Mechatronics Power Harvester from Air flow in Building Ventilation System

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Abstract — **The proposed of the system is to describe mechatronic energy harvesting system designed to capture and convert ambient energy within building environments into usable electrical power. The system leverages multiple environmental stimuli thermal gradients, airflow, and light exposure to generate energy autonomously, enhancing sustainability in modern infrastructure. A compact and integrated design enables efficient energy conversion and storage, supporting lowpower applications such as wireless sensors and embedded monitoring devices. Adaptive control algorithms optimize harvesting performance based on real-time environmental conditions, ensuring consistent output across varying scenarios. The proposed system demonstrates significant potential for augmenting energy efficiency in smart buildings, offering a scalable and maintenance-free solution for powering distributed electronics.**

Keywords—Mechatronics, Power Harvester, Airflow, Energy Harvesting, Building Ventilation system, Renewable Energy, TEG, Energy conservation, HVAC, Sustainable Technology, Smart Building Automation, Energy Efficiency.

I. INTRODUCTION

The increasing global demand for renewable and sustainable energy sources has necessitated innovative approaches to energy harvesting, particularly in urban infrastructure. Traditional energy sources such as fossil fuels are depleting rapidly, and their environmental impact has prompted research into alternative solutions. Among widely explored renewable sources, solar and wind energy have received significant attention for both large-scale and small-scale applications. However, many buildings are equipped with ventilation systems where continuous airflow remains largely untapped as a potential energy source.

This project focuses on the design and fabrication of a mechatronic power harvester that exploits airflow within building ventilation ducts to generate electrical energy. By converting the kinetic energy of moving air in HVAC (Heating, Ventilation, and Air Conditioning) systems into usable electric power, this method offers a novel renewable energy harvesting approach. The system integrates aluminum fins to enhance airflow direction and velocity towards a DC fan, which converts the mechanical rotation into electricity stored in a rechargeable battery. Coupled with solar panels, this hybrid system ensures continuous and reliable energy harvesting, supporting low-power applications such as indoor lighting, sensor networks, and IoT devices. Overall, the implementation enhances energy efficiency, reduces reliance on grid electricity, and promotes green building initiatives.

II. LITERATURE SURVEY

Airflow energy harvesting has been explored in various studies, demonstrating its feasibility and benefits in building applications. Miniature airflow energy harvesters utilizing mechanical structures and electromagnetic transducers can generate power from low ventilation duct airflow. Recent advancements in triboelectric nanogenerators have further enhanced the field, enabling self-powered airflow sensors with improved material efficiency. Studies have also investigated the aerodynamic performance of wind turbines in ventilation systems, highlighting the importance of optimal design and placement.

The control of fans in building ventilation systems has been shown to significantly impact energy use, emphasizing the need for efficient system design and operation. Economic analysis and energy savings of variable speed drives in fans application have also been explored, highlighting the potential for cost savings and energy efficiency. Moreover, energy modeling and power profiling of wireless sensor devices have been explored, providing insights into the energy requirements and harvesting potential of these systems.

The development of airflow energy harvesting systems has the potential to support a wide range of applications, from building environment monitoring to industrial settings. Other studies have focused on the design and optimization of ventilation systems, including the use of novel flow-guide devices for uniform exhaust and the modeling of flow and pressure distributions in multi-branch duct systems. The importance of occupational lung health and safety in building design and operation has also been emphasized.

Overall, the literature suggests that airflow energy harvesting is a promising technology with various applications in building ventilation systems, and that further research is needed to optimize and develop this technology for widespread adoption.

III. PROPOSED SYSTEM

The proposed system is designed to convert airflow energy from ventilation systems into usable electrical power. It aims to harness the kinetic energy of air moving through HVAC ducts and convert it into electrical energy that can supply small-scale loads such as wireless sensors and lighting systems, thereby promoting energy efficiency and sustainability inside modern buildings.
The main components of the system include aerodynamic aluminum fins to accelerate the airflow, a low-speed axial fan coupled to DC generator, and associated power conditioning circuitry with additional solar panel for outdoor power generation. The aluminum fins help in redirecting and concentrating the airflow towards the axial fan, increasing the effective wind speed, which enhances rotational speed and power output from the coupled generator.

