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Preventive Maintenance Model for Heating, Ventilation, and Air Conditioning (HVAC) Based on Life Cycle Costing and Stakeholder Response Analysis: An Empirical Study at Hotel X

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Abstract

Hotels operate heating, ventilation, and air conditioning (HVAC) systems extensively, making HVAC a major contributor to electricity consumption, operating costs, and guest comfort. However, maintenance practices often remain reactive, while fragmented maintenance records limit the verification of completed activities and the traceability of guest complaints to specific equipment. This study aimed to develop an evidence-informed preventive maintenance model for hotel HVAC systems by integrating life cycle costing (LCC), stakeholder response analysis, and operational record assessment. An applied single-site case study was conducted at an anonymized hotel in Indonesia using three sources of evidence. First, an existing chiller-plant LCC analysis compared three scenarios over a 15-year period using a 6% discount rate: existing operations (S0), a building management system (BMS) scenario (S1), and an integrated building management and energy management system (BMS–EMS) scenario (S2). Second, three separate partial least squares structural equation modeling (PLS-SEM) analyses examined stakeholder responses among management personnel (n = 20), technicians (n = 33), and hotel guests (n = 120). Third, a documentary review assessed standard operating procedures (SOPs), maintenance schedules, operational logs, and utility records. The LCC analysis indicated that S1 had the lowest modeled life cycle cost (IDR 8,692,097,063), followed by S2 and S0. The PLS-SEM results supported hypotheses H1, H2, H4, and H5 ($p < 0.05$), whereas H3 was not statistically supported ($\beta = 0.285$; $p = 0.068$). The documentary review identified limitations in maintenance record traceability, with only 386 of 620 retained records (62.26%) satisfying the four-field completeness criterion. These findings were synthesized into a preventive maintenance model comprising five interconnected functions: economic decision-making, strategic maintenance governance, technical preventive maintenance execution, service delivery and guest response, and maintenance information management and continuous improvement. Each function incorporated defined responsibilities, documentation requirements, and coordination procedures. The study concluded that integrating economic analysis, stakeholder perspectives, and operational documentation provided a structured and traceable framework for planning preventive HVAC maintenance and supporting future site-specific operational evaluation.

INTRODUCTION

Heating, ventilation, and air conditioning (HVAC) systems in hotels require coordinated management of operating costs, equipment reliability, and continuity of guest services. Hotel energy consumption varies according to building characteristics and operational conditions,

complicating the interpretation of aggregate energy use (Arenhart et al., 2024). Consequently, maintenance extends beyond equipment repair to include systematic planning and coordination between management and engineering personnel (Longart, 2020). Different HVAC configurations also have distinct operational implications for hotels (Díaz Torres et al., 2020), while guests' perceptions of indoor environmental quality highlight the importance of thermal comfort, indoor air quality, and acoustic conditions in service delivery (Zhang et al., 2023).

The managerial challenge extends beyond selecting economically attractive technologies. Effective asset management requires documented decisions throughout the asset life cycle (Standardization, 2024), while maintenance performance indicators should align with operational objectives rather than function as isolated numerical measures (Muchiri et al., 2011). Reviews of maintenance optimization emphasize the importance of structured decision rules and reliable operational records in translating technical analyses into practical maintenance strategies (de Jonge & Scarf, 2020). In hotel operations, scheduled maintenance activities, verified interventions, guest complaints, and utility consumption records represent distinct sources of evidence. Treating these records as interchangeable can undermine the reliability of preventive maintenance assessments (Au-Yong et al., 2024; Dasandara et al., 2022; Palaić et al., 2023; Wang et al., 2022).

Life cycle costing (LCC) provides a systematic economic framework for comparing alternatives within clearly defined asset and cost boundaries (Kneifel & Webb, 2022; Standardization, 2017). In the Hotel X thesis research, the chiller-plant LCC comparison constituted the first analytical component. Its detailed economic methodology and comparative assessment of building management system (BMS) and integrated building management and energy management system (BMS–EMS) scenarios were addressed in a separate cost-focused manuscript. The present study incorporated the previously established LCC findings as an economic input to the preventive maintenance model rather than presenting them as a new economic analysis. However, economic rankings alone cannot determine responsibility for maintenance prioritization, work verification, complaint-to-asset traceability, or escalation procedures for management review (Hair et al., 2019; Rosita et al., 2023; Were & Maranga, 2022).

