

CHAPTER 1 - INTRODUCTION

1.1 Background

The development of data centers in Indonesia is growing from year to year, with development being very rapid in the fields of information and technology, including data centers as well. The need for reliable and efficient data centers themselves is also increasing, coupled with the growth of the digital economy and many have begun to adopt cloud-based technology.

Several factors that drive this development include the increase in internet users in Indonesia.

According to APJII (Association of Indonesian Internet Service Providers) as show in Figure 1.1, the number of Internet users in Indonesia will reach 221 million in 2024, this is an increase from 2023 of 215 million as show in Figure 1.2. This can be seen from the development table as (Yi, 2023).

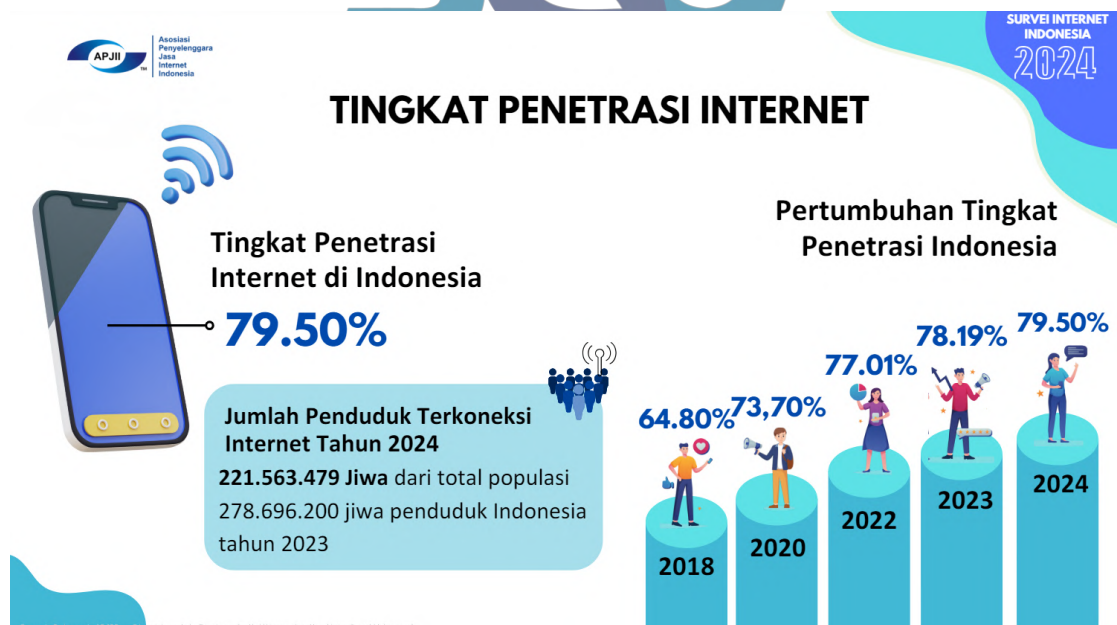


Figure 1.1. Internet Penetration Rate Year per Year (APJII, 2024)



Figure 1.2. Internet Penetration Rate at 2022 (Arif, 2022)

This increase shows that internet needs in Indonesia (see Figure 1.2) are increasing and must be accompanied by data center infrastructure which must be able to accommodate increased traffic or data traffic. Demand for digital services such as e-commerce, streaming services and several applications using cloud-based facilities has also increased significantly along with increasing internet and cloud access, which increasingly strengthens the need for larger, more sophisticated and more capable data centers.

The Mordor Intelligence survey (2023) shows the estimated growth of data centers in Indonesia with a CAGR of 16.92% from 2022 to 2027 as shown in Figure 1.3, supported by increasing adoption of cloud computing and the need for secure and reliable data storage solutions. Awareness of the importance of having a modern and dynamic data center infrastructure to support business needs is highlighted in this survey.



