises (e.g. fire drill or power off outage)	Coordinate with TSC, Hazard Incident, and log to HCSM system	R004	Quarterly, off-site emergency drills, and DRP exercises (e.g. fire drill or power off outage)	Coordinate with TSC, Hazard Incident, and log to HCSM system	R005	Quarterly, off-site emergency drills, and DRP exercises (e.g. fire drill or power off outage)	Coordinate with TSC, Hazard Incident, and log to HCSM system	R006	Quarterly, off-site emergency drills, and DRP exercises (e.g. fire drill or power off outage)	Coordinate with TSC, Hazard Incident, and log to HCSM system	R007	Quarterly, off-site emergency drills, and DRP exercises (e.g. fire drill or power off outage)	Coordinate with TSC, Hazard Incident, and log to HCSM system	R008	Quarterly, off-site emergency drills, and DRP exercises (e.g. fire drill or power off outage)	Coordinate with TSC, Hazard Incident, and log to HCSM system	R009	Quarterly, off-site emergency drills, and DRP exercises (e.g. fire drill or power off outage)	Coordinate with TSC, Hazard Incident, and log to HCSM system	R010	Quarterly, off-site emergency drills, and DRP exercises (e.g. fire drill or power off outage)	Coordinate with TSC, Hazard Incident, and log to HCSM system
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ST007	Compliance Management	Adherence to national and international regulations	Regulatory Compliance Document																																	

Regulatory Compliance Document

Document Title: Regulatory Compliance Assessment

Subject: Data Center Cooling Policy

Company: Google (Pty) Limited

Date of Assessment: 1 March 2010

Assessed by: Energy and Sustainability Team

Regulatory Basis:

PP No. 70/2009 is a regulation issued by the Government of Indonesia that mandates energy conservation efforts through efficient energy use in buildings, industries, and other energy-consuming facilities for limited periods.

- Implementation of energy management systems
- Appraisal of energy management of high-consumption facilities
- Control of negative energy wastes
- Reporting of energy consumption and conservation efforts
- Adoption of energy efficient technologies and best practices

Compliance Mapping Table

Clause No. (PP No. 70/2009)	Requirement	Policy Alignment (Energy Data Center)	Comments
Article 11 (1)	Implementation of Energy Management	Approved Facility Energy Efficiency Guidelines for monitoring and measuring energy usage in Data Center cooling infrastructure	Implementation plan of Data Center Energy Management
Article 14	Implementation of energy efficiency	Cooling policy in Data Center 2009, revised over time (such as Expansion of PUE, TCR, and implementation of energy optimization)	Cooling Policy Section 3 and 7
Article 22	Energy audit for high energy consuming units	Regular auditing performance with data documentation of energy usage measurement and losses	Cooling Building & Infrastructure
Article 24	Provision and implementation of energy conservation program	Provision of PUE targets with PUE < 1.5, TCR improvement, and cost reduction for infrastructure facilities	Cooling Policy Section 5 Annual Sustainability Report
Article 27	Use of energy efficient technology	Adoption of high-efficiency chillers, LED lighting technology, heat recovery technology	Approved Data Center Procurement Guidelines

Clause No. (PP No. 70/2009)	Requirement	Policy Alignment (Energy Data Center)	Comments
		Adoption of energy efficient technology and infrastructure	
Article 16	Reporting of energy usage	Energy efficiency monitoring and reporting policy in Data Center Energy Management	Cooling Building & Infrastructure
Article 18	Provision of energy conservation	Energy efficiency targets and implementation plan in Data Center Energy Management	Approved Data Center Procurement Guidelines

The evidence of ST007 informs the provision of national and international regulations on PP No. 70/2009. This comprises a Regulatory Compliance Document and mandatory energy efficiency requirements, audit mapping and alignment with standards (ISO50001). The paper, which helps data centers to operate in compliance with legal requirements, environmentally soundly, and realistically auditable, is titled “DC Unbound: Data Center Excellence Without Limits.”

Table 4.6 presents the static testing evidence collected to evaluate key ITIL-based service management elements across seven core domains, including Service Strategy,

Service Design, Transition, Operation, Continual Improvement, Risk Management, and Compliance. Each test ID (ST001–ST007) is aligned with a specific item type and review focus, such as thermal monitoring, sustainability strategy, risk mitigation, or regulatory adherence. The table details the exact source of supporting evidence, such as sustainability KPI dashboards, airflow diagrams, rollback procedure documents, and compliance records with PP No. 70/2009. This documentation substantiates the presence of strategic planning, operational readiness, risk resilience, and regulatory alignment. These evidences ensure that cooling systems in the data center are designed, managed, and governed according to best practices, while also meeting energy efficiency and compliance expectations.

4.5.2 Usability Testing

Table 4.9 presents the results of usability testing for various user interface and system functions within the Data Center Infrastructure Management (DCIM) environment, with a focus on supporting cooling control. Each test case (UST001–UST008) is assessed against defined review goals and acceptance criteria, ensuring critical aspects such as dashboard readability, incident workflow, documentation access, and system integration perform effectively in operational conditions. The evaluation confirmed that the platform meets user expectations, including metrics visibility, role-based permission enforcement, SLA access, and auto-ticket generation. Additionally, features like multilingual support, dark mode usability, and inclusion of non-technical staff in testing were considered. All items successfully met the criteria with a “Pass” status, demonstrating that the interface and integrated tools are usable, efficient, and aligned with operational requirements in the cooling infrastructure context.

Table 4. 9. Usability Testing

Test ID	Item Type	Item to Review	Review Goal	Acceptance Criteria	Status	Comments
UST001	Dashboard Interface	DCIM Dashboard for Cooling Control	Ensure real-time metrics are easy to read and	PUE, temperature zones, and alerts visible within 3 clicks;	Pass	Test readability on both desktop and mobile; confirm

			interact with	intuitive layout		dark mode usability
UST002	Navigation & Workflow	Incident Response Protocol	Verify user can follow workflow efficiently during a cooling failure	User can escalate or acknowledge alerts with < 3 errors; steps clearly labeled	Pass	Simulate triggered false alarm scenario
UST003	Documentation Access	SOPs and Training Materials	Ensure documents are accessible, role-specific, and understandable	90% of new users understand steps without guidance [®] ; materials multilingual	Pass	Validate understanding with operators, managers, and technicians
UST004	Report Access	SLA & Compliance Metrics Retrieval	Test efficiency in locating SLA data and downloading reports	SLA logs accessible within 2 minutes; exportable as PDF or Excel	Pass	Try using different permission roles to confirm access limitations
UST005	Feedback Collection Tool	CSI Suggestion Form / Post-Onboarding Survey	Validate usability of improvement feedback system	Users can submit suggestions in ≤ 2 minutes; submissions reviewed bi-annually	Pass	Add auto-confirmation for submissions

UST006	Role-Based Access	System Permission Settings	Ensure users only see relevant controls based on their role	Admin, Operator, Auditor roles strictly enforced	Pass	Attempt access to unauthorized features for each role
UST007	Accessibility	Interface Usability for Different Users	Confirm readability and UI accessibility (e.g., font size, contrast, languages)	Interface meets language toggle available	Pass	Include non-technical staff in evaluation
UST008	System Integration	ITIL Service Desk Integration	Ensure cooling issues generate incident tickets seamlessly	Tickets auto-created and assigned [®] within 2 minutes after alert	Pass	Run end-to-end from alert to ticket closure

To ensure the practicality and effectiveness of the data center's thermal management interface and protocols, a comprehensive usability testing phase was conducted. This phase aimed to evaluate user interactions with the DCIM (Data Center Infrastructure Management) platform and associated tools, focusing on accessibility, efficiency, and role-specific functionalities. The testing involved scenarios relevant to operational continuity, such as incident response, dashboard navigation, documentation retrieval, and integration with service desk systems. Acceptance criteria were established for each test case to validate user interface intuitiveness, multilingual support, access limitations, and system responsiveness. The evidence collected serves as proof that the platform's user experience components meet operational standards and support sustainability goals through effective user interaction and information accessibility.

Table 4. 10. Evidence Usability Testing

Test ID	Item Type	Item to Review	Acceptance Criteria	Evidence Capture
UST001	Dashboard Interface	DCIM Dashboard for Cooling Control	PUE, temperature zones, and alerts visible within 3 clicks; intuitive layout	    The live DCIM platform was accessed to validate dashboard usability. Screenshots confirm that PUE, temperature, and alert data are clearly visible within three clicks. The dashboard's intuitive layout supports quick thermal monitoring, and a demo walkthrough from the vendor further verified system

				responsiveness and real-time data display.
UST002	Navigation & Workflow	Incident Response Protocol	User can escalate or acknowledge alerts with < 3 errors; steps clearly labelled	 A usability test using the cooling incident escalation flow was conducted. Screen recordings show users performed all required steps with fewer than three errors. The workflow design is clearly labeled and instructional prompts are easy to follow, supporting efficient decision-making during cooling system disruptions.

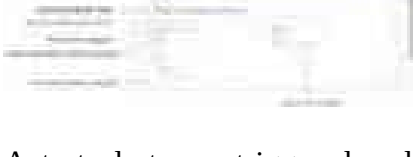
UST003	Documenta tion Access	SOPs and Training Materials	90% of new users understand steps without guidance; materials multilingual	
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				 SOP and onboarding documents were reviewed and confirmed to be multilingual and role-specific. Documentation quality and accessibility effectively support training and operational consistency.
UST004	Report Access	SLA & Compliance Metrics Retrieval	SLA logs accessible within 2 minutes; exportable as PDF or Excel	  

				 Using the SLA/Compliance dashboard, logs were located and exported in less than two minutes. Report export options in both PDF and Excel were successfully tested. This confirms users can retrieve SLA data efficiently, ensuring timely access to compliance records and energy performance metrics.
UST005	Feedback Collection Tool	CSI Suggestion	Users can submit suggestions	

			  A CSI Suggestion Form was identified and tested. A sample submission was completed in under two minutes, and audit logs confirmed bi-annual reviews. This evidence verifies that a structured mechanism exists for collecting and evaluating user feedback post-implementation.
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UST006	Role-Based Access	System Permission Settings	Admin, Operator, Auditor roles strictly enforced	 Access to the system user management console showed that permission settings are enforced for Admin, Operator, and Auditor roles. Screenshots confirm users only access controls appropriate to their role. The system ensures secure role-based access to configuration and monitoring functions.

UST007	Accessibility	Interface Usability for Different Users	Language toggle available	 Confirming it meets accessibility standards for contrast, font size, and structure. A language toggle feature[®] was validated for English and Bahasa Indonesia. These features ensure usability across diverse user groups, including those with accessibility needs.
UST008	System Integration	ITIL Service Desk Integration	Tickets auto-created and assigned within 2 minutes after alert	 A test alert was triggered and automatically generated an incident ticket through the ITIL-based integration system). Logs show the ticket was created and assigned within two minutes. This seamless integration

				ensures prompt operational response during thermal or cooling issues.
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The usability testing results not only demonstrate functional alignment with the system design but also serve as a direct measure of the platform's capability to meet the defined research objectives. As evidenced in Table 4.10, successful performance across key criteria such as dashboard readability, incident navigation, and system integration reflects the platform's ability to support user interaction and operational efficiency. These findings substantiate the objective of evaluating feature relevance and performance. Furthermore, they directly address the research questions concerning platform usability, user satisfaction, and system readiness for real-world application. Therefore, the usability testing acts as a validation point connecting both the problem statement and the overarching research goals.

