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Sustainable Management of Student Facilities through Resource Optimisation: An Occupancy-Linked Measure-Compare-Optimise - Verify (MCOV) Framework for College Campuses

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Abstract - Higher education campuses consume substantial energy, water, equipment capacity, and maintenance resources, often operating facilities on fixed timetables rather than actual occupancy. This disconnect generates significant avoidable resource waste and inflates operating costs without enhancing student experience.

This paper presents a low-capital resource-optimization framework structured around a Measure–Compare–Optimise–Verify–Institutionalise (MCOV) cycle. Evaluated on a representative campus comprising 40 classrooms, six laboratories, four computer labs, a 1,000-seat auditorium, and drinking-water treatment systems, the framework mathematically links physical space occupancy to equipment runtimes and resource demand. Proposed interventions include occupancy-responsive lighting and ventilation, daylight integration, schedule-matched HVAC control, water conservation, and structured preventive maintenance.

The methodology establishes facility-level indicators—such as per-student energy/water consumption and avoidable operating ratios—aligned with ISO 50001, ISO 50006, IPMVP, and ASHRAE Guideline 14 standards. Additionally, a prioritization matrix and risk register ensure student comfort, laboratory safety, and drinking-water quality remain fully protected.

The study concludes that data-driven operational discipline, scheduling, preventive maintenance, and monitoring can substantially eliminate avoidable resource consumption, extend equipment service life, and control operating expenditure without requiring major capital investment.

Keywords: sustainable campus; resource optimisation; energy efficiency; water conservation; student facilities; facility management; preventive maintenance; occupancy-based operation; energy management; higher education institutions.

1. INTRODUCTION

1.1 Background

A university or college campus functions much like a small township. Teaching blocks, laboratories, computing facilities, assembly halls, hostels, canteens and utilities operate side by side, and each follows its own pattern of use that is set by the academic calendar, the timetable, examination schedules, vacations and special events. The resources a campus consumes are therefore governed not only by what is installed but by how installed capacity is matched to real occupancy. Studies of university building stocks report that teaching buildings can account for a dominant share of campus energy demand and that consumption moves with the academic calendar [3], [4].

Global policy frameworks reinforce this concern. Sustainable Development Goal 4 addresses quality education, while Goals 6, 7 and 12 relate directly to water-use efficiency, affordable and clean energy, and responsible consumption and production [11]–[14]. Higher education institutions are expected to demonstrate these principles in their own operations as well as in their curricula.

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1.2 Problem context

In day-to-day practice, lights, fans, projectors, air-conditioners and water systems on many campuses are controlled by habit or by a fixed daily routine. Equipment commonly remains energised after classes end, cooling plant serving laboratories and auditoria starts early and stops late, and pumps run on clock timings instead of tank levels. Maintenance is often carried out only after a failure. The consequence is a persistent gap between the time a facility is *available* and the time it is actually *used*, and the difference appears as avoidable energy, water and maintenance expenditure.

1.3 Contribution of the paper

The paper makes the following contributions:

- an operational chain that connects occupancy, run-time, resource use, equipment condition, maintenance, cost and sustainability performance in a single management logic;
- the MCOV cycle, a five-stage and repeatable procedure for baselining, optimising and verifying facility operation;
- a compact set of facility-level indicators and a weather- and calendar-adjusted baseline model suited to routine campus data;
- facility-wise technical analysis that explains the physical mechanism behind each measure and the indicator that will confirm it; and
- a decision aid comprising a prioritisation matrix, a risk register and a twelve-month implementation roadmap.

The central premise is that the aim is not to curtail student facilities but to remove consumption that serves no occupant, while keeping the specified level of service intact.

2. REVIEW OF LITERATURE

2.1 Sustainable campus operations

A recent systematic review of sustainable operations in higher education groups the field around carbon neutrality, energy use, waste management, environmental management and the circular economy [6]. The UN 2030 Agenda supplies the wider policy setting: SDG 4 on education sits alongside SDGs 6, 7, 9, 11, 12 and 13, which cover water, energy, infrastructure, sustainable communities, resource efficiency and climate action respectively [11].

