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# Harnessing HVAC Exhaust Airflow for Small Scale Wind Energy Generation: A Novel Approach to Renewable Power Recovery

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**Abstract – The increasing global population has significantly elevated the demand for electrical power. As conventional energy resources are finite, the need for alternative and sustainable energy solutions becomes more pressing. This study explores the potential of harnessing HVAC exhaust airflow for small-scale renewable energy generation. Experimental results show an average airflow velocity of 6.14 m/s producing a stable 217 V AC output under a 50 W load. However, the system's power output remains modest and highly dependent on air conditioner operation cycles, which limits scalability and consistent energy supply. These findings highlight the practicality of energy recovery from existing HVAC systems, although improvements in turbine design, duct geometry, and energy storage are necessary to enhance efficiency and real-world integration.**

***Keywords: HVAC exhaust airflow, renewable energy, small-scale wind turbine, DC generator, inverter.***



## I. INTRODUCTION

The global demand for electrical energy continues to rise in parallel with population growth and the increasing use of electronic devices. Traditional energy generation methods, which primarily rely on fossil fuels, contribute significantly to environmental degradation and are inherently unsustainable due to the finite nature of fossil energy sources. Therefore, there is a pressing need to explore alternative and renewable energy solutions that are both efficient and environmentally friendly.

One promising renewable source is wind energy. Wind turbines have been widely used to convert kinetic energy from natural wind into electricity. Wind energy is clean, sustainable, and does not require complex processing. In addition to natural wind, artificially generated airflow such as that produced by the outdoor units of air conditioners represents an untapped source of kinetic energy that could be repurposed for small-scale electricity generation.

A previous study by Umbu introduced a prototype for harnessing airflow from air conditioning exhaust to generate electricity. However, the system lacked several critical components, including voltage and current monitoring, DC-to-AC conversion, and modification of the air outlet to enhance performance. These limitations hinder the practical application and reliability of the system in real-world scenarios.

This research aims to address these gaps by developing a small-scale wind energy system that utilizes the exhaust airflow from an AC outdoor unit. The system includes a wind turbine, DC generator, inverter, rechargeable battery (accumulator), and digital monitoring tools such as a voltmeter. The turbine converts airflow into mechanical rotation, which is then transformed into electrical energy by the generator. The inverter subsequently converts the DC output to AC voltage suitable for household use.

The innovation of this research lies in its integration of real-time voltage monitoring, improved DC-AC power conversion, and a more efficient utilization of airflow from existing HVAC infrastructure. Unlike prior models, the proposed system is more comprehensive and aims to demonstrate the viability of converting waste airflow into usable electrical energy in a practical, low-cost, and environmentally conscious manner.

Previous research has primarily focused on conceptual and small-scale prototypes of HVAC-based wind energy systems, with limited attention to efficiency, scalability, and energy stability under variable airflow conditions. Most studies reported output power below 100 W, indicating that such systems are more suitable for supplemental, rather than primary, power generation.

Therefore, the objective of this study is to design and evaluate a small-scale wind energy recovery system utilizing HVAC exhaust airflow, while identifying its practical limitations in terms of airflow variability, power output, and system efficiency. By analyzing these parameters, the research aims to assess both the potential and the constraints of integrating such micro-generation units into sustainable building energy systems.

Furthermore, this study contributes to the growing discourse on renewable micro-generation by demonstrating the adaptive reuse of existing HVAC systems to recover otherwise wasted energy. The outcomes are expected to provide insights into improving building energy efficiency, aligning with sustainable development goals (SDGs) related to clean energy and climate action. The findings also serve as a reference for future research in optimizing duct geometry, turbine blade design, and hybrid energy integration strategies for enhanced performance and scalability.

## II. METHOD

This study employed an experimental method integrated with an action research framework, enabling iterative testing, observation, and system improvement. The experimental setup was conducted in a controlled laboratory environment to simulate realistic HVAC exhaust airflow conditions, allowing precise measurement of wind speed, generator performance, and inverter stability. The research method emphasizes both quantitative measurement and practical evaluation of prototype feasibility.