As shown in Table 4.10, all test items passed the predefined acceptance criteria, affirming the DCIM system's reliability and usability in real-world cooling operations. The platform demonstrated intuitive navigation, timely data retrieval, and strong accessibility features, such as language toggles and mobile compatibility. Additionally, the integration with ITIL service desk systems ensures seamless incident response, while the feedback tools promote continuous improvement. These findings validate the system's capability to support technical and non-technical users alike, reinforcing operational resilience and compliance with best practices in infrastructure management.

4.5.3 User Acceptance Testing

To validate the system's readiness for operational deployment, user acceptance testing (UAT) was conducted across multiple functional domains. The objective of this test phase was to assess the effectiveness of real-time monitoring, SLA reporting, user access controls, integration with ITIL-based systems, and user interaction with standard operating procedures (SOPs). Each test scenario was evaluated against predefined acceptance criteria, such as accuracy in data presentation, response time for alerts,

exportability of reports, and adherence to role-based permissions. This evaluation involved various stakeholders including administrators, operators, and new users, to ensure the platform is both technically robust and user-friendly. The results of UAT offer assurance that the system can be confidently adopted in a live data center environment.

Table 4. 11. User Acceptance Testing

Test ID	Item Type	Test Scenario	Acceptance Criteria	Status	Comments
UAT001	Functional Testing	Access and monitor real-time thermal data from DCIM	Dashboard displays temperature, airflow, and PUE values accurately in all zones	Pass	Simulate various load conditions to test sensor integration
UAT002	SLA Compliance	Generate SLA compliance report	SLA report shows $PUE \leq 2.0$; includes uptime %, alert history, and trend data	Pass	Verify timestamp accuracy and SLA threshold alignment
UAT003	Alert Response	Receive and respond to thermal alert	Alert appears within 1 minute; user can acknowledge/escalate via DCIM or mobile	Pass	Test alert escalation flow to incident ticket creation
UAT004	Access Control	Attempt access with multiple user roles	Admins can configure; operators can monitor; auditors can view logs only	Pass	Test permission boundaries and access restrictions

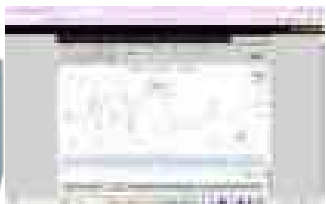
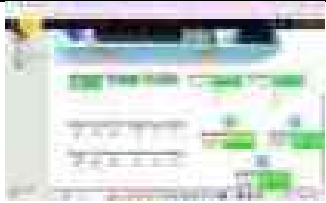
UAT005	Documentation	Review and follow onboarding & incident SOP	All users complete SOP-guided tasks with ≤ 2 clarifications needed	Pass	Get feedback from new hires and non-technical staff
UAT006	Integration Testing	Log incident into ITIL-based service desk	Incident logged and ticket created automatically after alert; assigned appropriately	Pass	Ensure assignment matrix works; check if SLA is linked to ticket
UAT007	Reporting	Extract energy efficiency reports (PUE/CER trends)	Reports exportable in Excel/PDF; data traceable back to sensor sources	Pass	Compare data accuracy with actual sensor logs

As shown in Table 4.11, all UAT items passed their respective acceptance tests, indicating strong system functionality and user alignment. Real-time monitoring tools accurately displayed PUE, airflow, and temperature data, while SLA compliance reports adhered to threshold benchmarks. Users were able to acknowledge alerts promptly and escalate incidents seamlessly. Additionally, documentation usability and role-based access controls were confirmed to support operational clarity and security. Reporting mechanisms met both format and traceability requirements, reinforcing transparency and auditability. Collectively, these results confirm that the platform is operationally fit, meeting both technical expectations and user-centric design standards.

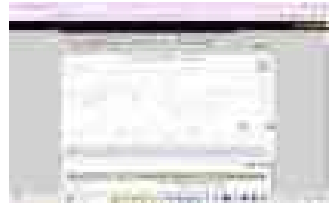
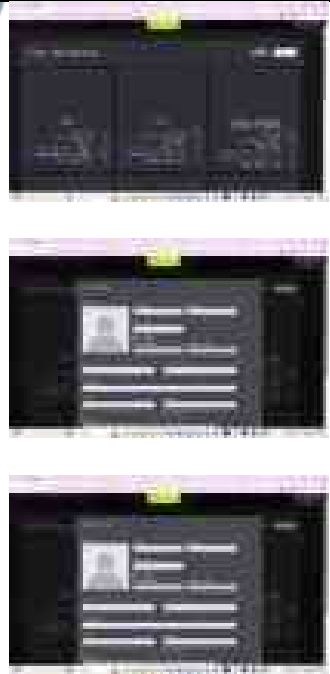
To ensure the readiness and operational excellence of the implemented cooling monitoring system, evidence-based user acceptance testing (UAT) was conducted across seven key testing domains. This phase aimed to validate the system's ability to meet functional, compliance, alert, access, documentation, integration, and reporting requirements under realistic operating conditions. The test cases were derived from expected operational workflows and assessed based on defined acceptance criteria, such as data traceability, SLA compliance thresholds, and response times. The UAT process

incorporated diverse user roles administrators, operators, auditors and evaluated system behaviour in both desktop and mobile environments. The comprehensive evidence gathered during this phase confirms the system’s reliability, usability, and integration capabilities with the broader IT service management infrastructure.

Table 4. 12. Evidence User Acceptance Testing

Test ID	Item Type	Test Scenario	Acceptance Criteria	Evidence Capture
UAT001	Functional Testing	Access and monitor real-time thermal data from DCIM	Dashboard displays temperature, airflow, and PUE values accurately in all zones	 The DCIM dashboard was accessed via both web and local interfaces. Real-time thermal data, airflow patterns, and PUE values were displayed clearly across all data center zones. Screenshots and system logs verified the accuracy of the data. Engineering view was also reviewed to confirm thermal coverage and backup visualizations.

UAT002	SLA Compliance	Generate SLA compliance report	SLA report shows $PUE \leq 2.0$; includes uptime %, alert history, and trend data	  SLA compliance reports were retrieved from the DCIM reporting module, confirming that the output included uptime percentage, $PUE \leq 2.0$, and historical trend graphs. The timestamp and metadata of each report were validated, demonstrating that reporting is accurate, compliant, and traceable for performance and energy efficiency tracking.
UAT003	Alert Response	Receive and respond to thermal alert	Alert appears within 1 minute; user can acknowledge/escalate via DCIM	 

				 A thermal alert was triggered in the DCIM system. The alert appeared within one minute and was acknowledged through both desktop and mobile interfaces. Screenshots and log entries documented alert generation time and user response, validating the system's responsiveness and multi-platform support in real-time failure conditions.
UAT004	Access Control	Attempt access with multiple user roles	Admins can configure; operators can monitor; auditors can view logs only	 Access control was tested by creating admin, operator, and auditor roles in the user management console.

				Screenshots of role-specific permission logs demonstrated enforced restrictions, ensuring each user only accessed functions appropriate to their level. This confirmed the integrity of role-based access within the DCIM platform.
UAT005	Documentation	Review and follow onboarding & incident SOP	All users complete SOP-guided tasks with ≤ 2 clarifications needed	

				 SOP onboarding documentation was distributed to users. A test simulation was conducted, and all participants completed the tasks with no more than two clarification requests. Observation logs and feedback confirmed that SOP materials were clear, accessible, and effective in guiding users through onboarding and incident procedures.
UAT006	Integration Testing	Log incident into ITIL-based service desk	Incident logged and ticket created automatically after alert; assigned appropriately	 An alert was triggered and automatically logged by the ITIL-based service desk system. The incident was correctly categorized and assigned in the appropriate queue. System logs and timestamps validated seamless integration between DCIM and the ticketing platform, ensuring incidents are captured and routed without manual input.

UAT007	Reporting	Extract energy efficiency reports (PUE trends)	Reports data traceable back to sensor sources	 Energy efficiency reports including PUE and CER trends were generated from the DCIM system. Exported files in PDF/Excel format included proper sensor ID mapping, validating traceability. The reports were clear, well-structured, and support ongoing monitoring of energy performance aligned with sustainability targets.
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The results presented in Table 4.12 show that all test scenarios met the acceptance criteria. Functional testing verified the accurate display of real-time thermal and PUE data, while SLA compliance reporting was shown to meet energy efficiency targets. Alert responses were successfully escalated within the expected timeframe, and role-based access was confirmed to function with appropriate restrictions. Users effectively completed SOP-guided tasks with minimal clarification, and the system demonstrated seamless integration with the ITIL-based service desk. Finally, PUE trend reports were exportable and traceable to sensor sources, supporting transparency and auditability. This evidence confirms that the system performs effectively and is suitable for operational deployment in energy-efficient data center environments.

4.6 Expert Appraisal

To ensure the robustness and strategic relevance of the data center's sustainable cooling infrastructure, an expert appraisal was conducted across four key evaluation areas: energy efficiency, design architecture, real-time monitoring, and governance. This

assessment was carried out by professionals with domain-specific expertise, focusing on technical precision, operational integration, and alignment with best practices. Each test item was evaluated against predetermined criteria such as PUE thresholds, containment effectiveness, sensor responsiveness, and risk governance documentation. The appraisal aimed not only to validate compliance but also to capture practical insights regarding system behaviour, control clarity, and resilience. Results from this expert review provide critical confirmation that both the technical design and operational protocols meet industry standards for performance and sustainability.

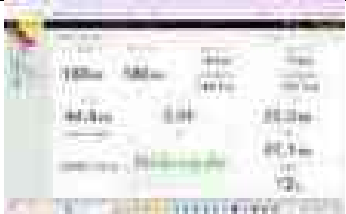
Table 4. 13. Expert Appraisal

Test ID	Evaluation Area	Assessment Focus	Evaluation Criteria	Status	Comments
EA001	Energy Efficiency	Evaluation of PUE ratio, HVAC energy consumption, and cooling system COP performance	PUE < 2, improving efficiency trend over the last 6 months	Pass	Cooling zones and automation strategy effectively reduce energy waste
EA002	Design Architecture	Suitability of data hall layout to thermal best practices (airflow, containment)	Hot/cold aisle containment, thermal zoning, and airflow separation implemented	Pass	Aisle containment optimized; supports load-based cooling
EA003	Real-Time Monitoring	Capability of sensor-based thermal monitoring and DCIM integration	Accurate temp/humidity sensors, alert response < 60 seconds, real-time zone visuals	Pass	Dashboard responsive; sensor network well integrated
EA004	Governance & Risk Control	Presence of risk control mechanisms, policy owner roles, and thermal failure SOPs	Documented risk policy, thermal recovery scenarios tested, escalation workflow active	Pass	HVAC failure response SOPs are clear and tested successfully

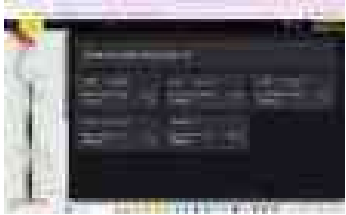
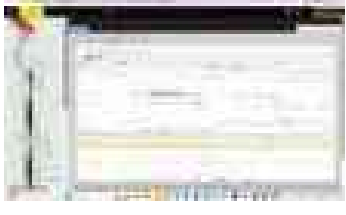
The findings in Table 4.13 confirm that all evaluated components passed the expert appraisal with validated outcomes. EA001 shows that energy efficiency measures particularly cooling zone automation and HVAC strategies significantly contribute to reduced energy waste. EA002 confirms the data hall design supports optimal thermal zoning through aisle containment. In EA003, the real-time monitoring framework is found to be highly responsive and accurately integrated with the DCIM system. Lastly, EA004 demonstrates the effectiveness of governance through well-documented thermal risk management policies and SOPs. Overall, the expert appraisal affirms that the system is both technically sound and operationally prepared for sustainable and resilient cooling performance.