Figure 1.3. Survey for Indonesia Data Centre Market Size – Growth Trends and Forecast up to 2029

Through this research, it is hoped that it can provide a deeper understanding of the dynamics of data center development in Indonesia and provide recommendations for stakeholders in designing effective strategies and policies. It is also hoped that this research can help identify future trends in the data center industry as well as recommend solutions to overcome challenges, so that the data center industry in Indonesia can continue to grow and develop sustainably as show in Figure 1.4.

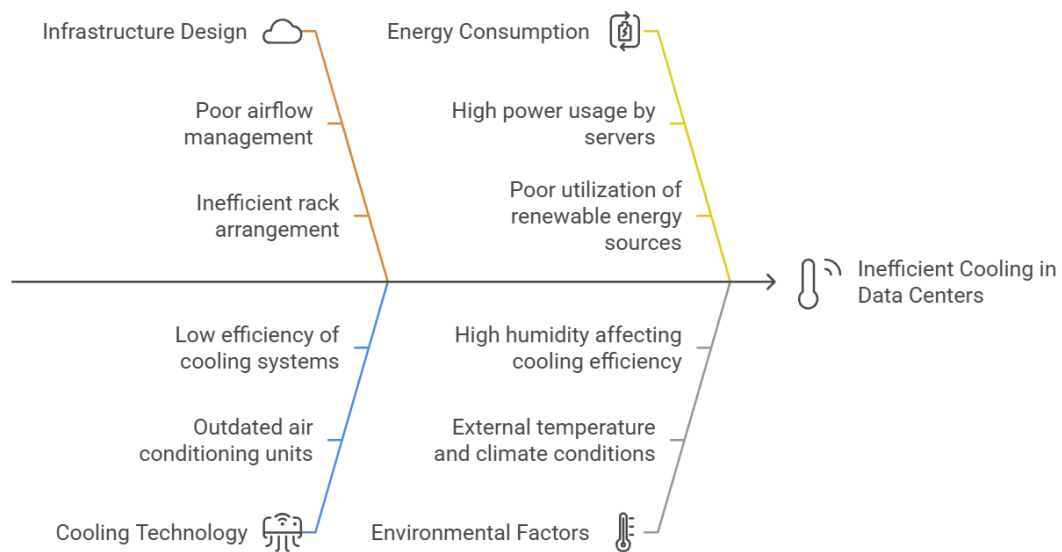


Figure 1.4. Fishbone diagram for Inefficient Cooling in Data Centers

With the explosive growth of digital services and advances in technology such as the emergence of cloud computing and artificial intelligence, the number and scale of data centers around the globe have increased rapidly. They play a key role in the processing, storage, and management of massive amounts of digital information. However, they are also one of the most energy-intensive infrastructures, accounting for 1-2% of world-wide electricity (Shehabi et al., 2016). A large portion of these energy systems nearly 40% is dedicated to cooling systems to maintain the servers and networking equipment within operational temperature limits (Shehabi et al., 2016).

Air conditioning and mechanical cooling, the most commonly used cooling methods, are widely considered ineffective solutions and not environmentally friendly. This leads to high operational costs, high carbon footprints, and thermal inefficiencies due to overloading of coolants. Climate change anxiety and corporate sustainability targets are forcing industries to adopt energy-efficient replacements for the old systems. A new generation of solutions like liquid cooling, free-air cooling, AI-driven thermal optimization, and renewable energy integration shows the potential to mitigate these challenges (Onyinyechukwu Chidolue et al., 2024)

Many organisations have embraced green data centre practises, incorporating green technologies to optimise cooling efficiencies. For example, AI-assisted cooling systems in Google could result in profound savings in cooling energy consumption by alluding such feature able changes (Onyinyechukwu Chidolue et al., 2024). In addition, the atmospheric liquid cooling complex demonstrated a significant reduction in the losses associated with heat dissipation and has become a viable alternative to the current data centers (Onyinyechukwu Chidolue et al., 2024). However, this progress is being hampered by the fact that traditional thermal management approaches are still entrenched in the data center space creating largely inefficient systems and leading to high energy costs.

