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RESEARCH ARTICLE

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Physical Energy Performance and Operational Management Gap in a Vocational School Building

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Abstract: This study investigates the gap between physical energy-efficiency provisions and operational energy management in an existing vocational school building. The case study was conducted at SMKN 4 Balikpapan, Indonesia, a nine-building educational complex with energy-intensive teaching facilities for culinary arts, fashion, beauty, and hospitality. Data were obtained through field observation, technical document review, interviews with facility managers, six months of electricity-bill records, and expert validation. The assessment isolated energy-related criteria from the Indonesian Green Building performance framework and reorganized them into two analytical domains: physical provisions and operational management. A domain compliance ratio was calculated using applicable criterion points. The physical domain achieved 18 of 22 applicable points (81.8%), supported by an overall thermal transfer value of 32.77 W/m², a window-to-wall ratio of 6.76%, limited air-conditioning in passive spaces, efficient split-unit air conditioners, and separated lighting circuits near daylight zones. In contrast, documented operational management achieved only 2 of 7 applicable points (28.6%), while institutionalized routine practice was effectively absent because the six-month trend was reconstructed by the researchers rather than produced by the school. The school had no formal energy-management procedure, baseline model, load-level submetering, reference-consumption comparison, or recommissioning program. The findings demonstrate an asset-capability–management-capability gap: compliant physical features create potential savings, but the absence of monitoring, accountability, and feedback prevents the school from verifying and sustaining those savings. A staged improvement pathway is proposed, beginning with governance and monthly logging, followed by targeted submetering, baseline development, and periodic operational tuning under limited institutional resources.

Keywords: Building Energy Management; Energy Performance Gap; Green Building; Submetering; Vocational School

1. INTRODUCTION

Energy efficiency in buildings is often discussed as a design problem, yet long-term performance is equally shaped by how buildings are operated, monitored, maintained, and adapted after occupancy. A building may have a favorable envelope, efficient mechanical equipment, and reasonable daylight access, but those assets do not automatically produce measurable energy savings. The difference between expected capability and actual operation is commonly framed as an energy performance gap. Early studies described this gap as the difference between predicted and measured energy use, while later research emphasized that it is also generated by organizational practices, data limitations, occupant behavior, maintenance quality, and unclear responsibilities (de Wilde, 2014; Menezes et al., 2012; van Dronkelaar et al., 2016). For existing public buildings, where full simulation data are often unavailable, the practical challenge is not only to compare prediction and consumption but also to determine whether the institution has the capability to measure, interpret, and act on its own energy use.

Monitoring is central to this capability. Whole-building utility bills can show whether monthly consumption rises or falls, but they cannot identify which end use is responsible for the change. Metering and environmental monitoring provide the information layer required for benchmarking, fault detection, operational tuning, and accountability (Ahmad et al., 2016). More recent work shows that submetering by system or load category improves the diagnostic value of energy data because lighting, cooling, plug loads, and process equipment can be evaluated separately rather than being hidden within a single total (Li et al., 2023). Data quality is equally important: inconsistent time intervals, incomplete records, unclear units, and missing contextual information can make monitoring technically present but managerially ineffective (Morewood, 2023).

Educational buildings present a distinctive operational context. Their schedules vary with examinations, holidays, extracurricular activities, and room-specific teaching requirements. Vocational schools are more complex than conventional classroom buildings because practical learning spaces may include kitchens, laundry rooms, salons, workshops, computer laboratories, and hospitality facilities. These functions create concentrated and variable electricity demand that cannot be interpreted only from the characteristics of classrooms. Research in schools has shown that structured energy-management programs can reduce consumption through a combination of managerial routines, awareness, low-cost controls, and technical actions (AlFaris et al., 2016). A low-carbon school program in Australia similarly demonstrated that many effective actions were low or zero cost, but the participating schools first needed utility tracking, assigned responsibilities, and feedback mechanisms (Odell et al., 2021).