### A. Research Design

The action research approach was chosen because it allows continuous refinement through cycles of *planning, acting, observing,* and *reflecting.* This method enables the researcher to intervene directly in the experimental environment, analyze feedback from system performance, and adjust the design for optimal energy recovery. The research steps consisted of the following stages:

1. Problem Identification – recognizing inefficiency and waste in HVAC exhaust airflow that can potentially be harnessed as an energy source.
2. System Design and Fabrication – creating a miniature model of an HVAC exhaust-based wind energy recovery system.
3. Implementation and Testing – running experiments to simulate actual HVAC conditions and measure electrical performance.
4. Evaluation and Reflection – analyzing data, validating prototype performance, and identifying potential improvements for future studies.

The research procedure was carried out systematically through several stages to ensure accuracy and repeatability. The steps were as follows:

1. System Design and Planning – Identifying the problem of wasted HVAC exhaust airflow and designing a miniature recovery system consisting of a duct cone, fan turbine, DC generator, inverter, and monitoring instruments.
2. Prototype Construction – Fabricating the model based on the design specifications using lightweight and low-cost materials to simulate real-world HVAC conditions.
3. Instrument Calibration – Setting up measurement devices, including an anemometer for airflow velocity, a digital tachometer for RPM, and multimeters for voltage and current readings.
4. Experimental Testing – Conducting performance tests by varying indoor air conditioner temperature settings (16°C, 19°C, 22°C, 25°C, and 28°C) and recording corresponding airflow velocity, generator speed, voltage, and current.
5. Data Analysis and Reflection – Processing and analyzing collected data to identify correlations among parameters and reflect on prototype performance for further improvement.

This procedure ensured structured experimentation and direct feedback for optimizing the small-scale HVAC energy recovery system.

### *B. Experimental Setup*

The prototype system consists of three main functional stages: generation**,** power storage, and inversion (Figure 1). Each stage works collaboratively to convert mechanical energy from HVAC exhaust airflow into usable electrical power.

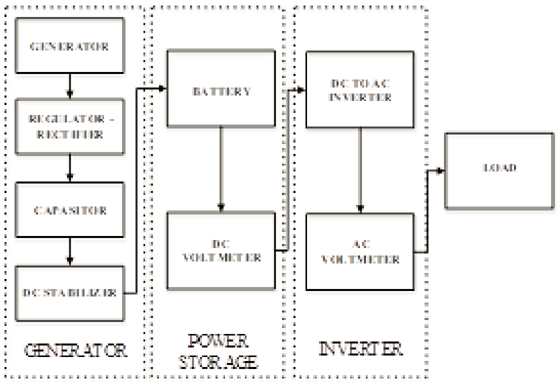


Figure 1. Hardware Block Diagram

1. Generation Stage – The airflow drives a fan turbine connected to a DC generator, producing alternating current (AC). The output passes through a rectifier-regulator circuit that converts AC to direct current (DC) while stabilizing voltage fluctuations. A capacitor is used to smooth voltage ripples, and a DC stabilizer ensures steady voltage output.
2. Power Storage Stage – The regulated DC is stored in a 12V rechargeable battery, monitored by a DC voltmeter for real-time voltage and current readings. This setup ensures the availability of power for subsequent conversion stages.
3. Inverter Stage – A 300W DC-to-AC inverter converts stored DC into 230V AC, compatible with standard household appliances. An AC

voltmeter monitors the inverter's output voltage to ensure system reliability under varying loads.

This modular configuration promotes scalability, ease of maintenance, and efficient energy transformation. The overall system aligns with sustainable energy principles by recovering otherwise wasted HVAC exhaust energy.

C. Mechanical and Electrical Design

Figure 2 illustrates the mechanical configuration designed to optimize airflow capture. The setup consists of a duct cone**, a** three-blade fan (47 cm diameter), and a DC generator mounted coaxially. The duct cone channels the HVAC exhaust airflow directly onto the fan blades, increasing airflow velocity and maximizing kinetic-to-mechanical energy conversion. The generator converts this mechanical energy into electrical power.

