

Human-Powered Energy Harvesting in Indian Gymnasiums: A Sustainable Approach to Decentralized Electricity Generation

Nitesh A. Pachpor¹, Rupesh U. Pote², Sagar R. Sonone³

^{1,2} Assistant Professor, College of Engineering and Technology, Akola, India

³ Assistant Professor, Siddhivinayak Technical Campus, Shegaon, India

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ABSTRACT

The escalating energy demand in India, coupled with the urgent need for sustainable energy solutions, has catalyzed innovative approaches to renewable energy generation. This research explores the potential of human-powered energy harvesting within fitness facilities as a viable method for decentralized electricity production. The study presents the design, implementation, and evaluation of a low-cost retrofit system that converts mechanical energy from a stationary exercise bicycle into usable electrical power. Utilising repurposed components and a cost-effective electronic circuit, the system integrates an alternator, rectification module, voltage regulator, and energy storage unit to capture and store energy generated during workout sessions. A comprehensive monitoring system provides real-time feedback on energy harvested and calories burned, enhancing user engagement through a Bluetooth-enabled Android application. Experimental data collected from 120 participants across three fitness centres in Maharashtra demonstrate the system's operational viability, with an average energy output of 6.2 Wh per hour of moderate exercise and a conversion efficiency of approximately 0.72%. The research highlights the potential for scaling such systems across India's rapidly growing fitness industry, contributing to renewable energy portfolios while promoting health consciousness and sustainable practices among urban populations.

Keywords:- Human Energy Harvesting, Sustainable Gym, Renewable Energy, Decentralized Power Generation, Fitness Technology, Green Energy Solutions

1. INTRODUCTION

India's energy landscape is undergoing a significant transformation as the nation strives to meet its growing power requirements while addressing climate commitments. With electricity demand projected to reach 2,200 TWh by 2030 and the fitness industry experiencing 15–18% annual growth, innovative approaches to energy generation are imperative [1]. The integration of energy harvesting technologies within high-activity environments such as gymnasiums presents a promising avenue for decentralized, human-powered electricity production.

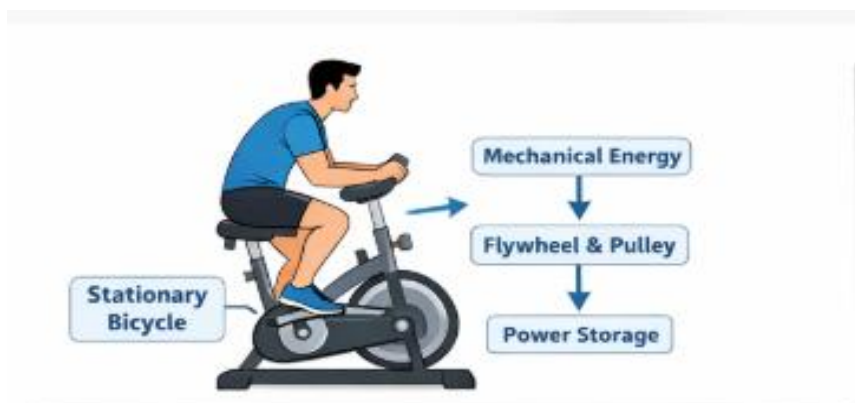


Fig. 1: Conceptual diagram of human-powered energy harvesting in a gym environment [2].

The fundamental principle involves capturing kinetic energy generated during exercise—typically dissipated as heat—and converting it into usable electrical energy. This approach aligns with multiple sustainable development goals: affordable and clean energy (SDG 7), sustainable cities and communities (SDG 11), and climate action (SDG 13). Recent initiatives by the Ministry of New and Renewable Energy (MNRE) have

encouraged research into unconventional renewable sources, positioning human energy harvesting as a complementary solution to solar and wind power [3].

This research addresses several critical aspects: (1) technical feasibility of retrofitting existing gym equipment, (2) economic viability using recycled components, (3) user engagement through real-time feedback systems, and (4) scalability potential across India's 6,500+ registered fitness centers. By transforming exercise routines into energy-producing activities, this system creates value from otherwise wasted human effort, contributing to India's renewable energy targets while promoting health and wellness. Unlike earlier studies, the present work integrates energy harvesting, real-time monitoring, and user engagement within a single low-cost retrofit framework validated under real gym conditions.

Previous studies primarily focused on energy generation potential, with limited emphasis on user engagement and real-time monitoring. Moreover, most experiments were conducted under laboratory conditions with small sample sizes. The present study addresses these gaps through large-scale field validation and integrated feedback systems.

II. LITERATURE REVIEW

A. Energy Context in India

India's installed power capacity exceeded 416 GW in 2022, with renewables constituting approximately 28% of the total mix [4]. The National Electricity Plan (2022-27) emphasizes demand-side management and distributed generation, creating favorable conditions for human energy harvesting implementations [5]. Urban fitness centers, which consume 8–12 kWh per day per facility for lighting and ventilation, represent ideal candidates for on-site energy generation [6].