This study addressed two principal objectives derived from the underlying thesis: incorporating a consistent chiller-plant LCC assessment into maintenance decision-making and examining stakeholder responses through three independently estimated models (M1–M3). These findings, together with an assessment of available operational records, informed the development of a five-function preventive HVAC maintenance model. The study's specific contribution involved interpreting stakeholder associations within their analytical boundaries, evaluating the evidentiary limitations of operational documentation, and linking findings to accountable personnel, maintenance registers, and feedback mechanisms. Although the economic assessment was restricted to the chiller plant, the proposed maintenance workflow encompassed broader HVAC documentation, including air-handling units (AHUs) and fan-coil units (FCUs). The five functions represented operational components of the proposed model rather than additional statistically estimated latent variables.

The research gap addressed in this study concerned the limited integration of heterogeneous evidence into a traceable framework for preventive HVAC maintenance. Economic assessments, stakeholder response analyses, and operational documentation provide different types of information that require distinct analytical treatment. Existing approaches may emphasize economic comparisons, stakeholder perspectives, or maintenance documentation without explicitly establishing how these evidence sources can collectively inform operational decisions. This limitation is particularly relevant in hotel HVAC maintenance, where schedules, maintenance logs, utility records, and guest complaints may be available but insufficiently integrated to support reliable decision-making. Accordingly, a framework was needed to translate these differentiated evidence sources into clearly defined maintenance functions while preserving their respective analytical boundaries.

The importance of addressing this gap was reinforced by limitations identified in Hotel X's historical maintenance records. Of the 641 records initially screened, 386 (62.26%) satisfied the four-field administrative completeness criterion covering location, date, maintenance action, and responsible personnel. However, the original maintenance transactions could not be independently reconstructed. Inconsistencies between room identifiers in preventive maintenance schedules and fan-coil unit records also required reconciliation. These findings highlighted weaknesses in the available documentation for verifying maintenance completion, identifying recurring equipment failures, and linking guest complaints to specific HVAC assets. Consequently, an effective preventive maintenance model needed to incorporate explicit documentation and traceability requirements to support implementation, monitoring, and subsequent auditing.

The novelty of this study lay in the systematic separation and subsequent integration of three complementary evidence domains. First, the previously established chiller-plant LCC ranking was incorporated as a bounded economic decision input. Second, partial least squares structural equation modeling (PLS-SEM) was used to examine stakeholder associations through three independently estimated models involving management personnel, technicians, and hotel guests. Third, operational records were assessed according to their completeness, traceability, and evidentiary limitations. These findings informed the development of a five-function preventive HVAC maintenance model encompassing economic decision-making, strategic maintenance governance, technical preventive maintenance execution, service delivery and guest response, and maintenance information management and continuous improvement. Each function was linked to supporting evidence, accountable personnel, required documentation, and coordination procedures. This approach produced an evidence-to-function traceability matrix rather than a pooled statistical model.

The purpose of this study was to develop and justify an evidence-informed preventive maintenance model for hotel HVAC systems by integrating economic considerations, stakeholder perspectives, and operational documentation requirements. The proposed model was designed to support economically informed maintenance decisions, clarify organizational responsibilities, and strengthen the traceability of maintenance activities. The study did not seek to demonstrate post-implementation cost savings or establish causal relationships between maintenance practices and

guest satisfaction. Instead, it identified the evidence supporting individual model components and specified the documentation required for prospective operational evaluation. Its principal contribution was conceptual and methodological, providing a structured approach for translating heterogeneous evidence into accountable maintenance functions. Although developed within a hotel setting, the approach may also inform maintenance planning in other continuously occupied facilities where economic, technical, and service-related considerations intersect.

