Small-Scale Wind Energy Harvesting Through Turbine Systems for Exhaust Vents

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Executive Summary

This paper delves into small-scale energy harvesting, specifically looking at harvesting wind energy from exhaust sources. There are a select few previous papers on this topic, most of which focus on turbine integration with exhaust systems and look at digitally designing a prototype. However, there is a gap in current research in that none have done real-world testing, and they also fail to address large scale applicability and societal/environmental implications of such technology. This paper then details the design process and results for a prototype turbine for placement at the end of an exhaust outlet. This prototype was then tested on the roof of the Broadhead Center at Duke University, a building with both kitchen and bathroom exhausts. The prototype was able to generate more than enough power to charge a phone, and hopefully enough to power a small system like a streetlight or security camera. This technology shows promise and potential social and environmental benefits, including potential for education, cost savings, and reducing carbon emissions. This technology also shows promise as a potential product that would be able to be sold to companies looking to decrease their reliance on nonrenewable energy as well as potentially save money by generating their own power instead of buying it. Looking into the future, the prototype can be perfected to maximize efficiency and lower costs, while also looking into measurable effects that the long term and widespread implementation would have on carbon emissions.

Introduction

Researchers and engineers continuously explore novel avenues to harness untapped energy sources in the pursuit of sustainable energy solutions. One such promising frontier is the energy harvesting from conventional exhaust systems ubiquitous in our living spaces. Our research endeavors to investigate the feasibility of energy harvesting from everyday exhaust sources found in kitchens, buildings, and laundromats. By exploring this new way of energy harvesting, we aim to assess the viability of employing exhaust energy for powering small-scale devices, ranging from street lights to security cameras, thereby contributing to sustainable energy practices on a broader scale.

Conventional exhaust systems, prevalent in domestic, commercial, and industrial settings, represent a significant yet largely overlooked source of thermal and kinetic energy. These systems expel hot gasses and air as a byproduct of various processes, such as cooking, heating, ventilation, and drying. Despite their omnipresence, the energy dissipated through exhaust remains largely untapped, presenting an opportunity for innovative energy harvesting solutions. Our research team recognizes the potential of exhaust energy as a renewable and environmentally friendly resource. By capturing and converting the wasted kinetic energy from exhaust streams, we seek to harness sustainable power sources that can supplement or replace conventional electricity generation methods. Furthermore, repurposing exhaust energy aligns with the overarching goals of reducing carbon emissions and mitigating the environmental impact of human activities.

The scope of our study encompasses a comprehensive analysis of exhaust systems across different environments, including residential, commercial, and communal spaces. Through data collection and empirical measurements, we aim to quantify the energy content of these exhaust streams and evaluate the technical feasibility and economic viability of energy harvesting technologies. Additionally, we will explore the scalability of these solutions to assess their potential for widespread adoption and integration into existing infrastructure.

Literature Review

Small-scale energy harvesting using wind turbines integrated into urban infrastructure is a relatively new, yet fast growing source of clean energy. In spite of its recent birth, the field has diversified quite extensively, with exploration and innovation in several different directions that adds an element of excitement to this field. This literature review attempts to provide an overview of those already explored paths, in the process providing a magnifying glass to expose gaps in this research that can be improved upon by this project.

