

Solar Smart Bench with Charging and WiFi in College Garden

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Abstract: *The increasing demand for sustainable energy solutions and smart infrastructure in educational institutions has motivated the development of innovative public utilities such as solar-powered smart benches. This paper presents the design and implementation of a Solar Smart Bench with charging and Wi-Fi facilities installed in the college garden. The system is designed to harness solar energy through photovoltaic (PV) panels, which supply power to a battery-based storage unit, ensuring continuous operation even during non-sunny hours. The bench integrates multiple features including USB charging ports, wireless charging pads, and a Wi-Fi router to provide students and visitors with uninterrupted digital connectivity and device charging in outdoor environments. Energy management is achieved using a solar charge controller to optimize battery charging and load distribution. In addition to functionality, the bench emphasizes environmental sustainability by reducing dependency on conventional electricity, promoting the integration of solar-powered public facilities has become highly relevant. This paper introduces the design and implementation of a Solar Smart Bench installed in the college garden, providing both device charging and Wi-Fi connectivity. The system is powered by a photovoltaic (PV) solar panel, which stores energy in a battery bank through a solar charge controller for round-the-clock operation. The bench is equipped with USB charging ports, wireless charging pads, and a Wi-Fi router, allowing students and visitors to stay digitally connected in outdoor spaces.*

Keywords: Solar Smart Bench, Renewable Energy, Battery Storage, USB Charging, Wireless Charging, Wi-Fi Connectivity, Smart Campus, Green Infrastructure, Sustainable Energy, Solar Charge Controller, IoT Integration, Smart Cities

I. INTRODUCTION

The rapid growth of technology and the increasing demand for sustainable infrastructure have transformed the way public and educational institutions provide services to students and communities. In recent years, the concept of smart cities and smart campuses has gained significant momentum, aiming to combine renewable energy, digital connectivity, and intelligent design to improve quality of life. As educational institutions serve as hubs of innovation and knowledge, integrating green technology into their infrastructure has become both a necessity and a responsibility.

One such innovation is the Solar Smart Bench, which goes beyond the traditional function of a seating structure by integrating renewable energy harvesting, mobile charging, and wireless internet connectivity. A college garden is often a place where students spend their leisure time, collaborate on academic projects, or engage in outdoor learning. However, students frequently encounter two common challenges: limited access to charging facilities for their electronic devices and poor internet connectivity in open spaces. A Solar Smart Bench directly addresses these challenges while promoting eco-friendly practices.

The proposed system is powered by photovoltaic (PV) solar panels that convert sunlight into electricity, which is then stored in rechargeable battery systems to ensure uninterrupted operation during evenings or cloudy days. A solar charge controller regulates the charging process and efficiently distributes energy to the loads, including USB charging ports,



wireless charging pads, and a Wi-Fi router. Additionally, the bench structure is designed to be weather-resistant, ergonomic, and sustainable, ensuring long-term functionality in outdoor conditions.

Beyond technical convenience, the Solar Smart Bench aligns with the United Nations Sustainable Development Goals (SDGs) by promoting clean energy, digital inclusion, and climate-friendly infrastructure. It not only helps reduce dependence on grid electricity but also contributes to reducing the carbon footprint of the campus. The system acts as a practical demonstration of renewable energy utilization for students, thereby enhancing awareness and encouraging further research in the field of green technology.

Furthermore, this project represents a step toward future-ready campuses, where everyday infrastructure integrates multiple intelligent features. With additional upgrades such as IoT-based sensors for environmental monitoring, smart lighting systems, and real-time usage analytics, the Solar Smart Bench can evolve into a multifunctional node of the smart campus ecosystem.

Thus, the Solar Smart Bench in a college garden is not just a seating solution but a visionary infrastructure that bridges the gap between sustainability, digital accessibility, and smart living. By embedding renewable energy and technology into everyday life, this project demonstrates how small-scale innovations can create a lasting impact on both campus life and the environment.

II. RELATED WORK

Several commercial and academic efforts have been undertaken to integrate renewable energy into public seating infrastructure. Among commercial solutions, the Steora Smart Bench offers solar-powered USB and wireless charging, Wi-Fi connectivity, and environmental sensors, and has been deployed in numerous urban spaces worldwide [1]. Similarly, Strawberry Energy developed solar benches combining charging and digital engagement tools, often used as branding elements in smart-city projects [2]. These commercial solutions emphasize robustness and aesthetics; however, their proprietary nature limits customization, cost-effectiveness, and adaptability for educational institutions. Academic prototypes have also explored solar bench concepts. Studies in [3], [4] presented microcontroller-based benches with PV panels, batteries, and USB charging, validating technical feasibility but lacking advanced features such as energy optimization or secure campus-network integration. A multi-site analysis in [5] emphasized that the effectiveness of solar-powered urban furniture depends on local solar insolation, user behavior, and maintenance regimes, yet highlighted the absence of standardized evaluation metrics.