Accordingly, the study pursued four objectives: (1) to incorporate and interpret the established chiller-plant LCC findings as a bounded economic input to maintenance decision-making; (2) to estimate and assess stakeholder associations separately for management personnel, technicians, and hotel guests; (3) to evaluate the completeness and traceability limitations of available operational records; and (4) to synthesize the findings into a five-function preventive maintenance model with clearly defined responsibilities, documentation requirements, and coordination procedures. The anticipated practical benefits included a structured basis for authorizing and reviewing HVAC maintenance priorities, a documentation framework distinguishing scheduled activities from verified maintenance completion, and prospective performance indicators covering maintenance completion rates, recurring complaints, response times, and energy consumption reconciliation within defined system boundaries. These indicators could support subsequent operational assessments without implying causal relationships beyond those supported by the study's cross-sectional and documentary evidence.

METHOD

Study design and evidence boundaries

An applied single-site case study was conducted at an anonymized hotel (Hotel X) in Indonesia. The study comprised two analytical components: (1) a previously established life cycle costing (LCC) assessment of three chiller-plant alternatives and (2) cross-sectional surveys of management personnel, technicians, and hotel guests. Standard operating procedures (SOPs), maintenance schedules, administrative summaries, and utility records were also reviewed to inform model development. The surveys were conducted between late 2025 and early 2026. Each stakeholder dataset was analyzed separately using partial least squares structural equation modeling (PLS-SEM), including measurement and structural model assessments. The findings were subsequently integrated through an interpretive evidence-to-design synthesis, without statistically pooling the LCC results or stakeholder datasets.

The economic findings were adopted from the underlying thesis research without recalculating scenario cash flows. To distinguish this study from the separate LCC-focused manuscript, the previously established cost ranking was used exclusively as the economic decision-making input for Function 1 of the proposed preventive maintenance model. The analysis focused on independently estimated stakeholder relationships, maintenance record traceability, and the development of the five-function model. Detailed energy baseline calculations, scenario-specific cost breakdowns, and incremental building management system–energy management

system (BMS–EMS) cost analyses were excluded because they had been addressed in the separate economic assessment.

Table 1. Study evidence streams, samples and analytical boundaries

Stream	Data/cases	Model or source boundary	Permitted interpretation
Economic	Chiller plant; S0, S1, S2	15 years; 6% discount; constant prices; cost NPV	Economic decision input; plant boundary
M1: management	n = 20; FRM1–FRM8	ELO-M (reflective) → SMG-M (reflective); H1	Within-group association
M2: technicians	n = 33; FRT1–FRT8	FPT-T (formative) and MCO-T (reflective) → PBP-T (reflective); H2–H3	Within-group associations
M3: guests	n = 120; FRTa1–FRTa6	PKH-Ta (formative) → PPH-Ta (FRTa6) and PPK-Ta (FRTa5), each single item; H4–H5	Within-group associations
Operational archive	SOPs, preventive plans, logs, utility summaries	Record type and identity reconciliation	Qualified traceability and design inputs

The 173 main-survey responses were held in three unpooled datasets. Separate pilot assessments involved 10 management, 15 technician and 20 guest responses, respectively.

Economic evidence for the preventive-maintenance model

The first research component compared existing operation (S0), a building management system (BMS) alternative (S1), and BMS combined with an energy management system (EMS) (S2) for the Hotel X chiller plant. The established evaluation used a 15-year horizon, a 6% annual discount rate and constant prices (0% annual cost escalation). Its net present values (NPVs) represent modeled costs, not measured savings after installation. The existing preference and its assumptions inform the economic decision gate in the model. Detailed baseline construction, energy scenarios, cost schedules and sequential automation accounting are reserved for the separate economic manuscript rather than claimed anew in this article.

The underlying economic appraisal assumes that the chiller plant accounts for 50% of hotel electricity, selected as the midpoint of an engineering assumption range rather than verified by a dedicated plant submeter. Modeled technology savings are also assumptions, not observed post-installation outcomes. Accordingly, the economic gate retains a system-boundary and source-evidence register; any actual procurement decision would require matched bills, plant-level measurements and site-specific quotations. The chiller-plant ranking must not be extended automatically to all hotel HVAC assets.