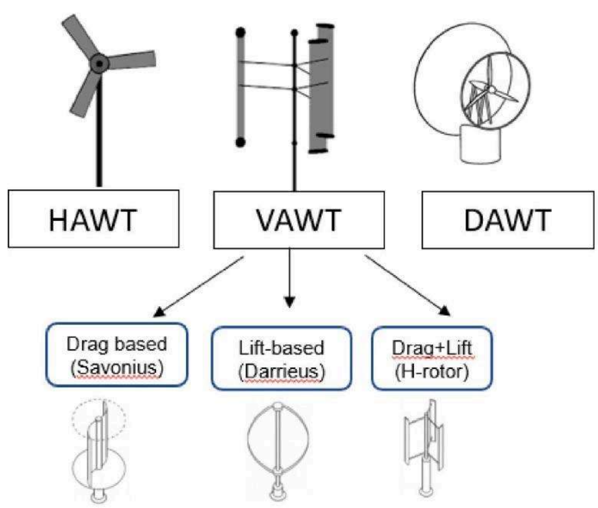
Preliminarily, it serves advantageous to provide a general overview of some of the challenges within this field. These factors will be carefully considered throughout initial design and subsequent iterations with hopes of optimizing final prototype efficiency. The most widespread problem that faces this field is turbulent and unpredictable flow due to the dynamic conditions of urban environments where these systems are often situated. Locating the optimal design to maximize efficiency is often difficult for these systems considering flow varies. This is not necessarily something that can be eliminated (inherent to the urban environment) but is still important to consider throughout the design process. Yet another ingrained quality is efficiency challenges that come from the small dimensions of the wind turbine. It is crucial to ensure that energy generation is a net positive for this technology to be useful. Other constraints include safety and noise concerns within the urban environment. Integrating this technology into a densely populated environment means taking precautions to ensure that said inhabitants are able to coexist with this technology, cohabitation that may lead to efficiency being compromised. Considerations must be taken to ensure that humans can interact with this technology safely and are not significantly affected by resultant noise generation. New innovations must also conform with requirements for local permits/regulations and allow for normal operations, especially when these energy generation systems are attached to ventilation sources. The mention of these ventilation systems smoothly transitions to a discussion of existing technology within the field.

Analyzing the metadata of these sources leads to the unsurprising realization that the US has left this resource as a largely untapped source of energy. Outdated and underfunded urban infrastructure in addition to energy networks deeply intertwined with fossil fuels provides background for this. Few academic sources discuss American developments within this field. The vast majority of current innovations are produced internationally - with the below examples sourced from The University of Strathclyde (located in Glassglow, UK) and The University of

Malaya (located in Malaysia). Although international sources were not prioritized during the source selection process, emphasis was given to recency of publication. All incorporated materials were published within the past ten years to ensure relevancy. Perhaps the United States can gather some inspiration from the innovations described below.

A discussion of current technology logically begins with a schism within this field. One strong dichotomy within this field of research is the integration, or lack thereof, of these wind harvesting systems with vents. Initial developments in this field prioritized stand-alone turbines. Meticulously placed on roofs and walls, harnessing natural airflow in urban centers in order to generate energy was the primary goal. Later developments suggested replacing this natural airflow with the more consistent and less turbulent flow provided by ventilation systems. The latter will serve as the focus for this project. Regardless of integration with vents, general geometry of wind turbines offers the same set of options: horizontal and vertical axes. **Figure 1** below provides a visual representation of these differing geometries. Additionally, also related to the subject of geometry, microtechnologies are another subset of this field that is increasingly being explored. In summary, microtechnologies are extremely small "turbines" that capitalize on resultant vibration from airflow in order to generate energy. Although geometry is certainly important (and thus deserves mentioning within this review), an extensive discussion of geometry or microtechnologies is not necessary. This is not a key area of experimentation for this project.

Figure 1: Small scale wind turbine geometries



Duct geometry is another intriguing subset of questions in this field. Labeled in Figure 1 as DAWT, duct axial wind turbines are traditional horizontal or vertical wind turbines that are surrounded by shrouds in order to channel airflow and attempt to increase efficiency. These ducts offer a rich springboard for further research. Optimization in terms of cross-sectional geometry and overall dimensions have yet to be explored extensively. Although this was initially an area of focus for this project, duct geometry proved to be too challenging to explore considering time constraints. A more simple mounting system to affix the turbine to vents will instead be explored. With that being said, this field still offers a plethora of avenues in terms of innovation. Individuals seeking to expand upon the existing catalog of research and the research presented here would be wise to invest time exploring duct geometry, blade geometry, or microtechnologies.