2.2 Energy management and verification standards

ISO 50001:2018 specifies requirements for establishing, operating and continually improving an energy management system, and places measurement and review at its centre [1]. ISO 50006:2023 provides guidance on selecting energy performance indicators and constructing energy baselines so that performance can be compared fairly over time [2]. For quantifying the outcome of an intervention, the International Performance Measurement and Verification Protocol (IPMVP) defines options based on metering scope [15], and ASHRAE Guideline 14 prescribes statistical acceptance criteria for baseline models [16]. These documents together give a methodological base that can be transferred to educational buildings.

2.3 Occupancy, academic calendar and scheduling

Campus load profiles differ from those of commercial offices because use is concentrated in timetable blocks and interrupted by vacations. Work on university building complexes has analysed how the peaks of individual buildings coincide [3], and an examination of calendar effects has shown that institutional scheduling influences annual consumption independently of equipment efficiency [4]. More recent studies introduce occupant mobility and flexible load scheduling [8] and coordinated scheduling of building clusters that responds to student energy behaviour [9]. The common message is that a fixed schedule is a poor stand-in for real demand.

2.4 Heating, ventilation and air-conditioning

Air-conditioning is among the largest electrical loads in educational buildings. A multi-dimensional analysis of teaching buildings points to operating hours, room size and temperature set-point as the controlling parameters for energy-saving

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management [5]. These three variables are directly adjustable by facility staff, which makes them natural targets for an operational framework.

2.5 Water management

SDG 6 contains an explicit target of raising water-use efficiency across sectors [12]. At the campus scale, recent work applies entropy-weighted multi-objective optimisation to water infrastructure for smart teaching campuses [7]. Such methods are valuable, but they presuppose reliable metering and demand data, which many colleges do not yet collect.

2.6 Comfort, indoor air quality and laboratory ventilation

Reducing run-time must not erode the indoor environment. ASHRAE Standard 55 defines thermal conditions acceptable to occupants [17], and ASHRAE Standard 62.1 sets minimum ventilation for acceptable indoor air quality [18]. Laboratory spaces often require substantially higher air-change rates than ordinary rooms, and published facility guidance emphasises that energy measures there must preserve safety and air quality [10]. In India, the National Building Code of India 2016 provides the applicable lighting, ventilation and water-supply provisions [19].

2.7 Synthesis

The literature treats energy efficiency, HVAC control, occupancy modelling, water optimisation and green building design thoroughly but mostly as separate topics. Few contributions give a college facility manager a simple, repeatable route from a timetable and a meter reading to a defensible optimisation decision. The next section states this gap formally.

3. RESEARCH GAP AND PROBLEM STATEMENT

Existing studies cover individual technologies and methods in depth. What is missing is an operational bridge that connects the use of student facilities with the resources consumed and the maintenance effort required to keep them running. The problem shows itself in routine observations: classroom lights, fans and projectors remain on after sessions; laboratory air-handling continues beyond practical hours; computer laboratories are cooled when only a few seats are occupied; auditorium cooling starts well ahead of and continues after events; drinking-water coolers operate regardless of demand; pumps follow fixed timings; and equipment is repaired only after it fails.

The study addresses this by treating the campus as a chain in which each link influences the next (Figure 1).



Figure 1. Operational chain linking occupancy to sustainability performance.

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4. OBJECTIVES

To bridge the operational gap between facility utilization and resource management, this study establishes an integrated evaluation framework. The primary research objectives are defined as follows:

- Facility-Level Quantification Architecture: Formulate a standardized operational procedure to continuously measure electrical energy and water metrics across discrete campus facilities.
- Empirical Load-Occupancy Modeling: Quantify the functional relationship linking room occupancy profiles and academic operating schedules to real-time energy and water consumption behaviors.
- Elimination of Non-Productive Baseline Loads: Identify and isolate avoidable resource wastage during zero- or low-occupancy periods while maintaining environmental safety, indoor environmental quality (IEQ), and academic service standards.
- Maintenance-Integrated Resource Optimization: Embed preventive maintenance protocols into the core operational framework to mitigate equipment degradation and improve system efficiency.
- Performance Indicator Framework & MCOV Standardization: Develop a set of facility-level Key Performance Indicators (KPIs) and operationalize a repeatable Measure–Compare–Optimise–Verify (MCOV) cycle for continuous institutional sustainability management.

