

**Article**

# Integrating Energy Systems Thinking into Sustainable Design Education through Residential PV-Battery Energy Management Simulations

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**Abstract:** The integration of renewable energy literacy into sustainable design education is increasingly important as design disciplines evolve toward system-level thinking. This paper introduces a structured framework for embedding residential photovoltaic (PV) and battery energy storage system (BESS) simulations into design curricula, not as a teaching case but as a reproducible methodological platform to cultivate energy systems thinking. A one-day hourly simulation of a residential PV–BESS system under a time-of-use (TOU) tariff was developed to demonstrate how different energy management strategies influence cost, self-consumption, and peak load performance. Three control strategies were defined: direct PV supply (A), cost minimization (B), and self-consumption maximization (C). Quantitative results show that Strategy C yields the lowest cost (49.08 TWD), highest self-consumption (77.19 %), and lowest grid peak demand (2.5 kW), demonstrating the pedagogical value of simulation-based reasoning in sustainable design. Beyond its technical results, the study demonstrates how simulation can serve as a conceptual scaffold that strengthens energy literacy, quantitative interpretation, and systems thinking in design education.

**Keywords:** Sustainable design education, Energy systems thinking, Photovoltaic–Battery integration, Simulation–Based learning, Interdisciplinary design

## 1. Introduction

The urgency of the global energy transition and the accelerating decarbonization of the built environment require designers to move beyond form-making and engage with energy systems as integral components of design practice. Although renewable technologies, particularly photovoltaic (PV) panels and battery energy storage systems (BESS), have become increasingly accessible at the residential scale, their pedagogical integration into design curricula remains limited and uneven.

Design students are typically introduced to sustainability through qualitative perspectives such as materials, form, and spatial strategy, yet they seldom encounter the quantitative dimensions of energy flow, cost dynamics, or system performance. This gap restricts their ability to evaluate design decisions in terms of measurable impacts. Conversely, engineering education has long embraced modeling and simulation, but these tools are often detached from the creative, human-centered frameworks that shape design thinking.

This research connects these pedagogical domains by proposing an integrative approach that employs PV–BESS simulation not simply as a tool for technical analysis but as a medium for design reasoning. By exploring multiple energy management strategies within a representative residential context, the study demonstrates how numerical feedback can inform sustainable design decision-making, cultivate systems awareness, and strengthen students' capacity to interpret trade-offs and understand fundamental concepts in energy management.

## 2. Background and Theoretical Framework

### 2.1. Sustainable Design Pedagogy and Systems Thinking

Sustainable design education has increasingly moved beyond traditional environmental performance metrics toward a systems-oriented perspective that links technology, human behavior, and the built environment. This shift encourages learners to understand buildings not simply as static objects but as part of broader networks composed of material, energetic, and informational flows.

Such a perspective aligns with the growing importance of systems thinking in preparing students to engage with complex sustainability challenges.

Recent research underscores the value of simulation-based and data-driven learning approaches that help students visualize feedback, interpret dynamic system behavior, and evaluate trade-offs among competing design objectives. Empirical studies on residential PV-battery performance demonstrate how system outputs emerge from the interaction of load patterns, energy generation, and tariff conditions, highlighting the pedagogical potential of representing these relationships in design education (Gomes et al., 2024). Complementary work on supervisory control and state estimation provides additional insight into how computational modeling can translate technical system behavior into interpretable performance indicators for learners (Kurucan et al., 2025).

By integrating these analytical tools into sustainable design pedagogy, educators can support the development of quantitative reasoning while maintaining the exploratory and creative orientation of design practice. This creates opportunities for students to interpret energy data, experiment with system behavior, and connect conceptual design intentions to operational outcomes.

## 2.2. Energy Systems Thinking in Design Education

Energy systems thinking further strengthens students' ability to conceptualize buildings as active participants in distributed energy networks. Understanding how PV production, storage behavior, and control strategies interact enables design students to engage with energy as a meaningful design parameter rather than an external engineering constraint.