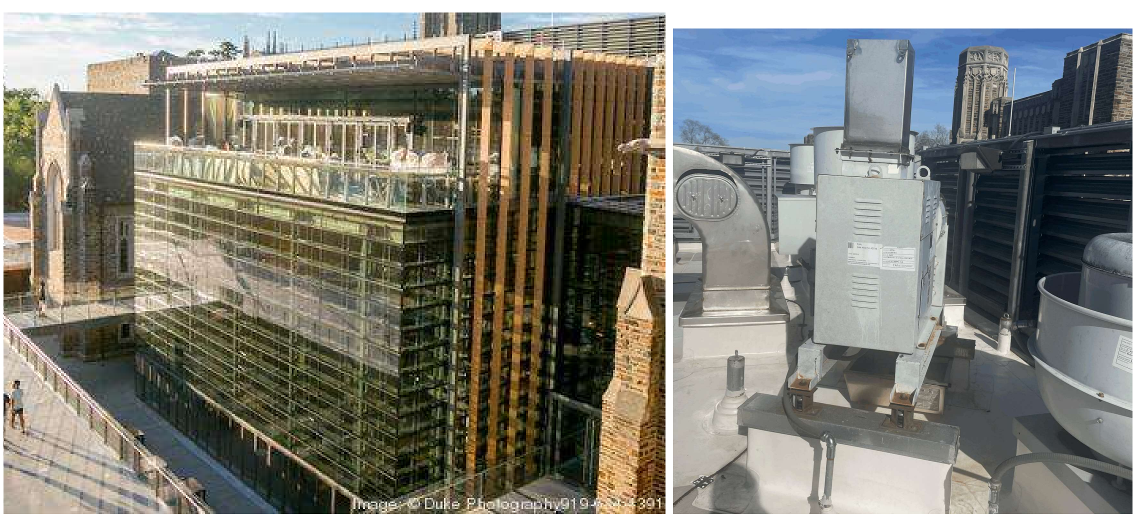
Gaps in research also exist when it comes to large-scale applicability of these technologies considering general environmental, social, and economic factors. Thus, this will also serve as a focus of this project. Greater insight will hopefully be revealed when it comes to questions regarding feasibility of this technology as a reliable source of clean energy that could potentially reduce reliance on fossil fuels and lead to environmental and economic benefits. The specifics of this will be discussed further throughout the business plan and the environmental and social assessments of this report. Overall, the primary goal of this project is collecting data on the integration of wind turbines with ventilation systems, determining in the process if this is something that could generate a reliable, net-positive source of energy and potentially be applied on a national or global scale. Advanced prototypes of a system that satisfies these requirements may look something like **Figure 2.**

Figure 2: Exemplary DAWT/Ventilation System

As a final thought, there is a positive externality that this project brings to the table. Although not the primary focus of this project, another challenge cited among published sources is generalizability to physical environments due to the largely virtual nature of modern experimentation. Computational Fluid Dynamics (CFD) is the most popular software utilized for this purpose. Experiments often alter aforementioned factors such as blade geometry, ventilation systems, or location of turbines in a virtual environment that minimizes costs and affords flexibility. With that being said, simulations are only so representative of the dynamic natural world. For the purposes of this project, all data shall be collected in person, using ventilation systems located on the top of the Broadhead Center, the dining hall on Duke University's campus located in Durham, North Carolina. Physical data collection will hopefully improve the reliability of results and provide clarity on whether or not systems such as these could be applied in similar locations. **Figure 3** provides visual representation of the site of data collection.

In summary, small-scale energy harvesting using wind turbines is a dynamic and explosive field that offers many pursuable directions. This project focuses specifically on in-person data collection in addition to assessing general environmental, social and economic feasibility. The experimental group hopes to gain clarity on whether this technology, the design of which is discussed in the next section, could be applied on a national or global scale. Answers to these questions will hopefully continue to push this field to grow and flourish as the world embarks on its quest for reliable and clean energy.

Figure 3: Site of Data Collection



Data was collected on the roof of the building pictured left that featured several ventilation systems as pictured right.

Technical Design

Technical Design – Description of Approach

This project began with the idea to generate power on a small scale from wind, so at first we considered multiple sources of wind energy as potential avenues. We then set up a decision matrix to determine which idea to pursue. Due to the small-scale nature of the project, we focused on potential sources that allowed for small-scale generation that were also relatively unexplored. Exhaust had the highest score, so we moved to designing a prototype for harnessing wind power from exhaust.