Despite these developments, several limitations persist. Existing commercial units are costly, closed-source, and optimized for generic urban deployment rather than academic environments. Academic prototypes, while low-cost, often remain proof-of-concept with limited scalability, inadequate attention to lifecycle costs, and minimal integration with broader smart-campus initiatives. Furthermore, issues such as energy management under variable weather, secure Wi-Fi provisioning, and modular maintainability remain underexplored.

Our proposed Solar Smart Bench for a college garden addresses these gaps by:

- Implementing an energy-aware management system that prioritizes essential loads
- Tailoring the design to campus requirements with secure Wi-Fi authentication and research-friendly IoT Instrumentation
- Emphasizing local fabrication and cost-effectiveness
- Positioning the bench as both a sustainable amenity and a living laboratory for students and faculty.

By bridging the gap between commercial robustness and academic flexibility, this work advances the concept of solar-powered smart benches toward sustainable, scalable, and educationally empowering smart-campus infrastructure.

III. PROBLEM STATEMENT

Traditional college garden infrastructure provides only basic seating facilities, lacking the ability to support the growing digital and energy needs of students. In modern academic environments, students frequently rely on mobile phones, tablets, and laptops for learning, communication, and project collaboration. However, one of the recurring issues in



outdoor campus spaces is the absence of accessible charging points and unreliable internet connectivity, which directly limits productivity and convenience.

While classrooms and indoor facilities are equipped with grid-powered outlets and Wi-Fi, students spending time in outdoor gardens face difficulties when their devices run out of battery or when they require internet access for research or communication. This leads to interrupted learning experiences, reduced outdoor engagement, and a dependency on indoor facilities, which restricts the potential of open academic spaces.

Although commercial solar smart benches have emerged in some urban contexts, they are expensive, proprietary, and designed for general public spaces rather than academic environments. Such solutions are often not cost-effective for educational institutions, lack campus-network security features, and do not provide modular flexibility for student learning or research integration. Academic prototypes, on the other hand, remain proof-of-concept models with limited scalability and insufficient attention to real-world usability, energy optimization, and sustainability.

Thus, there exists a clear gap: the lack of an affordable, sustainable, and campus-centric smart bench solution that combines renewable energy, device charging, and Wi-Fi connectivity in outdoor learning environments. Addressing this problem is not merely a matter of convenience but also of sustainability, as it promotes renewable energy adoption, digital inclusion, and alignment with smart campus and smart city visions.

The challenge, therefore, lies in developing a system that:

- Efficiently harvests solar energy and ensures reliable operation even during low-sunlight conditions.
- Provides user-friendly features such as USB and wireless charging with safe energy management.
- Integrates secure Wi-Fi connectivity aligned with campus networks.
- Ensures cost-effectiveness, modularity, and maintainability for long-term usage.
- Contributes to the green infrastructure goals of the institution.

Our proposed Solar Smart Bench for the college garden is designed to directly address these challenges, making outdoor academic spaces more functional, sustainable, and digitally connected.

IV. SYSTEM DESIGN

The Solar Smart Bench with Charging and Wi-Fi is designed as a self-sustained, renewable-energy-powered outdoor infrastructure that integrates multiple functionalities for modern academic spaces. The primary objective is to provide sustainable energy, device charging, internet connectivity, and illumination in a single compact bench, while promoting green energy utilization and smart-campus initiatives.

The system harnesses solar energy through a 20 W photovoltaic (PV) panel, which converts sunlight into electrical energy. This energy is routed through a solar charge controller to safely charge a 12 V battery, ensuring protection against overcharging, deep discharge, and reverse current flow. The battery serves as an energy reservoir, providing power to connected loads during periods of low sunlight or at night, guaranteeing 24/7 operational reliability.

The stored DC energy is managed and distributed via a combination of voltage regulators, DC-DC buck converters, and transistor-based switching circuits mounted on a Zero PCB. Voltage regulators stabilize the output for sensitive devices like USB charging ports, providing 5 V DC, while the buck converter efficiently steps down voltage to supply components like the Wi-Fi router, optimizing energy efficiency and minimizing power loss. Transistors and switches act as control elements, allowing selective power distribution to various loads, including an LED lamp for nighttime illumination, USB charging interfaces for mobile devices, and the Wi-Fi router for digital connectivity.