Indonesia has established a formal framework for Green Building performance through the Regulation of the Minister of Public Works and Public Housing No. 21 of 2021 and its technical guidance. For existing buildings at the utilization stage, the framework includes governance, adaptation construction, performance during use, and occupant roles. Energy-related criteria address the building envelope, ventilation, air-conditioning, lighting, electrical systems, monitoring, reference consumption, and recommissioning. These criteria are supported by national standards for envelope conservation, lighting, and air-conditioning systems (Badan Standardisasi Nasional, 2020a, 2020b, 2020c; Kementerian PUPR, 2021, 2022). Recent Indonesian studies have applied the framework to laboratories, villas, hospitals, offices, and educational buildings, typically reporting an aggregate compliance score or green-building rating (Habibi et al., 2025; Muka, 2024; Safrini et al., 2025; Zulistian et al., 2023). Aggregate ratings are useful for certification, but they can conceal an important internal imbalance: a building may score well for physical provisions while having weak operational management, or the reverse.

SMKN 4 Balikpapan provides a relevant case for examining this imbalance. The school occupies an 11,650 m² site and contains nine building units serving approximately 1,322 students, teachers, and staff. Its vocational programs include culinary arts, fashion, beauty, and hospitality, and its facilities include ordinary classrooms as well as food-processing rooms, laundry equipment, computer laboratories, beauty-practice rooms, and an educational hotel. The building complex already contains several energy-relevant features, such as limited air-conditioning in passive spaces, natural and mechanical ventilation, daylight-responsive lighting zoning, and a relatively low transparent-envelope ratio. At the same time, preliminary inspection indicated that energy use was recorded through a main meter without routine load-level analysis, and that formal operational procedures were limited.

This study reframes the assessment around one question: how large is the gap between the physical energy performance of the building and the institution's operational energy-management capability? The contribution is threefold. First, it isolates the energy parameter instead of repeating the overall Green Building rating. Second, it distinguishes physical provisions from documented and institutionalized management practices. Third, it treats researcher-generated analysis differently from a routine process embedded in the school organization. This distinction is important because an audit can temporarily produce a graph or score, but the building will not continue learning after the audit unless the responsible organization owns the data process. The objectives are therefore to: (1) evaluate the performance of applicable physical energy provisions; (2) evaluate operational energy-management practices; (3) quantify and interpret the gap between the two domains; and (4) formulate a staged pathway that is proportionate to the technical and financial capacity of a public vocational school..

2. METHOD

2.1 Case Study and Data Sources

The research used a descriptive quantitative case-study design supported by qualitative evidence. The unit of analysis was the existing SMKN 4 Balikpapan building complex during its utilization stage. The study did not re-evaluate the complete Green Building rating. Instead, it extracted energy-related evidence from the broader assessment and reorganized the evidence to answer the narrower research question concerning physical performance and operational management.

Primary data were collected through direct observation of the building envelope, ventilation, air-conditioning, lighting controls, electrical distribution, and management practices. Interviews were conducted with school personnel responsible for facilities and infrastructure. Secondary evidence included as-built drawings, equipment specifications, maintenance records, electricity bills, applicable regulations, and national standards. Six consecutive months of electricity-bill data, covering October 2025 to March 2026, were reviewed to identify changes in total consumption. Three technical experts with relevant building and Green Building competence were involved in validating the interpretation of criteria and the technical adequacy of evidence.

The case characteristics are summarized in Table 1. The combination of ordinary learning spaces and practice facilities makes the complex suitable for studying the relationship between physical provisions and management capability. In particular, a single whole-building meter may be insufficient because teaching activities differ significantly in operating hours and energy intensity.

Evidence was evaluated through source triangulation. A physical provision was treated as present only when it could be supported by direct observation, a drawing or equipment specification, and, where relevant, a technical calculation. A management practice was treated as institutionalized only when responsibility, frequency, record format, and review action could be identified. Verbal statements without a repeatable record were retained as contextual information but were not counted as a routine process. This hierarchy was adopted to avoid equating an installed device with a managed outcome and to distinguish between information produced once for the audit and information routinely generated by the school.