5. STUDY CONTEXT: REPRESENTATIVE CAMPUS CONFIGURATION

To develop the method, a representative college campus is defined in Table 1. It is a constructed case for methodological purposes and does not describe measured data from any named institution. Quantities in the table are used consistently through the paper.

Table 1. Representative campus configuration

Facility	Quantity	Principal loads	Main optimisation lever
Classrooms	40	Lighting, fans, natural ventilation	Timetable- and occupancy-linked switching
Laboratories	6	Lighting, ventilation, instruments, HVAC	Session-based HVAC with ventilation preserved
Computer laboratories	4	Computers, lighting, air-conditioning	Power management; usage-based cooling
Auditorium	1 (1,000 seats)	Cooling, lighting, audio-visual, electrical	Event-driven cooling sequence
Drinking-water system	1	Treatment, pumping, cooling	Metering, tank-level and demand-based pumping
Water distribution	Campus-wide	Pumps, storage, piping	Leak detection; pump scheduling
Maintenance system	Campus-wide	Manpower, spares, equipment	Planned instead of reactive maintenance

6. METHODOLOGY: THE MCOV FRAMEWORK

6.1 Stages of the cycle

The methodology is organised as a loop of five stages (Figure 2) that is repeated indefinitely, in contrast to a one-off energy audit.

- **Measure:** record occupancy, equipment run-hours, electricity and water for each facility.

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- **Compare:** set consumption against occupancy and scheduled hours to expose mismatch.
- **Optimise:** change how equipment is operated so that avoidable running is removed.
- **Verify:** test post-intervention performance against a baseline adjusted for external conditions.
- **Institutionalise:** convert proven practices into standard operating procedures (SOPs) and indicators.

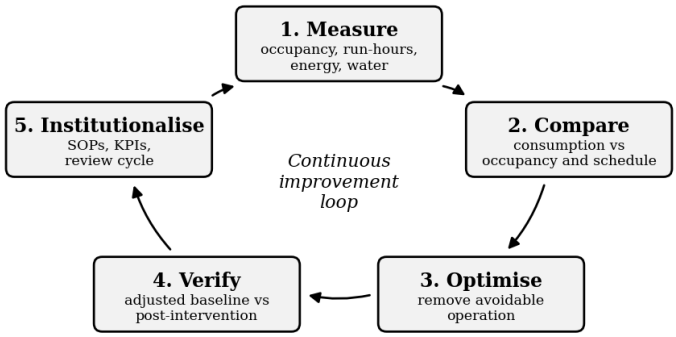


Figure 2. The MCOV cycle. Equipment operation changes at the Optimise stage; the Verify stage checks results; Institutionalise fixes them as practice before the loop repeats.

6.2 Research design

The study proceeds in eight phases (Table 2). Phases 2 to 4 build the evidence base, Phase 5 identifies opportunity, and Phases 6 to 8 deliver, test and embed change.

Table 2. Research design

Phase	Activity	Output
1	Facility and asset inventory	Asset database with ratings and locations
2	Baseline measurement	Energy and water baseline
3	Occupancy study	Utilisation profile by space and time
4	Equipment study	Operating profile of major loads
5	Gap analysis	Ranked optimisation opportunities
6	Intervention	Operational improvements implemented
7	Verification	Measured, adjusted performance
8	Standardisation	SOPs and KPI system

6.3 Instrumentation and data collection

A baseline of preferably twelve months should be gathered so that seasonal swings and the full academic calendar are represented. Electricity should be sub-metered at feeder level for classroom lighting and fans, HVAC, computer laboratories, the auditorium and pumping, using meters of accuracy class 1 or better. Water should be metered at the source inlet, after treatment, at tank outlets and on the reverse-osmosis reject line. Equipment run-time can be captured by current-based data loggers where dedicated meters are not feasible. Occupancy is best taken from timetable and event records, supported on a sample basis by door counters, passive-infrared sensors or indoor CO_2 concentration used as a proxy. Table 3 lists the parameters.