Criteria	Weights	Humans	Highways	Metros	Ships	Exhaust
Durability	10%	2	1	5	3	3
Profitability (Lifetime)	15%	1	3	5	2	5
Feasibility - Skills	20%	3	4	4	5	3
Feasibility-Materials & Access	15%	5	4	2	2	3
Affordability (Front End)	20%	1	3	3	3	2
Testability	20%	5	3	1	2	4
Score	100%	2.9	3.15	3.15	2.9	3.3

Figure 4: Decision Matrix for new sources of wind energy

Figure 1 outlines the general types of possible turbines for harnessing wind energy. In deciding which design to move forward with, we primarily considered a HAWT and a Savonius VAWT, because those were the two used by previous sources, though we also briefly considered other options. In the end, we decided to move forward with a HAWT, because it is both easier to design around and more efficient for this application. In addition, HAWT turbines are much more common, and therefore they would be much more easier to access and repurpose for our project.

A major challenge in designing a turbine to be put above an exhaust outlet is ensuring that the turbine is able to generate enough energy to have a net positive output on the system. This meant ensuring the exit velocity of air from the exhaust reached the minimum threshold for the turbine and making sure our turbine was optimized for common exhaust air velocities.

Another critical element of the design is viability in many different locations – this means making the product adjustable to various sizes and shapes of exhaust outlets, as well as making sure the turbine can generate sufficient energy at varying wind speeds.

A turbine which created significant drag force near the exhaust outlet would affect the pressure of the system and require more energy upstream in the HVAC system. In order to avoid this effect, the prototype would have to be offset from the outlet and not include a nozzle system.

Finally, our prototype would be installed outside and exposed to weather elements. This means that everything on our prototype needed to be water and windproof.

Technical Design – Describing the Prototype

Our prototype is shown in **Figure 5**. Due to the size of outlets relevant to our project, we decided to purchase a horizontal axis turbine, the Infinite Air 18 from TexEnergy. This product encompasses the turbine and blades, as well as a power generator that outputs power to a USB-A port.

The mount for the turbine is a tripod with variable radius to adjust to a variety of exhaust fan designs. It has weighted legs in order to keep the turbine in place to counter the drag force of the exhaust air. It has high thickness in the elbows for strength. It has a tension string and obtuse angled elbows for stability. It has high friction rubber feet to keep it in place when crosswinds and other weather events occur. At high intensity conditions, the model should be stored away but in the future, models with a permanent attachment method would be available which would not have to be stored during this kind of event.