Technical calculations followed the applicable Indonesian conservation standards. Envelope capability was represented by Overall Thermal Transfer Value (OTTV) and Window-to-Wall Ratio (WWR). OTTV aggregates conductive and solar heat gains through opaque and transparent façade components, while WWR expresses the proportion of transparent opening area relative to the gross external wall area. Ventilation, air-conditioning, and lighting were assessed against the relevant provisions of the Green Building checklist and supporting standards. The analysis did not claim that physical compliance alone represented actual annual savings; rather, it assessed whether the building possessed energy-relevant design and equipment characteristics that could support efficient operation when properly managed.

Table 1 Case-study characteristics

Characteristic	Description
Location	Balikpapan, East Kalimantan, Indonesia
Site area	11,650 m²
Building units	9 units; predominantly two-storey buildings
Population	Approximately 1,322 students, teachers, and staff
Main programs	Culinary arts, fashion, beauty, and hospitality
Energy-intensive spaces	Food processing, laundry, educational hotel, computer laboratories, beauty-practice rooms, and workshops
Assessment period	Field assessment in 2026; electricity records from October 2025 to March 2026

2.2 Analytical Domains and Scoring

The analytical framework separated applicable criteria into two domains. The physical-provision domain represented the installed or spatial capability of the building: envelope performance, ventilation strategy, air-conditioning efficiency, and lighting configuration. Vertical transportation was excluded because the school has no lift or escalator and the criterion was not applicable. The operational-management domain represented processes needed to sustain and verify performance: a formal energy procedure, an energy baseline or simulation, load-level metering, routine monthly monitoring, comparison with reference consumption, and periodic recommissioning. A centralized building management system was treated as non-applicable because the school uses decentralized split air-conditioning rather than a central plant; its absence was discussed qualitatively but not used to reduce the normalized management score.

For each domain, a domain compliance ratio (DCR) was calculated as the achieved points divided by the maximum applicable points. The ratio is an analytical device developed for this article and is not an official Green Building certification score. It was used only to compare domains with different point totals.

$$DCR_j = (\Sigma \text{ achieved applicable points} / \Sigma \text{ maximum applicable points}) \times 100\% \qquad (1)$$

Two versions of the operational result were reported. The documented-evidence ratio followed the evidence available during the study, including the six-month trend reconstructed by the researchers from electricity bills. The institutionalized-routine ratio counted only processes that the school itself performed as a recurring management activity before the assessment. This distinction prevents an audit-generated output from being misinterpreted as an established management system.

The physical domain had 22 applicable points: envelope (8), ventilation (2), air-conditioning (5), and lighting (7). The documented operational domain had seven applicable points: monthly monitoring and evaluation (2), maintenance of consumption within a reference threshold (1), additional savings relative to the reference (1), and recommissioning (3). The criteria concerning construction adaptation conformity and lift maintenance were not used in the normalized operational comparison because the first lacked sufficient construction data and the second was not applicable. Baseline calculation, submetering, and formal procedures were analyzed as enabling management conditions and reported separately because they originated in the planning and governance portions of the national framework.

2.3 Interpretation of the Gap

The gap was interpreted as the difference between the physical DCR and the operational DCR. A large positive difference indicates that the building has physical potential that is not matched by management capability. Evidence was triangulated across observations, documents, interviews, and expert review. Contradictions were resolved by prioritizing directly observed conditions and documentary evidence. Where the school had raw data but no routine process, the condition was classified as data availability without institutionalization.

The analysis also considered the diagnostic depth of the available data. A monthly total can reveal temporal deviation, but it cannot attribute the deviation to a particular program, room type, or end use. Therefore, the presence of utility bills was not considered equivalent to an operational energy-management system.

3. RESULTS

3.1 Physical Energy-Performance Provisions

The building envelope met the two principal criteria used in the assessment. The calculated overall thermal transfer value was 32.77 W/m², below the maximum threshold of 35 W/m². The window-to-wall ratio was 6.76%, substantially below the 30% threshold. These values indicate that the existing envelope limits solar and conductive heat gain relative to the regulatory limits. The result is particularly relevant in Balikpapan's warm-humid climate, where cooling demand can be strongly influenced by the external envelope.

