Optimizing Chiller Plant Performance Through OEE Analysis: A Case Study at Terminal 3 Soekarno-Hatta International Airport

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Abstract: The Air Conditioning System (ACS) in airports plays a crucial role in maintaining user comfort and operational efficiency. However, declining performance in chiller machines negatively affects the overall effectiveness of the system. This study aims to evaluate the Overall Equipment Effectiveness (OEE) value of chiller machines at Terminal 3 of Soekarno-Hatta International Airport during July–December 2024, identify the causes of performance degradation, and propose improvement strategies. The research employed a quantitative approach using primary data (observation and interviews) and secondary data from maintenance records. The measurement results indicate that the OEE values are still below the company's target, with the lowest recorded in Chiller 4 at 77.95% and the highest in Chiller 1 at 80.07%. Analysis of Six Big Losses and Root Cause Analysis (Fishbone Diagram, 5 Why's, and 5W+1H) revealed that performance degradation was mainly caused by human and method factors, such as the absence of technician training and the lack of sequencing control SOPs. Additionally, problems were identified in materials, machinery, and environmental conditions, including damaged coils, ducting, balancing valves, and cooling tower fillers. Proposed solutions include predictive maintenance, the establishment of SOPs, replacement of damaged components, and the enhancement of technician skills. Implementing these strategies is expected to improve OEE values, reduce downtime, extend chiller lifespan, and support sustainable energy efficiency.

Keywords: *Air Conditioning System (ACS), Chiller, Overall Equipment Effectiveness (OEE), Performance, Six Big Losses, Fishbone Diagram, 5 why's Analysis, 5W+1H.*

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I. INTRODUCTION

Terminal 3 of Soekarno-Hatta Airport, one of the largest terminals in Indonesia, has the capacity to accommodate 25 million passengers annually. Built on an area of 422,804 m² with a length of 2.4 km, the terminal consists of five floors: the first for arrivals, the second for departures, and the remaining three floors for offices and lounges. One of the major challenges in supporting operational activities and passenger services in Terminal 3 is maintaining air temperature comfort throughout the terminal area.

To condition indoor air, the terminal operates an Air Conditioning System (ACS) comprising 5 Chiller Units (each 2,100 TR capacity), 183 Air Handling Units (AHUs) of various capacities, 5 Cooling Towers (2,600 TR each), ±18,000 meters of chilled-water piping, ±12,500 m² of air ducting, 127 VRV/Split Cassette/Ceiling AC units, 61 Standing Floor AC units, 168 Rooftop AC units, 176 Split Duct AC units, 83 Split Wall AC units, and 94 Air Curtains.

As the operator of Soekarno-Hatta International Airport, PT Angkasa Pura Indonesia is committed to meeting customer needs with world-class airport facilities. Excellent service is essential, given that Soekarno-Hatta serves as Indonesia's main gateway, making reputation risk management a top priority. Passenger satisfaction surveys highlight that cleanliness, comfortable air temperature, and facility services are key factors in shaping a positive customer experience, achievable through ACS optimization (Hegyi & Csonka, 2022).

Comfortable indoor air is also a critical element in Skytrax's airport quality assessments. In its 2023 audit, Skytrax rated Terminal 3 low in the "Terminal Ambience" category, with a score of 3.0–3.5. This underlines the urgent need for improvements in service quality, passenger comfort, and operational efficiency to compete with globally leading airports.

