JURNAL TEKNIK SIPIL CENDEKIA
e-ISSN : 2723-3375
doi : **10.51988/jtsc.v7i4.731**
pp : 838-844

Life Cycle Cost Analysis of Building and Energy Management System Strategies for a Hotel Chiller Plant

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Received : 31 Agustus 2026 Revised : 13 Oktober 2026 Accepted : 28 Oktober 2026

Abstract

This study addresses the economic decision gap between a first-stage building management system (BMS) retrofit and a subsequent energy management system (EMS) addition in a hotel chiller plant. Using Hotel X operational records, explicitly reconstructed inputs, and declared modeling assumptions, three strategies were compared: existing operation (S0), BMS (S1), and BMS–EMS integration (S2). The contribution is a sequential 15-year life-cycle cost assessment (6% discount rate; constant prices) that applies the incremental EMS saving to residual post-BMS energy and charges only additional EMS costs, preventing double counting. Modeled electricity demand is 700,555.753, 630,500.178, and 598,975.169 kWh/year, respectively. The locked Base-case present-value costs are IDR 9.075, 8.692, and 8.708 billion, with S1 lowest despite S2 having the lowest modeled energy consumption. The 50% baseline chiller allocation and assumed technology savings are not independently metered outcomes. S1 is the preferred Base-case first stage; any EMS extension should be reassessed with site-verified incremental performance and procurement costs.

Keywords: *Life-Cycle Cost; HVAC; Building Management System; Energy Management System; Net Present Value*

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INTRODUCTION

Heating, ventilation, and air-conditioning (HVAC) is central to hotel operation because prolonged equipment use entails substantial energy demand and costs over the asset life. Hotel energy demand reflects both physical characteristics and operational patterns [1]. Consequently, choosing between existing controls and an automation retrofit requires the joint appraisal of investment, energy, operations, maintenance, replacements, and the time value of money.

Life-cycle costing (LCC) expresses expenditures incurred at different times on a common present-value basis, allowing a higher initial investment to be assessed against potential operating savings [2], [3]. Studies of hotel retrofit projects demonstrate that improved energy performance does not necessarily deliver the lowest life-cycle cost [4], while retrofit feasibility responds to investment, energy prices, and realized savings [5], [6]. Building-retrofit research further supports examining economic and energy performance together [7], [8]. Indonesian building studies have also employed LCC to evaluate future expenditure and asset-management choices [9], [10]. Earlier research related to this study identified important LCC factors for hotel HVAC [11] and evaluated building-maintenance strategies using LCC [12]; these works establish research continuity

rather than supply the technical inputs for the present scenarios.

A building management system (BMS) can provide integrated monitoring, alarms, logging, set-point control, and operational coordination. Its savings depend on the initial conditions, system configuration, climate, occupancy, and method of assessment [13], [14]. Automation also provides data useful for facility-management decisions [15]. An energy management system (EMS) adds energy analytics, anomaly identification, optimization, and decision support [16], while continuous commissioning can help detect deviations from intended performance [17]. Additional automation may nevertheless require hardware, integration, operation, and upgrades [18].

Previous hotel-retrofit and building-automation studies establish the importance of combining energy and economic appraisal [4]–[8], [13]–[18], but the present case addresses a narrower decision that must be evaluated sequentially: whether the additional EMS layer is economically justified after BMS has already reduced the energy baseline. The methodological contribution is a transparent S0-to-S1-to-S2 accounting structure: the 5% EMS saving is applied only to the 90% energy remaining after the assumed 10% BMS saving, while the S2 cost adds only incremental EMS investment, operation, and replacement to S1. This avoids both energy-benefit and automation-cost double counting. Rather than claiming measured retrofit performance or a universally superior control technology, the study compares the 15-year present value of costs for Hotel X under a common system boundary and reports the implications for staged investment.

METHOD

Study design and system boundary

A quantitative case study was conducted for Hotel X, an anonymized hotel in Indonesia. The chiller plant is the principal analytical boundary. The analysis covers a 15-year horizon, applies a 6% annual discount rate, and assumes constant prices without energy, operating, or maintenance cost escalation. All NPV figures represent the present value of costs; a lower result indicates a more economical alternative [2], [3]. The study is a prospective scenario comparison, not a post-installation measurement of BMS or EMS performance.