The ventilation strategy also performed well. Air-conditioning was limited to staff rooms, computer laboratories, and selected practice rooms. Corridors, stairs, toilets, and lobbies were not mechanically cooled, and some enclosed spaces used exhaust fans to support air movement. This configuration reduces the area served by active cooling and uses natural or simple mechanical ventilation for passive spaces. The ventilation criterion achieved its full two points.

The air-conditioning criterion achieved four of five applicable points. Equipment documentation indicated a cooling capacity of approximately 12,000 BTU/h and a coefficient of performance of 3.45 W/W, which complied with the applicable equipment-efficiency requirement. However, the study could not verify whether all conditioned rooms maintained the prescribed temperature and relative humidity because access for direct measurement was limited. The physical presence of efficient equipment therefore represented strong potential, but the lack of comprehensive in-use measurements prevented complete confirmation.

Lighting achieved four of seven points. A small storage room used a single switch appropriate to its area, and perimeter lighting near daylight zones was separated from interior lighting. This zoning allows occupants to switch off lamps close to windows while retaining artificial light in deeper parts of the room. However, the school had no occupancy sensors and no daylight sensors for automatic control. Direct measurement of power density and illuminance was also incomplete. The lighting configuration was therefore partly efficient but remained dependent on user behavior.

Across the four applicable physical categories, the school obtained 18 of 22 points, equivalent to a physical DCR of 81.8%. Table 2 shows that the strongest elements were the envelope and ventilation strategy, while lighting automation was the most visible physical limitation.

Table 2 Physical energy-provision assessment

Component	Evidence	Achieved	Applicable maximum	DCR
Envelope	OTTV 32.77 W/m²; WWR 6.76%	8	8	100%
Ventilation	Passive spaces not air-conditioned; natural/mechanical ventilation used	2	2	100%

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Component	Evidence	Achieved	Applicable maximum	DCR
Air-conditioning	Split-unit COP 3.45 W/W; room condition not fully measured	4	5	80.0%
Lighting	Separated daylight-zone circuits; no occupancy or daylight sensors	4	7	57.1%
Total	Applicable physical provisions	18	22	81.8%

3.2 Operational Energy Management

Operational management was substantially weaker than the physical domain. The school did not have a formal standard operating procedure for energy conservation. Energy-saving behavior existed informally, for example through limited air-conditioning and manual switching, but responsibilities, schedules, targets, and reporting requirements were not documented. Without a formal procedure, energy performance depended on individual initiative rather than an organizational cycle.

No energy baseline or simulation was available. The technical framework requires comparison with a reference derived from applicable standards or prior consumption. The absence of a baseline meant that the school could not quantify whether the building was saving energy relative to a defined expectation. Envelope compliance demonstrated that the building had favorable physical characteristics, but it did not establish the magnitude of total operational savings because internal loads, schedules, equipment use, and occupancy were not modeled.

Electrical loads were grouped functionally, but consumption was recorded through a main meter rather than through load-level submeters. Consequently, the school could not separate electricity used by lighting, cooling, kitchen equipment, laundry equipment, computer laboratories, or other plug loads. This limitation is critical in a vocational school because the energy profile of a culinary laboratory differs markedly from that of a classroom. A monthly increase can be detected at the main meter, but it cannot be diagnosed without additional data or temporary measurement.

The school also did not routinely monitor and graph monthly electricity consumption. The research team reconstructed a six-month trend from utility bills. Consumption declined from October through January, increased sharply in February, and decreased again in March. Interviews associated the February increase with Grade XII examinations, when additional rooms and equipment were used. This reconstructed trend demonstrated that existing bills can produce useful operational insight. However, because the graph was created for the study and was not part of the school's routine, it represented documented evidence rather than institutionalized management.