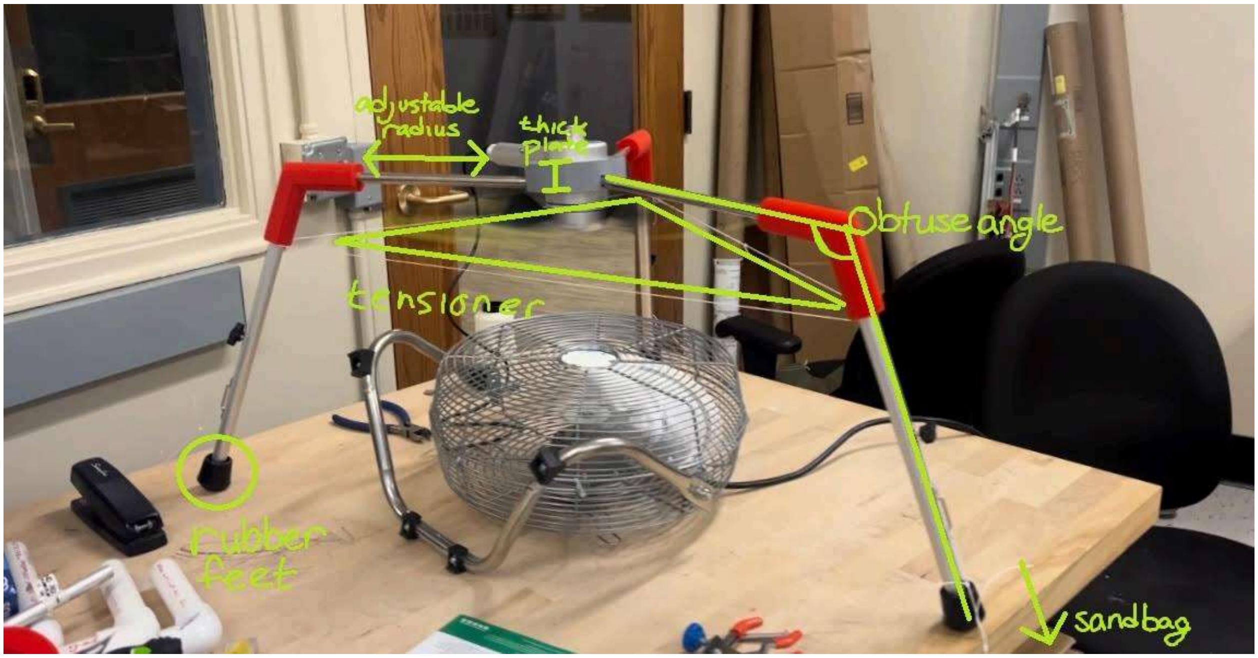


Figure 5: Prototype turbine stand

A number of calculations were done to determine feasibility of the design (Eq 1, Eq 2) as well as required weight of the design to keep the turbine installed in normal use cases (Eq 3).

Equation 1: Theoretical power output of the turbine operating under minimum actuating speed

$$P = \frac{1}{2}\rho V^3 A C_P$$

$$P = \frac{1}{2}\left(1.2\ {kg}/_{m^3}\right)(3.3\ {m}/_{s})^3(\pi \cdot 0.5\ m^2)(0.593 \cdot .95)$$

$$P = 9.54\ {kg\ m^2}/_{s^3}$$

$$P = 9.54\ W$$

Equation 2: Theoretical power output of the turbine operating under maximum measured speed

$$P = \frac{1}{2}\rho V^3 A C_P$$

$$P = \frac{1}{2}\left(1.2\ {}^{kg}/_{m^3}\right)(22\ {}^{m}/_{s})^3(\pi \cdot 0.5\ m^2)(0.593 \cdot .95)$$

$$P = 2826.6\ {}^{kg\ m^2}/_{s^3}$$

$$P = 2826.6\ W$$

Equation 3: Theoretical drag value under maximum measured speed conditions

$$Drag_{blade} = \frac{1}{2} c_d p u^2 A$$

$$Drag_{turbine} = \frac{1}{2}(0.8)\left(1.2\ {}^{kg}/_{m^3}\right)(22\ {}^{m}/_{s})^2(0.5\ m \cdot 0.8\ m)(3\ {}^{blades}/_{turbine})$$

$$Drag_{turbine} = 278.78\ N$$

Equation 4: Theoretical weight required to withstand drag force under maximum measured speed conditions

$$F = ma$$

$$278.78\ N = 9.8\frac{m}{s^2} \cdot m$$

$$\frac{278.78\ N}{9.8\ {}^{m}/_{s^2}} = m$$

$$28.44\ kg = m$$

Using these calculations, the prototype was determined to be feasible to produce useful energy and designed to be capable of weighing 28.44 kg through the use of sandbags.

Testing Procedure and Results

Our main location for testing was the Broadhead Center, which has many different exhaust outlets on its roof. These include both kitchen exhausts and bathroom exhausts, which provide two different opportunities for testing. The first set of data collected was a set of wind velocities and temperatures at the various exhaust outlets on the top of the Broadhead Center. These outlets let us test the turbine at various speeds and ensure its applicability to a variety of locations beyond the Broadhead Center.

Outlet	Air Velocity (m/s)	Air Temp (F)
1	21.0	75
2	5.8	85
3	26.6	70
4	6.7	67
5	4.4	76
6	4.4	71
7	2.5	74
8	10.5	90
9	21.8	101
10	12.4	77
11	16.9	80
12	12.7	70

Figure 6: Air velocity and temperature for exhaust outlets on the Broadhead Center roof.