Data sources, baseline reconstruction, and provenance

The hotel-supplied Monthly Engineering Utilities Reporting 2024 & 2025 workbook supplies electricity use and cost records (2024 sheet, C40:C47, C52, C70 and E70; 2025 sheet, C40:C47, C52, C70 and E70). HVAC inventory and maintenance records document the operational setting but do not directly measure chiller-plant electricity or establish BMS/EMS procurement costs. Where those scenario inputs were unavailable, the original study employed actual quotations or records where available, manufacturer or official material, market references, literature, and engineering proxies. Table 1 explicitly distinguishes reported workbook totals, derived rates and ratios, reconstructed energy, and modeling assumptions. No 2026 billing figures are substituted for the historical analysis period.

The seasonal-share annualization uses the sum of January–August 2024 electricity entries (982,039.890 kWh) divided by the workbook-reported 2024 full-year summary (1,456,740.481 kWh), yielding f = 0.6741351001 (67.41351%). The independently recorded January–August 2025 total is 907,037 kWh. Dividing it by the unrounded 2024 seasonal share gives 1,345,482.530 kWh as the annualized 2025 estimate, rather than applying a simple 12/8 factor. Thus 438,445.530 kWh assigned to September–December 2025 is reconstructed, not an observed meter reading. The 2024 full-year cell is a supplied workbook summary: some 2024 underlying monthly/formula cells currently display errors, so it is not represented as independently re-summed from all twelve original bills.

$$f = 982{,}039.890 \,/\, 1{,}456{,}740.481 \quad (1)$$

$$E2025 = 907{,}037 \,/\, f \quad (2)$$

The arithmetic mean of the reported 2024 full-year hotel use and reconstructed 2025 annual use is 1,401,111.505 kWh/year. Because no dedicated chiller-plant submeter was available, the original analytical design bracketed its

share of whole-hotel electricity at 40%, 50%, and 60%; the central 50% share was selected for the Base case as the midpoint of this engineering-assumption range, not as a calibrated or directly metered plant fraction. Thus the Base S0 allocation is 0.50 × 1,401,111.505 = 700,555.753 kWh/year. The 40–60% bracket expresses uncertainty in end-use allocation and must not be interpreted as an empirically observed confidence interval. Dedicated submetering is needed to verify the actual share.

$$Emean = (E2024 + E2025) / 2 \quad (3)$$

$$E(S0) = 0.50 \times Emean \quad (4)$$

The historical reporting periods produce two different effective hotel-electricity rates: IDR 1,925,412,157.267 divided by 1,456,740.481 kWh in 2024 equals approximately IDR 1,321.726/kWh, and IDR 1,130,017,743.630 divided by 907,037 kWh in January–August 2025 equals approximately IDR 1,245.834/kWh (workbook summaries: each year, cells C70 and C52; displayed rate E70). Their simple, unweighted arithmetic mean is IDR 1,283.780/kWh (more precisely, approximately IDR 1,283.780249/kWh). The archived, locked constant-price LCC input schedule instead specifies an adopted model rate of IDR 1,283.80/kWh, a difference of IDR 0.020/kWh from the displayed historical mean. This is an input distinction, not conventional decimal rounding: IDR 1,283.80/kWh is the rate that reproduces the locked Base-case NPV values. Neither quantity is presented as a statutory PLN tariff or a consumption-weighted pooled rate. Modeled first-year S0 plant energy cost at the adopted rate is approximately IDR 899.37 million. Original 2024 bill components and broken historical workbook links were not independently reconciled.

Table 1. Baseline inputs and evidentiary status

Input	Value	Status
2024 Jan–Aug use	982,039.890 kWh	Summed
2024 annual use	1,456,740.481 kWh	Recorded*
2025 Jan–Aug use	907,037 kWh	Reported
2024 Jan–Aug share	67.41351%	Derived
2025 annualized use	1,345,482.530 kWh	Estimated
Mean annual hotel use	1,401,111.505 kWh	Derived
Plant share	50% (40–60% bracket)	Assumed midpoint; not metered
S0 plant use	700,555.753 kWh/y	Estimated
2024 effective cost	IDR 1,321.726/kWh	Derived
2025 Jan–Aug cost	IDR 1,245.834/kWh	Derived
Model electricity cost	IDR 1,283.80/kWh	Adopted model input; distinct from derived mean
S0 year-1 energy cost	≈ IDR 899.37 m	Calculated
BMS; extra EMS saving	10%; 5% of S1	Assumed
Horizon; discount rate	15 y; 6%	Assumed