Technical insights from supervisory control and PV-battery modeling illustrate how system performance depends on the dynamic relationships among forecasted loads, generation availability, and storage constraints (Kurucan et al., 2025). These findings highlight the importance of viewing energy systems as adaptive components that respond to temporal patterns, user behavior, and environmental conditions. Incorporating such perspectives into design pedagogy helps students appreciate how design decisions related to form, program, and technology can influence energy outcomes over time.

Simulation-based tools serve as effective translational mechanisms for this purpose. By allowing learners to adjust parameters, observe system feedback, and analyze performance metrics, simulations bridge creative reasoning with quantitative evaluation. This supports data-informed decision-making and deepens students' understanding of sustainability as a system-level design problem.

## 3. Methodology

### 3.1 Simulation Overview

The study employs a transparent and pedagogically oriented simulation framework to model a residential PV–battery energy storage system over a single 24-hour summer day. The framework is designed to support educational clarity rather than engineering-level precision, enabling learners to trace how system behavior emerges from simple and interpretable control rules. The simulation structure aligns with empirical observations and modeling approaches used in residential energy studies that examine tariff-dependent load shifting and PV utilization (Autuori et al., 2021; Dai et al., 2025).

The model operates at an hourly resolution, capturing PV generation, household demand, battery behavior, and grid interaction. This level of abstraction allows students to understand how operational strategies influence economic and performance outcomes without being overwhelmed by unnecessary technical complexity.

### 3.2 System Parameters

The simulation models a residential PV–BESS system over a 24-hour summer day using an hourly time step ( $\Delta t = 1$  h). The household electricity demand follows a typical Taiwanese summer load profile, characterized by a peak of approximately 4 kW and a total daily consumption of 43.7 kWh. PV generation is provided by a 5 kWp rooftop array operating between 06:00 and 18:00. The output profile is represented using a sine-based approximation of daytime irradiance:

$$P_{PV}(t) = \begin{cases} 5 \times \sin\left(\frac{\pi(t-6)}{12}\right), & 6 < t < 18 \\ 0, & \text{otherwise} \end{cases}$$

Electricity pricing follows a Taiwanese-style time-of-use (TOU) tariff with three import price periods: off-peak (2.0 TWD/kWh from 00:00–07:00), mid-peak (3.8 TWD/kWh from 07:00–16:00 and 22:00–24:00), and peak (5.8 TWD/kWh from 16:00–22:00). A fixed feed-in price of 1.5 TWD/kWh is applied to exported PV energy.

The battery storage system is modeled with a usable capacity of 10 kWh, a maximum charge and discharge power of 3 kW, and a one-way efficiency of  $\eta_{\text{batt}} = 0.95$ . The state of charge (SOC) evolves according to the standard energy balance:

$$\text{SOC}(t + 1) = \text{SOC}(t) + \eta_{\text{batt}} P_{\text{ch}}(t)\Delta t - \frac{1}{\eta_{\text{batt}}} P_{\text{dis}}(t)\Delta t,$$

where  $P_{\text{ch}}(t)$  and  $P_{\text{dis}}(t)$  denote battery charging and discharging power. The SOC is constrained within

$$0 \leq \text{SOC}(t) \leq 10 \text{ kWh},$$

and battery power limits satisfy

$$0 \leq P_{\text{ch}}(t), P_{\text{dis}}(t) \leq 3 \text{ kW}.$$

Grid interaction is computed at each timestep using:

$$P_{\text{grid}}(t) = P_{\text{load}}(t) - P_{\text{PV}}(t) - P_{\text{dis}}(t) + P_{\text{ch}}(t),$$

where positive values indicate imports from the grid and negative values indicate exports.