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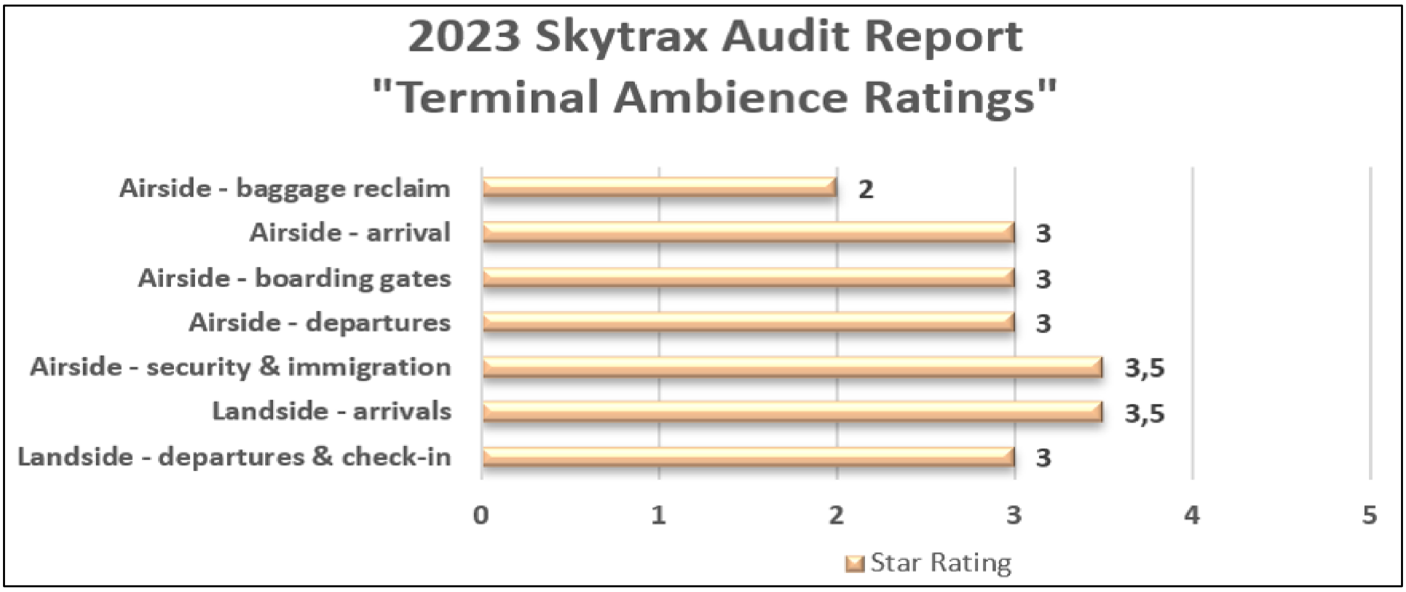

Fig 1 Skytrax Audit Report

The ACS contributes up to 60% of annual airport electricity consumption, though innovations such as displacement ventilation and radiant floor cooling can reduce usage by up to 34% without compromising comfort (X. Liu et al., 2021). Furthermore, maintenance strategy improvements have been shown to enhance ACS efficiency by 13%, directly impacting service quality and passenger satisfaction (Da Costa et al., 2022).

A 2023 customer satisfaction survey by PT Angkasa Pura Indonesia during the Eid holiday travel period found that ACS-related complaints ranked second among the five lowest-rated service categories, alongside Wi-Fi access, smoking areas, check-in queue times, and baggage claim speed. Combined with Skytrax's low ratings, these findings highlight persistent performance issues in the ACS, lowering its OEE and pointing to opportunities for operational and maintenance improvements.

Further details of the survey results are presented in Figure 2.