Stakeholder sampling and measurement

Management (M1, n = 20) and technicians (M2, n = 33) were approached through total sampling within their defined internal target groups, not across all hotel employees. Guests (M3,

n = 120) were recruited by non-probability convenience sampling among accessible and willing guests. The initial guest sample-planning calculation does not convert the actual sample into a random sample or establish an inferential margin of error. Pilot responses (10/15/20) were assessed separately using SPSS and were not automatically included in the main datasets. The main instruments contained 22 unique statements: eight management items, eight technician items and six guest items, each on a five-point agreement scale.

For M1, economic and life-cycle orientation (ELO-M; FRM1–FRM4) and strategic maintenance governance orientation (SMG-M; FRM5–FRM8) were specified as reflective constructs. For M2, technical execution-enabling factors (FPT-T; FRT2, FRT3 and FRT6) were formative; maintenance cost orientation (MCO-T; FRT7–FRT8) and perceived preventive maintenance benefits (PBP-T; FRT1, FRT4 and FRT5) were reflective. For M3, experienced HVAC conditions (PKH-Ta; FRTa1–FRTa4) were formative, and the outcomes were distinct single-item perceptions: evaluation of hotel management through cooling performance (PPH-Ta; FRTa6) and perceived contribution of HVAC comfort to stay satisfaction (PPK-Ta; FRTa5). The FRTa5 wording was accessible to nontechnical guests; FRTa4 positively described non-disturbing air-conditioning noise and was not automatically reverse-scored.

Model estimation and interpretation rules

M1, M2 and M3 were assessed independently in SmartPLS 4 (Henseler et al., 2015; Kandiyoh et al., 2025; Ringle et al., 2024) using their prescribed reflective (Mode A) and formative (Mode B) specifications. Controlled principal "Most important (faster)" bootstrap exports reported 10,000 subsamples, two-sided $\alpha = 0.05$ and 95% percentile confidence intervals. An additional M2 "Complete (slower)" attempt encountered a singular-matrix problem and was not substituted for the principal stored output. The reported coefficients were transcribed from controlled thesis results, not re-estimated in drafting this article. This SEM-PLS procedure constitutes the empirical assessment of the specified stakeholder measurement and structural models; its coefficients describe within-group cross-sectional associations.

Measurement assessment included reflective loadings, Cronbach's alpha, rho_A, composite reliability, average variance extracted (AVE), heterotrait–monotrait ratio (HTMT) point estimates, formative weights and the scope of single-item outcomes (Es-sakali et al., 2022; Ringle et al., 2024). Available evidence and its limitations are reported together: HTMT inference intervals were unavailable, some formative-weight significance indicators did not agree across interval types, and independent formative redundancy assessment was unavailable. These qualifications describe the limits of the performed SEM-PLS assessment, without replacing its reported results or implying an unperformed cross-group or LCC-to-survey statistical test.

Documentary review and evidence-to-function protocol

Available sources included chiller, air-handling unit (AHU) and fan-coil unit (FCU) SOPs; room maintenance schedules and FCU records; historical administrative summaries; and utility materials. Each source was classified as planned schedule, reported recap, candidate completion

record, model parameter or bounded measurement before being used. The six-stage synthesis procedure comprised boundary definition; evidence extraction; interpretation according to evidence type; mapping to model functions; specifying responsible actors, actions, records and hand-offs; and defining prospective performance measures. This procedure translated analytical and documentary results into the operational model.

Mapping required (a) an identified evidence stream for every function, (b) a responsible actor and an explicit action, (c) an auditable record or hand-off, and (d) an interpretation consistent with the source. Thus, supported stakeholder paths were used to inform function design, while the unsupported H3 and limitations of maintenance and energy records were carried into the relevant documentation requirements. The evidence-to-function synthesis was distinct from the separately performed SEM-PLS estimation.