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Table 3. Baseline data requirements

Parameter	Unit	Frequency	Typical source
Electricity consumption	kWh	Daily / monthly	Sub-meters, utility bills
Water consumption	kL	Daily / monthly	Flow meters, tank levels
Classroom and laboratory occupancy	persons	Per session	Timetable, counters
Auditorium occupancy	persons per event	Event-wise	Booking and ticket records
Total operating hours	h	Daily	Run-time loggers
Air-conditioning operating hours	h	Daily	Current loggers, BMS
Lighting operating hours	h	Daily	Circuit loggers
Computer utilisation	h	Daily	Login records, plug meters
Pump operation	h, starts	Daily	Run-time and start counters
Equipment breakdowns	number	Monthly	Maintenance register
Maintenance effort	h	Monthly	Work orders
Student complaints	number	Monthly	Complaint log
Indoor temperature	°C	Periodic / continuous	Data loggers
Relative humidity	%	Periodic / continuous	Data loggers
Outdoor temperature / degree-days	°C	Daily	Local weather record

6.4 Baseline model and normalisation

Raw before-and-after totals are misleading when weather, student numbers or calendar differ between periods. Following the intent of ISO 50006 [2], a regression baseline is therefore fitted to daily or weekly data from the baseline period:

$$E_d = \beta_0 + \beta_1 CDD_d + \beta_2 N_d + \beta_3 A_d + \varepsilon_d \quad (1)$$

where E_d is the energy used on day d, CDD_d the cooling degree-days, N_d the head-count present, A_d an indicator of academic activity (teaching day, examination day, vacation) and ε_d the residual. Model adequacy is judged using ASHRAE Guideline 14 criteria, which for monthly data recommend a normalised mean bias error within ±5% and a coefficient of variation of the root-mean-square error not above 15% (the corresponding hourly limits are ±10% and 30%) [16]. Savings are then computed against the baseline recalculated for post-intervention conditions, not against the original totals. Weekly normalised consumption before and after intervention can be compared with a paired t-test, or a Wilcoxon signed-rank test where normality fails, and reported with a confidence interval so that a real effect is separated from noise. The metering scope maps to IPMVP Option B for sub-metered systems and Option C for whole-campus analysis [15].

7. FACILITY-WISE OPTIMISATION AND TECHNICAL ANALYSIS

Each facility is treated separately because its occupancy pattern, safety obligations and comfort requirements differ. For every facility the measures are stated, their physical basis is explained, and the verifying indicator is named. The effects described are mechanisms to be confirmed by measurement and are not reported savings.

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7.1 Classrooms (50)

Measures. Timetable-linked or occupancy-sensor switching of lights and fans; LED luminaires; use of daylight; natural ventilation where conditions permit; a closing checklist or automatic shutdown after the last session; periodic illuminance (lux) surveys against the levels recommended in the National Building Code [19]; and student awareness.

Technical basis. Lighting energy for a room is the product of installed fixture power, number of fixtures and hours of use:

$$E_L = \frac{N_f \times P_f \times t_{on}}{1000} \tag{7}$$

with N_f the fixture count, P_f the fixture power in watts and t_{on} the annual hours the lights are on (E_L in kWh). Reducing t_{on} to the occupied hours therefore reduces E_L proportionally. For ceiling fans and other centrifugal or axial loads, power varies approximately with the cube of speed under the fan affinity relations:

$$\frac{P_2}{P_1} = \left(\frac{n_2}{n_1}\right)^3 \tag{8}$$

so a modest speed reduction produces a disproportionately large power reduction; for instance, running a fan at 80% of full speed needs about $0.8^3 \approx 0.51$ of full-speed power in the ideal case. Motor and electronic-regulator losses will make the real figure somewhat higher. Fewer running hours also reduce lamp and motor wear and cut the internal heat gain that otherwise adds to cooling demand in air-conditioned spaces.