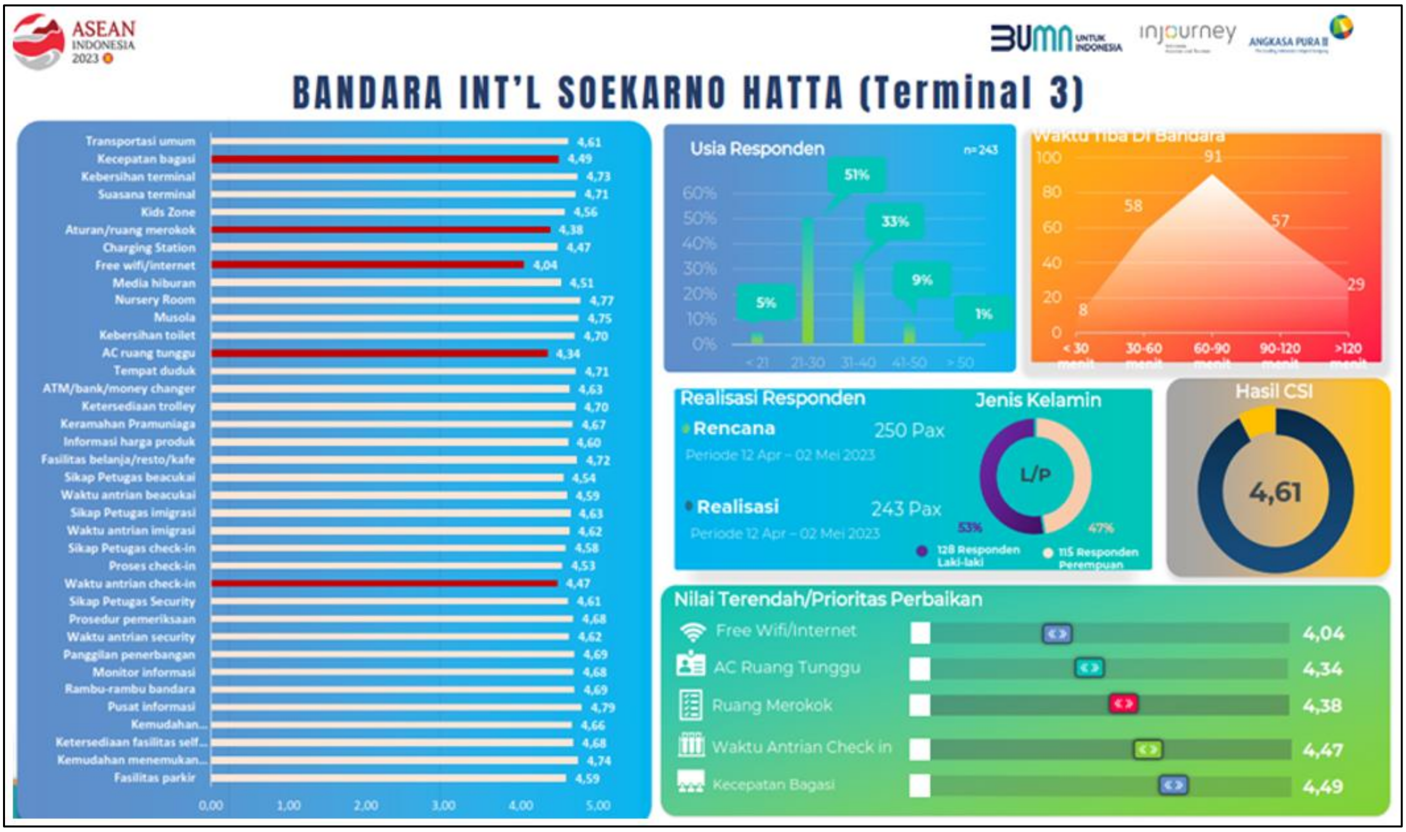

Fig 2 Skytrax Audit Report

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Recent studies emphasize that OEE-based condition monitoring in cooling systems improves energy efficiency and enables better decision-making for preventive maintenance (Sangotayo et al., 2023). Within ACS, OEE is a key tool to identify performance gaps. Its three main components—availability, performance efficiency, and quality—enable comprehensive system evaluation. IoT-based OEE monitoring has increased efficiency by 63.15% in cooling systems (Zheng Yew et al., 2023), reduced downtime-related losses by 27.6% in pulp manufacturing (Sayuti et al., 2019), and boosted operational efficiency by 10% in HVAC industries through lean integration (Sripriyan & Janakiraman, 2018). Preventive maintenance strategies grounded in OEE have raised ACS performance efficiency to 88%, surpassing global benchmarks (Alexander et al., 2024), while also lowering maintenance costs and extending equipment lifespan (Assunção de Lira et al., 2019).