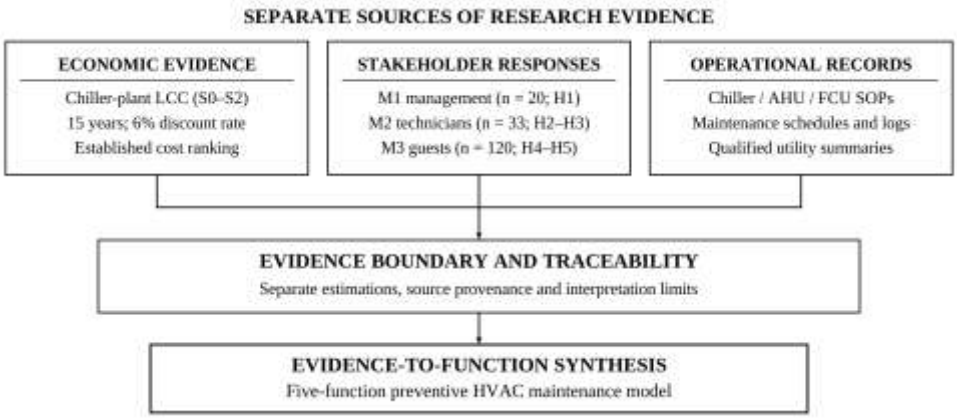


Figure 1. Separate economic, stakeholder and documentary streams used to formulate the preventive-maintenance model. Arrows indicate evidence synthesis rather than additional estimated statistical paths.

RESULTS AND DISCUSSION

Chiller-plant economic decision evidence

The established chiller-plant LCC component provides the fixed economic basis for Function 1. The modeled present-value costs (IDR) are S0 9,075,292,997; S1/BMS 8,692,097,063; and S2/BMS–EMS 8,707,781,281, using a 15-year horizon, 6% discount rate and constant prices. S1 has the lowest modeled cost within the declared assumptions, followed by S2 and S0. The values are retained from the thesis research as shared economic evidence; this article does not reproduce the cost-flow model, energy-demand table, staged savings arithmetic or a new sensitivity analysis. Table 2 clarifies how the established findings inform the preventive-maintenance model.

Table 2. Established economic evidence and its role in the preventive-maintenance model

Economic element	Established research evidence	Role in the maintenance model	Interpretive boundary
Scenario ranking	S1 has the lowest cost NPV; S2 follows, then S0	Record the alternative, assumptions, owner and approval	Chiller plant; modeled costs only
Parameter schedule	15 years; 6% discount; constant prices; 0% escalation	Keep an appraisal record for priority review	No new cash flows or sensitivity test
Energy assumptions	50% plant share and projected automation savings are assumptions	E-02 links meter, plant information and bills	Not measured energy reduction

Note: NPV values reported in Section 3.1 are existing cost-model outputs from the same thesis research and are not recalculated in this article. The cost boundary is the chiller plant; the five-function model addresses broader HVAC maintenance processes.

Within-group stakeholder associations

The five prespecified hypotheses were examined within their own stakeholder groups (Table 3). H1 links management life-cycle orientation to strategic maintenance governance; H2 links technician execution-enabling factors to perceived preventive benefits; and H3 examines maintenance cost orientation alongside the other M2 predictor. H4 and H5 associate guests' perceived HVAC conditions with two distinct, specifically worded outcomes. The SEM-PLS assessment supported H1, H2, H4 and H5 at $\alpha = 0.05$, while H3 was not supported ($p = 0.068$; its percentile interval spans zero). These results provide the empirical stakeholder component used in designing the operational functions, rather than statistical paths between the functions themselves.

Table 3. Structural results from three separately estimated stakeholder models

Hypothesis / group	Association	β	p	95% percentile CI	Decision
H1 / M1	ELO-M → SMG-M	0.748	<0.001	[0.583, 0.960]	Supported
H2 / M2	FPT-T → PBP-T	0.673	<0.001	[0.447, 0.965]	Supported
H3 / M2	MCO-T → PBP-T	0.285	0.068	[−0.038, 0.545]	Not supported
H4 / M3	PKH-Ta → PPH-Ta	0.760	<0.001	[0.664, 0.852]	Supported
H5 / M3	PKH-Ta → PPK-Ta	0.704	<0.001	[0.591, 0.806]	Supported

Note: β denotes the standardized association within its own estimated model. No coefficient represents a path between the five proposed functions or between economic and questionnaire evidence.