The school had not established a reference-consumption threshold based on the previous year, so it could not determine whether a monthly value exceeded the reference by more than 10%. Nor could it verify a 10% saving relative to the reference. Periodic recommissioning was also absent: there was no documented six-month cycle for measuring and verifying the efficiency of major systems and restoring performance through corrective action. Maintenance cards existed for some equipment, but they did not constitute an integrated energy-performance verification process.

Using the evidence available during the assessment, the operational domain achieved two of seven applicable points because the researchers were able to create a six-month trend and explain one deviation. This produced a documented operational DCR of 28.6%. When only pre-existing, recurring school practices were counted, the institutionalized-routine ratio was 0%, because the school had not independently performed monthly analysis, reference comparison, savings verification, or recommissioning. Table 3 summarizes the distinction.

Table 3 Operational Energy-Management Evidence

Management function	Condition at the school	Documented evidence	Institutionalized routine
Energy policy and responsibility	No formal energy-conservation SOP or assigned reporting cycle	Absent	Absent
Baseline and target	No simulation or reference baseline	Absent	Absent
Load-level metering	Main meter only; no end-use submetering	Absent	Absent

Management function	Condition at the school	Documented evidence	Institutionalized routine
Monthly monitoring	Six-month trend reconstructed from bills by researchers	Available through study	Absent
Deviation evaluation	February peak linked to examination activity	Available through study	Absent
Reference comparison and saving verification	No prior-year reference or quantified saving	Absent	Absent
Recommissioning	No periodic measurement and verification program	Absent	Absent

3.3 Magnitude and Character of the Gap

The physical DCR of 81.8% exceeded the documented operational DCR of 28.6% by 53.2 percentage points. The difference increased to 81.8 percentage points when physical provisions were compared with institutionalized routine practice. Figure 1 illustrates this profile. The result does not imply that the physical systems are optimal or that actual energy use is low in absolute terms. It shows that the building has more technical capability than the organization has capacity to manage and verify.

The gap is best described as an asset-capability–management-capability gap. The asset side includes a favorable envelope, limited conditioning of passive spaces, efficient split units, and lighting zones that can take advantage of daylight. The management side lacks a continuous cycle of measurement, interpretation, corrective action, and verification. This makes physical savings fragile. Manual switching can work when occupants are attentive, but there is no feedback mechanism to show whether the expected behavior occurs consistently.

A second finding is the difference between data availability and data use. The school had electricity bills, and these bills were sufficient to construct a six-month trend. Yet the data were not transformed into regular management information before the study. The February peak became visible only after the researchers organized the records. This condition can be called audit-induced visibility: the audit temporarily reveals a pattern without establishing a system that will continue to reveal future patterns.