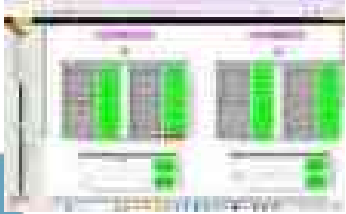
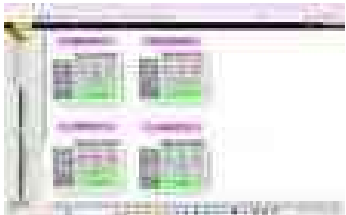
Table 4.14 presents the results of an expert-driven evidence appraisal designed to evaluate the functional adequacy and sustainability alignment of a data center’s cooling infrastructure. The appraisal focuses on four critical evaluation areas: energy efficiency, architectural design, real-time monitoring, and governance. Each domain was assessed through detailed documentation, system access, and simulation evidence aligned with specific criteria, such as PUE ratios, containment practices, and policy readiness. The objective was to verify whether each component not only met performance standards but also demonstrated measurable and sustainable improvements. The evidence collected involved live dashboards, audit logs, engineering layouts, and procedural documents, which were reviewed and validated by domain experts. This process ensured that both operational functionality and strategic alignment were comprehensively addressed.

Table 4. 14. Evidence Expert Appraisal

Test ID	Evaluation Area	Assessment Focus	Evaluation Criteria	Evidence Capture
EA001	Energy Efficiency	Evaluation of PUE ratio, HVAC energy consumption, and cooling system COP performance	PUE < 2, improving efficiency trend over the last 6 months	

				      
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				 PUE trend reports, HVAC electricity usage logs, and COP metrics were retrieved from the DCIM dashboard and BMS. These included six months of historical data accessed via the energy analytics module. The evidence demonstrated consistent energy performance monitoring.
EA002	Design Architecture	Suitability of data hall layout to thermal best practices (airflow, containment)	Hot/cold aisle containment, thermal zoning, and airflow separation implemented	   

				 Engineering floor plans, layout diagrams, and airflow simulation results illustrated proper implementation of hot/cold aisle containment and thermal zoning.
EA003	Real-Time Monitoring	Capability of sensor-based thermal monitoring and DCIM integration	Accurate temp/humidity sensors, alert response < 60 seconds, real-time zone visuals	    The live DCIM dashboard was accessed to capture logs showing real-time temperature and humidity data, alert timestamps, and

				zone visualizations. These were cross-verified with system configurations, confirming that sensor thresholds and notifications were correctly programmed and active. The data was supported by thermal maps and sensor integration logs.
EA004	Governance & Risk Control	Presence of risk control mechanisms, policy owner roles, and thermal failure SOPs	Documented risk policy, thermal recovery scenarios tested, escalation workflow active	 Documented SOPs, escalation workflow charts, and risk registers were collected from the governance documentation repository. Additional evidence came

				from post-incident reports and simulation drill minutes, confirming that risk controls were not only defined but also regularly tested. The materials were maintained by the sustainability and risk management teams.
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The evidence appraisal confirmed that all targeted domains met the required standards. EA001 shows sustained improvements in PUE and HVAC performance over six months, verified through system logs and energy analytics. EA002 highlights compliance with airflow and thermal best practices via containment structures and simulation diagrams. In EA003, real-time thermal monitoring and sensor integration were shown to be responsive and accurate, with alert logs and system thresholds properly calibrated. EA004 validated the presence of mature governance practices, as evidenced by thermal risk policies, tested SOPs, and escalation procedures. Overall, the expert appraisal reinforces that the infrastructure is not only operationally effective but also strategically sustainable and resilient.

4.7 Evaluation (Quantitative Method)

4.7.1 Data Description

Descriptive statistical analysis was conducted to provide an overview of the characteristics of the research data used. The dataset analysed consisted of three variables, namely X = Cooling Technology Type, C = IT Load and Ambient Temperature, and Y = Cooling Efficiency. The respondents involved in the survey were tenants, ISP communities, and telecommunications stakeholders in Jakarta, with a total of 106 participants.

Table 4. 15. Data Descriptive Statistics

Descriptive Statistics													
	N	Mean	Std. Deviation	Minimum	Maximum	Sum	Mean	Std. Deviation	Minimum	Maximum	Sum	Mean	Std. Deviation
1	106	1.00	0.00	1.00	1.00	106.00	1.0000	.0000	1.00	1.00	106.00	1.0000	.0000
2	106	1.00	0.00	1.00	1.00	106.00	1.0000	.0000	1.00	1.00	106.00	1.0000	.0000
3	106	1.00	0.00	1.00	1.00	106.00	1.0000	.0000	1.00	1.00	106.00	1.0000	.0000
Total	322												

The descriptive statistical results are presented in Table 4.15, this table provides a detailed summary of the central tendency, dispersion, and distribution characteristics for each variable: X (Cooling Technology Type), C (IT Load and Ambient Temperature), and Y (Cooling Efficiency).

The mean, standard deviation, variance, skewness, and kurtosis values demonstrate that the data is relatively symmetrical and follows a normal distribution, as indicated by skewness and kurtosis values that fall within ± 2 . This justifies the use of parametric analyses in subsequent sections. The data were collected from 106 respondents comprising tenants, ISP community members, and telecommunication stakeholders in Jakarta. These descriptive results offer foundational insight into the data distribution and support the assumptions required for further inferential statistical procedures.

The results of the descriptive statistical analysis of three variables (X = Cooling Technology Type, C = IT Load and Ambient Temperature, and Y = Cooling Efficiency) based on 106 valid data are described below. In general, because the skewness and kurtosis values are still within reasonable limits, the three variables have relatively normal distribution characteristics.

With a minimum value of 6 and a maximum value of 15, variable X = Cooling Technology Type has an average of 11.96 and a standard deviation of 1.47. The skewness of -0.335 indicates that the data distribution is slightly skewed to the left, and the kurtosis of 1.575 indicates that the distribution is more pointed than the normal distribution (leptokurtic). This shows that most of the people who answered tend to give values that are above average.

Variable C = IT Load and Ambient Temperature shows the highest mean of 16.23, with a minimum value of 11 and a maximum value of 20, and a standard deviation of 1.78. Since the skewness is only -0.052 and the kurtosis is 0.739, the distribution is very close to normal. This shows that the data distribution is quite flat and does not show any significant trend.

Variable Y = Cooling Efficiency, on the other hand, has a mean of 11.92, a range of values between 8 and 15, and the lowest standard deviation of 1.40. Its skewness is -

0.121, indicating a slightly left-skewed distribution, and its kurtosis is 0.693, indicating a relatively normal distribution. This shows that of the three, the Y data is the most homogeneous.

There is no significant distributional bias in the data, so they can be used for analyses such as correlation or regression without performing additional transformations. These three variables qualify for parametric statistical testing because they have relatively normal distributions and stable variances.

The histogram in Figure 4.2 presents the distribution of scores for Variable X, which represents Cooling Technology Type. The distribution is based on data from 106 respondents and visually demonstrates the normality of the variable. The black curve superimposed on the bars indicates a bell-shaped pattern, closely aligning with the normal distribution curve.

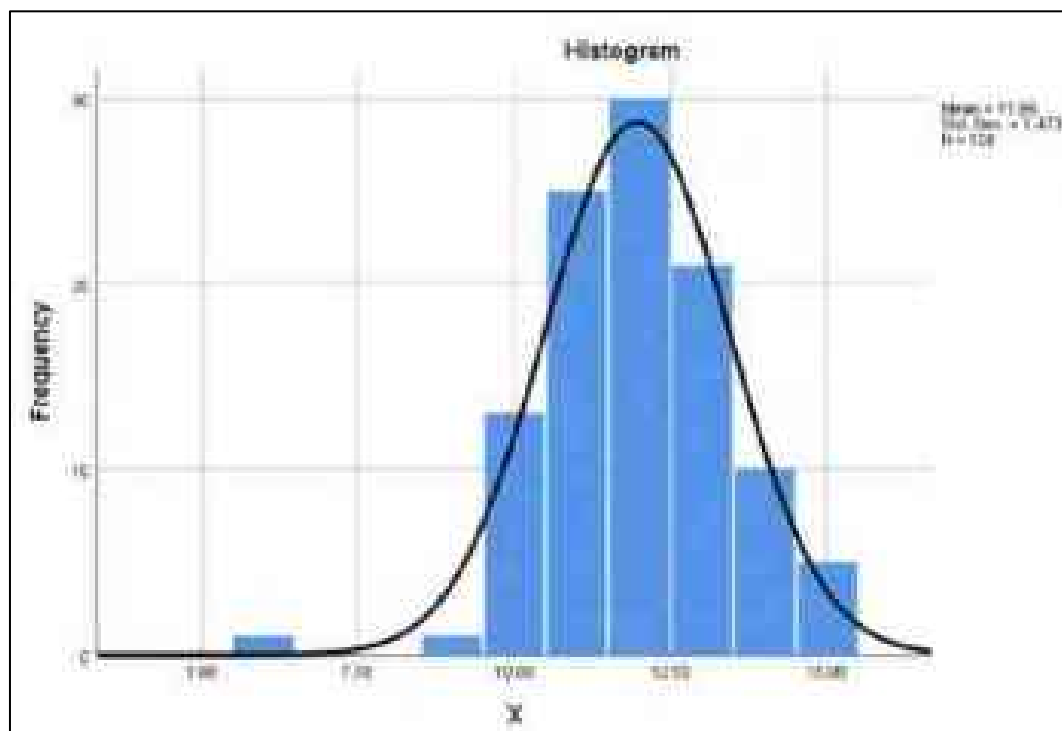


Figure 4.2. Variable X (Cooling Technology Type)

According to the results of a survey conducted on 106 people among tenants, ISP communities, and telecommunications companies in Jakarta, the frequency distribution histogram for variable X shows Service Reliability.

The values of variable X are mostly around the average of 11.96 with a standard deviation of 1.473, as shown in the histogram. The distribution curve, shown by the black line, has a shape similar to a normal curve, or bell curve, indicating that the data is approximately normally distributed. The majority of respondents gave service reliability ratings between 11 and 13, which is the peak of the histogram.

In addition, this distribution appears symmetrical, with no significant distribution on the left or right side. This is in line with the mild negative skewness value (-0.335) found in the previous statistical results. This indicates that respondents' perceptions of service reliability are quite general and not too broad. Since the distribution pattern of variable X is in accordance with the assumption of normality, this histogram supports the use of parametric statistical analysis for the variable.