The Wi-Fi router is integrated to provide internet access to students and visitors in the garden, with the option for campus authentication via a captive portal. This ensures secure and reliable network access, tailored for educational environments.

The LED lamp adds value by improving visibility and safety during evening hours, demonstrating the multifunctional nature of the bench.

Mechanically, the bench structure supports the solar panel on its upper surface with optimal tilt for maximum sun exposure. Electronics and batteries are housed in a weather-resistant enclosure beneath the seating area, protecting sensitive components from environmental conditions such as rain, dust, and heat. The design emphasizes ergonomics,



durability, and ease of maintenance, ensuring that both the energy and digital services are accessible, safe, and long-lasting.

The system also allows for future upgrades, such as the integration of IoT sensors for environmental monitoring (temperature, humidity, air quality), energy usage analytics, and smart lighting control. These features transform the bench from a simple utility into a living laboratory, providing students and faculty with real-time data for research and learning, while simultaneously contributing to the campus's sustainability goals.

V. HARDWARE COMPONENTS

The Solar Smart Bench is designed as a self-sustained outdoor infrastructure that integrates renewable energy harvesting, energy storage, power regulation, device charging, and Wi-Fi connectivity in a single compact unit. The system begins with a 20 W solar panel mounted on the bench, which captures solar energy and converts it into DC electricity. This energy is directed to a solar charge controller that manages safe charging of a 12 V battery, preventing overcharging or deep discharge. The stored energy in the battery powers multiple outputs including a Wi-Fi router, LED lamp, and USB charging ports, ensuring continuous operation even during low sunlight or nighttime. To regulate voltage and ensure stable power delivery, voltage regulators and DC–DC buck converters are used. These components protect sensitive devices, minimize energy loss, and optimize efficiency. Transistors, resistors, and switches form the control circuitry, enabling safe load switching and manual control of individual devices. The electronic components are mounted on a Zero PCB, which provides modularity and ease of maintenance. All electronics are housed in a weather-resistant bench structure, which also supports user seating ergonomically. The system is designed to be scalable and allows future integration of IoT sensors for environmental monitoring and energy usage analytics, turning the bench into a smart campus node.

- Solar Panel (20 W): Captures sunlight and converts it into DC electricity to power the bench system.
- Solar Charge Controller: Ensures safe battery charging; prevents overcharge and deep discharge.
- 12 V Battery: Stores solar energy; powers the system during night or cloudy conditions.
- Voltage Regulators: Provide stable, constant voltage to devices like USB ports and LEDs.
- DC–DC Buck Converter: Steps down voltage efficiently for high-current devices like Wi-Fi routers.
- Wi-Fi Router: Provides wireless internet access in the garden; can be integrated with campus authentication.
- LED Lamp: Provides illumination at night, enhancing safety and usability.
- Zero PCB: Base for mounting electronic components; enables modular assembly and maintenance.
- Transistors: Switch or control loads safely; part of automation and protection circuits.
- Resistors: Limit current, bias transistors, and protect sensitive components like LEDs.
- Switches: Allow manual control of devices to conserve energy and provide user flexibility.
- Bench Structure: Houses all components, supports solar panel, provides seating, and protects electronics from environmental elements

VI. CONCLUSION

The Solar Smart Bench project successfully demonstrates the integration of renewable energy, energy storage, regulated power distribution, and digital connectivity into a compact, outdoor seating infrastructure suitable for college gardens. By combining a 20 W solar panel, 12 V battery, charge controller, voltage regulators, DC–DC converter, and IoT-ready components, the bench provides continuous USB and wireless charging, LED illumination, and Wi-Fi connectivity for students and visitors.

This system addresses the key challenges of outdoor learning environments, including lack of accessible power, unreliable internet, and energy inefficiency, while promoting sustainability and smart campus initiatives. The modular design, combined with a weather-resistant bench structure and easily maintainable electronics, ensures long-term reliability and scalability. Furthermore, the integration of transistors, resistors, switches, and a Zero PCB ensures safe and efficient operation of all electrical loads.



The project also opens avenues for future enhancements, such as IoT-based environmental monitoring, energy usage analytics, and expansion into a network of smart benches across campus, thereby transforming outdoor spaces into interactive, eco-friendly, and technologically empowered learning areas. Overall, the Solar Smart

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