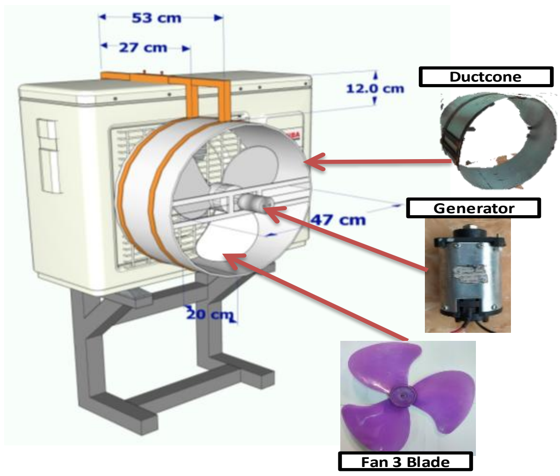


Figure 2. Mechanical Design

Figure 3 shows the electrical schematic of the hybrid energy c onversion system. The generator's output is rectified and stabilized before being stored in the battery. The stored DC is then inverted to AC voltage, ensuring compatibility with conventional loads. Monitoring instruments, including voltmeters and ammeters, track system performance in real-time.

This integrated mechanical-electrical design represents a compact and low-cost renewable energy recovery system adaptable to various HVAC installations.

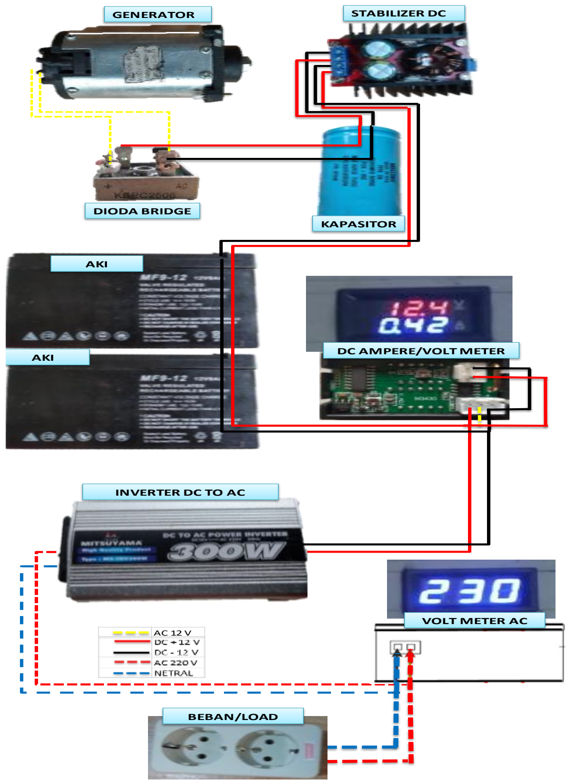


Figure 3. Wiring Diagram

D. Testing and Evaluation Procedure

Performance testing was carried out to verify the prototype's operational reliability from both mechanical and electrical perspectives (Figure 4).

Figure 4. Load Test with Lighting Units

The evaluation process consisted of several key phases:

1. Mechanical Testing – Assessing the turbine's rotational response and generator activation under actual HVAC airflow. A successful energy generation indicates proper mechanical operation.
2. Electrical Testing – Connecting the output to 220V AC-rated electronic components to verify voltage stability and current delivery.
3. Load Testing – Using ten 5W LED lamps arranged in parallel to simulate variable load conditions. Tests were conducted in ten iterations, each with a different number of lamps to analyze system stability and inverter response.

4. Data Measurement and Validation – Recording airflow velocity (using Benetech GM816 anemometer), generator RPM (using digital tachometer), voltage, and current across multiple trials at five air conditioner temperature settings (16°C, 19°C, 22°C, 25°C, and 28°C). Data consistency and correlation were statistically analyzed.

This systematic testing ensured comprehensive evaluation of the prototype's performance, validating the feasibility of converting HVAC exhaust airflow into usable electrical energy. The results provide a strong foundation for future optimization in turbine geometry, airflow ducting, and energy storage efficiency.

## III. Results and Discussion

### A. Wind Speed

Figure 5. illustrates a direct wind speed measurement taken in front of the HVAC exhaust outlet using a Benetech GM816 digital anemometer. This measurement was conducted as part of the performance evaluation for the small-scale wind energy harvesting system proposed in this study. The aim was to determine the effectiveness of airflow generated by the indoor air conditioning unit in driving the wind turbine prototype.


Figure 5. Wind Speed Measurement

During the observation, the air conditioning unit was set to an indoor temperature of 28°C, which corresponds to one of the highest operating temperatures in the experimental series. The anemometer reading, as shown in the figure, displays an airflow velocity of 5.6 meters per second (m/s) along with an ambient air temperature of 40.7°C at the measurement location.