Table 5. Classroom optimisation matrix

Parameter	Existing practice	Proposed practice	Verifying indicator
Lighting	Fixed operation	Timetable / occupancy based	kWh per class-hour
Fans	Fixed schedule	Occupancy based; speed control	Operating hours; AOR
Daylight	Not used systematically	Daylight-linked switching zones	Lighting hours
Ventilation	Manual	Natural or controlled	Indoor comfort, CO_2
Shutdown	Manual, inconsistent	Closing checklist or automation	Unoccupied hours

7.2 Laboratories (10)

Measures. HVAC scheduled to practical sessions while required ventilation rates are held; shutdown of non-critical instruments after sessions; management of standby loads; instrument calibration; filter maintenance; and laboratory-specific sub-metering.

Technical basis. Laboratories cannot be treated like classrooms. Airflow in spaces with fume cupboards or hazardous processes is dictated by safety, and any reduction of supply or exhaust must be approved by the laboratory safety officer and must keep fume-cupboard face velocity within the specified range [10], [18]. Savings are therefore sought in the margins: setting back temperature and ventilation only in rooms and hours that are confirmed to be free of hazardous work, switching off idle benches and instruments, and keeping filters and coils clean so that fans do not work against avoidable resistance. Calibration preserves measurement accuracy and prevents repeat experiments, which are themselves a source of wasted resources.

Verifying indicators. HVAC utilisation ratio, standby kWh per laboratory and verified airflow compliance.

7.3 Computer laboratories (4)

Measures. Automatic sleep and shutdown after scheduled sessions; occupancy-based air-conditioning; set-point management; efficient lighting; scheduled cleaning of filters; separation of any server equipment into its own thermal zone; and plug-load monitoring.

Technical basis. Almost all electrical power drawn by computers is released as heat inside the room, so each kilowatt of equipment load appears again as a kilowatt of sensible cooling load. The compressor power needed to remove it is

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the heat load divided by the coefficient of performance (COP) of the cooling system. The effective electrical burden of the room equipment is therefore

$$E_{total} = E_{eq} \times \left(1 + \frac{1}{COP}\right) \quad (9)$$

with E_{eq} the equipment energy. Switching off an idle computer thus saves energy twice: once at the plug and once at the compressor. Clean filters and sensible set-points improve COP and lengthen the life of compressors and fans. Where the cooling units are inverter-type, running at part load generally improves seasonal efficiency, but excessive on–off cycling of fixed-speed units should be avoided by enforcing a minimum off-time in the control logic.

Verifying indicators. Plug-load kWh, utilisation ratio and compressor hours.

7.4 Auditorium (1,000 seats)

Measures. The auditorium is a large, intermittent space and is managed as an event-driven facility, using the sequence: event booking → expected occupancy → pre-cooling → event operation → post-event shutdown → verification. Zoning and variable-capacity operation are considered where technically feasible.

Technical basis. An audience generates a considerable heat load. Using an indicative total heat emission of about 115 W per seated person from engineering reference data, 1,000 occupants release roughly 115 kW, equivalent to about 33 tons of refrigeration (1 TR = 3.517 kW), before lighting, stage equipment and envelope gains are added. This load appears only during the event, while the building fabric and air volume take time to cool. A pre-cooling period sized to the thermal response of the hall allows comfortable conditions at the start without running plant for long idle spells. Linking plant capacity to the booked head-count avoids operating large machines at inefficient part-load, and a performance inspection before major events lowers the chance of failure during a function. Ventilation should be set according to the occupancy-based provisions of ASHRAE 62.1 and the National Building Code [18], [19].

Verifying indicators. Event-wise kWh per occupant and cooling-plant hours per event.

7.5 Drinking-water system

Measures. The system is analysed as a single chain: raw water → treatment → storage → pumping → cooling → distribution → consumption. Actions include metering at each stage, leakage monitoring, pump scheduling, tank-level control, filter and membrane maintenance, performance monitoring of the reverse-osmosis (RO) unit, reject-water management, cooling-unit efficiency, demand analysis and preventive maintenance. Conservation must never compromise drinking-water quality, which has to continue to meet the Indian standard for drinking water [20] and any statutory health requirements.