The selection of the thesis title, "Sustainable Data Center Practices for Cooling Efficient: A Case Study of Sinergy Data Center," is rooted in the escalating energy consumption of data centers globally and the disproportionate contribution of cooling infrastructure to this consumption. As digital transformation[®] accelerates, the demand for data processing and storage capacity intensifies, leading to a proliferation of data centers. These facilities are inherently energy-intensive, and a substantial portion of their operational energy is dedicated to maintaining optimal thermal conditions for IT equipment (Shehabi et al., 2016). Traditional air-based cooling methods, while prevalent, are often inefficient, contributing to high operational costs, significant carbon footprints, and thermal inefficiencies (Onyinyechukwu Chidolue et al., 2024).

The term "Sustainable Data Center Practices" in the title underscores the overarching objective of minimizing environmental impact, optimizing resource utilization, and ensuring long-term operational viability. This aligns with global efforts towards green IT and corporate social responsibility. The specific focus on "Cooling Efficient" highlights the most critical and energy-demanding aspect of data center operations. Research consistently indicates that cooling systems can account for up to 40% of a data center's total energy consumption (Shehabi et al., 2016). Therefore, achieving efficiency in cooling is paramount to realizing genuine sustainability within these infrastructures. The inclusion of "A Case Study of Sinergy Data Center" provides a practical, real-world context, allowing for the application of theoretical frameworks and the validation of findings within a specific operational environment.

This research tries to explore the "Sustainable Data Center Practices for Cooling Efficiency" due to the demand and the energy-efficient and eco-friendly solution. By investigating leading-edge cooling technology, operating practices, and environmental footprint, this research seeks to provide guidance on how data centre energy usage can be reduced, costs limited, and sustainability efforts maintained in the data centre cooling sector. This will assist data centre operators, IT infrastructure providers and policymakers in achieving better cooling efficiency and a lower environmental impact.

1.2 Research Problem

Numerous academic and industry research papers consistently identify cooling as a primary challenge and a significant area for improvement in the pursuit of sustainable data centers. The following top research papers, among others, substantiate this claim:

1. United States Data Center Energy Usage Report. Lawrence Berkeley National Laboratory (Shehabi et al., 2016).

Proof: This seminal report highlights that data centers account for a substantial portion of global electricity consumption, with cooling systems being a major energy sink, often consuming up to 40% of the total energy. This directly validates the premise that cooling is a critical energy problem.

2. Data centers cooling: A critical review of techniques, challenges and future directions. *Energy Reports*, 10, 202–218. (Onyinyechukwu Chidolue et al., 2024)

Proof: The paper underscores that air-based cooling methods are often unable to maintain uniform temperature distribution within data centers. This leads to thermal hotspots, equipment degradation, and increased energy demand from overcompensation by HVAC systems.

Despite the widespread implementation of technical measures to improve cooling performance, many data centers continue to face operational inefficiencies and regulatory compliance gaps. One contributing factor is the absence of clear, enforceable governance policies governing energy use and cooling infrastructure operations. Furthermore, where policies do exist, they are often insufficiently tested or disconnected from practical workflows. This study acknowledges this governance gap as part of the

problem landscape and integrates policy development and validation as a crucial dimension of its sustainability framework.

Air conditioning and mechanical cooling, the most commonly used cooling methods, are widely considered ineffective solutions and not environmentally friendly. This leads to high operational costs, high carbon footprints, and thermal inefficiencies due to overloading of coolants. Climate change anxiety and corporate sustainability targets are forcing industries to adopt energy-efficient replacements for the old systems. This directly supports the argument that traditional cooling methods are problematic and unsustainable.

1. Data center cooling: New technologies and the path to sustainable efficiency. PageThink Insights. (Page, 2025)

Proof: This article emphasizes that 'By adopting new cooling solutions and raising acceptable operating temperatures, data centers have an opportunity to move toward more sustainable and efficient operations.' This highlights the ongoing need for innovation in cooling to achieve sustainability.

2. Towards energy-efficient data centers: A comprehensive review of cooling strategies. Journal of Cleaner Production. (Al-Wakeel & Al-Wakeel, 2024)

Proof: This paper provides a comprehensive analysis of various cooling strategies aimed at enhancing the energy efficiency of data centers, underscoring that cooling is a central theme in energy efficiency research for data centers.