Stakeholder measurement assessment and interpretation

For the four reflective constructs, AVE values exceeded 0.50 (ELO-M 0.618; SMG-M 0.753; MCO-T 0.894; PBP-T 0.806), with composite reliability values of 0.865, 0.924, 0.944 and 0.926, respectively. These values provide reported internal-consistency and convergent-assessment evidence in the stakeholder measurement models. The ELO-M loading for FRM3 was 0.693; two-item MCO-T had rho_A = 0.956. Available HTMT point estimates were 0.863 (ELO-

M/SMG-M) and 0.853 (MCO-T/PBP-T), without corresponding HTMT confidence intervals. Some FPT-T formative-weight p-values and alternative interval types did not agree; each single-item guest outcome had loading 1 by model specification rather than independently estimated measurement precision. Interpretation follows the specific tests performed.

Operational record traceability

Indexed chiller, FCU and AHU SOPs provided procedural context, but the reviewed archives did not establish a complete transaction-level history with dated completion, measured condition and verification fields. A secondary historical recap stated that 641 rows were screened, 21 were flagged as possible duplicates, 620 were retained and 386 of those (62.26%) fulfilled a defined four-field administrative test (location, date, action and performer). The original transactions and deduplication decisions were not independently reconstructable in the checked materials. This figure is therefore a qualified reported completeness measure, not a measured SOP-compliance or completed-work rate.

One room preventive-maintenance schedule contained 196 unique room identifiers and 211 weekly marks; an FCU closing summary listed 196 rooms, while a principal FCU/AHU sheet listed 194 identifiers. Codes 2206 and 5208 required reconciliation. These reported counts reveal a need to match identifiers and distinguish schedule marks from verified completed events; they do not establish which tasks were performed. Hotel-level electricity totals likewise cannot be treated as direct chiller-plant measurements. The proposed register design responds specifically to those evidentiary boundaries.

Evidence-to-function synthesis of the preventive-maintenance model

The principal applied result is an evidence-to-function traceability matrix (Table 4) translating the two thesis components and qualified operational records into a preventive HVAC maintenance model. The retained chiller-plant LCC ranking informs an economic decision gate; the management, technician and guest associations inform governance, technical execution and service response; and source-document identity gaps inform the maintenance information and continuous improvement function. Each of the five functions is assigned an evidence basis, an accountable action and a record or hand-off.

The five functions are the outputs of the interpretive synthesis, rather than five additional SEM-PLS constructs. Function 1 structures an economic choice using the established LCC result; Function 2 reflects H1 in strategic authorization and review; Function 3 uses H2, the unsupported H3 and procedural evidence to define traceable technical work; Function 4 preserves the distinct guest outcomes in a service-response process; and Function 5 links documentation, closure and bounded energy information to subsequent decisions. Tables 4 and 5 specify the associated hand-offs and records.

Table 4. Traceability from empirical and economic evidence to five operational functions

Model function	**Evidence basis**	**Proposed action / hand-off**	Evidence/interpretation boundary
1. Economic Decision Gate	S1 had the lowest modeled plant cost NPV	Document comparable assumptions, appraisal and approval	No demonstrated savings; plant boundary only
2. Strategic Maintenance Governance	H1 supported in M1	Assign budget, priority, accountable owner and review cycle	Cross-sectional within-group association

Model function	**Evidence basis**	**Proposed action / hand-off**	Evidence/interpretation boundary
3. Technical Preventive Maintenance Execution	H2 supported; H3 not supported; SOPs exist	Link asset IDs, materials, schedule, SOP action and verified F-01	Unsupported H3; a schedule is not proof of completion
4. Service and Guest Response	H4 and H5 supported in M3	Create F-02 complaint ID, assign technical response and confirm service closure	Two specific single-item outcomes
5. Maintenance Information and Continuous Improvement	Qualified and inconsistent historical records	Link F-01/F-02/F-03, E-01 periodic review and E-02 bounded metering log	Prospective control, not an achieved KPI

Proposed operating and feedback sequence

In the operational model, the economic appraisal enters a management authorization step, approved priorities pass to technical scheduling and work verification, guest HVAC complaints are linked to identifiable locations or assets, and follow-up, review and matched utility information return to the next decision cycle (Figure 2). The hand-offs describe the proposed management and information sequence. They are conceptually derived from the analytical results, not fitted as additional SEM paths, and the five functions are distinct from the stakeholder measurement constructs.