The total electricity cost over the 24-hour period is given by:

$$C_{\text{total}} = \sum_{t=1}^{24} [\max(P_{\text{grid}}(t), 0) \lambda(t) \Delta t] - \sum_{t=1}^{24} [\min(P_{\text{grid}}(t), 0) \lambda_{\text{feed}} \Delta t],$$

where  $\lambda(t)$  is the TOU tariff at hour  $t$ ,  $\lambda_{\text{feed}} = 1.5 \text{ TWD/kWh}$ , and  $\Delta t = 1 \text{ h}$  is retained for completeness.

These parameter choices reflect contemporary benchmarks for residential PV–battery systems (Ramasamy et al., 2023; Dehghanimadvar et al., 2024).

### 3.3 Energy Management Strategies

The simulation evaluates three operational strategies that represent distinct priorities in residential PV–battery management. These strategies reflect common approaches identified in residential energy research concerning cost optimization and PV self-consumption (Li et al., 2023; Ramos et al., 2025).

(1) Strategy A: PV Direct Supply: Strategy A serves as the baseline in which PV generation supplies the household load directly. Any surplus PV power is exported to the grid, and all deficits are met by grid imports. Battery operation is disabled, and the commanded values are fixed at:

$$P_{\text{ch}}^*(t) = 0, P_{\text{dis}}^*(t) = 0.$$

Thus, the realized power also satisfies:

$$P_{\text{ch}}(t) = 0, P_{\text{dis}}(t) = 0.$$

(2) Strategy B: Cost Minimization: Strategy B is a price-responsive policy that reduces the total electricity cost under the TOU tariff. The battery charges during off-peak hours and discharges during peak hours whenever feasible. The commanded values follow:

$$P_{\text{ch}}^*(t) = \begin{cases} P_{\text{ch,max}}, & \lambda(t) = \lambda_{\text{off}} \\ 0, & \text{otherwise,} \end{cases}$$

$$P_{\text{dis}}^*(t) = \begin{cases} P_{\text{dis,max}}, & \lambda(t) = \lambda_{\text{peak}} \\ 0, & \text{otherwise,} \end{cases}$$

where  $\lambda_{\text{off}}$  and  $\lambda_{\text{peak}}$  denote the off-peak and peak tariff levels.

The realized charging and discharging powers are obtained by enforcing the SOC and power limits described in Section 3.2:

$$P_{\text{ch}}(t) = \min \left( P_{\text{ch}}^*(t), P_{\text{ch,max}}, \frac{\text{SOC}_{\text{max}} - \text{SOC}(t)}{\eta_{\text{batt}} \Delta t} \right),$$

$$P_{\text{dis}}(t) = \min \left( P_{\text{dis}}^*(t), P_{\text{dis,max}}, \frac{\eta_{\text{batt}} \text{SOC}(t)}{\Delta t} \right).$$

This strategy aligns with cost-driven operational models examined in predictive and rule-based energy management systems (Li et al., 2023).

(3) Strategy C: Self-Consumption Maximization: Strategy C prioritizes the use of onsite PV energy by storing surplus PV generation during the daytime and discharging the battery whenever PV is insufficient to meet the load. The commanded powers follow:

$$P_{ch}^*(t) = \begin{cases} P_{PV}(t) - P_{load}(t), & P_{PV}(t) > P_{load}(t) \\ 0, & \text{otherwise,} \end{cases}$$

$$P_{dis}^*(t) = \begin{cases} P_{load}(t) - P_{PV}(t), & P_{load}(t) > P_{PV}(t) \\ 0, & \text{otherwise.} \end{cases}$$

The realized values incorporate the same SOC and power constraints:

$$P_{ch}(t) = \min\left(P_{ch}^*(t), P_{ch,max}, \frac{SOC_{max} - SOC(t)}{\eta_{batt}\Delta t}\right),$$

$$P_{dis}(t) = \min\left(P_{dis}^*(t), P_{dis,max}, \frac{\eta_{batt}SOC(t)}{\Delta t}\right).$$

This rule-based strategy aligns with self-consumption-focused residential energy management models that aim to reduce grid dependence and enhance local energy autonomy (Ramos et al., 2025).