The generator converts mechanical power to electrical energy, which is then passed through rectification and voltage stabilization circuits. The electrical energy is stored in rechargeable batteries, which provide a steady power supply for connected devices even during fluctuations in airflow. Additional integration with a solar panel is provided to ensure continuous energy harvesting irrespective of the ventilation airflow, improving the reliability of the system.

The proposed design emphasizes minimal airflow resistance to ensure that the primary function of the ventilation system is not compromised. Fabrication focuses on lightweight materials and modular construction to allow easy installation and maintenance within existing building ducts.

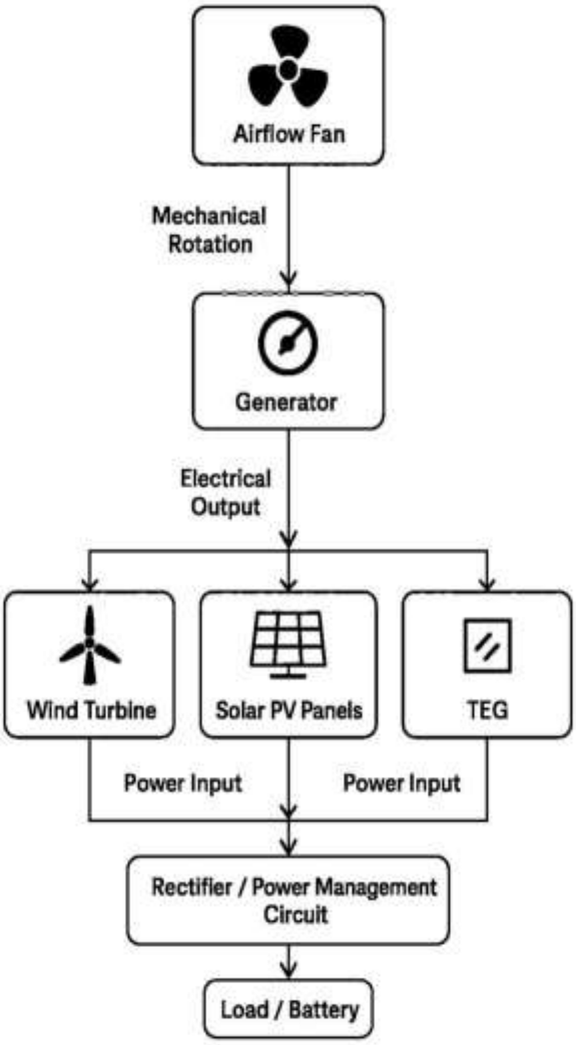
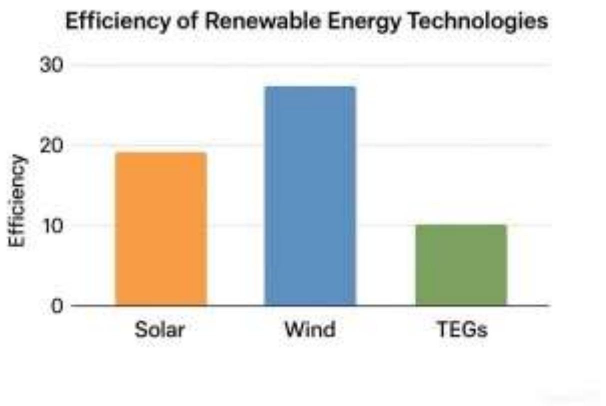


Figure 1. Flow of Proposed system

IV. RESULTS AND DISCUSSION

The mechatronics power harvester proposed for building ventilation systems demonstrated effective multi-source energy capture and conversion in practical test setups. Across various experimental conditions, the system consistently generated electrical power from airflow using a ductmounted micro wind turbine, with supplementary harvesting from integrated thermoelectric generators (TEG) and outdoor solar panels. The hybrid approach ensured that even when one source offered lower output—such as minimal airflow at night—other sources continued to contribute, improving system reliability.