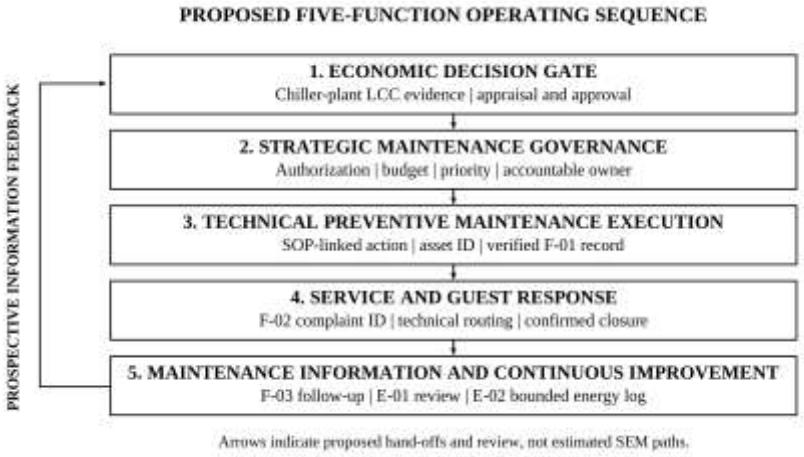


Figure 2. Five-function preventive HVAC maintenance model. Arrows indicate designed operating and feedback hand-offs, not additional estimated SEM paths.

Operational registers and assessment indicators

Three linked event registers and two periodic or measurement tools give the model an explicit information structure (Table 5). These proposed fields make responsibilities, decisions, work events and review cycles traceable and provide criteria that may be used in subsequent operational assessment. The listed performance indicators are design specifications, not retrospectively measured effects of introducing these new tools.

Table 5. Supporting records and prospective operational assessment indicators

Artifact / proposed owner	Minimum event or periodic record	Prospective assessment
F-01 / technician and verifier	Unique asset/work ID; planned/actual times; SOP step; measures; material; evidence; verifier; F-02/F-03 links	Verified planned-versus-completed rate; asset-level data completeness
F-02 / guest services and technician	Complaint ID; anonymized location; timestamps; issue; assignee; response; confirmed closure	Response and resolution intervals; repeat complaints
F-03 / supervisor	Finding ID; linked F-01/F-02; owner; severity; due date; closure evidence; sign-off	Verified closure and repeated-finding rates
E-01 / management	Period-matched modeled versus actual cost; faults; quality gaps; overdue actions	Trends in record integrity and priority closure
E-02 / utility owner	Meter ID; chiller/hotel boundary; beginning/ending kWh; matching period and bill; reviewer	Completeness and boundary-matched energy reconciliation

Evidence-informed design as the principal contribution

The main scientific contribution is the formulation of an evidence-informed preventive HVAC maintenance model from the thesis's two analytical components. The LCC result establishes the bounded economic decision basis, while the three separately assessed stakeholder models supply group-specific empirical findings. Qualified operational records identify the need for linked work, service, follow-up and measurement information. Their synthesis specifies five operating functions, their responsible actors, hand-offs and register fields. The detailed economic scenario calculation is addressed in a separate cost-focused manuscript; this article advances the stakeholder interpretation and its translation into a traceable applied model, consistent with asset-management and maintenance-performance principles.

The SEM-PLS assessment provides evidence for the measured stakeholder relationships H1–H5. The subsequent five-function synthesis makes those findings usable for preventive-maintenance planning without implying that the economic and respondent datasets were jointly estimated. This separation is the methodological basis for connecting economic, technical, managerial and guest-service perspectives within one applied model.

