Proceedings of the 4th International Conference on Functional Materials and Civil Engineering
DOI: 10.54254/2755-2721/2026.35031

# *Multi-Energy Storage Microgrids for Intelligent Backup Power Management in Smart Buildings*

**Yihong Wang**

*Department of Architecture and Built Environment, University of Nottingham, Nottingham, UK*
*laxyw58@nottingham.ac.uk*

***Abstract.*** This paper investigates how multi-energy storage microgrids provide intelligent backup power functions under diverse operating conditions for intelligent buildings. With increasing renewable energy penetration and growing concerns about grid reliability, building-integrated microgrids provide a promising solution for enhancing resilience, flexibility and sustainability. This research first reviews the framework of the building integrated microgrid, the key storage technologies including battery, thermal and hydrogen storage and intelligent control strategies. Four representative scenarios are then analyzed: short-duration outages, long-duration outages, extreme climate conditions, and normal grid-connected operation. The results of recent studies reveal that battery systems are effective for rapid response while hybrid multi-energy storage significantly improves long-duration autonomy and climate adaptability. In grid-connected mode, intelligent optimization and requirement response can drastically reduce operation costs. Finally, future trends such as digital twins, peer-to-peer energy trading and AI predictive control are playing important roles. The results from this review show that coupling multi-energy storage technologies with advanced control strategies is essential for achieving resilient, low-carbon and autonomous building energy systems.

***Keywords:*** Building integrated microgrid, Multi-energy storage, Backup power supply, Energy resilience, Energy management system

## 1. Introduction

The global transition toward low-carbon energy systems has accelerated rapidly in response to climate change and energy security challenges. The integration of large-scale renewable energy sources (RES), such as solar and wind plays a core role in reducing carbon emissions. Their inherent intermittency and uncertainty, however, bring new challenges to power system stability and reliability, particularly under extreme conditions and supply disruptions [1, 2]. Therefore, enhancing energy resilience has become an equally important objective alongside decarbonization in modern energy systems.

Therefore, the construction of building energy systems is changing at present. Traditionally, buildings have been passive energy consumers that are not connected to the grid. Recently, with the development of distributed energy resources (DERs), energy storage technologies and intelligent control systems, buildings have begun to operate as active energy nodes for local generation, storage and management [3, 4]. To ensure the continuous operation of the essential load and improve flexibility, a modification will be made to change the passive power supply in the system to an active power supply.

Microgrids have become the core support for the change in this process and are applied to buildings at present. Couple distributed generation with several energy storage facilities, including electricity and heat, to improve the flexibility, stability and autonomy of the microgrid. They can make the building run in both grid-connected and islanded modes and provide continuous power during a power outage to enhance system reliability [1, 5]. The high-level control function can be used to coordinate multiple energy-supply devices simultaneously for high-efficiency operation of the entire system under all circumstances.

Some problems still exist in the face of the above improvements. Most of the existing research focuses on energy-saving and economical operation, but has not addressed backup power operation during a grid failure. At the same time, the coordinated use of multi-energy storage systems in building-scale microgrids has not been extensively studied. Most of the existing research uses fixed assumptions and lacks scenarios under different loads and environments.

Therefore, this review evaluates the performance of intelligent building-integrated microgrids equipped with multi-energy storage systems in backup-power applications. Assessment of the performance of various system configurations and energy-saving strategies in different outage and operation circumstances to determine energy resilience, reliability, economic feasibility and sustainability. Based on the comparison of existing research, this paper will explore which structure and control method are more suitable for strengthening the backup power supply of smart buildings. The research has provided support for the development of stable, low-carbon and flexible building energy systems.

## 2. Building integrated microgrids and multi-energy storage systems

Building-integrated microgrids have been developing as an effective method to strengthen energy security and advance the transformation towards a low-carbon energy system. By combining distributed energy resources and energy storage devices, these systems can work in a flexible and stable manner when connected to the grid or in an islanded operation mode [6, 7]. In addition, multi-energy storage and high-efficiency energy-management technology will be employed to ensure uninterrupted power supply for backup power applications. This section will introduce the system structure and key storage technology of a building-integrated microgrid, as well as the control strategy, thus providing the basis for scenario analysis in the following.