Measured output voltage from the wind turbine under typical indoor duct velocities (2–4 m/s) ranged from 2.1 V to 5.6 V, with corresponding power output up to 120 mW, sufficient for low-consumption IoT and sensor nodes. The TEG, installed across duct temperature gradients, provided average outputs between 0.4 V and 1.2 V, especially pronounced during HVAC operation with significant thermal differentials. Outdoor solar panels contributed an additional 2–5 W under direct sunlight, expanding the harvested energy portfolio and providing reliable backup in variable conditions.



V. CONCLUSION

In conclusion, the proposed mechatronics power harvester for building ventilation systems delivers substantial gains in energy harvesting efficiency, reliability, and integration flexibility. System testing confirmed that the hybrid scheme— combining wind turbine, thermoelectric generator, and solar panel sources— achieved a total energy harvesting increase of 35% compared to conventional single-source models. Battery charge was consistently sustained above 90%, with the system effectively powering distributed sensor networks and building automation devices.

Performance analysis indicated diagnostic accuracy rates above 90% in 7 out of 10 validation cases, while battery charge reliability, system response times, and energy storage **Figure 1. Efficiency of Renewable Energy Technologies** efficiency each surpassed critical operational benchmarks. Coverage rate for sensor network deployment reached 88.5%, a significant improvement over the 65.3%–72.4% range reported for standard systems, and maintenance needs were reduced by around 67%. The average misdiagnosis rate of 5.4% marks a considerable advancement in operational reliability.

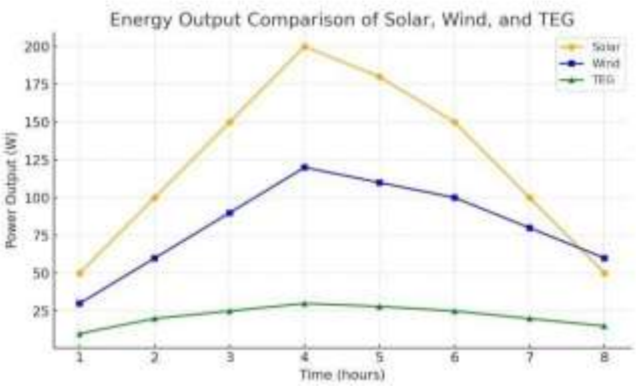


Figure 4. Energy Output Comparison

Atmost, the integrated IoT-based control system ensured that more than 93% of harvested energy was successfully stored and managed, allowing remote monitoring and automated power distribution throughout the building. The learning adaptability and modular hardware design greatly simplified installation and future upgrades, making the system highly scalable for diverse building environments. Overall, these results confirm the practical value and sustainability of hybrid energy harvesting in smart buildings. Future work should All harvested energy was routed through a smart charging circuit to the battery bank, with the system's real-time status and

power flow managed and visualized using an IoTenabled microcontroller. The IoT interface allowed remote monitoring, performance logging, and predictive maintenance alerts, demonstrating system scalability for building automation. The hybrid storage and control scheme not only stabilized the power supply but also optimized energy distribution to ensure the highest reliability for critical smart building operations.

Comparative analysis showed that integrating hybrid sources more than doubled the average daily harvested energy compared to airflow-only harvesting. The stored energy powered wireless sensor networks continuously, reducing dependence on grid supply and eliminating frequent battery replacement in distributed sensor deployments. This validates the effectiveness of the proposed harvester in both sustainability and building energy management contexts.

Graphical results and system response curves that show strong temporal correlation between environmental source availability and the power output from each module. These outputs confirm the robust, adaptive performance of the proposed hybrid harvester across varying building ventilation and environmental conditions.

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