Economic basis and scope of the maintenance decision

The economic decision gate retains the established S1 cost preference within the declared chiller-plant scenario assumptions. The more detailed comparative LCC treatment is reported separately and is not repeated here as a new methodological finding. The economic result supports consideration of a BMS-led first stage, subject to actual plant measurements, site quotations and budget authorization; it is not a modeled cost result for every HVAC asset. Its distinct use in this article is to trigger an explicit authorization, documentation and feedback process linked to the other four model functions.

Stakeholder patterns and the unsupported H3

The supported H1 association informs a governance review linking economic and life-cycle orientation to responsibility, budget and follow-up; it does not by itself demonstrate that

perceptions caused better maintenance. H2 gives an empirical basis for including parts availability, understandable SOPs and usable work histories in the technical function. H3 was not supported ($\beta = 0.285$, $p = 0.068$; CI includes zero); therefore, technician cost orientation is not presented as a supported driver of perceived preventive benefits, although routine cost documentation remains necessary. H4 and H5 inform distinct service feedback and resolution routes, with interpretations limited to the two specific guest items rather than broad hotel-quality or overall-satisfaction scales.

Interpretation of measurement and documentary evidence

The SEM-PLS measurement and structural assessment was conducted for M1, M2 and M3 as specified. Its interpretation retains the available HTMT point estimates without inventing confidence intervals, reports the discordance among some formative-weight significance indicators, and distinguishes the stored principal bootstrap output from an unsuccessful supplementary complete-bootstrap M2 run. Internal group sizes, guest convenience sampling and single-item outcomes also bound inference. The archival figures are secondary summaries: weekly schedule marks do not establish verified work completion, and a hotel aggregate electricity meter does not determine chiller-plant use. These distinctions directly inform the proposed information fields.

Operational use and future performance assessment

For operational use, the model specifies management authorization, a common asset/room dictionary, traceable event records, defined verifier roles and linked F-01/F-02/F-03 records. E-01 is designed for period-matched management review, while E-02 identifies the measurement boundary for utility information. These provisions create a basis for a future site-specific assessment of completion rates, recurring faults, complaint-response intervals, mean time between failures, mean time to repair and bounded energy use. Those assessment indicators specify what would be observed during operation; no measured post-introduction improvement is inferred from the survey associations.

Study scope and transferability

This study concerns one anonymized hotel and three separately estimated cross-sectional survey models; convenience recruitment of guests and small internal respondent groups limit population-level generalization. The economic result remains bounded by its modeled chiller-plant assumptions, including an unmetered plant allocation. SmartPLS outputs were checked against controlled thesis tables without an independent rerun of native project files, and historical archive counts were not transaction-by-transaction re-audited for article preparation. The performed SEM-PLS assessment applies to the stated stakeholder measurement and structural relationships; the five-function operating model is their evidence-informed synthesis with LCC and documentary inputs. Transfer to another building would require matching its assets, roles, source records and decision boundaries.

CONCLUSION

The Hotel X thesis research provided two complementary foundations for developing a preventive heating, ventilation, and air conditioning (HVAC) maintenance model: a previously established 15-year life cycle costing (LCC) analysis conducted using a 6% discount rate and constant prices, and independently assessed stakeholder responses from management personnel, technicians, and hotel guests. The economic analysis identified the building management system (BMS) scenario (S1) as having the lowest modeled chiller-plant life cycle cost. Partial least squares

structural equation modeling (PLS-SEM) results supported hypotheses H1, H2, H4, and H5, whereas H3 was not statistically supported. These findings, together with the assessment of available maintenance and utility records, informed the development of five interconnected functions: economic decision-making, strategic maintenance governance, technical preventive maintenance execution, service delivery and guest response, and maintenance information management and continuous improvement. The study's primary contribution was the integration of these distinct evidence sources into an evidence-to-function framework incorporating traceable maintenance activities, guest complaints, follow-up actions, management reviews, and energy consumption records within defined system boundaries. The detailed LCC analysis was addressed separately. The proposed model provided a structured foundation for site-specific preventive maintenance planning, organizational accountability, and prospective operational performance assessment.

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