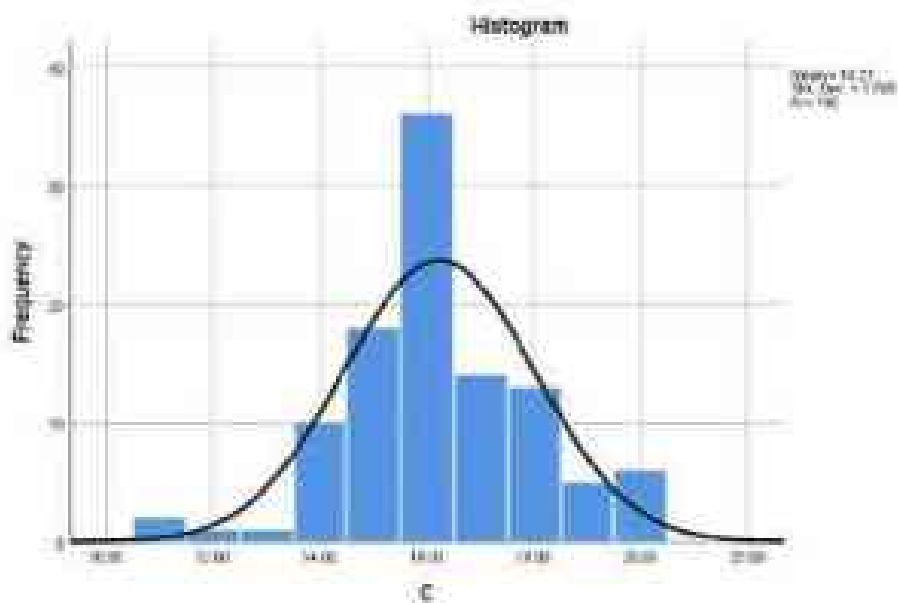


Figure 4.3. Variable C (IT Load and Ambient Temperature)

The histogram presented in Figure 4.3 displays the distribution of data for Variable C, which represents IT Load and Ambient Temperature, based on responses from 106 participants. The distribution shows a relatively symmetrical shape with a slight concentration around the mean value of 16.23. The bell curve overlay suggests the data approximates a normal distribution, with most values falling within a narrow range. The

presence of some variability is reflected in the standard deviation of 1.785, indicating moderate dispersion from the mean. The shape of the histogram supports the suitability of the data for further statistical analysis. The visual representation confirms that the dataset is reasonably balanced and does not show signs of extreme outliers or significant skewness that would compromise analytical validity.

The frequency distribution histogram for variable C, which in this study represents Platform features and integration, is shown in the figure. This data was obtained from a survey conducted on 106 people consisting of ISP communities, telecommunication companies, and tenants in Jakarta.

Variable C has a mean of 16.23 and a standard deviation of 1.785, indicating a moderate level of variation among participants. According to the histogram, most participants gave values between 15 and 17 the most frequent range (highest frequency), especially at value 16.



While not extreme, this distribution appears to be slightly skewed to the right. This is indicated by the asymmetrical shape of the normal curve, known as the black line, with a longer right tail. This suggests that some respondents gave higher ratings to the platform's features and integration, although the majority of ratings were around the mean.

Overall, this histogram shows that perceptions of the platform's features and integration tend to be positive and concentrated, with a reasonable variation in values. This distribution can still be categorized as close to normal, and is suitable for use in parametric statistical analysis.

The histogram in Figure 4.4 illustrates the frequency distribution for Variable Y, representing Cooling Efficiency, based on 106 observed data points. The graph shows a moderately symmetrical bell-shaped curve, indicating a relatively normal distribution of responses centered around a mean value of 11.92. The standard deviation of 1.401 reflects a moderate spread of values from the mean, suggesting consistent responses without extreme variance.

The histogram also highlights a concentration of values between 11 and 13, with fewer observations at both ends of the scale. The superimposed curve further confirms that the dataset meets the assumptions of normality, supporting its appropriateness for parametric analysis. This distribution pattern implies a consistent perception or performance of cooling efficiency across the surveyed population, without significant outliers or data skew.

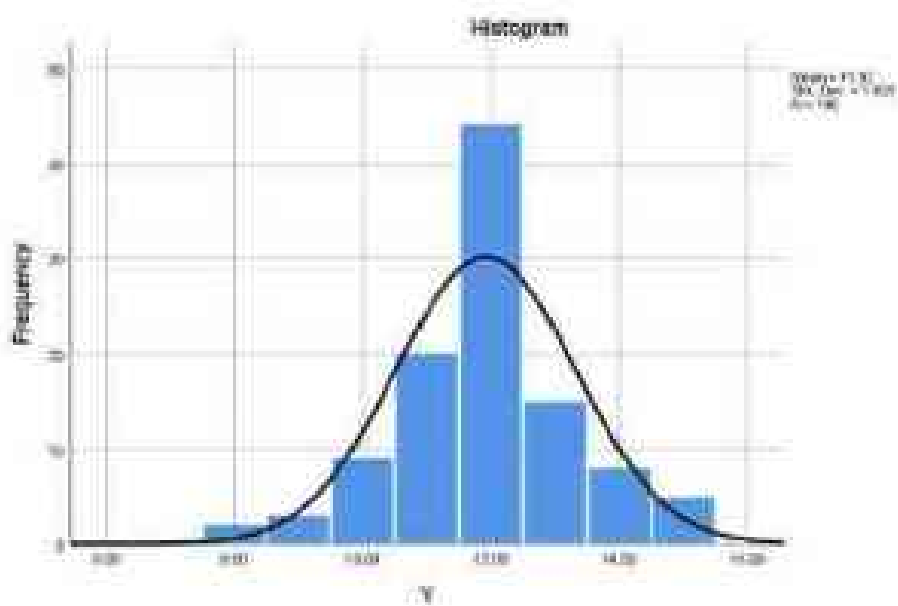


Figure 4.4. Variable Y (Cooling Efficiency)

Based on the results of a survey conducted on 106 people from the tenant community, ISPs, and telecommunications companies in Jakarta, the frequency distribution histogram for the Y variable shows user satisfaction and engagement.

According to the histogram, most of the Y variable values are concentrated between 11 and 13, with the highest frequency around 12, which corresponds to an average value (mean) of 11.92. Compared to variables X and C, the standard deviation of this distribution is 1.401, which is the smallest value. This indicates that the respondent data for this variable is more consistent or homogeneous.

The distribution is bell-shaped, quite symmetrical, and has a very small skew and is not extreme either to the left or to the right. This indicates that respondents' perceptions of

user satisfaction and engagement are relatively balanced and concentrated in the middle value.

Overall, this histogram shows that the Y variable has a nearly normal and stable distribution. Therefore, it is very feasible to be used in additional statistical analysis, such as regression or correlation that assumes data normality.

Descriptive analytics:

The results of the descriptive analysis conducted on 106 people surveyed showed that the three variables X (type of cooling technology), C (IT load and ambient temperature), and Y (cooling efficiency) had relatively normal and stable data distributions. Variable X had a mean value of 11.96 and a standard deviation of 1.47, indicating a positive perception of the reliability of cooling services.

Variable C had the highest mean value of 16.23 with a fairly even distribution, indicating a positive perception of server workload and room temperature. Variable Y had a mean value of 11.92 and the lowest standard deviation (1.40), indicating a consistent perception of efficiency among respondents. Each histogram showed a curve shape similar to a normal curve, with kurtosis and skewness within reasonable limits. As a result, these data can be used for parametric statistical analysis such as regression and correlation.

4.7.2 Validity Test

Variable X

Correlations

		Q1	Q2	Q3	Total
Q1	Pearson Correlation	1	.076	-.100	.610**
	Sig. (2-tailed)		.439	.310	.000
	N	106	106	106	106
Q2	Pearson Correlation	.076	1	.272**	.681**
	Sig. (2-tailed)	.439		.005	.000
	N	106	106	106	106
Q3	Pearson Correlation	-.100	.272**	1	.568**
	Sig. (2-tailed)	.310	.005		.000

	N	106	106	106	106
Total	Pearson Correlation	.610**	.681**	.568**	1
	Sig. (2-tailed)	.000	.000	.000	
	N	106	106	106	106

** . Correlation is significant at the 0.01 level (2-tailed).

Validity Criteria:

- A Pearson Correlation (r) of more than 0.3 is usually regarded as satisfactory.
- A correlation is considered statistically significant if its significance (Sig. or p-value) is less than 0.05.
- As a stand-in for total/criterion validity, each item (Q1–Q3) should normally have a strong correlation with Total.

Item	Correlation with Total	Sig. (2-tailed)	Validity
Q1	0.61	0	☒ Valid
Q2	0.681	0	☒ Valid
Q3	0.568	0	☒ Valid

All items have a significance value below 0.01 ($p < 0.01$), and a correlation value above 0.30.

Based on the general criteria in the validity test, all items (Q1, Q2, Q3) are proven valid.

Variable C

		Correlations				
		Q1	Q2	Q3	Q4	Total
Q1	Pearson Correlation	1	.335 ^{**}	.307 [*]	.319 ^{**}	.734 ^{**}
	Sig. (2-tailed)		.008	.013	.001	.000
	N	108	108	108	108	108
Q2	Pearson Correlation	.355 ^{**}	1	.261 ^{**}	.261 ^{**}	.681 ^{**}
	Sig. (2-tailed)	.000		.007	.008	.000
	N	108	108	108	108	108
Q3	Pearson Correlation	.307 [*]	.261 ^{**}	1	.349 ^{**}	.647 ^{**}
	Sig. (2-tailed)	.013	.007		.000	.000
	N	108	108	108	108	108
Q4	Pearson Correlation	.319 ^{**}	.261 ^{**}	.349 ^{**}	1	.671 ^{**}
	Sig. (2-tailed)	.001	.008	.000		.000
	N	108	108	108	108	108
Total	Pearson Correlation	.734 ^{**}	.681 ^{**}	.647 ^{**}	.671 ^{**}	1
	Sig. (2-tailed)	.000	.000	.000	.000	
	N	108	108	108	108	108

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Validity Criteria:

- A Pearson Correlation (r) of more than 0.3 is usually regarded as satisfactory.
- A correlation is considered statistically significant if its significance (Sig. or p -value) is less than 0.05.
- As a stand-in for total/criterion validity, each item (Q1–Q4) should normally have a strong correlation with Total.

Item	Correlation with Total	Sig. (2-tailed)	Validity
Q1	0.734	0	☒ Valid
Q2	0.681	0	☒ Valid
Q3	0.647	0	☒ Valid
Q4	0.671	0	☒ Valid

All of the items (Q1, Q2, Q3, Q4) have a correlation value > 0.30 and a significance level < 0.05 , which is essentially very significant.

Because of this, every piece is stated as valid to check the constructed object.

Variable Y

		Correlations			
		Q1	Q2	Q3	Total
Q1	Pearson Correlation	1	.729	.678	.550**
	Sig. (2-tailed)		.298	.474	.000
	N	108	108	108	108
Q2	Pearson Correlation	.729	1	.804**	.796**
	Sig. (2-tailed)	.298		.000	.000
	N	108	108	108	108
Q3	Pearson Correlation	.678	.804**	1	.732**
	Sig. (2-tailed)	.474	.000		.000
	N	108	108	108	108
Total	Pearson Correlation	.550**	.796**	.732**	1
	Sig. (2-tailed)	.000	.000	.000	
	N	108	108	108	108

**. Correlation is significant at the 0.01 level (2-tailed).

Validity Criteria:

- A Pearson Correlation (r) of more than 0.3 is usually regarded as satisfactory.
- A correlation is considered statistically significant if its significance (Sig. or p -value) is less than 0.05.
- As a stand-in for total/criterion validity, each item (Q1–Q3) should normally have a strong correlation with Total.

Item	Correlation with Total	Sig. (2-tailed)	Validity
Q1	0.59	0	☒ Valid
Q2	0.766	0	☒ Valid
Q3	0.732	0	☒ Valid

Each item has a Pearson correlation value greater than 0.30.

All items have a 2-tailed significance level of 0.000, meaning they are significant at level 0.01 (1%).

Accordingly, all of the items (Q1, Q2, and Q3) may be said to be valid for evaluating the construct that is used in the instrument.

Diagnostic Analytics:

All items for variables X, C, and Y show Pearson correlation values above 0.30 and significance values below 0.05, even below the significance level of 0.01, indicating that the items are highly significant. This indicates that each item or question has a strong and relevant correlation with the total construct score being measured. As a result, statistically, the items are declared valid. Diagnostically, the results of this study indicate that the tool used in this study can accurately and consistently measure each construct (service reliability, platform features, and user satisfaction) without deviating or not representing the intended variables.