This measured wind speed value aligns with the broader dataset collected for varying AC temperature settings, as reported in the experimental results section. It confirms the trend that higher indoor temperature settings produce slightly lower wind velocities compared to lower settings. The reading at 28°C is consistent with the average wind speed of 6.03 m/s, observed across multiple trials, supporting the overall reliability of the HVAC exhaust as a feasible airflow source for micro-scale wind energy generation.

This result underscores the significance of airflow velocity in determining the system's energy conversion efficiency and helps establish operational benchmarks for integrating such systems into existing HVAC infrastructures.

Figure 6 and Table 1 collectively illustrate the relationship between indoor air conditioner (AC) temperature settings and the resulting wind speed expelled from the HVAC system. The objective of this analysis is to determine how changes in indoor temperature affect airflow velocity, which is a critical factor in the effectiveness of the proposed micro-scale wind energy recovery system.

Table 1. Wind Speed Measurement Results

| Trial | Temp AC (°C) | Wind Speed (m/s) 1 | 2 | 3 | 4 | Average |
|---|---|---|---|---|---|---|
| 1 | 16 | 6,5 | 6,3 | 6,2 | 5,9 | 6,23 |
| 2 | 19 | 6,4 | 6,1 | 5,9 | 6,4 | 6,20 |
| 3 | 22 | 9,8 | 6,5 | 5,9 | 6,3 | 6,13 |
| 4 | 25 | 5,7 | 5,9 | 6,3 | 6,5 | 6,10 |
| 5 | 28 | 5,6 | 6,4 | 6,3 | 5,8 | 6,03 |
| **Average** | | | | | | **6,34** |

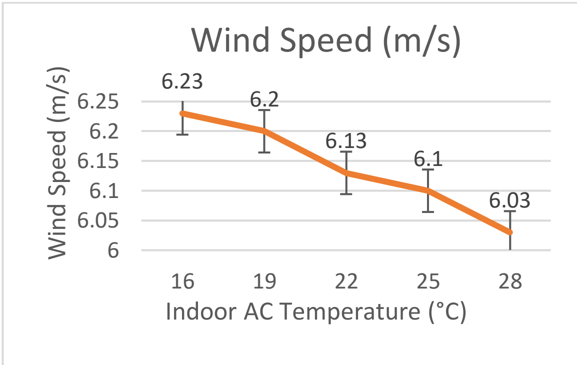


Figure 6. Graph Wind Speed Measurement

As presented in Table 1, five experimental trials were conducted at different indoor AC temperature 16°C, 19°C, 22°C, 25°C, and 28°C. For each temperature setting, four consecutive wind speed measurements were taken using a digital anemometer, and the average values were calculated. The average wind speed at 16°C was recorded at 6.23 m/s, which gradually decreased with rising temperatures, reaching 6.03 m/s at 28°C.

The corresponding line graph in Figure 6 provides a visual representation of this downward trend. The curve clearly demonstrates a negative correlation between indoor temperature and wind speed, suggesting that lower temperature settings result in stronger airflow output from the AC unit. This finding is significant because greater airflow velocities translate to more kinetic energy available for conversion by the wind turbine system.

These results confirm that AC temperature control is a key parameter in optimizing energy harvesting from HVAC exhaust systems. Operating the AC at lower temperatures can potentially enhance the performance of the energy conversion system without requiring modifications to the HVAC unit itself. The consistency of data across repeated measurements reinforces the reliability of this conclusion and supports further exploration into adaptive HVAC-wind energy integration strategies.

B. Generator Rotational Speed Analysis

Figure 7, Table 2 and the corresponding line graph collectively present the experimental results of generator rotational speed measurements in the proposed HVAC-based micro-scale wind energy recovery system. The measurements were carried out using a digital tachometer, as shown in the figure, to quantify the rotational speed (in revolutions per minute or RPM) of the wind turbine system driven by HVAC exhaust airflow.


Figure 7. Generator Rotational Speed

Five trials were performed at different air conditioner (AC) indoor temperature settings: 16°C, 19°C, 22°C, 25°C, and 28°C. For each temperature setting, four RPM readings were recorded to ensure accuracy and reduce observational error. The average rotational speed of the generator at 16°C was 784.95 RPM**,** which gradually decreased with increasing temperature. At 19°C, the average speed was 784.50 RPM, followed by 783.33 RPM at 22°C, 782.30 RPM at 25°C, ad 781.53 RPM at 28°C.