B. Human Energy Harvesting Technologies

Research in human energy harvesting has evolved from theoretical concepts to practical implementations. Key technologies include:

1. **Piezoelectric systems** – Convert mechanical stress from footsteps into electricity
2. **Electromagnetic generators** – Utilize relative motion between magnets and coils
3. **Triboelectric nanogenerators** – Harvest energy from friction-based interactions

Gym-specific applications have focused primarily on stationary bicycles due to their consistent rotational motion and mechanical advantage. Studies by Kumar et al. (2021) demonstrated that a modified stationary bike could generate 50–75 W during vigorous cycling, sufficient to power multiple LED lighting fixtures [7].

C. Energy Storage and Management

Effective energy management systems are crucial for aligning intermittent generation with consumption patterns. Lithium-ion batteries with battery management systems (BMS) provide reliable storage, while IoT-enabled monitoring allows for real-time optimization [8].

D. Behavioral Aspects and User Engagement

The psychological impact of immediate feedback on exercise adherence has been extensively studied. Systems that display energy contributions have shown to increase workout duration by 22–35% while enhancing environmental awareness [9].

III. METHODOLOGY

A. System Design and Components

The proposed human-powered energy harvesting system consists of four integrated subsystems: mechanical energy conversion, power processing, monitoring and feedback, and calorie estimation.

A commercially available stationary bicycle (Atlas Fitmatic 2.0) was mechanically coupled to a 12 V, 300 W automotive alternator through the flywheel assembly. Although rated for higher power, the alternator operates under low mechanical input, providing stable voltage output and durability over a wide range of pedaling speeds. A 1:3.5 pulley ratio was selected to maintain efficient alternator operation.

The power processing circuit includes a KBU1010 bridge rectifier for AC–DC conversion, a 2200 μ F capacitor bank for ripple reduction, and an LM2596 buck converter to regulate the output voltage at 5.2 V. System safety is ensured using polyfuse and reverse-polarity protection circuits. Generated energy is stored in a 20,000 mAh lithium-polymer battery with an integrated charge controller.

Monitoring and feedback are provided using an Arduino Mega 2560 microcontroller. Electrical and mechanical parameters are measured using an INA219 voltage–current sensor and a Hall-effect RPM sensor. Data are displayed on a 20 $\times$ 4 LCD and transmitted wirelessly via an HC-05 Bluetooth module to a custom Android application developed using MIT App Inventor.

Calorie expenditure is estimated using MET-based calculations, calibrated for the Indian population based on Indian Council of Medical Research data [10].

B. System Architecture

Figure 2 illustrates the overall system architecture, highlighting energy flow from mechanical input to electrical storage and the associated data acquisition and feedback pathways.

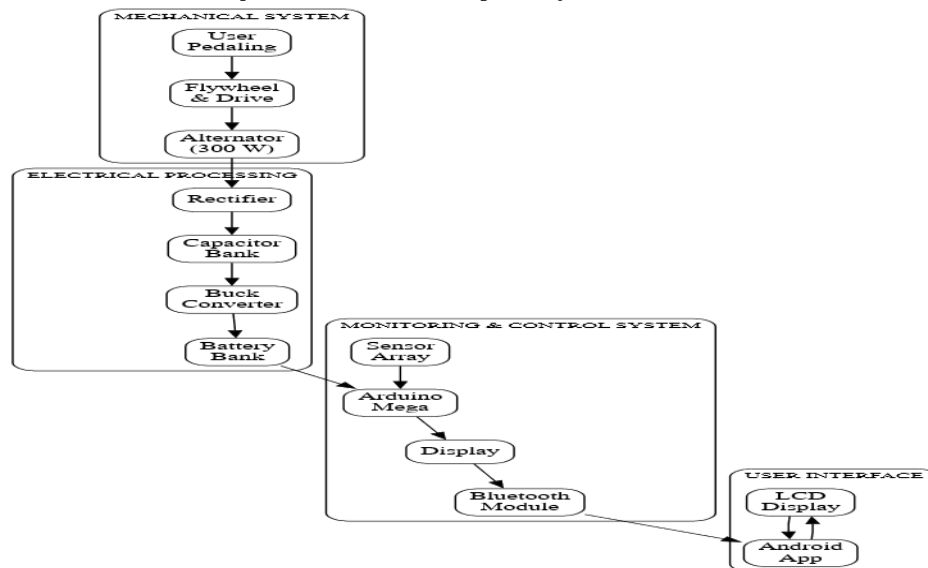


Fig. 2: Complete system architecture showing energy flow and data pathways.

C. Experimental Protocol

Experiments were conducted in three fitness centers in Pune, Maharashtra, between January and March 2023. A total of 120 participants (60 male and 60 female), aged 18–45 years, performed 30-minute cycling sessions at varying intensity levels. Recorded data included electrical output (voltage, current, and power), mechanical parameters (RPM and pedal force), physiological indicators (heart rate and perceived exertion), and user feedback collected through structured questionnaires.