3. Optimization Control Strategies and Evaluation Metrics of Cooling Systems in Data Centers: A Review. Sustainability, 16(16), 7222. (Yang et al., 2024)

Proof: This review uses bibliometric analysis to explore the classifications, control optimizations, and energy metrics of data center cooling systems, further confirming that cooling systems are a major focus of research for energy optimization.

4. Strategies for Improving the Sustainability of Data Centers via Energy Mix, Energy Conservation, and Circular Energy. ResearchGate. (Gholami & Lim, 2025)

Proof: This research identifies 'innovative cooling technologies' as a key strategy for improving the sustainability of data centers, directly linking cooling to sustainability efforts.

5. Using life cycle assessment to drive innovation for sustainable cooling in data centres. Nature. (Shao & Li, 2025)

Proof: This study uses Life Cycle Assessment (LCA) to analyze three cooling technologies, demonstrating the academic rigor applied to evaluating the environmental impact and sustainability of different cooling approaches.

6. The Future of Data Center Cooling: Innovations for Sustainability. Digital Realty Resources. (Digital Realty, 2025)

Proof: This industry article discusses common methods like air cooling and liquid cooling, and emphasizes 'innovations for sustainability,' reinforcing the industry's focus on sustainable cooling solutions.

7. Liquid Cooling: A Sustainable Revolution in Data Center Efficiency. Data Center Frontier. (Stream Data Centers, 2024)

Proof: This white paper explicitly states that 'Liquid cooling, due to its higher heat transfer efficiency, offers sustainability benefits, including reduced energy consumption, infrastructure,' highlighting a specific cooling technology as a sustainable solution.

8. Optimizing Energy Efficiency in Datacenters with Advanced Cooling Technologies. Communications of the ACM Blog. (ACM, 2024)

Proof: This article explores the latest advancements in data center cooling technologies and how they are helping operators optimize energy efficiency, further supporting the idea that advanced cooling is crucial for efficiency.

Main Issue: Inefficient Cooling in Data Centers

1. Infrastructure Design
 - 1.1. Poor airflow management
 - 1.2. Inefficient rack arrangement
2. Energy Consumption
 - 2.1. High power usage by servers
 - 2.2. Poor utilization of renewable energy sources
3. Cooling Technology
 - 3.1. Low efficiency of cooling systems

3.2.Outdated air conditioning units

4. Environmental Factors

4.1.High humidity affecting cooling efficiency

4.2.External temperature and climate conditions

1.2.1 Stakeholder-Centered View of the Problem (ITIL 4 Perspective)

According to ITIL 4, effective service management must begin with a deep understanding of stakeholder needs, relationships, and value perceptions. In the context of sustainable cooling practices within data centers, several key stakeholders have distinct yet interdependent concerns that shape the underlying problem of inefficient cooling and excessive energy use.

Data Center Managers are primarily concerned with operational reliability and uptime. For them, inefficient cooling directly threatens service continuity and SLA compliance. Facility Engineers focus on maintaining optimal thermal environments, but are often constrained by outdated infrastructure or lack of integrated monitoring tools. IT Operations Teams experience difficulty responding to thermal anomalies without real-time visibility, leading to reactive maintenance rather than predictive management. Meanwhile, Sustainability Analysts and Corporate Leadership are under increasing pressure to demonstrate carbon reduction and alignment with regulatory policies such as Indonesia's PP No. 70/2009 or global energy management standards like ISO 50001.

The absence of an integrated cooling strategy that considers these diverse stakeholder needs often leads to siloed operations, data fragmentation, and inefficient energy use. Without a framework that harmonizes technical optimization with governance alignment and user role clarity, cooling inefficiencies will persist despite technological upgrades. ITIL 4's emphasis on value co-creation and continuous improvement highlights the urgency to address this problem through cross-functional collaboration and evidence-based decision-making.

By incorporating a stakeholder-oriented perspective into this study, the research not only aims to optimize cooling performance but also seeks to align technological

improvements with stakeholder expectations and governance best practices. This approach is consistent with the ITIL 4 guiding principles, particularly Focus on Value, Collaborate and Promote Visibility, and Think and Work Holistically.