### 2.1. Architecture of building integrated microgrids

Build an integrated microgrid (BIM) now to create a distributed, fault-tolerant power system. A representative BIM is distributed energy resources (DERs), such as PV systems, energy storage devices, controllable loads and grid connections. The above parts enable bidirectional power flow from the building to and from the utility grid, thus supporting both grid-connected and islanded operation modes. Grid-connected mode is used to connect to the main grid for cost and efficiency optimization, and in islanded mode, it can operate independently and provide a stable power supply to essential facilities during power outages. Recently, some researchers have shown that these structures can improve both the operation and stability of building energy systems [6, 8].

## 2.2. Multi-energy storage technologies

Energy storage will be used to build some of the backup-power facilities for BIM applications. Battery power-storage systems have a fast response time and are suitable for short-term voltage regulation, but they are not suitable for extended power-off periods. Therefore, at present, many kinds of storage are being introduced, such as thermal energy storage (TES) and hydrogen-based storage. These systems can use several sources of energy, such as electricity and heat, to increase the efficiency of the whole system and extend the duration of energy supply. Based on the above studies, to improve the stability of the system and reduce the dependency on external power grids, several kinds of energy storage should be used together [7, 9]. Management of many types of storage is complex and thus presents more problems in system design and operation.

Table 1 shows the functions of different energy storage technologies in backup power microgrids and compares their performance features and application scopes.

Table 1. Comparison of energy storage technologies for backup applications

| Storage Type | Response Time | Energy Capacity | Suitable Scenario | Advantages | Limitations |
|---|---|---|---|---|---|
| Battery (BESS) | Very fast | Medium | Short outage | Fast response, high efficiency | Limited duration |
| Thermal storage (TES) | Medium | High | Long outage / extreme climate | Cost effective for heating/cooling | Not directly usable as electricity |
| Hydrogen storage | Slow | Very high | Long-duration outage | Long term storage capability | High cost, low efficiency |
| Hybrid storage | Flexible | High | All scenarios | Combines advantages of multiple systems | Complex control |

Based on the above, it can be seen that no single energy storage technology can meet the backup-power needs of smart buildings. Battery Energy Storage Systems (BESS) are fast-response, high-efficiency and suitable for short-term power fluctuations; however, they have a limited storage time. Thermal Energy Storage (TES) is a low-costly high-capacity energy storage system for heating and cooling needs but cannot directly power electrical loads. Hydrogen storage can provide extended-duration power supply during prolonged power outages, but it is relatively expensive and has a low round-trip efficiency. Hybrid Storage Systems have demonstrated some flexibility, but the actual results are often dependent on the effectiveness of combining all kinds of storage and control strategies.

Therefore, multiple types of storage technologies can be used in a microgrid to combine the quick response of batteries, the high-capacity thermal support of TES, and the long-term backup capability of hydrogen storage. A multi-energy storage system can be built to meet the different operational needs of smart buildings in various outage situations more effectively and improve the stability, adaptability and general reliability of the system. Thus, the reasons for the development of multi-energy storage microgrids as backup power sources for smart buildings have been provided.

## 2.3. Energy management and control strategies

Optimize the Use and Control of Energy to Coordinate the Operation of BIMs. An EMS is generally employed to optimize the dispatch of power, keep the system stable and provide a stable power supply for essential loads. Traditionally, most of the methods have been based on optimization techniques, but now more advanced ones such as machine learning and reinforcement learning have begun to address the problem of dynamism. The Control Strategy for the backup power field should also prioritize the hierarchy of loads and promptly respond to changes in the power grid. Although research has shown that intelligent control can improve the performance of a system, its application in outage conditions and scenario-dependent operation is still limited [10, 11].