The central cooling system at Terminal 3 integrates six key components: Chillers, Cooling Towers, Distribution Pumps, Chilled Water Piping, AHUs, and Ducting/Diffusers. Together, these ensure optimal cooling across the terminal. Initial preliminary observations using monitoring dashboard data (November 30, 2024) suggest uneven cold-air distribution, hypothesized to be caused by underperforming chillers. This study therefore focuses on evaluating chiller performance, analyzing efficiency losses through the Six Big Losses framework, and identifying root causes to propose corrective measures.

II. LITERATURE REVIEW

A. *Equipment Maintenance*

Total Productive Maintenance (TPM) is a systematic approach designed to enhance equipment effectiveness through maintenance involving all organizational levels. TPM integrates operators, maintenance technicians, and management within a unified framework to ensure optimal equipment performance throughout its life cycle. The philosophy aims to foster shared responsibility across the organization, not only to reduce breakdowns and failures but also to optimize overall performance (Hutchins, 1998).

TPM emphasizes the elimination of losses related to downtime, production defects, and low operational efficiency by involving all employees in maintenance activities. This approach also aligns with lean manufacturing principles, ensuring streamlined and sustainable operations (Smith & Hawkins, 2004).

➢ *Customer Satisfaction Indicators According to Daryanto and Ismanto (2014) Include:*

- Confidence in usage after receiving product information,
- Choosing the product because it is the preferred brand,
- Using the product because it meets desires and needs.

B. *Definition and Components of OEE*

Overall Equipment Effectiveness (OEE) is a widely used metric to measure machine efficiency and effectiveness. OEE evaluates performance across three main components: availability, performance, and quality. It helps organizations identify hidden losses such as downtime, reduced speed, and defective outputs (Bamber et al., 2003).

The importance of OEE lies in its role as a diagnostic tool for identifying opportunities for operational improvement. Through its practical application, OEE enables organizations to minimize downtime, improve quality, and optimize productivity, ultimately enhancing profitability (Ullah et al., 2023). Moreover, OEE serves as a driver of cultural transformation, fostering efficiency awareness at all managerial levels (Esa & Yusof, 2016).

➢ *Repurchase Intention Indicators Include:*

- Transactional interest (responses to expectations),
- Behavioral responses related to purchasing action,
- After-sales service satisfaction.

C. *Components of a Central AC System (Chiller System)*

The term Central AC System (Chiller System) refers to air-conditioning installations for entire buildings that lack independent temperature control in individual rooms. Broadly, central cooling systems include major components: the Chiller Unit, Distribution Pumps, Air Handling Units (AHUs), Cooling Towers, piping systems, air ducting, and control & electrical systems (Komarudin & Manik, 2018).

In this study, the indicators of the price variable are adopted from Kotler and Armstrong (2020): affordability, price-quality suitability, and competitiveness.

D. *Energy Efficiency and ACS Technologies*

ACS efficiency is strongly influenced by factors such as refrigerant quality, the condition of main components, and cooling load. Refrigerant quality determines heat absorption and release effectiveness. Component condition—such as condenser and evaporator cleanliness—also impacts system performance. Excessive cooling load, on the other hand, decreases efficiency and increases energy consumption.

Studies show that environmentally friendly refrigerants such as R134a and R290 improve efficiency and reduce environmental impact compared to conventional refrigerants like R22 (Nugroho et al., 2022; Yuan et al., 2023).

Promotion indicators according to Rachmawati & Patrikha (2021) include responsiveness, assurance, and physical evidence.

E. *Root Cause Analysis*

According to Okes (2019), Root Cause Analysis (RCA) is a structured approach to identifying influential factors behind past events so that they can be used to improve future performance. Latino et al. (2019) highlight that RCA is a commonly used tool in Lean Six Sigma initiatives. RCA helps teams uncover the underlying causes of current problems (Latino et al., 2020).