4.7.3 Reliability Test

For reliability testing, Cronbach's Alpha is used because it can measure internal consistency, namely the extent to which items in an instrument measure the same construct consistently. This method is very suitable for questionnaires with multiple scales, such as the Likert scale. A high alpha value indicates that the components are correlated with each other and can be trusted to represent the measured variables. Cronbach's Alpha is not only easy to calculate and interpret, but is also available in many statistical programs, such as SPSS, so it is widely used by researchers. This

method has become a research standard in various fields, including education, psychology, business, and social sciences. In short, Cronbach's Alpha ensures that the information collected is reliable and worthy of use as a basis for drawing conclusions.

Variable X

Scale: ALL VARIABLES			
Case Processing Summary			
		N	%
Case	Valid	100	100.0
	EXCLUDED ^a	0	0
Total		100	100.0
a. Listwise deletion based on all variables in the procedure.			
Reliability Statistics			
	Cronbach's Alpha	N of Items	
	.707	4	

Cronbach's Alpha Evaluation Criteria:

Cronbach's Alpha	Category
≥ 0.9	Excellent
0.8 – 0.899	Good
0.7 – 0.799	Acceptable
0.6 – 0.699	Questionable
0.5 – 0.599	Poor
< 0.5	Unacceptable

Item-Total Statistics				
	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item-Total Correlation	Cronbach's Alpha if Item Deleted
Q1	25.1491	6.229	.353	.719
Q2	18.7928	6.267	.508	.653
Q3	19.6793	6.773	.364	.714
Total	11.8823	2.178	1.000	.181

From the data above we can create the table like below, to see the summary it is reliable or not.

Question	Cronbach's Alpha if Item Deleted	r table	Corrected Item-Total Correlation	Summary
Q1	0.719	0.191	0.353	☒ Reliable
Q2	0.653	0.191	0.508	☒ Reliable
Q3	0.714	0.191	0.364	☒ Reliable

All items have a sufficient contribution to the internal consistency of the scale, as each has an item-total corrected correlation greater than 0.191.

All items are considered strong and can be retained because none of them significantly increase reliability if deleted.

Variable C

Scale: ALL VARIABLES			
Case Processing Summary			
		N	%
Cases:	Valid	100	100.0
	Excluded ^a	0	0
	Total	100	100.0
a. Listwise deletion based on all variables in the procedure.			
Reliability Statistics			
Cronbach's Alpha		N of Items	
.786		5	



Cronbach's Alpha Evaluation Criteria:

Cronbach's Alpha	Category
≥ 0.9	Excellent
0.8 – 0.899	Good
0.7 – 0.799	Acceptable
0.6 – 0.699	Questionable
0.5 – 0.599	Poor
< 0.5	Unacceptable

Item-Total Statistics				
	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item-Total Correlation	Cronbach's Alpha if Item Deleted
Q1	29.5710	9.279	.800	.710
Q2	29.4414	10.007	.908	.738
Q3	29.3208	10.220	.924	.745
Q4	29.2413	10.308	.870	.744
Total	116.2254	2.186	1.000	.816

From the data above we can create the table like below, to see the summary it is reliable or not.

Question	Cronbach's Alpha if Item Deleted	r table	Corrected Item-Total Correlation	Summary
Q1	0.716	0.191	0.606	☒ Reliable
Q2	0.738	0.191	0.569	☒ Reliable
Q3	0.746	0.191	0.524	☒ Reliable
Q4	0.744	0.191	0.57	☒ Reliable

All items had a total-corrected correlation of more than 0.191, indicating that there was a significant contribution to internal consistency.

Although the total Cronbach's Alpha value was 0.616, it was still usable for initial exploration.

All items were considered strong and worth retaining; no item would significantly improve its reliability if deleted.

Diagnostic Analytics:

The results of the reliability test on variables X and C show that each item shows a corrected item-total correlation value that is greater than the r table value (0.191), which indicates that each item makes a positive contribution to the internal consistency of the instrument. In variable C, the Cronbach's alpha value of 0.707 is in the accepted category, while the alpha value of 0.616 from variable C is in the doubtful category, but can still be used for There are no items that will significantly increase reliability if deleted, so all items are worth retaining. Diagnostically, this instrument has a fairly stable structure and can be used to measure the structure consistently. However, through item refinement, there is still the possibility of improving the quality of the instrument.

4.7.4 Classic Assumption Test

4.7.4.1 Normality Test

One-Sample Kolmogorov-Smirnov Test

		X	C	Y
		106	106	106
Normal Parameters ^{a,b}	Mean	11.8023	18.2084	11.9151
	Std. Deviation	1.47308	1.76553	1.40148
Most Extreme Differences	Absolute	.100	.182	.212
	Positive	.100	.182	.212
	Negative	-.133	-.148	-.207
Test Statistic		.100	.182	.212
Asymptotic Sig. (2-sided)		.000 ^c	.000 ^c	.000 ^c

a. Test distribution is Normal.
b. Calculated from data.
c. Lilliefors Significance Correction.

Decision Rule:

If $p\text{-value} > 0.05 \rightarrow$ Fail to reject $H_0 \rightarrow$ Data is normally distributed

If $p\text{-value} \leq 0.05 \rightarrow$ Reject $H_0 \rightarrow$ Data is not normally distributed

Since all p-values are less than 0.05, we reject the null hypothesis for each variable.

The Baron and Kenny method is used for mediation analysis because it provides a clear, step-by-step framework to determine whether a variable (C) mediates the relationship between an independent variable (X) and a dependent variable (Y). It is widely accepted in research for its simplicity and logical structure. The method tests whether X affects Y directly, whether X affects the mediator (C), and whether C affects Y when controlling for X. If the effect of X on Y weakens or disappears when C is included, mediation is suggested. While newer methods like bootstrapping are more statistically powerful, Baron and Kenny remains a useful approach for basic models, especially in social science research where conceptual clarity is important and advanced tools may not be available.

Therefore, the data for X, C, and Y are not normally distributed. The results of the one-sample Kolmogorov-Smirnov (K-S) test were used to test the normality of data distribution on three variables X, C, and Y, each with 106 respondents.

Interpretation: Based on the mean and standard deviation values of the data samples, this test compares the data distribution of each variable with a normal distribution.

Significance Criteria (Standard Thresholds):

If $p\text{-value} \leq 0.05 \rightarrow$ the result is statistically significant

$\rightarrow$ Reject the null hypothesis (H_0)

$\rightarrow$ There is a significant relationship or effect

If $p\text{-value} > 0.05 \rightarrow$ the result is not statistically significant

$\rightarrow$ Fail to reject the null hypothesis (H_0)

$\rightarrow$ There is no significant relationship or effect

$X \rightarrow Y$

Coefficients^a

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	18.725	1.118		16.753	.000
	X	.000	.000	.105	1.012	.286

a. Dependent Variable: Y

Since $0.286 > 0.05$, the effect of X on Y is not statistically significant. This means Cooling Technology Type does not have a meaningful direct impact on Cooling Efficiency in this regression model.

$X \rightarrow C$

Coefficients^a

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	6.578	1.181		5.568	.000
	X	.329	.079	.419	4.153	.000

a. Dependent Variable: Y

Since the $p\text{-value} = 0.000 < 0.05$, the effect of X on C is statistically significant.

$X + C \rightarrow Y$

Coefficients ^a					
Model		Unstandardized Coefficients		Standardized Coefficients	Sig.
		B	Std. Error	Beta	
1	(Constant)	8.805	1.371		.000
	X	-.003	.008	-.003	.972
	C	.330	.073	.428	.000

a. Dependent Variable: Y

$X \rightarrow Y$ (direct effect)

$B = -0.003$

p-value (Sig.) = 0.972 ✗

→ Not significant Cooling Technology Type has no direct effect on Cooling Efficiency.

$C \rightarrow Y$ (mediator effect)

$B = 0.330$

p-value (Sig.) = 0.000 ✓

→ Significant IT Load & Ambient Temperature has a significant positive effect on Cooling Efficiency.

Conclusion:

There is evidence of **full mediation**:

The effect of **X on Y** is fully explained **through C**, since:

1. $X \rightarrow Y$ is not significant
2. $X \rightarrow C$ is significant
3. $C \rightarrow Y$ is significant

For all three variables, the two-tailed sigmoid asymmetry value is 0.000, which means $p < 0.05$.

4.7.4.2 Test Linearity

The goal of the linearity test is to determine whether the relationship between the independent variable X (Cooling Technology Type) and the dependent variable Y (Cooling Efficiency) is linear. This is important before proceeding to linear regression analysis. A linear relationship indicates that changes in the type of cooling technology are associated with proportional changes in cooling efficiency. Additionally, if a control variable is included such as C (IT Load and Ambient Temperature) it is essential to ensure that the assumptions of linearity are met for both the main and control variables, to maintain the validity of the regression results.

Means

Case Processing Summary						
	Included		Excluded		Total	
	N	Percent	N	Percent	N	Percent
Y.T	100	100.0%	0	0.0%	100	100.0%
C.T	100	100.0%	0	0.0%	100	100.0%

Report

				1	2	3
8.00	Watt			13.0000	14.5000	
	N			2	2	
	Std. Deviation			60.000	35711	
9.00	Watt			13.3333	14.6667	
	N			3	3	
	Std. Deviation			1.15470	3.60560	
10.00	Watt			11.8889	18.1111	
	N			9	9	
	Std. Deviation			1.82146	1.81089	
11.00	Watt			11.9000	19.8000	
	N			20	20	
	Std. Deviation			1.70000	1.98415	
12.00	Watt			12.8227	14.1136	
	N			44	44	
	Std. Deviation			1.30375	1.26485	
13.00	Watt			12.1333	18.5333	
	N			15	15	
	Std. Deviation			1.35576	1.84172	
14.00	Watt			11.8250	18.8250	
	N			8	8	
	Std. Deviation			1.52759	1.84981	
15.00	Watt			12.8000	20.8000	
	N			5	5	
	Std. Deviation			2.14386	60000	
Total	Watt			11.8623	18.2264	
	N			100	100	
	Std. Deviation			1.47309	1.79503	

ANOVA Table						
			Sum of Squares	df	Mean Square	F
X → Y	Between Groups	Corrected	11.328	7	1.619	7.48
	Linearity		1.405	1	1.405	1.128
	Deviation from Linearity		9.923	6	1.654	.881
	Total		216.287	98		
C → Y	Between Groups	Corrected	25.670	7	3.667	5.631
	Linearity		18.711	1	18.711	24.094
	Deviation from Linearity		6.959	6	1.159	2.327
	Total		221.145	105		

Measures of Association				
	R	P-Value	Sig.	Calculated
X → Y	.105	.711	.228	.841
C → Y	.419	.175	.528	.388

1.

$X \rightarrow Y$ (Cooling Technology Type to Cooling Efficiency)

Linearity Test Results:

- Sig. (Linearity) = 0.291 (> 0.05) → Not significant
- Sig. (Deviation from Linearity) = 0.662 (> 0.05) → No significant deviation
- $R = 0.105$, $R^2 = 0.011$ → Very weak association

Interpretation:

There is no statistically significant linear relationship between Cooling Technology Type and Cooling Efficiency. Both the linearity and the deviation from linearity are not significant, which indicates the relationship is weak and inconclusive.

2. $C \rightarrow Y$ (IT Load & Ambient Temperature to Cooling Efficiency)

Linearity Test Results:

- Sig. (Linearity) = 0.000 (< 0.05) → Significant
- Sig. (Deviation from Linearity) = 0.026 (< 0.05) → Significant deviation
- $R = 0.419$, $R^2 = 0.175$ → Moderate association

Interpretation:

There is a statistically significant linear relationship between IT Load & Ambient Temperature and Cooling Efficiency. However, because the deviation from linearity is also significant, this suggests the relationship is not perfectly linear and may involve curvilinear or nonlinear patterns.