Table 2. Generator Rotational Speed Measurement Results

| Trial | Temp AC (°C) | Wind Speed (m/s) 1 | 2 | 3 | 4 | Average |
|---|---|---|---|---|---|---|
| 1 | 16 | 793,9 | 784,6 | 775,8 | 785,5 | 784,95 |
| 2 | 19 | 783,5 | 792,7 | 772,4 | 789,4 | 784,50 |
| 3 | 22 | 780,0 | 782,4 | 778,6 | 792,3 | 783,33 |
| 4 | 25 | 779,6 | 791,4 | 776,9 | 781.3 | 782,30 |
| 5 | 28 | 777,6 | 783,2 | 788,5 | 776,8 | 781,53 |
| **Average** | | | | | | **783,32** |

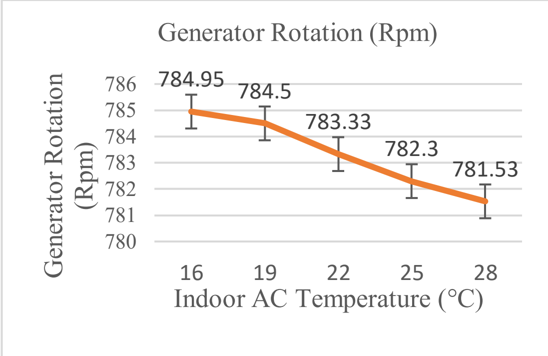


Figure 8. Generator Rotational Speed Graph

The line graph illustrates a subtle but consistent downward trend in generator RPM as the indoor temperature increases. This behavior correlates with the previously observed reduction in wind velocity, confirming that higher indoor AC temperatures result in weaker exhaust airflow, which in turn reduces the mechanical energy available to drive the generator.

These findings validate the influence of HVAC thermal settings on the mechanical performance of the system and highlight the critical role of airflow dynamics in energy conversion efficiency. Maintaining lower indoor temperature settings could optimize generator speed and, by extension, electrical output, without requiring additional mechanical interventions. This insight provides a valuable reference for the practical deployment and optimization of HVAC-assisted wind energy systems.

C. Generator Voltage

The experimental analysis focused on measuring the generator's voltage output generated by the exhaust airflow from a residential air conditioning unit (HVAC system). Voltage measurements were carried out using a manual digital multimeter (as shown in Figure 9), with data collected under five distinct indoor AC temperature settings: 16°C, 19°C, 22°C, 25°C, and 28°C.


Figure 9. Generator Voltage Output Measured

Table 3 presents the voltage output data measured at four different intervals for each temperature condition. The results demonstrate a consistent trend in which lower AC temperature settings—associated with stronger airflow—produce slightly higher voltage values. For instance, at 16°C, the generator produced an average voltage of 50.91 V, while at 28°C, the voltage slightly dropped to

50.74 V. This behavior is further visualized in Figure 10, which shows a gradual decline in generator voltage as the indoor temperature increases.

Table 3. Generator Voltage Output at Various Indoor AC Temperatures

| Trial | Temp AC (°C) | Generator Voltage (V) | | | | Average |
|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | |
| 1 | 16 | 50.30 | 51.20 | 50.10 | 49.02 | 50.91 |
| 2 | 19 | 53.20 | 50.40 | 49.80 | 50.08 | 50.87 |
| 3 | 22 | 53.15 | 51.08 | 49.00 | 50.09 | 50.83 |
| 4 | 25 | 53.11 | 50.41 | 50.25 | 49.28 | 50.76 |
| 5 | 28 | 53.08 | 51.08 | 49.70 | 49.09 | 50.74 |
| **Average** | | | | | | **50.82** |

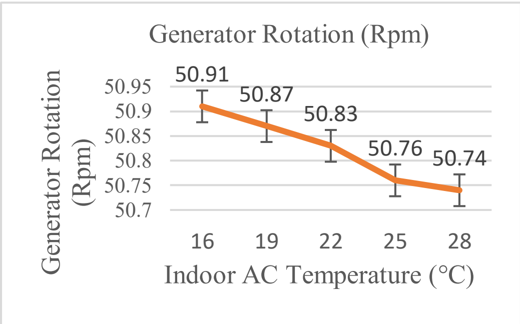


Figure 10. Generator Voltage Output vs. Indoor AC Temperature

This decline can be attributed to the decreasing intensity of the exhaust airflow at higher temperature settings, which leads to reduced rotational speed of the turbine and consequently a lower electrical output. Although the voltage variations appear minimal, they validate the hypothesis that HVAC exhaust airflow can indeed be harnessed as a viable source of small-scale renewable energy, with performance influenced by the thermal settings of the air conditioning system.