Technical basis. A water balance for each storage tank closes the accounting:

$$V_{in} = V_{use} + V_{loss} + \Delta V_{storage} \quad (10)$$

so that any unexplained volume, V_{loss}, is exposed as leakage, overflow or metering error. Pump electrical power is

$$P_p = \frac{\rho g Q H}{1000\eta}\ kW \quad (11)$$

where ρ is water density (kg/m^3), g gravitational acceleration (m/s^2), Q flow (m^3/s), H total head (m) and η the combined pump–motor efficiency. Energy equals P_p multiplied by running hours, so tank-level control and demand-based scheduling cut energy by shortening run-time, while avoiding leaks lowers Q and the volume that must be pumped. Under the pump affinity laws, flow varies with speed, head with the square of speed and power with the cube, which is why variable-speed drives are attractive for variable demand. RO recovery is

$$R = \frac{Q_{permeate}}{Q_{feed}} \times 100 \quad (12)$$

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and the reject stream is $Q_{feed} - Q_{permeate}$. Monitoring R, membrane differential pressure and product conductivity indicates fouling early, so that cleaning or replacement is planned before efficiency and water quality deteriorate. Demand-based cooling of dispensed water shortens refrigeration run-time.

Verifying indicators. Litres per student, pump hours and starts, kWh per kL, RO recovery and unaccounted-water fraction.

8. INTEGRATION OF PREVENTIVE MAINTENANCE

Sustainability cannot be separated from maintenance. Fouled filters and coils raise HVAC power for the same cooling effect; worn bearings and seals make pumps less efficient; unattended leaks waste both water and pumping energy; and poorly maintained equipment fails sooner, increasing downtime and spare-part consumption. Table 6 sets out a preventive programme, with the failure mechanism that each task is meant to prevent.

Table 6. Preventive maintenance framework

Equipment	Maintenance activity	Frequency	Failure mode addressed
AC units	Filter and coil cleaning	Monthly / need based	Airflow restriction, high compressor power
Pumps	Bearing and seal inspection	Monthly	Wear, leakage, falling efficiency
Electrical panels	Thermal inspection	Periodic	Loose or overheating connections
Water treatment	Filter and membrane monitoring	Per OEM / process	Fouling, reduced recovery
Lighting	Functional inspection	Monthly	Failed or mis-controlled fixtures
Computers	Power-management review	Quarterly	Disabled sleep settings
Auditorium HVAC	Performance inspection	Before major events	In-event failure
Water coolers	Cleaning and service	Scheduled	Scaling, refrigerant loss
Distribution network	Leak inspection	Monthly	Water loss, pump over-running

Planned maintenance keeps equipment close to design efficiency so that a given duty needs less energy. Breakdown rate, mean time to repair and equipment availability then serve as measurable reliability indicators, and PM compliance becomes a leading measure of whether efficiency gains will persist.

9. CAMPUS SUSTAINABILITY DASHBOARD

A single dashboard consolidates the indicators so that managers can see why a facility consumes what it does, not just the monthly bill (Table 7). Exception rules, for example equipment operating during unoccupied hours or an asset whose consumption drifts upward, trigger alerts that can be acted on within days instead of at the next billing cycle.

Table 7. Dashboard modules

Module	Indicators displayed
Energy	Daily and monthly kWh; kWh per student; kWh per occupied class-hour; peak demand; HVAC consumption
Water	Daily and monthly volume; litres per student; treatment output; recovery and reuse; leakage
Maintenance	PM compliance; breakdown frequency; mean time to repair; equipment availability; status of critical assets
Facility utilisation	Utilisation of classrooms, laboratories, computer laboratories and the auditorium

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10. ILLUSTRATIVE CALCULATIONS

No measured utility data are supplied with this manuscript. The calculations in Table 8 therefore demonstrate the method on assumed inputs and are not research findings. A theoretical difference in hours or kWh is not a saving: on real data the estimate must also allow for part-load operation, equipment diversity, HVAC cycling, outdoor temperature, occupancy, standby load and seasonal variation.