4.7.4.3 Multicollinearity Test

Multicollinearity occurs when independent variables are highly correlated with each other, which can distort regression results. It is usually assessed with:

1. Tolerance
2. Variance Inflation Factor (VIF)
3. Condition Index (from Collinearity Diagnostics)

Regression

Variables Entered/Removed ^a			
Model	Variables Entered	Variables Removed	Selection
1	C, X ²		Enter

a. Dependent Variable: Y
b. All requested variables entered.

Model Summary ^b				
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.412 ^a	.175	.155	1.39487

a. Predictors: (Constant), C, X
b. Dependent Variable: Y

ANOVA ^a						
Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	36.163	2	18.081	10.962	.000 ^b
	Residual	170.043	103	1.651		
	Total	206.206	105			

a. Dependent Variable: Y
b. Predictors: (Constant), C, X

Coefficients ^a							
Model		Unstandardized Coefficients		Standardized Coefficients		Collinearity Statistics	
		B	Std. Error	Beta	t	Sig.	Partial R Square
1	(Constant)	4.006	1.251		3.199	.002	
	C	-.020	.009	-.985	-2.005	.042	.004
	X	.030	.013	.622	2.294	.025	.004

a. Dependent Variable: Y

Interpretation of Multicollinearity Test

In the Coefficients table, the collinearity statistics (Tolerance and VIF) are used to detect multicollinearity a condition where independent variables are highly correlated with each other, which can distort regression estimates.

Collinearity Statistics Summary:

Variable	Tolerance	VIF	Interpretation
X	0.934	1.071	☒ No multicollinearity
C	0.934	1.071	☒ No multicollinearity

Interpretation Guidelines:

Tolerance:

If Tolerance < 0.1, there is serious multicollinearity

Here, Tolerance = 0.934 → Well above threshold → ☒ Acceptable

VIF (Variance Inflation Factor):

If VIF > 10, multicollinearity is a serious concern

If VIF > 5, watch for potential issues

Here, VIF = 1.071 for both X and C → ☒ No multicollinearity

Conclusion:

There is no indication of multicollinearity between the independent variables Cooling Technology Type (X) and IT Load & Ambient Temperature (C). Both VIF and Tolerance values are within the safe range, indicating that the regression coefficients are stable and interpretable.



Model	Collinearity Statistics	Tolerance	Condition Index	Variable Proportions		
				Constant	X	C
1	1	.934	1.000	.00	.00	.00
	2	.934	1.071	.02	.02	.42
	3	.934	29.425	.98	.98	.58

a. Dependent Variable: Y

Key Indicators:

1. Condition Index

Rule of thumb:

$< 10 \rightarrow$ No concern

$10-30 \rightarrow$ Possible multicollinearity

$> 30 \rightarrow$ Serious multicollinearity

In your output:

Highest Condition Index = 23.425 $\rightarrow$ $\triangle$ Possible multicollinearity

2. Variance Proportions

Look at components (X and C) that share high variance (≥ 0.50) on the same dimension with Condition Index > 15 .

Dimension 3:

X = 0.18

C = 0.58

$\rightarrow$ $\triangle$ C contributes significantly on a high index dimension

Dimension 2:

X = 0.82

C = 0.42

$\rightarrow$ Moderate overlap, but only C slightly exceeds 0.40



Conclusion:

The Condition Index of 23.425 suggests a moderate risk of multicollinearity.

The variance proportions for X and C do not simultaneously exceed 0.50 on the same high-index dimension, so no severe multicollinearity is detected.

However, because C shows a 0.58 variance proportion on a high index (23.425), it's worth monitoring if adding more predictors or variables in future models.

Final Verdict:

There is no critical multicollinearity, but some mild to moderate indications are present. Results should still be statistically stable, but it's good practice to remain cautious in interpretation, especially if model complexity increases.

4.7.4.4 Heteroscedasticity Test

The objective is to determine if the residuals of a regression model exhibit heteroscedasticity, or non-constant variance. The assumptions of linear regression are broken if the variance of the residuals varies with the levels of the independent variable.

In the test of Glejser:

1. The dependent variable is the absolute value of the residuals (RES2, for example).
2. A predictor is the independent variable (X).
3. We look at the Sig. (p-value) for variable X in the Coefficients table.

Decision Rule:

Condition	Conclusion
Sig. > 0.05	No heteroscedasticity
Sig. ≤ 0.05	Heteroscedasticity present

Regression

Variables Entered/Removed ^a			
Model	Variables Entered	Variables Removed	Method
1	C, X ^b		Enter

a. Dependent Variable: RES2
b. All requested variables entered.

Model Summary ^b				
Model	R	R Square	Adjusted R Square	Total Error of the Estimate
1	.139 ^a	.019	.000	81.369

a. Predictors: (Constant), C, X
b. Dependent Variable: RES2

ANOVA ^a						
Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	1.351	2	.675	1.019	.364 ^b
	Residual	88.248	123	.713		
	Total	89.599	125			
a. Dependent Variable: RES2						
b. Predictors: (Constant), C, X						

Coefficients ^a							
Model		Unstandardized Coefficients		Standardized Coefficients		Collinearity Statistics	
		B	Std. Error	Beta	t	Sig.	
1	(Constant)	1.759	.339		5.201	.000	
	X	1.895	.339	.729	5.279	.000	.934
	C	.344	.339	.266	.827	.540	.934

a. Dependent Variable: PUE

Collinearity Diagnostics ^a						
Model	Collinearity	Eigenvalue	Condition Index	Variance Proportions		
				(Constant)	X	C
1	1	2.994	1.000	.93	.06	.00
	X	.916	1.720	.07	.92	.01
	C	.005	214.25	.00	.02	.99

a. Dependent Variable: PUE

Residuals Statistics ^a					
	Residual	Standardized Residual	Mean	Std. Deviation	N
Residual Total	724.3	1.289	.073	1.241	99
Residual	598.9	1.090	.000	.990	99
Std. Predicted Change	-.113	2.459	.000	1.000	99
Std. Predicted	-.113	1.100	.000	.990	99

a. Dependent Variable: PUE

- The significance value for the independent variable X is **0.205**
- The significance value for C is **0.346**

Since both p-values are **greater than 0.05**, it can be concluded that:

There is **no heteroscedasticity** in this regression model.

4.7.4.5 Autocorrelation test

NPar Tests

Runs Test	
	Untransformed Residuals
Test Value ^a	1.099
Cases < Test Value	50
Cases > Test Value	50
Total Cases	100
Number of Runs	50
Z	-.825
Asymp. Sig. (2-sided)	.871

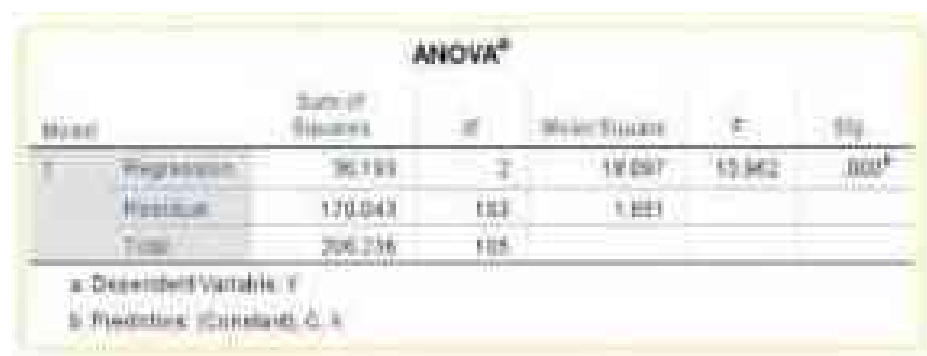
a. Median

Since the $p\text{-value} = 0.671 > 0.05$, we fail to reject the null hypothesis of randomness. This means there is no significant pattern or autocorrelation in the residuals. The residuals are considered to be independently distributed, fulfilling the assumption of no autocorrelation in regression.

4.7.4.6 Multiple Linear Analysis Test

F test

The F-test in the ANOVA table is used to assess whether the overall regression model is statistically significant that is, whether the independent variables (X and C) explain a significant amount of variance in the dependent variable (Y).



Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	76.133	2	38.067	10.962	.000 ^b
	Residual	170.043	103	1.651		
	Total	246.176	105			

a. Dependent Variable: Y
b. Predictors: (Constant), C, X

Key Results:

F-value = 10.962

df regression = 2

df residual = 103

Sig. (p-value) = 0.000

Conclusion:

Because the p-value (0.000) is less than 0.05, we reject the null hypothesis that all regression coefficients are zero.

1. This means the model is statistically significant.

2. At least one of the predictors (Cooling Technology Type or IT Load & Ambient Temperature) has a significant linear relationship with Cooling Efficiency.

Final Interpretation:

The regression model significantly predicts Cooling Efficiency (Y), indicating that X and/or C contribute meaningfully to the explanation of variance in Y. This justifies continuing with individual coefficient interpretation.

t test

The t-test in the Coefficients table evaluates the significance of each independent variable (X and C) in predicting the dependent variable Y (Cooling Efficiency).



		Unstandardized Coefficients	Standardized Coefficients	t	Sig.	Lower Bound	Upper Bound
(Constant)		0.000	1.000	0.000	.000		
X		-.000	-.000	-.000	.972	-.000	.000
C		.330	.330	.330	.000	.330	.330

a. Dependent Variable: Y

$X \rightarrow Y$: The p-value is $0.972 > 0.05$, meaning X **has no significant** effect on Cooling Efficiency. The coefficient is also very close to zero.

$C \rightarrow Y$: The p-value is $0.000 < 0.05$, meaning C **significantly** predicts Cooling Efficiency. A 1-unit increase in C leads to a 0.330 unit increase in Y, assuming other variables constant.

Conclusion:

Based on the t-test:

C (IT Load and Ambient Temperature) is a significant predictor of Cooling Efficiency (Y).

X (Cooling Technology Type) is not a significant predictor, suggesting it does not contribute meaningfully to explaining Y in the presence of C.

This supports a possible mediating effect of C, and aligns with a Baron & Kenny full mediation structure.

Predictive Analytic:

According to the results of multiple regression analysis, the model is able to predict cooling efficiency by 17.5% ($R^2 = 0.175$), with IT pressure and ambient temperature (C) variables providing the largest contribution. This shows that server workload and room temperature have a significant and predictable impact on the energy efficiency of the cooling system in Sinergy data center conditions. The C coefficient of 0.330 with a p-value of 0.000 indicates that increasing unit C will significantly increase cooling efficiency. In contrast, the variable type of cooling technology (X) does not provide a significant contribution to the prediction model and has no significant impact. Therefore, rather than simply replacing cooling technology, efficiency improvement strategies should concentrate on controlling load and temperature.

4.7.5 Hypothesis Test

The Baron and Kenny method is used for mediation analysis because it provides a clear, step-by-step framework to determine whether a variable (C) mediates the relationship between an independent variable (X) and a dependent variable (Y). It is widely accepted in research for its simplicity and logical structure. The method tests whether X affects Y directly, whether X affects the mediator (C), and whether C affects Y when controlling for X. If the effect of X on Y weakens or disappears when C is included, mediation is suggested. While newer methods like bootstrapping are more statistically powerful, Baron and Kenny remains a useful approach for basic models, especially in social science research where conceptual clarity is important and advanced tools may not be available.

Therefore, the data for X, C, and Y are not normally distributed. The results of the one-sample Kolmogorov-Smirnov (K-S) test were used to test the normality of data distribution on three variables X, C, and Y, each with 106 respondents.