D. Generator Current

To evaluate the electrical performance of the generator driven by airflow from an HVAC indoor unit, current measurements were conducted using a digital multimeter. The experimental setup aimed to capture the influence of indoor air conditioner temperature on the output current produced by the wind turbine generator.


Figure 11 . Generator Current Output Measured

Measurements were carried out across five different AC temperature settings (16°C, 19°C, 22°C, 25°C, and 28°C), each involving four repetitions to ensure data reliability. The measured output current ranged from approximately 0.073 A to 0.265 A. As presented in Table 1, the average current output showed a gradual decline with increasing indoor temperature, starting from 0.170 A at 16°C and reaching 0.160 A at 28°C.

Table 4. Generator Current Output at Various Indoor AC Temperatures

| Trial | Temp AC (°C) | Generator Current (A) | | | | Average |
|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | |
| 1 | 16 | 0.085 | 0.149 | 0.254 | 0.192 | 0.170 |
| 2 | 19 | 0.078 | 0.214 | 0.199 | 0.188 | 0.170 |
| 3 | 22 | 0.077 | 0.175 | 0.237 | 0.183 | 0.168 |
| 4 | 25 | 0.076 | 0.209 | 0.197 | 0.177 | 0.165 |
| 5 | 28 | 0.073 | 0.178 | 0.265 | 0.122 | 0.160 |
| **Average** | | | | | | **0.167** |

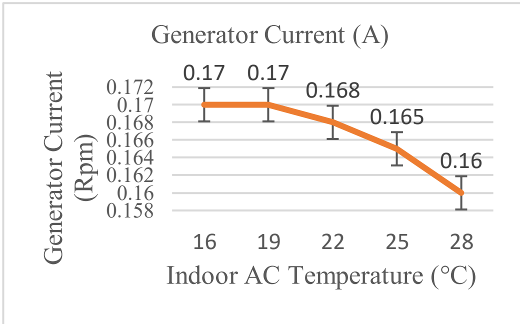


Figure 12. Generator Current Output vs. Indoor AC Temperature

This trend is further visualized in Figure 1, which illustrates a slightly negative correlation between the AC indoor temperature and the generator's current output. The decrease in current generation can be attributed to a corresponding reduction in air

E. Inverter Output Voltage


Figure 13. Inverter Output Volyage

The process of measuring the output voltage of the inverter was conducted by varying the load from 0 watts to 50 watts in incremental steps. This measurement aimed to evaluate the performance and voltage stability of the inverter when subjected to different electrical loads. The experiment was designed to ensure that the inverter was capable of maintaining a consistent voltage output as the load increased, which is critical for the reliability of small-scale renewable energy systems.

To improve the accuracy and validity of the results, two different measurement approaches were employed. The first method involved using the built-in digital display on the inverter unit, which provides real-time output voltage readings. The second method utilized a calibrated handheld digital multimeter (manual multitester) to independently measure the voltage output across the inverter terminals under identical load conditions.

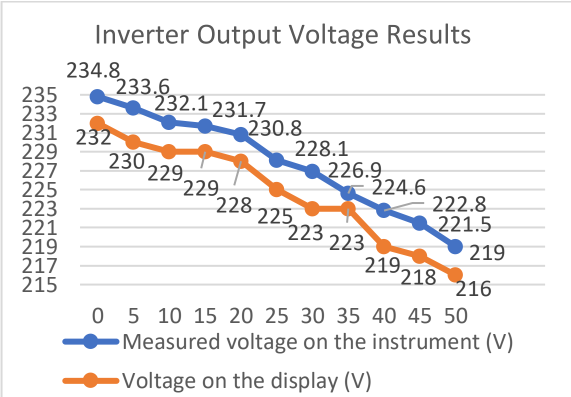


Figure 14. Graph of Inverter Output Voltage Measurement Results

The comparison between the readings from the internal inverter display and the manual measurements aimed to identify any discrepancies and validate the precision of the inverter's built-in monitoring system. This dual-method approach enhances the credibility of the data and allows for more robust analysis of inverter behavior under load.