### 3.4 Key Performance Indicators (KPIs)

System performance is evaluated using three key performance indicators that correspond to the economic, operational, and grid-interactive behavior of the residential PV-BESS. These indicators are commonly used in empirical and techno-economic assessments of residential energy systems, providing a clear and consistent basis for comparing strategy performance.

(1) Total Electricity Cost (TWD): The total electricity cost over the 24-hour period accounts for both imported and exported energy under the TOU tariff. Using  $P_{grid}(t)$  as the net grid power (positive for imports, negative for exports), the cost is computed as:

$$C_{total} = \sum_{t=1}^{24} [\max(P_{grid}(t), 0) \lambda(t) \Delta t] - \sum_{t=1}^{24} [\min(P_{grid}(t), 0) \lambda_{feed} \Delta t],$$

where  $\lambda(t)$  denotes the TOU import tariff at hour  $t$ ,  $\lambda_{feed} = 1.5$  TWD/kWh is the feed-in price for exported energy, and  $\Delta t = 1$  h. The first term represents the cost of imported electricity, and the second term represents the revenue from PV exports, which reduces the net cost.

(2) PV Self-Consumption Rate (%): The PV self-consumption rate measures the fraction of PV generation that is used onsite rather than exported to the grid. Total daily PV generation is:

$$E_{PV,total} = \sum_{t=1}^{24} P_{PV}(t) \Delta t.$$

Exported energy corresponds to hours when  $P_{grid}(t) < 0$ . Using the sign convention adopted earlier, the total exported energy is:

$$E_{export} = \sum_{t=1}^{24} \max(-P_{grid}(t), 0) \Delta t.$$

The PV self-consumption rate is then defined as:

$$SC_{PV}(\%) = \frac{E_{PV,total} - E_{export}}{E_{PV,total}} \times 100.$$

This metric reflects the degree to which onsite PV generation contributes directly to meeting household demand.

(3) Grid Peak Load (kW): The grid peak load represents the maximum hourly import power during the simulation period:

$$P_{grid,peak} = \max_t [\max(P_{grid}(t), 0)].$$

This metric indicates the system's contribution to peak demand on the distribution grid and is relevant for grid planning, demand management, and tariff design.