Fantin (2014) describes root causes as factors (events, conditions, or organizational issues) that contribute to or trigger an undesirable outcome. Similarly, Barsalou (2014)

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emphasizes RCA as an accessible Lean tool for identifying and addressing root problems.

➢ *Product Perception Indicators (2015) for Determining Product Quality Include:*

- Advertising,
- Sales promotions,
- Competitive publicity.

F. Sustainable Development Goals (SDGS)

The Sustainable Development Goals (SDGs) are a global agenda adopted by the United Nations (UN) in 2015 as a continuation of the Millennium Development Goals (MDGs), with broader, more inclusive coverage. Consisting of 17 goals, SDGs address global challenges including poverty, inequality, climate change, environmental degradation, peace, and justice.

The SDGs serve as a comprehensive roadmap for achieving a balance between economic growth, social inclusion, and environmental sustainability. By integrating these goals into national policies, countries are encouraged to foster inclusive, sustainable, and equitable development for both current and future generations.

Based on the above theoretical foundations, the conceptual framework of this research is illustrated in Figure 2.

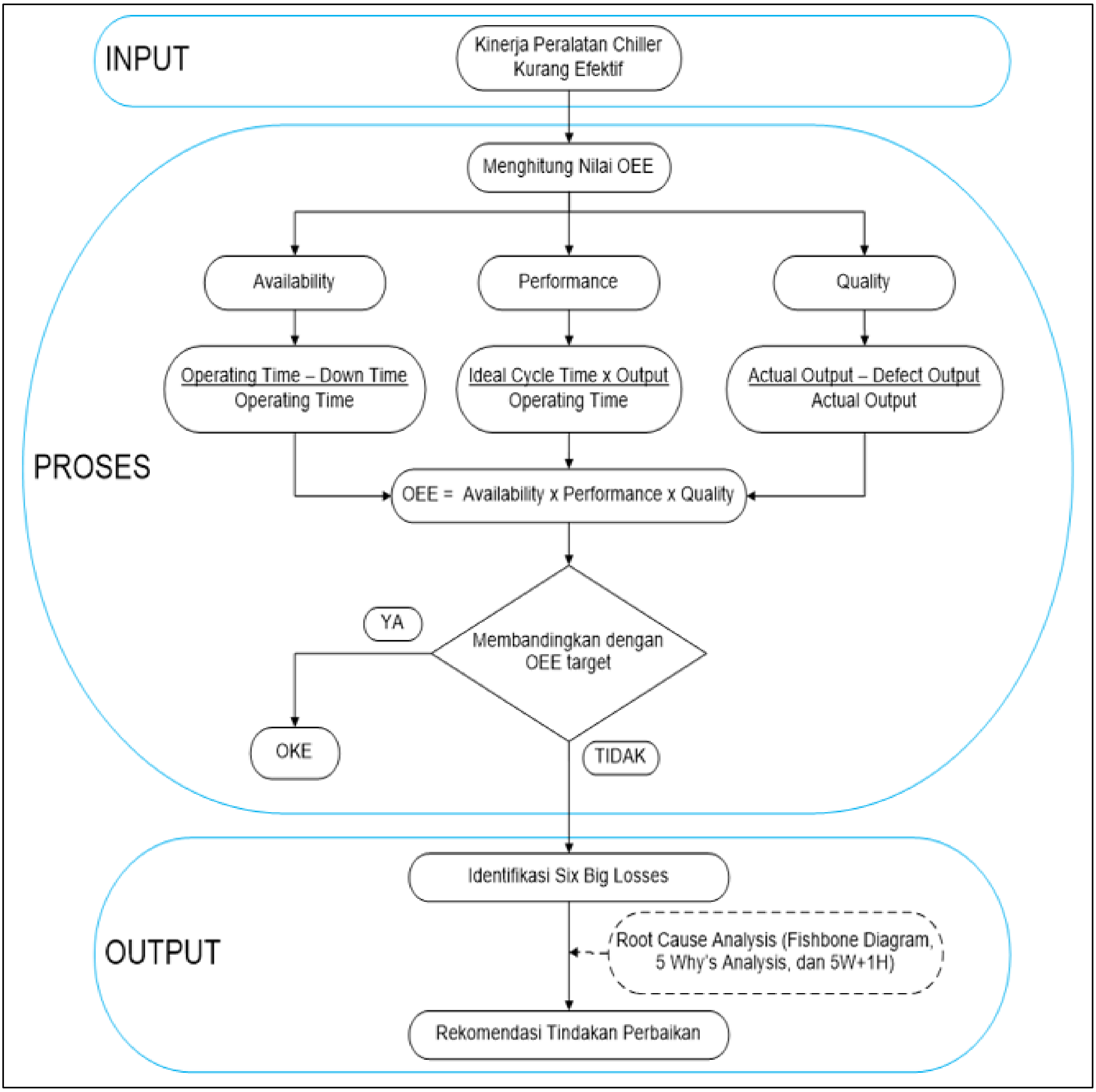

Fig 3 Conceptual Framework

III. RESEARCH METHODOLOGY

This study adopts a quantitative descriptive method. To investigate causes and corrective actions, a survey approach was used with descriptive characteristics, supported by tools such as the Fishbone Diagram, 5 Whys Analysis, and 5W+1H. The descriptive-quantitative method is expected to generate findings with managerial implications for PT Angkasa Pura Indonesia's management.

- Independent variable: equipment performance (dimensions: equipment running hours, maintenance patterns, operating patterns).
- Dependent variable: Overall Equipment Effectiveness (OEE) of chiller machines.
- Population: internal data from PT Angkasa Pura Indonesia – Soekarno-Hatta branch, specifically chiller output and downtime data recorded in daily maintenance reports.
- Sample: data collected from July to December 2024.

IV. RESULTS

The study population consists of internal records of PT Angkasa Pura Indonesia at Soekarno-Hatta branch, specifically chiller output and downtime data reported in daily maintenance logs. The sample covers the period July–December 2024.