**The reported 2024 summary (cell C52) is retained: broken formula links prevent an independent re-summation of every underlying bill. September–December 2025 is annualized rather than metered. The period-effective rate mean is IDR 1,283.780/kWh, whereas the archived final constant-price cost model uses the distinct adopted rate IDR 1,283.80/kWh; the latter is not a statutory tariff. The 50% plant share is the midpoint of an exploratory*

historical 40–60% engineering bracket, not a metered or independently calibrated site fraction.

Scenario specification and non-additive savings

S0 represents the existing plant, without a new BMS or EMS capital charge. S1 adds a modeled BMS with 10% electricity saving relative to S0. S2 consists of the full S1 arrangement plus incremental EMS components: its additional 5% saving is applied only to S1 residual electricity, giving a total saving of $1 - (0.90 \times 0.95) = 14.5\%$, not 15%. Both automated cases retain the same modeled general preventive-maintenance/repair allowance as S0; no unsupported maintenance saving is attributed to automation. In the Base case, S1 includes IDR 344 million initial BMS capital, IDR 10.32 million/year control OPEX, and IDR 82.50 million year-10 replacement; S2 adds IDR 172 million EMS capital, IDR 20.64 million/year EMS OPEX, and IDR 65.00 million year-10 EMS replacement, without charging the BMS a second time. These are declared case-model inputs rather than completed vendor transactions or verified post-installation benefits.

$$E(S1) = 0.90 \times E(S0) \quad (5a)$$

$$E(S2) = 0.95 \times E(S1) \quad (5b)$$

Table 2. Main scenario assumptions

Parameter	S0	S1	S2
Configuration	Existing	BMS	BMS + EMS
Horizon (y)	15	15	15
Discount (%)	6%	6%	6%
Escalation (%)	0%	0%	0%
Energy (kWh/y)	700,555.753	630,500.178	598,975.169
Total saving	0%	10.0%	14.5%
Plant share of hotel (%)	50%	50%	50%
Effective electricity cost (IDR/kWh)	1,283.80	1,283.80	1,283.80
General PM/repair (IDR/y)	35,043,775	35,043,775	35,043,775
Initial CAPEX, t=0 (IDR)	0	344,000,000	516,000,000
Control-system OPEX (IDR/y)	0	10,320,000	30,960,000
Replacement, year 10 (IDR)	0	82,500,000	147,500,000
Incremental EMS (S2 vs. S1)	—	—	CAPEX 172m; OPEX 20.64m/y; repl. 65m

Life-cycle cost and comparison conditions

The constant-price Base model includes common electricity and general maintenance/repair costs, initial investment, annual control-system operating expenditure, and year-10 replacement where applicable. All alternatives share a 15-year horizon, a 6% annual discount rate, and 0% escalation for energy, operating, and maintenance costs. Table 2 discloses the reconciled Base input schedule, including the adopted electricity-model rate of IDR 1,283.80/kWh. The central 50% plant-share assumption is the only allocation supported by a complete, reconciled constant-price S1/S2 input schedule; consequently, numerical results are restricted to this fully specified Base comparison. The 40% and 60% share values in the original engineering bracket document the provenance of the midpoint, not additional reported NPV sensitivity results. Annual costs are converted into present values using the equations below.

$$NPV = C0 + \Sigma[t = 1 \ldots 15]\, PV(A(t)) \quad (6)$$

$$PV(A(t)) = A(t)/(1 + r)\text{^}t \quad (7)$$

$$A(t) = E(t) + M(t) + O(t) + R(t) \quad (8)$$

All terms are indexed by scenario s (suppressed in the equations for readability). C0 is initial investment; E, M, O, and R denote energy, general maintenance, control-system operating, and replacement costs, respectively;

r = 0.06 and t runs from 1 to 15. PV denotes present value. The three exact Base-case NPV outputs were checked against the disclosed input schedule for arithmetic consistency.

RESULTS AND DISCUSSION

Energy demand of the three scenarios

S1 reduces the modeled annual electricity demand of the chiller plant from 700,555.753 to 630,500.178 kWh, whereas S2 reduces it further to 598,975.169 kWh. Thus the energy-efficiency ranking is S2–S1–S0. That energy result alone cannot determine the investment choice because each automation increment also carries costs.