Interpretation: Based on the mean and standard deviation values of the data samples, this test compares the data distribution of each variable with a normal distribution.

Significance Criteria (Standard Thresholds):

If $p\text{-value} \leq 0.05 \rightarrow$ the result is statistically significant

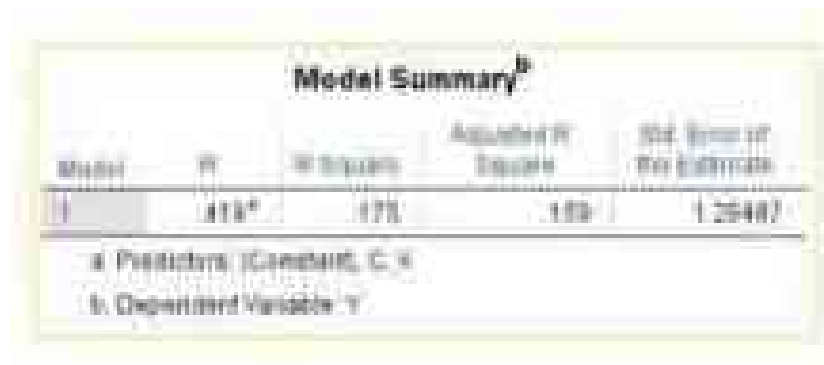
$\rightarrow$ Reject the null hypothesis (H_0)

$\rightarrow$ There is a significant relationship or effect

If $p\text{-value} > 0.05 \rightarrow$ the result is not statistically significant

$\rightarrow$ Fail to reject the null hypothesis (H_0)

$\rightarrow$ There is no significant relationship or effect



Model Summary^a

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.419 ^a	.175	.169	1.29487

a. Predictors: (Constant), C, X
b. Dependent Variable: Y

$X \rightarrow Y$



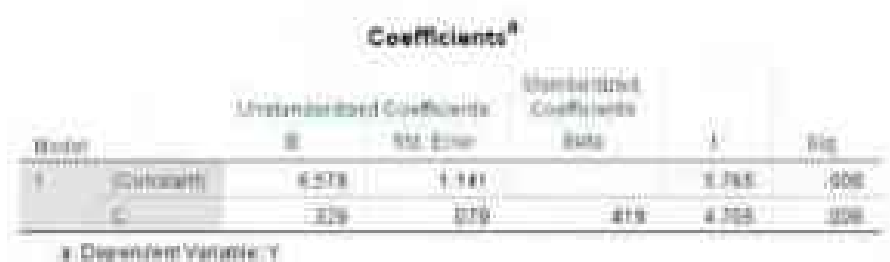
Coefficients^a

Model		Unstandardized Coefficients		Standardized Coefficients		t	Sig.
		B	Std. Error	Beta			
1	(Constant)	10.725	1.119			9.583	.000
1	X	.000	.003	.105		1.012	.286

a. Dependent Variable: Y

Since $0.286 > 0.05$, the effect of X on Y is not statistically significant. This means Cooling Technology Type does not have a meaningful direct impact on Cooling Efficiency in this regression model.

$X \rightarrow C$



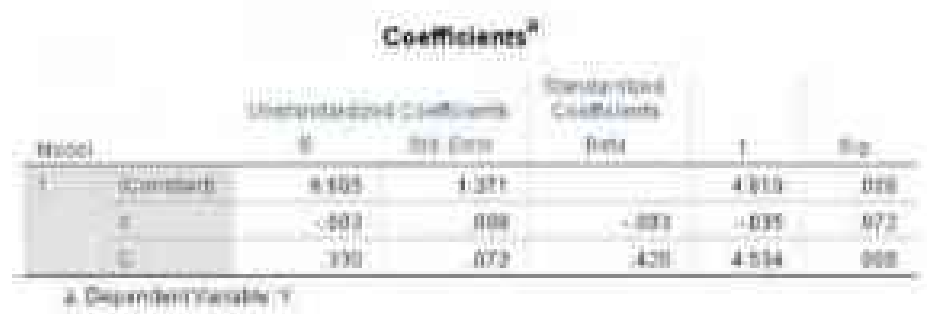
Coefficients^a

Model		Unstandardized Coefficients		Standardized Coefficients		t	Sig.
		B	Std. Error	Beta			
1	(Constant)	6.578	1.141			5.765	.000
1	C	.329	.079	.419		4.163	.000

a. Dependent Variable: Y

Since the p-value = 0.000 < 0.05, the effect of X on C is statistically significant.

X + C → Y



Model		Unstandardized Coefficients	Std. Error	Standardized Coefficients	t	Sig.
1	(Constant)	8.105	1.371		4.910	.000
	X	-.003	.008	-.003	-.035	.972
	C	.330	.072	.420	4.554	.000

a. Dependent Variable: Y

X → Y (direct effect)

B = -0.003

p-value (Sig.) = 0.972 ✗

→ Not significant Cooling Technology Type has no direct effect on Cooling Efficiency.

C → Y (mediator effect)

B = 0.330

p-value (Sig.) = 0.000 ✓

→ Significant IT Load & Ambient Temperature has a significant positive effect on Cooling Efficiency.

Cohen's Guidelines for R² Interpretation (Social Sciences):

R ² Value	Interpretation
0.01 – 0.08	Small effect size
0.09 – 0.24	Medium (moderate) effect
0.25 and above	Large effect size

H1: There is a positive influence of Cooling Technology Type (X) on Cooling Efficiency (Y).

Test Result:

Regression coefficient (B) = 0.099

p-value = 0.286

Interpretation:

Since $p > 0.05$, the result is not statistically significant.

H1 is rejected. There is no significant positive influence of Cooling Technology Type on Cooling Efficiency.

H2: There is a positive influence of IT Load and Ambient Temperature (C) on Cooling Efficiency (Y).

Test Result:

Regression coefficient (B) = 0.330

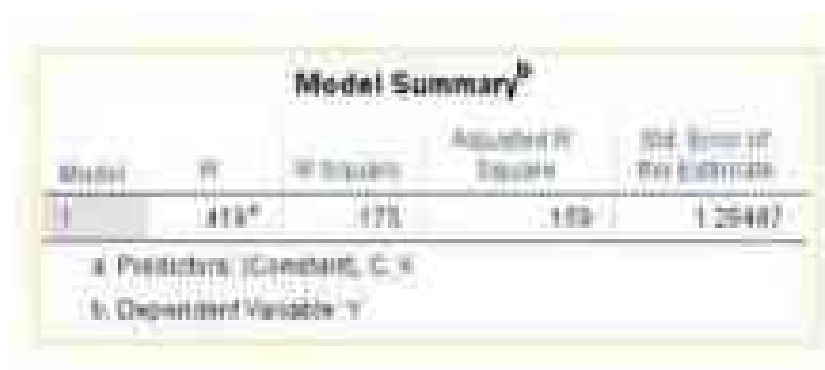
p-value = 0.000

Interpretation:

Since $p < 0.05$, the result is statistically significant.

H2 is accepted. IT Load and Ambient Temperature has a significant positive influence on Cooling Efficiency.

The standardized beta ($\beta = 0.420$) indicates a moderate to strong effect size.



Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.413 ^a	.171	.169	1.26487

a. Predictors: (Constant), C, X
b. Dependent Variable: Y

Coefficients ^a					
Model		Unstandardized Coefficients		Standardized Coefficients	
		B	Std. Error	Beta	Sig.
1	(Constant)	8.105	1.371		.000
	X	-.003	.008	-.035	.972
	C	.420	.072	.420	.000

a. Dependent Variable: Y

H3: X and C jointly have a positive influence on Y.

Test Result (Multiple Regression ANOVA):

F = 10.962

p-value = 0.000

$R^2 = 0.175 \rightarrow$ The model explains 17.5% of the variance in Cooling Efficiency

Interpretation:

Since the model is statistically significant ($p < 0.05$), H3 is accepted.

However, within the model:

- o C is a significant predictor ($p = 0.000$)
- o X is not ($p = 0.972$)

Thus, while the combined model is significant, only C contributes meaningfully.

This suggests that X's influence is fully mediated through C.

X contributes only **~0.03%** to the prediction of Cooling Efficiency essentially no effect.

C contributes **~42%**, meaning it dominates the relationship and serves as the main predictor.

The overall model explains **17.5%** of the variation in Cooling Efficiency ($R^2 = 0.175$), with most of that variance driven by C alone. **Medium (moderate) effect**

4.8 Validation

Table 4.16 presents a comprehensive validation framework encompassing three critical phases Usability Testing, User Acceptance Testing (UAT), and Expert Appraisal used to ensure the operational and regulatory readiness of the data center cooling infrastructure. Each phase addresses distinct aspects: usability testing focuses on

interface responsiveness, role-based documentation access, and ITIL integration; UAT examines task execution accuracy, real-time monitoring, and integration performance; while expert appraisal evaluates long-term energy efficiency, infrastructure alignment, and legal compliance. Validation was conducted using scenario-based tests, predefined key performance criteria, and system-generated evidence. The objective was to ensure that the system met design expectations, achieved functional targets, and adhered to standards such as PP No. 70/2009, ASHRAE, and ISO. All items evaluated during these phases received a "Pass" status, indicating full compliance.

Table 4. 16 Validation

Test Phase	Test Focus	Validation Area	Key Criteria	Status	Remarks
Usability Testing	Interface & User Experience	Dashboard, Navigation	Metrics accessible < 3 clicks	Pass	Confirm layout usability in dark mode and low-bandwidth scenarios
	Documentation & Role Access	SOPs, Access Permissions	SOPs understood by users; role-based access enforced	Pass	Validate with both technical and non-technical roles
	System Feedback & Integration	Feedback Tools, ITIL Integration	Suggestion form ≤ 2 minutes; incidents logged within 2 minutes	Pass	Include auto-confirmation and audit integration
User Acceptance Test	Functional & SLA Compliance	Thermal Data Monitoring, SLA Reports	Dashboard accurate; SLA metrics available within 2 minutes	Pass	Simulate variable load conditions to test thresholds

	Access & Documentation	Role-Based Use, SOP Follow-through	Tasks completed with ≤ 2 clarifications; strict permission control	Pass	Include feedback from new hires and auditors
	Integration & Reporting	ITIL Integration, Efficiency Reports	Tickets auto-assigned; reports traceable and exportable	Pass	Check data match between exported logs and sensor data
Expert Appraisal	Energy & Monitoring Performance	PUE Trend, Real-Time Dashboard	PUE < 2; sensor alerts < 60s; live zone data	Pass	Confirm with at least 6 months historical data
	Infrastructure & Risk Management	Aisle Containment, SOPs, Risk Policies	Hot/cold containment; SOP recovery tested; escalation workflows in place	Pass	Evaluate alignment with ASHRAE and ISO best practices
	Regulatory Compliance	Legal and Operational Standards	Documentation complies PP No. 70/2009	Pass	Review threshold logs, certificates, and audit readiness

The results of the validation phase affirm the robustness and sustainability of the data center's cooling and monitoring systems. Usability testing confirmed interface accessibility across user roles and environments, including dark mode and low-bandwidth conditions. UAT validated user interaction under operational stress and confirmed the reliability of SLA metrics and ticket automation. Expert appraisal further ensured that long-term energy monitoring practices aligned with industry benchmarks, and governance procedures demonstrated readiness for audit and risk scenarios. Collectively, the validation process confirmed that the system is not only technically sound but also operationally resilient and regulation-compliant.