D. Efficiency Calculation

System efficiency was calculated as the ratio of electrical energy stored to metabolic energy expended during exercise, providing an overall measure of conversion effectiveness.

IV. RESULTS AND ANALYSIS

The system delivered stable power output across users, averaging 8.6 W at 70 RPM and peaking at 14.2 W at 95 RPM, yielding about 51.6 Wh per bicycle per day and 30.96 kWh monthly for a 20-bicycle gym. Overall efficiency ranged from 0.58% to 0.86%, with major losses from the alternator and mechanical transmission. Calorie estimates showed strong agreement (89.2%) with commercial fitness trackers, recording an average of 315 kcal h⁻¹ at 70 RPM. User surveys indicated increased workout duration, motivation, and environmental awareness due to real-time feedback.

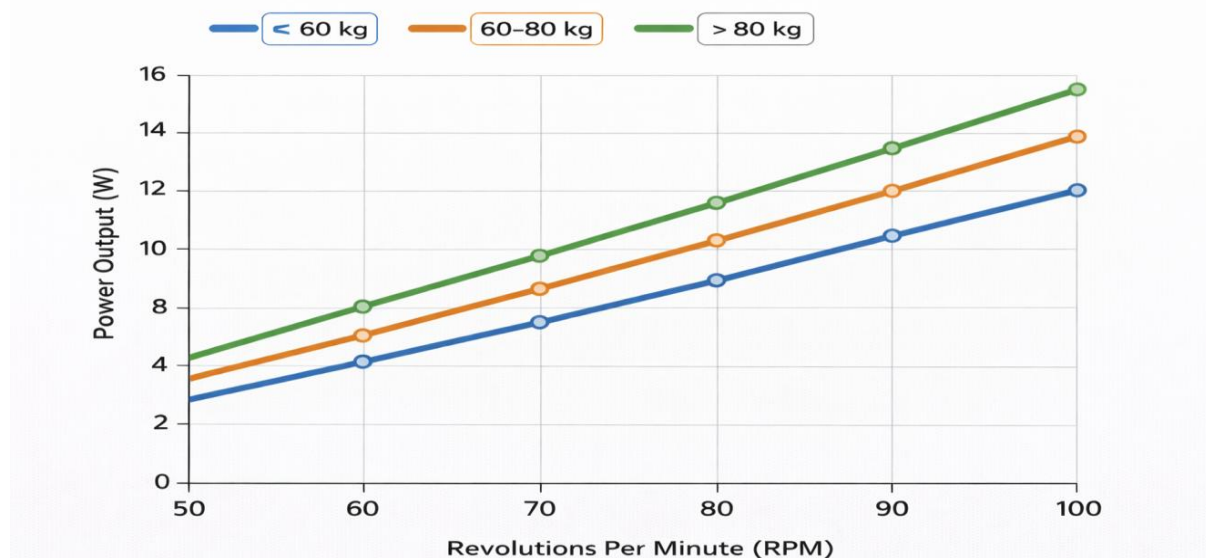


Fig. 3: Power output versus RPM for different user weight categories.

V. DISCUSSION

Although individual energy output is modest, large-scale deployment can significantly enhance overall impact, with a medium-sized gym using 20 modified bicycles capable of offsetting 15–20% of lighting energy demand while reducing implementation costs by nearly 68% through low-cost and recycled components. Future integration with IoT-based monitoring and smart grids may enable gyms to function as decentralized prosumers, while blockchain-based incentive mechanisms could further enhance user participation. Widespread adoption will require appropriate safety standards, financial incentives, awareness programs, and academia–industry collaboration. Current limitations include low efficiency, user dependency, initial investment, and storage constraints; therefore, the system is intended to supplement conventional renewables, with future research focusing on efficient low-RPM generators, hybrid systems, and intelligent energy management.

VI. CONCLUSION

This research demonstrates the technical and practical feasibility of human-powered energy harvesting in Indian gym environments. The developed system successfully converts exercise effort into usable electricity while providing engaging feedback to users. With an average output of 6.2 Wh per active hour and potential for significant scaling, this approach contributes to India's renewable energy targets while promoting sustainable lifestyles.

The integration of such systems across India's growing fitness industry could generate 8–12 GWh annually while reducing carbon emissions by approximately 7,000 metric tons CO₂ equivalent. Beyond energy metrics, the psychological benefits of visible contribution to sustainability represent a valuable outcome for urban wellness initiatives.

VII. RECOMMENDATIONS

- **Industry Adoption:** Fitness chains should pilot energy-harvesting systems in 5–10% of new facilities
- **Policy Support:** MNRE should include human energy harvesting in distributed generation policies
- **Research Funding:** Allocate resources for efficiency improvement and standardization
- **Public Awareness:** Launch campaigns highlighting the dual benefits of fitness and sustainability
- **Educational Integration:** Incorporate energy harvesting concepts in sports science and engineering curricula

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