## 4. Results

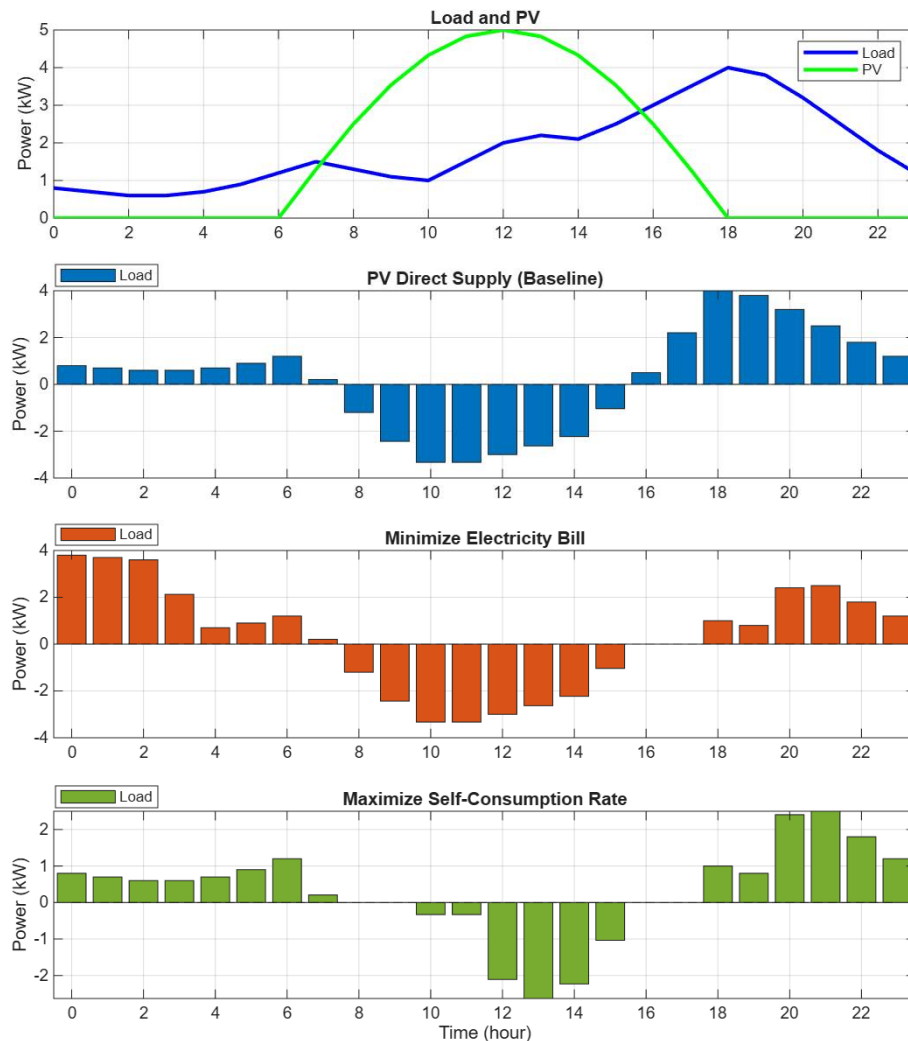
### 4.1. Quantitative Outcomes

The performance of the three energy management strategies was evaluated using the KPIs defined in Section 3.4. Table 1 summarizes the outcomes for the total electricity cost  $C_{total}$ , the PV self-consumption rate  $SC_{PV}$ , and the peak grid import  $P_{grid, peak}$ . These indicators align with assessment practices commonly applied in residential PV-battery analyses that examine cost behavior, self-consumption, and peak-load mitigation (Goryl, 2025).

Figure 1 illustrates the interaction among household load, PV generation, and grid power under the three strategies. Compared to the baseline Strategy A, Strategy B reduces  $C_{total}$  by charging during off-peak periods and discharging during peak-price hours. This shift decreases energy purchases at the highest-cost times. Strategy C further improves performance across all KPIs by maximizing the onsite use of midday PV surplus and deploying stored energy during evening demand peaks. As a result, Strategy C achieves the lowest total electricity cost, the highest PV self-consumption rate, and the smallest peak grid load.

**Table 1.** Performance Indicators for Three Strategies.

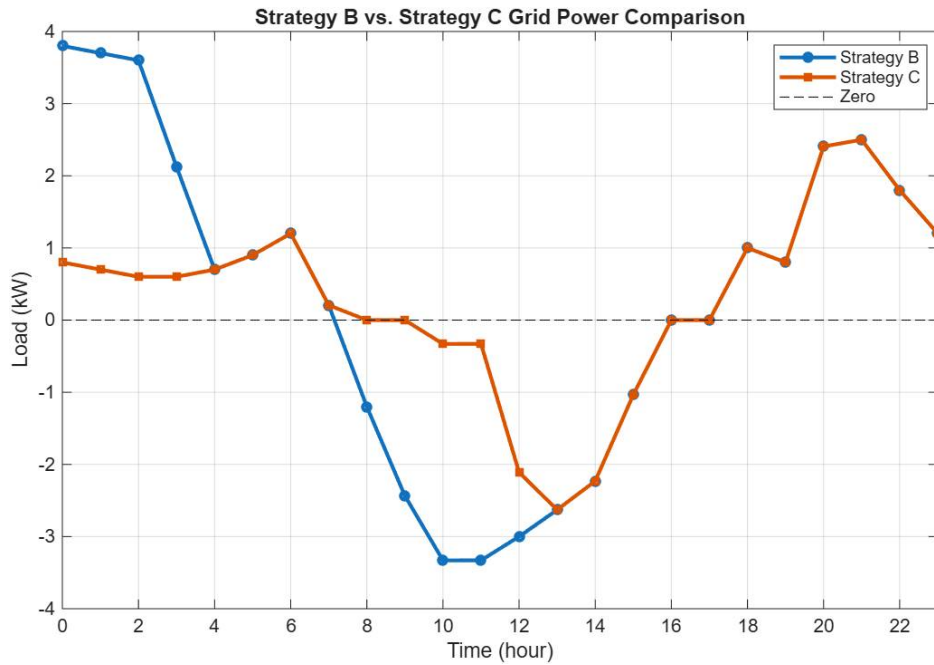
KPI	Strategy A (Direct Supply)	Strategy B (Cost Minimization)	Strategy C (Self-Consumption Maximization)
Total Cost (TWD)	88.39	54.34	49.08
PV Self-Consumption (%)	49.47	49.47	77.19
Grid Peak Load (kW)	4.00	3.80	2.50