Based on the above system framework, storage technology and control strategy have been selected; therefore, the performance of the building integrated microgrid will vary with operating conditions. Therefore, to determine the different applications and control methods of the backup power system in various places more specifically, a case study will be carried out.

## 3. Analysis of backup microgrids in different scenarios

The performance of building integrated microgrids is highly dependent on operating conditions, particularly when backup power is required. Different scenarios, such as grid outages, extreme environmental conditions and normal grid-connected operation, impose distinct technical requirements on system configuration and control strategies. Hence, the scenario analysis is essential to evaluate the effectiveness of multi-energy storage systems in enhancing resilience and operational flexibility.

The cases covered in this review are grouped by their primary operating constraints and are not considered to be exclusive. The main divisions of short-duration outages, long-duration outages and normal grid-connected operation are based on grid availability and outage length. Extreme climate conditions are considered a special type of stress that may occur under any of the above operating conditions and therefore need to be assessed separately.

### 3.1. Short-duration outage (fast response)

A brief power failure will only last for a few seconds or minutes; therefore, the system must have a fast response speed and continuously power the equipment normally. The main problem is how to switch between grid-connected and islanded modes normally at the same time without fluctuations in voltage or frequency.

Recently, some intelligent control strategies have been proposed to address the problems above. For example, Murshed and others have put forward a new hybrid data-driven optimization scheme combining LSTM, PSO and Monte Carlo outage prediction. Based on the above experiments, the new method has reduced system downtime by 25% and increased the efficiency of sustainable energy use by as much as 82%, showing excellent prospects for quick outage response and high-reliability short-term backup operation [10]. The second is a problem of low battery charge (SoC) during sudden load increases and decreases.

Lin and others have also introduced a deep reinforcement learning-based dispatch strategy for microgrids by employing the Deep Deterministic Policy Gradient (DDPG) algorithm. This model has reduced the error in load forecasting to less than 5% and lowered the daily operating expenses by 3.8%-7.4% compared with the old control method. The above strategy has also been tested in the OPAL-RT real-time simulation platform and is expected to perform well dynamically in a microgrid [11]. Based on the above results, it can be seen that reinforcement learning has increased the speed of response in an uncertain environment significantly.

Although the above studies have shown good prospects for intelligent optimization, most of the current research has focused on economic dispatch and predictive scheduling rather than ultrafast transient response in the first few seconds after an outage. Therefore, fast-switching control for short-duration outages is still an underdeveloped but necessary research direction.

### 3.2. Long-duration outage (sustained operation)

A prolonged outage condition of several hours or days is more damaging to the microgrid than a short-lived transient event. Therefore, the demand for quick switching performance has been replaced by that of extended autonomous operation; consequently, large-scale renewable energy sources, reasonably sized batteries and smart energy management must all be included.

Recently, some studies have shown that a well-designed off-grid building microgrid can maintain a stable power supply during extended periods without a grid connection. For example, Forrousso et al. have studied a building-integrated photovoltaic (BIPV), rooftop PV and lithium-ion battery microgrid in six different climate zones in Morocco. The optimized results achieved a zero-unmet-load state in the simulated year, showing that full autonomy is technically feasible with properly sized storage and renewable energy resources. The addition of BIPV systems also increased the load-cover factor from 0.68% to 2.58% and reduced the levelized cost of electricity by 11.92% from 8.7% to 20.72% for PV battery systems without façade integration. Due to various climate factors, the system costs were about $0.366/kWh to $0.664/kWh [12].

Besides hardware sizing, accurate load prediction is equally important for long-duration resilience. Sekhar et al. proposed a hybrid forecasting framework combining Grey Wolf Optimization, convolutional neural networks and BiLSTM models for diverse building types including campus, hospital, residential and industrial loads. The model successfully performed one day, two days and one week ahead forecasts, outperforming conventional deep learning approaches [7]. Such predictive control methods can help building microgrids schedule battery dispatch more effectively and preserve emergency reserves during extended outages.