One thing of note from the data in Figure 6 is that the outlets with a higher wind velocity also tend to have a higher temperature. Higher temperature results in lower air density, which has been accounted for in the calculations, using 1.2 kg/m^3 in place of 1.3 kg/m^3 in Eq 1 and Eq 2. In Eq 1, 0.593 refers to the betz limit and 0.95 is the listed maximum efficiency of a market competitor. Testing showed there were multiple kitchen and bathroom exhausts with a sufficient exit velocity to support energy generation.

In addition to being able to test on the roof of the Broadhead center, we were also able to conduct testing using a box fan in a lab, allowing for a more controlled environment. The maximum wind velocity measured from the box fan was 8.7m/s. While the fan couldn't achieve the same wind speed as select roof outlets, it still created a useful testing site, particularly for testing the effectiveness of the nozzle, as shown in Figure 7.

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Figure 7: Testing the turbine setup with a nozzle and box fan

Testing using the box fan revealed the limitation that the turbine had a voltage limiter set to 5V. Because the turbine was originally designed to output power with the purpose of charging a phone, it needed to output a constant 5V in order to keep the attached cell phone safe. The turbine achieved this through a circuit consisting of a combination of capacitors and resistors, as well as converting from three-phase power to single phase power. This affected the data we were able to collect as the voltmeter consistently read 5V.

In order to safely test the effectiveness of the turbine in front of the exhaust outlets on the roof of the Brodhead Center, we built an apparatus that allowed us to hold the turbine out over the outlet, as shown in Figure 8.

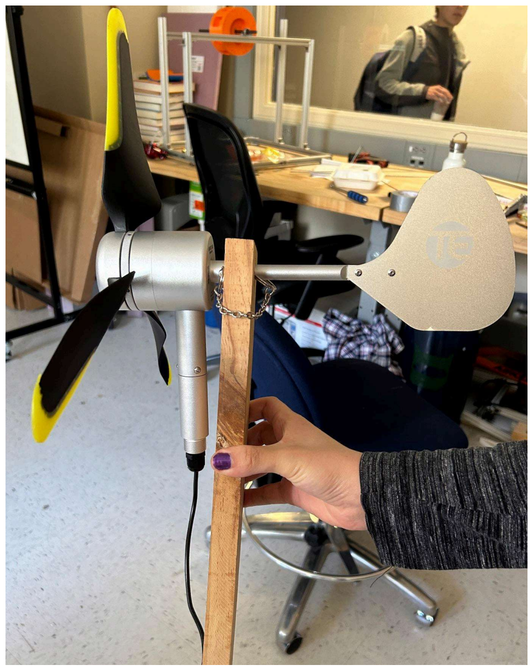

Figure 8: The wood block was put on the fin of the turbine to allow us to hold the turbine over the exhaust while standing at a distance

Almost all of the high-velocity exhaust outlets were able to output 5V. This made it clear that we were generating more than enough power to achieve the intended use of the turbine, to charge a mobile device. Additionally, because we had hit 5V at 8.7m/s from the fan and were able to power 0.5 A draw at this speed, we know that when on the actual exhaust outlet that the turbine is capable of generating significantly more power. We were not able to collect more specific data due to an inability to measure current which we suspect is related to the internal components of the limiter. Still, this data confirms that the turbine will generate enough power to achieve our goals.

Environmental Benefit Analysis

In the pursuit of sustainable energy solutions, exploring unconventional sources for energy harvesting has become our focus. The avenue that we have decided to move forward with involves the extraction of energy from exhaust systems, offering the potential to generate electricity for various applications, such as small electric devices while reducing carbon emissions.

One of the key advantages of this approach is its ability to harness energy that would otherwise be lost. Buildings, kitchens, and laundromats constantly generate streams of exhaust as a byproduct of their operations. By capturing and converting this energy, we not only reduce waste but also contribute to the overall conservation of energy. This concept aligns perfectly with the principles of sustainability and efficiency, as it maximizes the utility of existing systems without requiring significant additional inputs.