Table 3. Electricity demand and modeled savings

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Indicator	S0	S1	S2
Electricity (kWh/y)	700,555.753	630,500.178	598,975.169
Saving vs. S0	0%	10.0%	14.5%
Incremental base	—	S0	Residual S1

NPV comparison and economic ranking

The fully specified Base comparison is shown in Table 4. With the same boundary, discount rate, adopted electricity-model rate, and constant-price assumptions, existing operation (S0) has an NPV cost of IDR 9,075,292,997; BMS (S1) costs IDR 8,692,097,063; and BMS–EMS integration (S2) costs IDR 8,707,781,281. The economic ranking is therefore S1–S2–S0, while modeled energy demand is lowest for S2, followed by S1 and S0. All tabulated results refer to the Base case alone.

Table 4. Base-case NPV costs (IDR billion)

Case	S0	S1	S2
Base	9.075	8.692	8.708

Note: Table entries are in IDR billion, rounded to three decimals for the journal column width; exact locked IDR results are reported in the text directly above. All cases use the 15-year, 6%-discount, zero-escalation inputs disclosed in Table 2. The lower present-value cost is preferred. The 40–60% allocation bracket describes assumption provenance, not an independently replicated Low/High NPV comparison.

Relative to S0, S1 reduces the locked NPV cost by IDR 383,195,934 (4.22%), while S2 reduces it by IDR 367,511,716 (4.05%). Relative to S1, S2 has an additional modeled present-value cost of IDR 15,684,218. Hence the extra modeled energy saving of S2 does not offset its additional Base costs, even though S2 consumes the least electricity. The close Base costs should not be described as statistically equivalent: this is a deterministic case-model comparison, not an inferential equivalence test.

Incremental EMS benefit and staged decision

Under the locked Base inputs, the EMS addition increases initial capital by IDR 172 million, annual control OPEX by IDR 20.64 million, and replacement cost at year 10 by IDR 65 million. Its modeled energy effect is an additional 5% reduction of electricity remaining after BMS, not 5% of the original S0 baseline. The locked S2-minus-S1 NPV cost is IDR +15,684,218. This finding supports a conditional rather than categorical decision: it does not show that EMS is generally uneconomic, as monitoring, analytics, and continuous-commissioning functions may offer operational value [16], [17]. Any subsequent EMS procurement should instead be evaluated against verified site-specific residual electricity consumption and incremental vendor quotations.

The decision pathway suggested by the Base comparison is staged implementation: prioritize BMS as the initial economic option, use its monitoring to develop a more reliable operational baseline, and re-evaluate EMS against observed post-BMS demand and actual quotations. The analysis deliberately treats incremental EMS energy saving on residual BMS demand and avoids charging the S2 case for BMS components a second time. This accounting distinction is the methodological contribution of the staged approach.

Uncertainty, data provenance, and transferability

This single-hotel study has no dedicated chiller-plant submeter and adopts a 50% plant-electricity share as the midpoint of a documented engineering bracket, not a measured or calibrated fraction. The 10% BMS saving and further 5% saving of post-BMS residual energy are prospective model inputs

rather than verified post-installation effects. Some automation costs are engineering proxies rather than completed Hotel X vendor transactions; the original electricity bills and broken historical workbook formula links were not fully reconciled. The 2025 annualized value is not a substitute for unobserved September–December meter readings. This fully specified Base-case comparison does not establish sensitivity rankings across alternative allocation shares or procurement uncertainties. Application elsewhere requires plant submetering, bill reconciliation, comparable vendor quotations, and post-installation measurement and verification.

DATA AVAILABILITY AND SITE CONFIDENTIALITY

Supporting operational and technical records include energy-utility documents, HVAC inventory, maintenance records, procedures, and related technical material. Processed data may be requested from the corresponding author subject to reasonableness and Hotel X management approval. Some primary records contain confidential commercial or operational information. "Hotel X" is an anonymized identifier; anonymization has not been used to alter the scenario values, analytical procedures, or reported results.

CONFLICT OF INTEREST

The authors declare no conflict of interest affecting the study design, analysis, interpretation, or manuscript preparation.

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