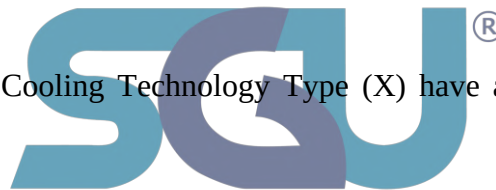
1.3 Research Objective

The general objective of this research is:

1. To determine the positive effect of Cooling Technology Type (X) on Cooling Efficiency (Y).
2. To determine the positive effect of IT Load and Ambient Temperature (C) on Cooling Efficiency (Y).
3. To determine the positive effect of Cooling Technology Type (X) and IT Load and Ambient Temperature (C) on Cooling Efficiency (Y).

1.4 Research Question

Question #1: Does the Cooling Technology Type (X) have a positive influence on Cooling Efficiency (Y)?



Question #2: Does the IT Load and Ambient Temperature (C) have a positive influence on Cooling Efficiency (Y)?

Question #3: Does the Cooling Technology Type (X) and IT Load and Ambient Temperature (C) have a positive influence on Cooling Efficiency (Y)?

Hypothesis

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

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

H3: Cooling Technology Type (X) and IT Load and Ambient Temperature (C) jointly have a positive influence on Cooling Efficiency (Y).

1.5 Research Scope and Limitation

Research Scope

This study focuses on analyzing sustainable data center cooling practices and evaluating the impact of innovative cooling technologies on energy efficiency and sustainability in data centers. The research primarily covers the following areas:

1. Cooling Technologies Analysis – Examining both traditional cooling systems (e.g., air-based cooling, HVAC).
2. Energy Efficiency Assessment – Measuring the energy consumption, cooling performance, and operational cost-effectiveness of different cooling methods.

Limitations of the Research

Despite its broad scope, this study has certain limitations that should be acknowledged: Data Availability Access to real-time operational data from data centers may be restricted due to confidentiality and proprietary concerns, limiting the depth of empirical analysis.

1.6 Significance of Study

The increasing energy demands of data centers have raised concerns regarding sustainability, operational efficiency, and environmental impact. Cooling systems account for nearly 40% of a data center's total energy consumption (Shehabi et al., 2016), making them a critical focus area for optimization and innovation. This research aims to explore how emerging cooling technologies, such as liquid cooling, AI-driven thermal management, and free-air cooling, can enhance energy efficiency and sustainability in data centers.

1. Academic Contribution

This work extends the literature on data centre sustainability, efficiency, and green computing with an in-depth examination of conventional and novel cooling techniques. This distinction will benefit subsequent research in academia regarding data center optimization, thermal management, and energy-

aware computing by determining the main factors that affect the efficiency of cooling.

2. Industrial and Technological Relevance

Data center operators seeking cost-effective and eco-friendly cooling solutions, as well as IT infrastructure managers and technology providers will benefit from the results of this study. This research will concentrate on the benefits and drawbacks of the proposed approach of the new cooling systems, based energy consumption reduction, in uptake adaptation which can assist enterprises in deciding where to drive energy use down (and hence costs), increase business efficacy and therefore help meet sustainability targets globally.

3. Environmental and Sustainability Impact

As data centers account for a substantial amount of carbon emissions globally, this study aligns with efforts to ensure that the industry is congruent with green initiatives such as the Paris Agreement and Corporate Net-Zero Goals. Through exploring energy-efficient cooling solutions, the research promotes the use of low-carbon technologies, thus supporting a more sustainable digital infrastructure.

4. Novelty of the Research

What is novel in our research is that it compares the performance of transformational AI-driven tiered cooling, liquid cooling, and free-air cooling against conventional HVAC -based systems in terms of energy savings, scalability, and sustainability. While its predecessors have examined particular forms of cooling methods, this report will deliver a system-level review and detailed recommendations on the types of cooling technologies that will come into play in next-generation data centers.