Table 8. Worked illustrations (assumed inputs)

Case	Assumed inputs	Calculation	Theoretical result
A. Computer laboratory run-time	25 kW load; 8 h scheduled; 5 h occupied; 200 days	25×8×200 = 40,000; 25×5×200 = 25,000 kWh/yr	Difference 15,000 kWh/yr
B. Cooling coupling for case A	COP assumed 3.0	15,000 ÷ 3.0 = 5,000 kWh	Total about 20,000 kWh/yr
C. Fan speed reduction	Speed at 80% of full	$0.8^3 = 0.512$	About 49% lower shaft power (ideal)
D. Pump run-time	Q = 20 m^3/h; H = 30 m; η = 0.55; 6 h cut to 4 h; 300 days	P = 9.81×(20/3600)×30 ÷ 0.55 ≈ 2.97 kW; 2×2.97×300	About 1,780 kWh/yr
E. Auditorium occupant load	1,000 seated at 115 W each	1,000×115 = 115 kW; 115 ÷ 3.517	About 33 TR
F. RO recovery	Feed 1,000 L/h; permeate 600 L/h	R = 600 ÷ 1,000 × 100	60%; reject 400 L/h

11. RESULTS AND DISCUSSION

As this is a framework paper without measured data, the results reported here are the expected technical effects of the proposed measures and the indicators by which each is to be confirmed.

11.1 Technical impact by facility

Table 9. Technical impact and verifying indicators by facility

Facility	Main lever	Technical impact	Verifying indicator
Classrooms	Occupancy- and timetable-based switching	Lower lighting and fan load in unoccupied hours; less heat gain; longer lamp and motor life	kWh per class-hour; AOR
Laboratories	Session-scheduled HVAC; ventilation preserved	Reduced idle HVAC and standby load without loss of safety	HVAC utilisation ratio
Computer laboratories	Power management; usage-based cooling	Lower computer load and fewer compressor hours	Plug-load kWh; UR
Auditorium	Event-driven cooling sequence	Plant runs only for pre-cooling and event	Event-wise kWh per occupant
Drinking-water system	Metering; pump and tank-level control	Fewer pump hours and starts; lower leakage and reject water	Litres per student; pump hours
Maintenance	Planned instead of reactive	Equipment near design efficiency; fewer breakdowns	PM compliance; breakdown rate

11.2 Prioritising measures

Not every measure can be introduced at once. A weighted score can rank them:

$$PS_j = \Sigma w_k s_{jk} \quad (16)$$

where s_{jk} is the score of measure j against criterion k (for example technical risk, cost, effort and expected benefit) and w_k the weight assigned by the institution, with weights summing to one. A qualitative ranking is given in Table 10.

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Table 10. Qualitative prioritisation of measures

Measure	Capital cost	Effort	Technical risk	Priority
Closing checklist and timetable switching	Very low	Low	Low	First
Computer power management	Very low	Low	Low	First
Tank-level and pump scheduling	Low	Low–medium	Low	First
Preventive maintenance programme	Low	Medium	Low	First
Auditorium event-driven cooling	Low–medium	Medium	Medium	Second
Laboratory HVAC set-back	Medium	Medium–high	High	Second, with safety approval
LED and sensor retrofit	Medium	Medium	Low	Second
Variable-speed drives, BMS, renewables	High	High	Medium	Third

11.3 Integrated management and sustainability hierarchy

In a conventional set-up, energy, maintenance, timetabling and water are handled by separate departments. The proposed approach places occupancy, schedule, equipment, energy, water, maintenance, cost and comfort in one view, which is consistent with campus research that increasingly treats energy, water, waste and circularity as interlinked [6]. Measures are sequenced by a five-level hierarchy that puts low-cost operational steps ahead of capital spending:

- **Avoid** unnecessary operation.
- **Optimise** by running equipment in line with actual demand.
- **Maintain** equipment so that it keeps operating efficiently.
- **Retrofit** inefficient equipment where the case is justified.
- **Generate** energy from renewable and other sustainable sources.

11.4 Student comfort, service quality and risk

Optimisation must not degrade essential services. Thermal comfort [17], indoor air quality [18], lighting adequacy, drinking-water availability, laboratory safety, equipment availability, complaints and timetable compliance should therefore be tracked alongside consumption. Energy reduction by itself is not the measure of sustainability; the appropriate objective is resource-efficient service delivery. Table 11 lists principal risks and safeguards.