**Fig 1.** Comparison of household load, PV generation, and grid power under the three energy management strategies. Strategy B reduces grid imports during peak-price periods through off-peak charging and peak-hour discharging. Strategy C further enhances system performance by maximizing the use of midday PV surplus and deploying stored energy during evening demand peaks.

#### 4.1.1 Grid Power Profiles

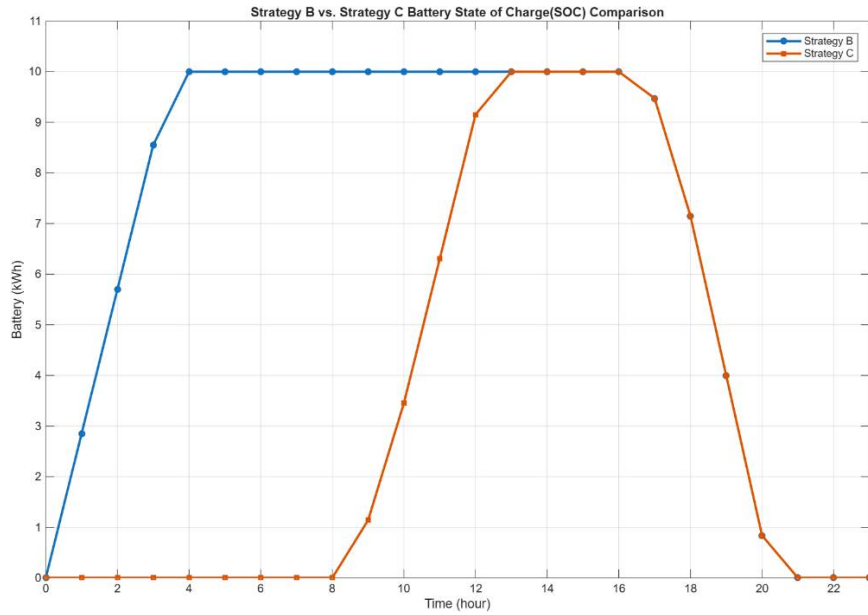
Figure 2 compares the grid power trajectories for Strategies B and C. Although Strategy B smooths the import profile through price-driven charging and discharging, it maintains moderate grid imports during mid-peak hours. In contrast, Strategy C achieves a pronounced reduction in grid imports between 16:00 and 22:00, which correspond to the highest TOU tariff periods. This results in the lowest recorded peak grid load  $P_{\text{grid, peak}} = 2.50 \text{ kW}$ , reflecting Strategy C's strong alignment between PV availability, battery discharge, and evening load demand.



**Fig 2.** Grid power profiles for Strategies B and C. Strategy B produces a smoother import pattern but maintains moderate mid-peak grid dependence. Strategy C substantially reduces grid imports during the evening peak tariff window, resulting in the lowest peak grid load among all strategies.