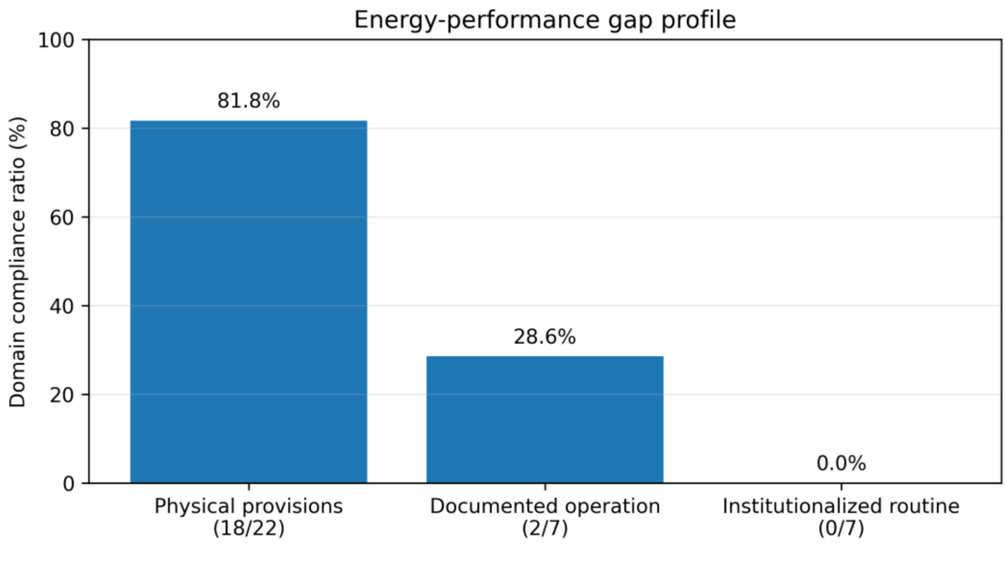

Figure 1 Energy-performance gap profile based on applicable criteria.

4 DISCUSSION

4.1 From Physical Compliance to Operational Performance

The case confirms that physical compliance is necessary but not sufficient for sustained energy performance. The envelope and ventilation results reduce the structural cooling burden, while efficient split air conditioners and daylight zoning create additional saving opportunities. However, these provisions describe what the building can do, not what it consistently does. This distinction is consistent with the broader performance-gap literature, which shows that operational outcomes are shaped by interactions among engineering systems, occupants, maintenance, and organizational arrangements (Liang et al., 2019; van Dronkelaar et al., 2016).

The study extends the conventional predicted-versus-measured concept by applying a capability perspective to an information-poor existing building. A full prediction gap could not be calculated because the school lacked an energy model and a normalized baseline. Nevertheless, the absence of those instruments is itself a management finding. In practice, many public buildings cannot begin with calibrated simulation or high-resolution sensing. They first need a minimum management architecture: assigned responsibility, consistent data collection, agreed indicators, and a decision routine. Without this foundation, more advanced modeling may produce a one-time report but not an enduring improvement process.

The envelope result illustrates this problem. An OTTV below the threshold and a low WWR indicate reduced external heat gain, but whole-building electricity still depends on internal equipment, operating hours, occupancy, and user behavior. Culinary equipment, laundry machines, computers, and salon appliances can dominate demand during practical activities. Therefore, a physically efficient envelope cannot be used as evidence that total operational energy is efficient. A baseline and end-use data are required to connect design potential with actual outcomes.

Lighting provides another example. Separate perimeter circuits are a useful passive-control measure, but their benefit depends on whether users switch them appropriately. Occupancy and daylight sensors would reduce dependence on behavior, yet they also introduce capital and maintenance requirements. Before investing in automation, the school can begin with operating instructions, labeling, room checklists, and monthly feedback. This staged approach is consistent with school energy-management research showing that organizational and low-cost measures can precede major retrofits (AlFaris et al., 2016; Odell et al., 2021).

4.2 Why Whole-Building Bills Are Not Enough

The six-month trend was useful for recognizing a February peak, but it could not identify the contribution of each load category. The interpretation that examinations caused the increase was plausible and supported by interviews, yet it could not be verified from the main meter alone. Additional rooms may have been occupied, air conditioners may have operated longer, computer laboratories may have been used intensively, or practice equipment may have been scheduled differently. A single total cannot distinguish these possibilities.

Submetering is therefore a diagnostic priority rather than merely a technological upgrade. Research on campus buildings demonstrates that sub-item data improve evaluation because each end use has a different normal pattern and saving potential (Li et al., 2023). In the SMKN 4 context, a full building management system would not be the first requirement. The school uses decentralized split units, and a sophisticated centralized platform may be disproportionate to current capacity. A more appropriate first step is targeted submetering of the highest and most variable loads: culinary and food-processing rooms, laundry and educational-hotel services, computer laboratories, and clusters of air-conditioned practice rooms.

Targeted submetering should be accompanied by data-governance rules. More meters do not guarantee better decisions if readings are irregular or incomparable. The monitoring literature emphasizes temporal resolution, completeness, consistency, contextual metadata, and transparent reporting (Ahmad et al., 2016; Morewood, 2023). At minimum, each record should include the meter identity, reading date, unit, covered spaces, operating schedule, major events, and responsible person. The examination period should be marked in the log so that future comparisons distinguish operational events from equipment faults.