Although these studies demonstrate the technical feasibility of autonomous microgrids, their suitability as long-duration backup power solutions for intelligent buildings remains debatable. Most investigations rely on simulation models that assume favourable renewable generation and simplified load profiles, while limited attention is given to prolonged winter outages, equipment degradation and occupant-driven demand uncertainty. Consequently, the resilience of these systems under real emergency conditions may be less robust than reported, suggesting that autonomous operation alone cannot yet be regarded as a universally reliable backup power strategy for large-scale buildings.

### 3.3. Extreme climate conditions

Severe weather events such as heatwaves, cold spells, storms and prolonged cloudy conditions can significantly affect the operational stability of building microgrids. Unlike normal outages, these scenarios simultaneously affect electricity demand and renewable generation, creating a dual stress on system resilience.

During heatwaves and cold waves, building cooling and heating loads rise sharply which increases pressure on distributed energy resources. Alzahrani et al. developed a real time optimization framework for buildings integrated with photovoltaic generation, wind energy, batteries, electric vehicles and flexible loads. Using the Lyapunov optimization technique, the model dynamically balanced electricity cost, thermal discomfort and storage dispatch within varying weather conditions [6]. This study demonstrated that adaptive real time scheduling can maintain indoor comfort while optimizing battery use and renewable energy consumption, making it highly relevant for climate caused stress events.

Climate diversity also has a major influence on the long-term feasibility of autonomous building microgrids. Forrousso et al. evaluated an off-grid PV/BIPV/battery residential building system across six Moroccan climate zones, ranging from hot desert regions to colder mountainous areas. Their results showed that fully self-sufficient operation with zero unmet load was achievable in all climates, although the levelized cost of electricity varied significantly from \$0.366/kWh to \$0.664/kWh depending on local solar conditions and distribution of temperature. This indicates that severe weather resilience is technically possible but strongly dependent on regional climate and system sizing strategy [12].

Many current studies still rely on simulation environments and simplified weather datasets; however, future research should test real world compound events, such as simultaneous heatwaves and grid failures, winter storms with low solar irradiance and battery degradation within repeated temperature extremes.

### 3.4. Grid-connected operation (normal conditions)

Although technical reliability is essential, the long-term adoption of building microgrids is ultimately determined by economic feasibility. High initial investment for photovoltaic systems, battery storage and control infrastructure often remains the primary barrier to implementation. Therefore, many studies evaluate whether microgrids can reduce operational costs while maintaining resilience.

For grid-connected public buildings, coupling photovoltaic generation, battery storage and demand response has shown strong financial benefits. Wamalwa and Ishimwe proposed an optimal control strategy for a solar PV battery microgrid supplying a public building under the demand response tariffs. Their results demonstrated a 49% reduction in annual energy costs, while integrating appliance scheduling achieved an additional 4.4% saving. Furthermore, system peak demand was reduced by 37.5%, which can help reduce demand charges and relieve grid pressure. The whole retrofit was considered economically viable with a payback period of 9 to10 years [8].

The economic benefits are even more significant when conventional backup generators are replaced. Hwang et al. assessed the transition from diesel backup generators to PV plus storage microgrids for California public buildings exposed to wildfire related outages. Using the REopt optimization model, the study found that replacing diesel systems in a single building can save nearly \$3 million over 20 years while reducing more than 10,000 tons of $CO_2$ emissions. At the state level, similar measures across public facilities can generate annual savings between \$31 million and \$385 million [13].

However, economic results remain highly sensitive to battery prices, electricity tariffs, subsidy mechanisms and outage frequency. In regions with low electricity prices or limited policy incentives, investment returns may be slower. Therefore, future studies should evaluate location specific technical economic models within dynamic market conditions.

According to providing a clearer comparison of microgrid strategies within different operating conditions, Table 2 summarizes the key characteristics of each scenario including system challenges, dominant strategies and suitable technologies.