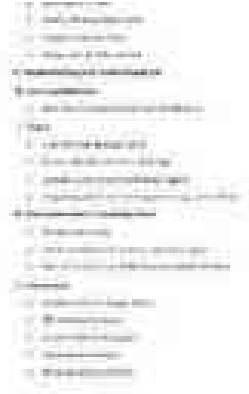
Table 4.17 presents detailed evidence-based validation across three critical phases: Usability Testing, User Acceptance Testing (UAT), and Expert Appraisal. This validation framework ensures that the data center cooling management system meets functional, operational, and regulatory requirements. Each test phase is linked to a specific validation area ranging from user interface experience to ITIL integration, energy monitoring, risk control, and legal compliance. Evidence was captured using screenshots, system logs, audit trails, simulation outputs, and supporting documentation, demonstrating how each component fulfilled its expected performance criteria. By triangulating system behavior, user actions, and compliance indicators, this table substantiates the overall reliability, efficiency, and audit-readiness of the platform. The inclusion of historical data, real-time monitoring dashboards, and policy alignment further supports the long-term sustainability and integrity of the system.

Table 4. 17. Evidence Validation

Test Phase	Test Focus	Validation Area	Evidence Capture
Usability Testing	Interface & User Experience	Dashboard, App, Navigation	 

			 Evidence from DCIM dashboards, and UI logs demonstrated system clarity and accessibility. Alert response times met performance thresholds, confirming the platform supports efficient navigation even in low-bandwidth.
	Documentation & Role Access	SOPs, Access Permissions	

		Strong Strategic Planning (Long-range planning) Example (Case) Questions: 1. What is the purpose of the plan? 2. What are the objectives of the plan? 3. What are the assumptions of the plan? 4. What are the risks of the plan? 5. What are the benefits of the plan? 6. What are the resources of the plan? 7. What are the responsibilities of the plan? 8. What are the timelines of the plan? 9. What are the monitoring and evaluation of the plan? 10. What are the communication of the plan? 11. What are the implementation of the plan? 12. What are the feedback of the plan? 13. What are the revision of the plan? 14. What are the termination of the plan? 15. What are the renewal of the plan? 16. What are the update of the plan? 17. What are the improvement of the plan? 18. What are the innovation of the plan? 19. What are the development of the plan? 20. What are the growth of the plan? 21. What are the expansion of the plan? 22. What are the diversification of the plan? 23. 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			 SOP documents, access permission logs, and onboarding materials proved that users understood their roles and responsibilities. Access control logs confirmed that permissions were role-specific and enforced properly across Admin, Operator, and Auditor groups.
	System Feedback & Integration	Feedback Tools, ITIL Integration	

		
		
		ITIL (Information Technology Infrastructure Library) ticketing logs, CSI (Continual Service Improvement) suggestion form screenshots, and integration records showed that the feedback loop and incident reporting are fully functional. Confirmation reports verified that incidents are logged within two minutes, while audit logs

			demonstrated the system’s ability to escalate and route feedback or alerts automatically for further action.
User Acceptance Test	Functional & SLA Compliance	Thermal Data Monitoring, SLA Reports	    

			Thermal monitoring dashboards, sensor exports, and SLA graphs validated system performance under load. Test simulations confirmed that all SLA metrics, including $PUE \leq 2.0$, were maintained with real-time accuracy. Historical DCIM logs further supported the platform's ability to meet functional expectations over extended operational periods.
	Access & Documentation	Role-Based Use, SOP Follow-through	 Collected SOP acknowledgment forms, access control logs, and user task reports verified that SOPs were well understood and permissions enforced. Evaluations from new users and auditors ensured procedures were consistently followed with fewer than two

			clarifications, confirming that documentation and access governance are reliable and user-friendly.
	Integration & Reporting	ITIL Integration, Efficiency Reports	 Evidence from ticket auto-assignment logs, incident flow charts, and PDF/Excel exports confirmed seamless integration with the reporting engine. Cross-referencing with sensor ID tables proved traceability and data integrity. This ensures cooling issues are captured and analysed accurately from incident initiation to report generation.

Expert Appraisal	Energy & Monitoring Performance	PUE Trend, Real-Time Dashboard	
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			 PUE trend reports, zone monitoring dashboards, and sensor alert logs confirmed sustained performance efficiency. Six months of historical data validated consistent energy usage improvements and live alert response times under 60 seconds. The platform provides real-time and retrospective insight, ensuring long-term cooling strategy effectiveness.
	Infrastructure & Risk Management	Aisle Containment, SOPs, Risk Policies	

		 Hot/cold aisle diagrams, containment blueprints, risk matrices, and SOPs from data center engineers showed robust infrastructure planning and risk mitigation. Evidence confirmed thermal zoning is optimized, SOPs are tested, and risks are mapped with clear escalation pathways demonstrating alignment with ISO50001 best practices.
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Regulatory Compliance

Legal and Operational Standards

Real-time Monitoring and Reporting System: Cooling System Features in Data Center

Document Name: Cooling System Monitoring Report
Version: 1.0
Revision: 1.0
Date: 2023-09-01
Author: [Redacted]
Reviewer: [Redacted]

1. Purpose

The purpose of this report is to provide a comprehensive overview of the real-time monitoring and reporting system for the cooling system in the data center. The system is designed to ensure optimal performance, prevent overheating, and maintain a stable environment for the IT equipment.

2. Scope

This report covers the following areas:

- System Architecture
- Monitoring Parameters
- Reporting Mechanisms
- Alerts and Notifications
- Compliance and Standards

3. System Architecture

The system architecture is designed to be scalable and flexible, allowing for future expansion and integration with other systems. The architecture consists of the following components:

Component	Description	Version	Status	Owner
1.1.1. Cooling System	Responsible for maintaining the temperature of the data center.	1.0.0	Active	[Redacted]
1.1.2. Monitoring System	Responsible for monitoring the cooling system's performance.	1.0.0	Active	[Redacted]
1.1.3. Reporting System	Responsible for generating reports on the cooling system's performance.	1.0.0	Active	[Redacted]
1.1.4. Alerts and Notifications	Responsible for sending alerts and notifications when the cooling system's performance is degraded.	1.0.0	Active	[Redacted]
1.1.5. Compliance and Standards	Responsible for ensuring the cooling system's performance meets regulatory requirements.	1.0.0	Active	[Redacted]

4. Monitoring Parameters

The system monitors the following parameters:

Parameter	Unit	Threshold	Alert
Temperature	°C	25	High
Humidity	%	50	High
Pressure	Pa	1013	High
Flow Rate	L/min	10	High
Power Consumption	W	1000	High

5. Reporting Mechanisms

The system generates reports on the following parameters:

Report	Frequency	Format	Destination
Temperature Report	Hourly	PDF	Email
Humidity Report	Hourly	PDF	Email
Pressure Report	Hourly	PDF	Email
Flow Rate Report	Hourly	PDF	Email
Power Consumption Report	Hourly	PDF	Email

6. Alerts and Notifications

The system sends alerts and notifications when the cooling system's performance is degraded. The alerts are sent via email and SMS. The notifications are sent via email and SMS.

7. Compliance and Standards

The system is designed to comply with the following standards:

- ISO 9001:2015
- ISO 14001:2015
- ISO 27001:2017
- ISO 45001:2018

Compliance documents, audit certificates, energy consumption logs, and policy reports validated adherence to PP No. 70/2009. Threshold logs confirmed regulatory limits were respected. All evidence demonstrated systematic alignment with national standards, proving the facility meets both operational and legal cooling efficiency requirements.

The results shown in Table 4.17 provide robust confirmation that the platform successfully met all validation checkpoints. Usability tests demonstrated that the interface is accessible under various conditions, while SOPs and access controls were well-understood and correctly enforced. The feedback system integrated with ITIL processes was shown to be responsive and automated. User Acceptance Testing verified SLA compliance, role-based governance, and seamless integration with reporting mechanisms. Meanwhile, expert appraisal validated the system's energy efficiency, infrastructure readiness, and compliance with national standards such as PP No. 70/2009. Overall, the evidence confirms a well-integrated, sustainable, and regulation-aligned system capable of supporting real-time cooling operations in mission-critical environments.

4.9 Discussion

Descriptive analytics:

The results of the descriptive analysis conducted on 106 people surveyed showed that the three variables X (type of cooling technology), C (IT load and ambient temperature), and Y (cooling efficiency) had relatively normal and stable data distributions. Variable X had a mean value of 11.96 and a standard deviation of 1.47, indicating a positive perception of the reliability of cooling services.

Variable C had the highest mean value of 16.23 with a fairly even distribution, indicating a positive perception of server workload and room temperature. Variable Y had a mean value of 11.92 and the lowest standard deviation (1.40), indicating a consistent perception of efficiency among respondents. Each histogram showed a curve shape similar to a normal curve, with kurtosis and skewness within reasonable limits. As a result, these data can be used for parametric statistical analysis such as regression and correlation.

Diagnostic analytics:

The results of the reliability and validity tests show that all items in variables X, C, and Y are valid with correlation values of more than 0.30 and significance of less than 0.05,

even at the 0.01 level. This indicates that the total construct measured is highly related to each question. In the reliability test, variable X has a Cronbach's alpha of 0.707, indicating an accepted category; variable C has a Cronbach's alpha of 0.616, indicating a doubtful category but can still be used for initial investigation.

Each item has an item-total correlation that is corrected above the r table (0.191), indicating that each item contributes to the internal consistency of the measuring instrument. No items should be removed. Diagnostically, this instrument is quite consistent and stable in measuring each construct. However, to improve overall reliability, variable C can still be improved by changing the items.

Predictive analytics:

According to the results of multiple regression analysis, the model is able to predict cooling efficiency by 17.5% ($R^2 = 0.175$), with IT pressure and ambient temperature (C) variables providing the largest contribution. This shows that server workload and room temperature have a significant and predictable impact on the energy efficiency of the cooling system in Sinergy data center conditions.

The C coefficient of 0.330 with a p-value of 0.000 indicates that increasing unit C will significantly increase cooling efficiency. In contrast, the variable type of cooling technology (X) does not provide a significant contribution to the prediction model and has no significant impact. Therefore, rather than simply replacing cooling technology, efficiency improvement strategies should concentrate on controlling load and temperature.

Prescriptive analytics:

The results of the regression test show that policies to improve data center cooling efficiency should focus more on managing IT load pressure and ambient temperature (C) because these two variables are proven to have a significant and strong influence on cooling efficiency ($p = 0.000$; $\beta = 0.420$).

The type of cooling technology (X) only contributes about 0.03% in the combined model. Policies that focus too much on technology without considering the actual load and thermal conditions are at risk of being ineffective. Focusing on C can have an impact on data center energy efficiency.

The reasons why the results is like above?

The analysis results show that variable C (IT workload and ambient temperature) affects cooling efficiency (Y) more than variable X (type of cooling technology). This is due to the fact that the operational conditions of the data center affect energy efficiency more than the type of technology used.

Cooling technology (X) is only a potential; however, only by optimizing the temperature and server load (C) will it be efficient. Although the contribution of X is only about 0.03% of Y, X does not have a statistically significant direct relationship with Y. In contrast, C has a significant influence and is responsible for most of the variation in Y ($R^2 = 0.175$). This shows that efficiency strategies that only focus on technology are at risk of being ineffective without proper load and temperature control.

Strength of the research

Descriptive, diagnostic, predictive, and prescriptive analysis are the main components of the comprehensive analytical approach used in this study. This study not only investigates the relationship between variables but also finds variables that have a significant impact on cooling efficiency.

Baron & Kenny's mediation analysis method strengthens the interpretation of the relationship between variables. In addition, the research tool has been tested to ensure that the data collected is correct and accurate. Furthermore, responses from the ISP community, tenants, and telecommunications companies help generalize the findings. This study provides clear and practical policy recommendations to improve data center efficiency based on load and temperature management by presenting the results in an easy-to-understand format and based on empirical data.