The school can also use normalized indicators before installing extensive sensors. Monthly kWh per square meter and kWh per student can be calculated from bills and basic occupancy data. A rolling twelve-month baseline would reduce seasonal distortion and provide a more defensible reference than a six-month series. Where local weather data are available, cooling-degree indicators or outdoor temperature can be added. These simple indicators will not replace end-use measurement, but they can transform utility bills from accounting documents into management information.

4.3 Governance, Maintenance, and Continuous Improvement

Operational energy management requires an organizational owner. The absence of an energy SOP at SMKN 4 meant that no person or unit was formally responsible for collecting bills, preparing graphs, investigating deviations, or reporting corrective actions. This is a governance gap rather than a purely technical gap. Studies of green commercial buildings have found that organizational, behavioral, and engineering factors are comparably important in explaining performance gaps (Liang et al., 2019). The practical implication is that technical interventions should be paired with a defined management process.

A basic procedure can follow a monthly plan-do-check-act cycle. The plan stage sets the baseline, monthly target, room schedules, and responsibilities. The do stage applies operating rules for air-conditioning, lighting, and high-load practice equipment. The check stage records bills and submeter data, compares them with the reference, and explains deviations. The act stage assigns corrective actions and verifies whether consumption returns to the expected range. This structure is compatible with the logic of energy-management systems without requiring immediate formal certification.

Maintenance should be integrated with energy performance rather than treated only as repair. Existing maintenance cards demonstrate that the school has a starting documentation practice, but equipment condition was not linked to energy indicators. System degradation, incorrect controls, and inadequate maintenance can increase operational energy use even when efficient equipment was initially installed (Alghanmi et al., 2022). For split air conditioners, the school can record filter cleaning, refrigerant checks, setpoint verification, operating hours, and power observations. For lighting, it can record lamp replacement, switch zoning, and sensor functionality if sensors are later installed.

Recommissioning is the bridge between maintenance and performance verification. Continuous or periodic commissioning compares how systems operate against intended performance and identifies faults or control drift. Monitoring platforms and component-level analysis have been proposed as effective ways to reduce performance gaps and support corrective action (Jradi et al., 2018; Zou & Alam, 2020). At SMKN 4, recommissioning can begin as a six-month manual review rather than a fully automated platform. The review should examine high-load rooms, verify air-conditioning setpoints, inspect ventilation paths, check lighting zoning, and compare energy records with occupancy and academic schedules.

4.4 Staged Improvement Pathway

The gap profile suggests that the first priority is not another physical retrofit but management institutionalization. Physical measures should still be improved where justified, particularly lighting sensors and direct verification of thermal conditions, but the school will gain more immediate value by creating a repeatable information and decision process. Table 4 proposes four stages. The stages are cumulative: later investments are more useful after earlier governance and data practices are functioning.

Stage 1 can be implemented with minimal cost. The school appoints an energy coordinator, issues a short energy SOP, collects the main electricity bill every month, and records academic events that may affect use. The coordinator produces a simple trend graph and reports deviations to management. Stage 2 adds diagnostic depth through targeted submetering or temporary clamp-meter campaigns. Permanent meters should be prioritized where loads are large, variable, and managerially controllable.

Stage 3 establishes a baseline and key performance indicators. A twelve-month baseline should be developed once sufficient records are available. Targets can be expressed as total kWh, kWh/m², and kWh/student, while selected practice areas can use kWh per operating hour or activity. Stage 4 introduces periodic recommissioning, corrective maintenance, and selective automation. Occupancy or daylight sensors should be installed only where their expected saving and maintenance requirements are clear. Renewable-energy planning can follow after the school has reliable demand data, because correct sizing depends on an understood load profile.