#### 4.1.2 Battery State-of-Charge Dynamics

Figure 3 presents the battery state-of-charge (SOC) patterns for Strategies B and C. Both strategies respect the SOC limits defined in Section 3.2. Strategy C, however, exhibits fuller daytime charging due to higher utilization of PV surplus, followed by deeper evening discharge. This more effective energy-balancing behavior explains the high PV self-consumption rate observed for Strategy C, with  $SC_{\text{PV}} = 77.19\%$ .



**Fig 3.** Battery state-of-charge trajectories for Strategies B and C. Both strategies operate within feasible SOC bounds. Strategy C achieves fuller daytime charging from PV surplus and deeper evening discharge, aligning storage behavior more effectively with daily load demand and contributing to a higher PV self-consumption rate.

#### 4.2 Interpretation

These results demonstrate that simple rule-based control policies can generate meaningful economic and operational benefits under a TOU tariff structure. Strategy B effectively reduces electricity cost by aligning battery operation with lower-priced periods. Strategy C further shows the advantages of prioritizing onsite PV utilization, achieving simultaneous improvements in  $C_{total}$ ,  $SC_{PV}$ , and  $P_{grid, peak}$ . Together, the three strategies illustrate how different operational priorities influence system-level outcomes and reveal the performance trade-offs that emerge in residential PV–battery systems.

From an educational perspective, these outcomes highlight the value of simulation as an accessible and transparent tool for teaching energy systems thinking. Students can directly observe how tariff structures, system efficiencies, battery constraints, and SOC dynamics shape overall system behavior. By connecting numerical outcomes with conceptual reasoning, the simulation framework promotes systems thinking and strengthens learners’ capacity for data-informed design decision-making.

### 5. Discussion

#### 5.1 Pedagogical Integration

The simulation framework does not function as a fixed instructional module, but rather as a flexible platform that allows students to explore how design decisions interact with energy systems. By presenting energy flows in both visual and quantitative formats, the framework enables learners, especially those from design backgrounds, to understand the built environment as an interconnected energy network. Integrating such simulations into sustainable design courses strengthens analytical literacy while preserving the exploratory and creative nature of design education.

Assignments that involve parameter variation, such as modifying tariff structures, adjusting PV capacity, or changing load profiles, allow students to observe the resulting differences in system performance. These exercises cultivate critical thinking by encouraging learners to evaluate trade-offs among economic, environmental, and experiential goals. In doing so, the framework helps connect the purpose of design with the operational behavior of energy systems, bridging the gap between qualitative sustainability concepts and quantitative system dynamics.

#### 5.2 Strategy Suitability Contexts

The three operational strategies evaluated in this study correspond to different residential contexts and user priorities. Strategy B, which aims to minimize cost, is most suitable in environments with pronounced TOU price differentials and stable grid conditions. In such settings, shifting charging to off-peak hours and discharging during evening peaks can significantly reduce electricity expenses. This strategy aligns well with urban households that prioritize economic efficiency.

Strategy C, which maximizes PV self-consumption, is more appropriate in contexts where feed-in prices are low or where households value energy autonomy. By storing midday PV surplus and using it to offset evening demand, this strategy reduces grid dependence and increases the value of onsite generation. It is particularly relevant in regions with strong solar resources or where resilience and decentralized energy practices are emphasized.

These suitability distinctions help learners understand that operational strategy selection depends not only on technical capabilities but also on economic conditions, energy policies, and user objectives.

### 5.3 Broader Implications for Design Education

The integration of energy systems simulation into design pedagogy reflects a broader movement toward evidence-based creativity. Quantitative reasoning enhances accountability in design decision-making, while real-time visual feedback supports intuitive understanding. By embedding analytical modules alongside traditional studio activities, the framework encourages students to evaluate energy performance in parallel with conceptual development, aligning creative exploration with system-level thinking.

In addition, the simulation environment fosters interdisciplinary collaboration by providing a shared analytical vocabulary. Design students gain familiarity with performance metrics commonly used in engineering practice, while engineering students develop a deeper appreciation for spatial, experiential, and human-centered considerations. This mutual literacy equips learners to engage more effectively with the complex sustainability challenges facing the built environment, many of which require systems thinking, technical fluency, and interdisciplinary coordination.