➢ *OEE Value of Chillers*

During the period July–December 2024 at Soekarno-Hatta Airport, the OEE values remained below the company's target.

- Lowest value: Chiller 4 (77.95%)
- Highest value: Chiller 1 (80.07%)

➢ *Factors Contributing to Low OEE*

- Man & Method: Absence of technician training → operational errors; lack of a sequencing control SOP.
- Material, Machine & Environment: Performance decline/damage to coils, ducting, balancing valves, and cooling tower fillers.

➢ *Improvement Plan*

Refers to the 5W+1H framework across five main factors (man, method, material, machine, and environment).

- Proposed actions: technician training, development and implementation of SOPs, and replacement of defective components (coils, ducting, fillers).

V. CONCLUSION

This study evaluated the performance of chiller machines at Terminal 3 Soekarno-Hatta International Airport using the Overall Equipment Effectiveness (OEE) framework. The findings indicate that all chiller units consistently performed below the company's OEE target, with values ranging between 77.95% (Chiller 4) and 80.07% (Chiller 1). Analysis through the Six Big Losses and Root Cause Analysis (Fishbone Diagram, 5 Whys, and 5W+1H) revealed that performance degradation stemmed from multiple factors, including human error, the absence of sequencing control SOPs, insufficient technician training, as well as technical issues such as damaged coils, ducting, balancing valves, and cooling tower fillers.

To address these issues, several improvement strategies were proposed, including the implementation of predictive and preventive maintenance programs, the establishment of clear SOPs, systematic replacement of defective components, and targeted technician capacity-building. These measures are expected to enhance equipment availability, performance efficiency, and output quality, ultimately improving OEE values.

Beyond operational gains, improvements in the chiller system directly contribute to better passenger comfort, reduced downtime, and increased energy efficiency, thereby supporting the airport's service excellence and sustainability agenda. Future research may focus on integrating IoT-based predictive monitoring tools with OEE analysis to provide real-time diagnostics and optimize long-term system performance.

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