Table 2. Scenario comparison of microgrid strategies

| Scenario | Key Challenge | Dominant Strategy | Storage Type | Control Strategy | Why Suitable |
|---|---|---|---|---|---|
| Short-duration outage | Fast transition and stability | Rapid response control | Battery (BESS) | AI / RL control | High power density enables immediate response and seamless mode switching |
| Long-duration outage | Energy sufficiency | Multi-energy coordination | Battery + Thermal storage | Energy scheduling | Multi-energy systems extend supply duration and reduce reliance on single storage |
| Extreme climate conditions | Load variability and uncertainty | Climate adaptive operation | Thermal + Hybrid Storage | Predictive control | Thermal storage effectively manages heating/cooling loads under extreme conditions |
| Grid-connected operation | Cost and efficiency | Demand response and optimization | Battery | Optimization EMS | Enables peak shaving and cost reduction through grid interaction |

As shown in Table 2, the selection of storage technologies and control strategies is highly scenario dependent, highlighting the importance of tailored system design for achieving optimal performance within varying conditions.

### 3.5. Synthesis and future perspective

As building energy systems become more decentralized and data driven, future microgrids are expected to evolve beyond conventional backup systems into intelligent, flexible and low-carbon energy platforms. Emerging technologies such as artificial intelligence, digital twins, peer-to-peer energy trading and integrated storage are likely to significantly enhance operational efficiency and resilience.

Beyond individual buildings, decentralized energy markets may further increase local efficiency. Farajollahi et al. introduced the peer-to-peer transactive market for multi-energy microgrids, where the proposed optimization achieved 40% lower energy losses, 47% lower peak demand and improved nodal voltage by 1.5%. Such market microgrids can allow buildings to trade surplus electricity with neighboring users [14].

Future systems must also address cyber physical resilience. Pasculescu et al. evaluated PV-BESS microgrids under physical and communication failures. Their control strategy reduced the voltage deviation index by 27% and energy not supplied by 12%, highlighting the importance of securing communication and intelligent recovery controls [15].

Digital twin technology is also becoming increasingly important for predictive operation. Jiang et al. developed a digital twin microgrid model for a university campus in Singapore using real time simulation, which found simulated system responses closely matched actual physical assets, enabling more accurate forecasting, plug-and-play renewable deployment and predictive battery dispatch [16]. This suggests that future buildings may rely on virtual replicas to optimize real time energy management.

Real time demand response is one of the key development directions in the future. Xu et al. proposed a two-stage real-time multi-energy demand response framework for high renewable building microgrids. Their simulation results showed that operating costs could be reduced by up to 36.9%, while simultaneously improving system flexibility [17]. This demonstrates the potential of dynamic control strategies to better coordinate renewable generation, energy storage and building loads.

Finally, deep decarbonization remains a major long-term objective. Huylo et al. modelled an islanded university campus microgrid and found that combining wind generation with battery and thermal storage could reduce annual $CO_2$ emissions by 45.4%, increasing to 54.7% when hydrogen gas and natural gas are mixed [18].

In general, these studies suggest that an ideal backup power microgrid should be characterized by the following features. Firstly, resilience driven system design capable of maintaining critical loads under disruptions; secondly, deep integration of multi-energy storage and conversion technologies and adaptive and climate responsive operation enabled by advanced control strategies. Such a system represents not only technical optimization of existing solutions but also a paradigm shift toward fully intelligent, autonomous and resilient building energy systems.

To highlight the potential advantages of an ideal backup power microgrid, Table 3 presents a comparison between conventional systems and the proposed integrated solution.

Table 3. Ideal and conventional system comparison

| Aspect | Conventional Microgrid | Ideal Backup Power Microgrid |
|---|---|---|
| Energy supply | Grid dependent | Highly autonomous |
| Storage | Single (battery) | Multi-energy (battery + TES + hydrogen) |
| Control | Rule / optimization | AI predictive control |
| Resilience | Limited | High (supports long-duration outages) |
| Climate adaptability | Low | Adaptive and climate responsive |
| Operation mode | Mostly grid-connected | Seamless grid-connected & islanded |

As illustrated in Table 3, the ideal system demonstrates superior performance in terms of resilience, flexibility and adaptability, indicating a promising direction for future building energy systems.