Title of thesis: Sustainable Data Center Practices for Cooling Efficient: A Case Study of Sinergy Data Center The title of the thesis is very suitable for the studied topic based on the current global environmental issue demand and data center industry change. Some general and literature-specific reasons for the choice of medium can be outlined in terms of issues of academic nature and actual practicability:

The title itself is appropriate as it captures the core issue discussed in the project, viz. energy intensive and environmentally damaging air-conditioning of data center facilities. This is supported by the study of (Shehabi et al., 2016) and (Onyinyechukwu Chidolue et al., 2024), cooling is a major source of data center energy, and can be as high as half of the usage from servers' operations themselves. The word "Cooling Efficient" makes the title effective at a stroke, announcing the focus of the study in a key aspect of energy-saving and environmental alleviation.

Second, the researchers "place it in the broader and more crucial realm of green IT and corporate sustainability" by using the term "Sustainable Data Center Practices". This indicates a recognition of the need for a holistic view of how to tackle the environmental impact of digital infrastructure. The ongoing research is not only in search of issues; it is also intended to suggest concrete and sustainable solutions reflecting the proactive tone implied in "Practices".

Finally, including the "A Case Study of Sinergy Data Center" brings an important practical perspective to the study. The academic rigor frequently benefits from real world application and validation. Case-study enables proactive exploration of the designs for operational context specific challenges and their solution approaches. This provides more tangible, credible and possibly transferable result of the research work targeted to such data center environment. It further permits primary data to be gathered and captive experience of real-life implementation problems and successes can add richly to the impact of the research.

The title is, last but not least, succinct and all-encompassing and provides the reader with a description of the aim of the study. It leaves no room for misunderstandings and sets clear limits to the study, which is important for academic preciseness. Keywords from the title "Sustainable Data Center," "Cooling Efficient," "Case Study" are well linked with current academic and industry trends, so the study can add a significant value to the existed knowledge.

Last but not least, the study contributes to the increasing quest for energy-efficient and environment friendly options in the digital infrastructure industry. With greater demands being placed on organizations to reduce their carbon emissions and comply

with environmental legislation, it's studies like these that provide useful advice on how to be more energy efficient when it comes to cooling. As such, the thesis tackles a timely and far-reaching problem and its findings are applicable to advancing academic knowledge and practices in the industry.

1.7 Thesis Structure

Each chapter systematically builds on the previous one to ensure a logical flow of research, analysis, and conclusions. The structure is as follows:

CHAPTER 1 – INTRODUCTION

This chapter provides an overview of the research, including the background, problem statement, research objectives, research questions, hypotheses, and scope of the study. It discusses the importance of sustainable cooling efficiency in data centers and the role of ITIL frameworks in managing cooling technologies. Additionally, it outlines the significance of the study and expected contributions to academia and industry.

CHAPTER 2 – LITERATURE REVIEW

This chapter presents a comprehensive review of existing research related to sustainable cooling practices, energy efficiency in data centers, and ITIL integration for operational improvement. It identifies gaps in the literature, discusses key theories and models relevant to the study, and highlights previous research findings in the domain. The chapter concludes with a conceptual framework, providing the theoretical foundation for the study.

CHAPTER 3 – RESEARCH METHODS

This chapter explains the methodological approach used to conduct the study. It details the research design, analytical methods quantitative, data collection techniques, instrument development, and validation methods. The chapter also describes how statistical tools and thematic analysis will be used to examine the effectiveness of ITIL-guided cooling strategies in data centers.

CHAPTER 4 – RESULTS AND DISCUSSIONS

This chapter presents the findings of the study, including both quantitative results (energy efficiency improvements, cost-benefit analysis). The findings are interpreted in relation to the research objectives and existing literature. A critical discussion of the implications, limitations, and potential improvements of ITIL-based cooling strategies is included.

CHAPTER 5 – CONCLUSIONS AND RECOMMENDATIONS

This final chapter summarizes the key research findings, providing answers to the research questions and discussing the broader implications for industry and academia. It outlines practical recommendations for data center operators, policymakers, and IT professionals. Additionally, the chapter suggests areas for future research, addressing unresolved questions and new opportunities for innovation in sustainable data center cooling management.