Table 11. Risk register

Risk	Where it arises	Safeguard
Inadequate ventilation or unsafe airflow	Laboratories	Safety-officer approval; no set-back where hazardous work is possible; airflow verification
Thermal discomfort	Classrooms, computer laboratories, auditorium	Comfort monitoring; adjustable pre-cooling; complaint tracking
Compressor short-cycling	Air-conditioners	Minimum on- and off-time in control logic
Drinking-water quality lapse	Treatment and storage	Water-quality testing to the national standard; no reduction of treatment or flushing without approval
Unreliable sensors or manual lapses	All facilities	Calibration, alarms, checklists and audits
Behavioural rebound	All facilities	Awareness programme; periodic review of AOR

12. DIGITALISATION AND IMPLEMENTATION ROADMAP

12.1 Digital extension

The framework can later be strengthened with IoT energy meters, smart water meters, occupancy sensors, a building management system, a computerised maintenance management system (CMMS), automated alerts, mobile maintenance

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applications and predictive analytics. Advanced technology is not a precondition, however. The first steps are to measure accurately, understand utilisation, adjust operation and verify results, which is in line with the systematic and continual-improvement approach of ISO 50001 [1].

12.2 Twelve-month roadmap

Implementation is planned over twelve months, running from inventory to an annual review, so that the programme operates as a continuing improvement system (Table 12).

Table 12. Twelve-month implementation plan

Period	Major activity
Month 1	Facility and equipment inventory
Month 2	Metering and data-collection system
Month 3	Occupancy study
Month 4	Energy and water baseline
Month 5	Facility-level analysis
Month 6	Identification of optimisation opportunities
Months 7–8	Pilot interventions
Month 9	Performance verification
Month 10	Extension of successful measures
Month 11	KPI dashboard commissioning
Month 12	Annual sustainability review

13. LIMITATIONS

The campus described is a representative construct, not a record of measured performance at a named institution, so no energy or water savings can be asserted until baseline and post-intervention data have been collected. Consumption is influenced by weather, academic calendar, building fabric, equipment condition, operating policy and student behaviour, each of which must be controlled in the baseline model. Laboratories need special treatment because safety and ventilation requirements limit the room for optimisation. The assumed values in Table 8 are indicative and must be replaced by site data. The MCOV framework should be validated using longitudinal data from real campuses.

14. FUTURE SCOPE

Subsequent work may examine IoT-based occupancy sensing, AI-based load forecasting, predictive HVAC control, smart water distribution, digital twins of campus buildings, solar photovoltaic and battery storage integration, rainwater harvesting, wastewater reuse, carbon-neutral campus pathways, the relation between student behaviour and consumption, and lifecycle cost analysis. Recent studies already combine occupant mobility, flexible load scheduling and on-site generation for campus optimisation [8], pointing towards more advanced versions of the present framework.

15. CONCLUSION

This paper presented a practical framework for the sustainable management of student facilities through resource optimisation. Its principal contribution is to place facility utilisation, energy, water, maintenance and student-service quality within one management logic, supported by an adjusted-baseline method, five facility-level indicators and facility-specific technical analysis.

The MCOV cycle offers an orderly means of establishing baselines, measuring true occupancy, comparing run-time with demand, locating avoidable consumption, optimising operation, integrating preventive maintenance, verifying improvement and fixing successful practice as routine. The expected technical effects are fewer unoccupied equipment hours, shorter HVAC and pump run-times, better equipment reliability and longer asset life, with safety and comfort maintained.

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Sustainable campus management therefore depends on more than efficient equipment. Operating discipline, scheduling, maintenance, monitoring and user behaviour are equally important. In this study, sustainability is understood as delivering the required academic, safety and comfort services with the least avoidable use of energy, water, equipment capacity, manpower and maintenance resources. The framework can act as a working link between campus sustainability policy and everyday engineering practice, in keeping with international objectives on education, water efficiency, energy efficiency and responsible consumption [11]–[14].

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