## 4. Conclusion

This review investigated the potential of multi-energy storage microgrids to provide intelligent backup power supply for intelligent buildings within different operating scenarios. The review demonstrates that building integrated microgrids can significantly enhance energy resilience while supporting decarbonization and operational flexibility.

The scenario analysis shows that system requirements vary substantially with operating conditions. For short-duration outages, rapid response battery storage combined with intelligent switching control is critical to maintaining supply continuity and power quality. For long-duration outages, the coordinated use of renewable generation, battery storage and thermal or hydrogen storage becomes essential to sustaining autonomous operation. Under extreme climate conditions, predictive and adaptive control strategies are necessary for managing fluctuating loads and uncertain renewable output. During normal grid-connected operation, optimised energy management and demand response can reduce costs, lower peak demand and improve economic viability.

The findings indicate that no single storage technology or control strategy is capable of satisfying all backup power requirements across different operating conditions. Consequently, resilient intelligent buildings will require hybrid multi-energy storage systems supported by coordinated and adaptive energy management platforms.

Despite the considerable potential of multi-energy storage microgrids for backup power applications, several challenges remain. The integration of batteries, thermal energy storage and hydrogen systems increases system complexity, capital investment and control requirements. In addition, the performance of such systems is highly dependent on accurate forecasting, coordinated energy management and the availability of renewable energy resources. Uncertainties associated with occupant behavior, equipment degradation and extreme weather events may further affect system reliability in real-world applications.

Future research should therefore focus on advanced control and optimization strategies capable of coordinating multiple storage technologies under uncertain operating conditions. Emerging technologies such as artificial intelligence, digital twins, cyber-secure control systems and predictive energy management platforms offer significant opportunities to improve system flexibility, resilience and operational intelligence. Furthermore, more experimental demonstrations and large-scale case studies are required to validate simulation results and assess the long-term technical and economic performance of multi-energy storage microgrids in intelligent buildings.

In conclusion, multi-energy storage microgrids represent one of the most promising approaches for providing resilient and sustainable backup power in intelligent buildings. While technical, economic and operational challenges remain, the integration of complementary storage technologies with advanced control systems offers a practical pathway towards highly autonomous, climate-responsive and low-carbon building energy systems. As intelligent buildings continue to evolve, multi-energy storage microgrids are expected to play an increasingly important role in enhancing energy security and supporting the transition towards a more resilient energy future.

## References

[1] Mansouri, S.A., Paredes, Á., González, J.M. et al. (2023). A three-layer game theoretic-based strategy for optimal scheduling of microgrids by leveraging a dynamic demand response program designer to unlock the potential of smart buildings and electric vehicle fleets. Applied Energy, 347, pp.121440–121440. doi: https: //doi.org/10.1016/j.apenergy.2023.121440.

[2] Iavorschi, E., Milici, L.D., Ifrim, V.C. et al. (2025). A Literature Review on the European Legislative Framework for Energy Efficiency, Nearly Zero-Energy Buildings (nZEB), and the Promotion of Renewable Electricity Generation. Energies, [online] 18(6), pp.1436–1436. doi: https: //doi.org/10.3390/en18061436.

[3] Siksnelyte-Butkiene, I., Štreimikienė, D., Agnusdei, G.P. et al. (2022). Energy-space concept for the transition to a low-carbon energy society. Environment, Development and Sustainability. doi: https: //doi.org/10.1007/s10668-022-02697-6.

[4] Baniya, B. and Giurco, D. (2024). Cost-effective and optimal pathways to selecting building microgrid components – The resilient, reliable, and flexible energy system under changing climate conditions. Energy and Buildings, 324, p.114896. doi: https: //doi.org/10.1016/j.enbuild.2024.114896.