The load was applied in stages, beginning with 0 watts (no load) and increasing progressively up to a maximum of 50 watts. Each measurement was recorded systematically, and the results were analyzed to determine the correlation between load variation and output voltage fluctuations. The consistency of the voltage output across different load levels is a key parameter in assessing the suitability of the inverter for use in wind energy systems driven by HVAC exhaust airflow.

These results are essential for evaluating the viability of integrating such systems into energy-efficient buildings and can contribute valuable insights to the field of distributed renewable energy generation.

F. Inverter Output Current

The output current of the inverter was measured to evaluate its performance under varying electrical load conditions. The testing aimed to determine how the inverter responds to increasing demand, particularly in systems powered by airflow-driven micro wind turbines, such as those utilizing HVAC exhaust.


Figure 15. Digital Multimeter Display for Inverter Output Current Measurement

Measurements were performed using a digital multimeter (model ZOYI ZT102A), as shown in Figure 15. The current readings were taken at incremental load levels ranging from 0 watts to 50 watts, in steps of approximately 5 watts. Each load step was applied, and the corresponding output current was recorded in amperes (A).

The results of these measurements are presented graphically in Figure 16. The data exhibit a linear increase in output current as the load increases, which is consistent with Ohm's law and reflects stable inverter operation. For instance, at 10 watts of load, the current was measured at approximately 0.05 A, and at 50 watts, the current rose to 0.39 A. This linear trend indicates that the inverter is capable of regulating its output effectively without significant fluctuation or voltage drop under moderate loads.

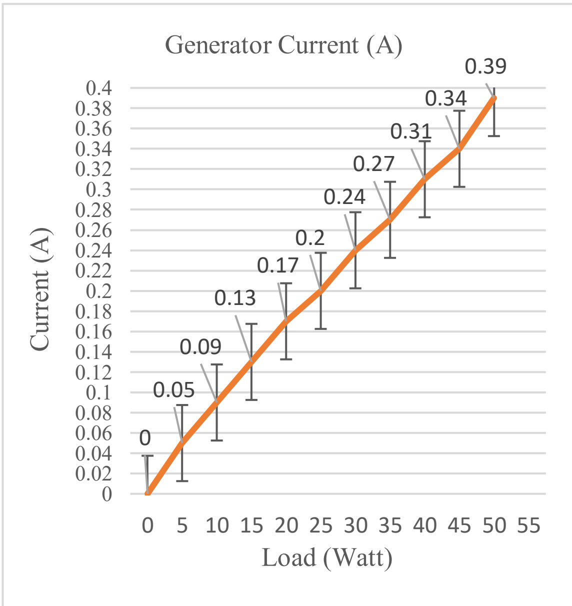


Figure 16. Graph of Inverter Output Current Measurement Results

This behavior demonstrates that the inverter performs reliably and proportionally distributes current relative to the power demand. Such performance is essential in renewable micro-generation applications, where load variability is common. The findings confirm that the inverter used in this study is suitable for small-scale wind energy systems powered by intermittent HVAC exhaust airflow.

## IV. Conclusion

This study successfully demonstrated the feasibility of utilizing exhaust airflow from a residential HVAC system as a renewable energy source for small-scale wind power generation. A prototype system was designed and tested, comprising a ducted fan turbine, generator, rectification and storage components, as well as a DC–AC inverter to deliver usable electrical output. Experimental results showed a direct relationship between indoor AC temperature settings, exhaust airflow velocity, and generator performance. The highest wind speeds and generator rotational speeds were observed at lower AC temperature settings, which in turn yielded higher voltage and current outputs. Specifically, the generator produced an average voltage of 50.91 V and an average current of 0.170 A at 16°C, which gradually decreased as temperature increased to 28°C. In addition, inverter performance under variable loads was evaluated. The inverter maintained stable voltage output and a linear current response as the electrical load increased from 0 to 50 watts, confirming its compatibility with micro-wind energy systems. The use of manual measurement instruments such as digital multimeters enhanced the accuracy and validation of the recorded data. These findings confirm that HVAC exhaust airflow can be effectively harvested for micro-scale electricity generation, especially in energy-conscious building environments. While the power output remains relatively modest, the concept holds significant potential for integration into smart building systems, energy recovery units, or hybrid renewable setups. Further research may focus on optimizing blade geometry, duct design, and energy storage to enhance system efficiency and scalability.

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