## 6. Conclusion

This study presented an instructional framework for integrating energy systems thinking into sustainable design education through the use of PV–battery simulations. By modeling a simplified residential system and evaluating three distinct operational strategies, the framework demonstrates how control logic, tariff structures, and system parameters influence energy cost, self-consumption, and grid interaction. Although the framework has not yet been implemented in a formal course setting, the simulation results highlight its potential to support both conceptual understanding and data-informed reasoning.

For design students, the use of simulation provides a concrete means of investigating how buildings interact with distributed energy systems. The framework enables learners to evaluate design decisions in relation to system performance, promoting an understanding of sustainability that extends beyond material choices or form-making. By allowing students to experiment with parameters, observe performance feedback, and interpret trade-offs, the approach strengthens systems thinking and fosters greater alignment between design intentions and operational outcomes.

Beyond its technical contributions, the framework offers a pathway for enhancing interdisciplinary collaboration within design education. It encourages communication across design and engineering domains by introducing a shared analytical language grounded in energy performance. As the demands of sustainable practice continue to grow, such integrative approaches will become increasingly important for preparing designers to navigate the complexities of energy, technology, and the built environment.

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## References

1. Autuori, J., Arbaoui, T., Ouazene, Y., & Yalaoui, F. (2021). Optimizing energy consumption using photovoltaic panels and batteries in smart homes. *SSRN Working Paper*, 4695718. <https://doi.org/10.2139/ssrn.4695718>
2. Dai, C., Ma, T., Zhang, Y., Weng, S., & Peng, J. (2025). Improvement of building energy flexibility with PV battery system based on prediction and load management. *Building Simulation*, 18(1), 65–85. <https://doi.org/10.1007/s12273-024-1216-4>
3. Dehghanimadvar, M., Egan, R., & Chang, N. L. (2024). Quantifying the costs of diversifying silicon PV module assembly with local economic policies. *Joule*, 8(5), 1322–1349. <https://doi.org/10.1016/j.joule.2024.02.006>

4. Gomes, A. M. F., de Andrade Pinto, G. X., & R  ther, R. (2024). Techno-economic assessment of small-size residential solar PV plus battery systems under different tariff structures in Brazil. *Solar Energy*, 267, 112238. <https://doi.org/10.1016/j.solener.2023.112238>
5. Goryl, W. (2025). Real-world performance and economic evaluation of a residential PV battery energy storage system under variable tariffs: A Polish case study. *Energies*, 18(15), 4090. <https://doi.org/10.3390/en18154090>
6. Kurucan, M., Michailidis, P., Michailidis, I., & Minelli, F. (2025). A modular hybrid SOC-estimation framework with a supervisor for battery management systems supporting renewable energy integration in smart buildings. *Energies*, 18(17), 4537. <https://doi.org/10.3390/en18174537>
7. Li, Y., Vilathgamuwa, D. M., Quevedo, D. E., Lee, C. F., & Zou, C. (2023). Ensemble nonlinear model predictive control for residential solar battery energy management. *IEEE Transactions on Control Systems Technology*, 31(5), 2188–2200.
8. Ramasamy, V., Zuboy, J., Woodhouse, M., O’Shaughnessy, E., Feldman, D., Desai, J., ... & Basore, P. (2023). *U.S. solar photovoltaic system and energy storage cost benchmarks, with minimum sustainable price analysis: Q1 2023* (No. NREL/TP-7A40-87303). National Renewable Energy Laboratory (NREL). <https://doi.org/10.2172/2005540>
9. Ramos, S., Roque, L. A., Gomes, A., Soares, J., Rolle, J. C., & Vale, Z. (2025). Multi-objective model for residential energy management in the context of individual self-consumption. *Mathematics and Computers in Simulation*, 231, 120–127. <https://doi.org/10.1016/j.matcom.2024.11.017>

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