[5] Kyriakou, D.G. and Kanellos, F.D. (2023). Optimal frequency support method for urban microgrids of building prosumers. Sustainable Cities and Society, 98, pp.104776–104776. doi: https: //doi.org/10.1016/j.scs.2023.104776.

[6] Alzahrani, A., Sajjad, K., Hafeez, G. et al. (2023). Real-time energy optimization and scheduling of buildings integrated with renewable microgrid. Applied Energy, 335, pp.120640–120640. doi: https: //doi.org/10.1016/j.apenergy.2023.120640.

[7] Sekhar, C. and Dahiya, R. (2023). Robust framework based on hybrid deep learning approach for short term load forecasting of building electricity demand. Energy, 268, p.126660. doi: https: //doi.org/10.1016/j.energy.2023.126660.

[8] Wamalwa, F. and Ishimwe, A. (2024). Optimal energy management in a grid-tied solar PV-battery microgrid for a public building under demand response. Energy Reports, [online] 12, pp.3718–3731. doi: https: //doi.org/10.1016/j.egyr.2024.09.054.

[9] Yu, P., Ma, L., Fu, R. et al. (2023). Framework design and application perspectives of digital twin microgrid. Energy Reports, 9, pp.669–678. doi: https: //doi.org/10.1016/j.egyr.2023.04.253.

[10] Murshed, M., Chamana, M., Kork, E. et al. (2023). Sizing PV and BESS for Grid-Connected Microgrid Resilience: A Data-Driven Hybrid Optimization Approach. Energies, 16(21), pp.7300–7300. doi: https: //doi.org/10.3390/en16217300.

[11] Lin, F.-J., Chang, C.-F., Huang, Y.-C. and Su, T.-M. (2023). A Deep Reinforcement Learning Method for Economic Power Dispatch of Microgrid in OPAL-RT Environment. Technologies, [online] 11(4), pp.96–96. doi: https: //doi.org/10.3390/technologies11040096.

[12] Forrousso, S., Kaitouni, S.I., Mana, A. et al. (2024). Optimal sizing of off-grid microgrid Building-Integrated-Photovoltaic system with battery for a Net Zero Energy Residential Building in different climates of Morocco. Results in Engineering, 22, pp.102288–102288. doi: https: //doi.org/10.1016/j.rineng.2024.102288.

[13] Hwang, S., Tongsopit, S. and Kittner, N. (2023). Transitioning from diesel backup generators to PV-plus-storage microgrids in California public buildings. Sustainable Production and Consumption, 38, pp.252–265. doi: https: //doi.org/10.1016/j.spc.2023.04.001.

[14] Farajollahi, A., Jalalvand, M. and Rostami, M. (2025). Double objective decentralized transactive energy market framework for multi-energy microgrid. Energy Informatics, 8(1). doi: https: //doi.org/10.1186/s42162-025-00579-5.

[15] Pasculescu, D., Riurean, S., Ilieva-Obretenova, M. et al. (2025). Intelligent Modeling of PV–BESS Microgrids for Enhanced Stability, Cyber–Physical Resilience and Blackout Prevention. Energies, [online] 19(1), p.148. doi: https: //doi.org/10.3390/en19010148.

[16] Jiang, H., Tjandra, R., Soh, C.B. et al. (2024). Digital Twin of Microgrid for Predictive Power Control to Buildings. Sustainability, [online] 16(2), pp.482–482. doi: https: //doi.org/10.3390/su16020482.

[17] Xu, D., Zhong, F., Bai, Z. et al. (2023). Real-time multi-energy demand response for high-renewable buildings. Energy and Buildings, 281, pp.112764–112764. doi: https: //doi.org/10.1016/j.enbuild.2022.112764.

[18] Huylo, M., Taheri, S. and Novoselac, A. (2025). Integration of renewable energy generation and storage systems for emissions reduction in an islanded campus microgrid. Building and Environment, [online] 274, p.112736. doi: https: //doi.org/10.1016/j.buildenv.2025.112736.