Table 4 Staged pathway for closing the management gap

Stage	Core actions	Primary output	Indicative priority
1 Governance and basic monitoring	Assign coordinator; issue SOP; archive bills; log academic events; produce monthly trend	Consistent ownership and monthly visibility	Immediate; low cost
2 Diagnostic metering	Install targeted submeters or conduct temporary measurements for kitchens, laundry, laboratories, and cooling clusters	Load attribution and anomaly diagnosis	Short term; moderate cost
3 Baseline and targets	Develop 12-month baseline; calculate kWh/m² and kWh/student; set deviation thresholds	Performance benchmark and measurable targets	Medium term
4 Recommissioning and selective automation	Review setpoints and schedules; verify equipment efficiency; add sensors where justified; assess renewable-energy feasibility	Sustained improvement and verified savings	Medium to long term

4.5 Implications and Limitations

For policy and certification practice, the findings indicate that point-based assessments should explicitly distinguish installed features from institutionalized processes. A criterion may appear satisfied because an assessor reconstructs information from available records, while the building manager has no routine for producing the same information after the assessment. Reporting both evidence compliance and process ownership would make recommendations more operational and reduce the risk that certification becomes a one-time documentation exercise.

For vocational-school management, the analysis shows that energy governance should reflect educational functions. Practical rooms should not be treated as generic classrooms. Their schedules, equipment, safety requirements, and learning objectives differ, so targets should be developed with teachers and technicians rather than imposed only by facility staff. User participation is also necessary because manual lighting and decentralized air-conditioning place substantial control in the hands of occupants.

The distinction between documented evidence and institutionalized routine also has implications for audit methodology. During this study, the research team could reconstruct a six-month trend from utility bills, but the same output would not necessarily be repeated after the study ended. This condition can be described as audit-induced visibility: an external assessment temporarily makes energy use visible without creating the internal capability to sustain that visibility. A robust assessment should therefore record not only whether a graph, baseline, or calculation exists, but also who produces it, how often it is updated, what threshold triggers investigation, and how corrective actions are closed. These process attributes determine whether evidence functions as an operational control or remains a static attachment.

The findings are transferable to other public vocational schools with similar decentralized systems and budget constraints. Such institutions may be tempted to begin with expensive automation, photovoltaic installation, or wholesale equipment replacement. However, capital measures cannot be evaluated reliably when load profiles, schedules, and baseline conditions are unknown. A governance-first sequence reduces this risk. Monthly utility review, activity logging, and temporary measurement campaigns can identify where permanent meters or retrofits will create the greatest value. This approach is particularly relevant in vocational settings because practice equipment may operate intermittently but at high power; annual totals can obscure these short, controllable peaks. By linking consumption to the academic calendar and room function, school managers can protect teaching quality while avoiding blanket restrictions that may disrupt learning.

The study has several limitations. It examined one school and therefore does not represent all vocational schools. The electricity series covered only six months and was not normalized for weather, holidays, or detailed occupancy. The study did not have continuous power measurements or end-use submeters, so it could not calculate energy-use intensity by system or determine the exact cause of the February increase. Some room-level thermal and lighting measurements were limited by access. The normalized domain ratios are an analytical reclassification rather than official certification scores. Future research should collect at least twelve months of high-quality data, install temporary or permanent submeters, and evaluate whether the proposed management stages produce measurable savings.

5. CONCLUSION

SMKN 4 Balikpapan exhibits a pronounced gap between physical energy capability and operational energy management. Applicable physical provisions achieved 18 of 22 points (81.8%), supported by a compliant envelope, a low window-to-wall ratio, limited conditioning of passive spaces, efficient split air conditioners, and daylight-oriented lighting zoning. Documented operational evidence achieved only 2 of 7 points (28.6%), and the institutionalized-routine ratio was effectively 0% because monthly analysis was produced by the research team rather than by an established school process. The building therefore has technical potential that cannot yet be consistently verified, diagnosed, or sustained. The most important intervention is to institutionalize management before pursuing complex automation: assign responsibility, establish an energy SOP, create a monthly record and review cycle, and develop a twelve-month baseline. Targeted submetering should then focus on high-load vocational functions, followed by periodic recommissioning and selective controls. This staged pathway

DISCLAIMER

The authors declare no conflict of interest.

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