Moreover, the applications of harvested stream energy are diverse and impactful. Streetlights and security cameras are essential components of urban infrastructure, providing safety and security to communities. By powering these devices with renewable energy derived from exhaust streams, we create a more sustainable and resilient urban environment. Decentralizing energy generation and consumption reduces the strain on centralized power grids and enhances the reliability of local energy systems (Elnaggar et al.). Companies can lower their utility bills and energy consumption over the years, fostering a long-term more cost-effective future while simultaneously advancing sustainability goals.

Furthermore, energy harvesting from exhaust systems opens doors to energy storage solutions, particularly through battery systems. The excess energy generated can be stored in batteries for later use, offering flexibility in energy utilization and enhancing overall efficiency. Examining the feasibility and effectiveness of energy storage in conjunction with exhaust system energy harvesting is crucial in assessing its practicality and potential for widespread adoption.

Social Benefit Analysis

The developed turbine system has multiple benefits across education, economics, and energy conservation, in addition to its environmental benefits. At the center of these benefits is the fact that exhaust is an integral part of various commercial systems within society. Ventilation systems, which can be seen in virtually every office space and commercial building, without fail always have accessible exhaust outlets. Furthermore, commercial businesses like laundromats, factories, and restaurants require exhaust outlets with constant exhaust outflow. Leveraging this abundant and untapped source of excess wind energy, the implementation of a small-scale turbine system with energy-generating and storing capabilities has multiple social benefits, which are outlined below.

Integrating renewable energy into our current energy sector becomes increasingly imperative as the use of fossil fuels continues to have adverse impacts on the environment. An important aspect of promoting this integration involves educating society about renewables to increase awareness and promote eco-friendly practices. For instance, implementing this system in schools provides more opportunities to educate students about the advantages and necessity of renewables in an interactive manner. Similarly, public charging stations with infographics about their source of power could also serve as educational tools. These stations would be widely visible and, as a result, could inform a large proportion of the public. The visibility of exhaust vents allows for the opportunity to create various public information displays, fostering education and engagement with renewable energy.

Moreover, the turbine system presents numerous cost-saving opportunities because of its versatility and widespread applicability. By capturing excess energy, it can be utilized in multiple ways, from charging stations to office lighting. Because exhaust is a form of wasted energy, the continued use of the turbine system would result in net positive energy output that would lead to a reduction in costs. The reliability of this excess energy source results in constant energy generation, which translates into substantial cost savings that would benefit the user. Overall, the implementation of the turbine system would allow for various economically beneficial opportunities due to its versatile use and reliability.

Arguably the most significant social benefit is the system's potential contribution to energy conservation and closing the energy loop. The comprehensive study on small-scale wind turbines mentioned in the previous section highlights the potential of reducing energy costs by substituting more expensive energy sources, such as fossil fuels, with wind energy from turbine systems. Additionally, replacing non-renewable energy sources with wind energy would lead to decreases in costs for treating air pollutant emissions, offering both environmental and economic benefits. Furthermore, in the context of the potential consumers of the turbine system, these decreased expenses from non-renewable energy sources would result in increased revenues for commercial businesses.

Overall, the turbine system offers a variety of social benefits because of its potential for versatile use and widespread implementation throughout various societal sectors. The commercial sector stands to benefit significantly from this system due to the abundance of exhaust systems and the never-ending opportunities for energy usage. By harnessing the wasted exhaust energy from these outlets, users can promote sustainable practices, save on energy costs in the future, and contribute to the efforts to mitigate the harmful effects that stem from non-renewable energy emissions.

Business Plan

Cost-reduction goals

Our company specializes in creating and manufacturing wind turbines tailored for small and medium-sized enterprises. Our journey began with purchasing a $395 turbine, marking the initial step in our quest to explore, refine, and economize our production processes. Our primary aim is to revolutionize our manufacturing methods significantly, driving down the costs of producing comparable turbines.

To achieve this objective, we have devised a series of cost-cutting strategies:

1. We are optimizing our turbine designs to tailor them specifically for smaller-scale applications. By doing so, we anticipate using fewer materials while maintaining or enhancing effectiveness and performance.
2. We are exploring the integration of cutting-edge lightweight composite materials into our designs.
3. We are committed to automating and refining our production processes to achieve economies of scale and reduce production costs.

Governments worldwide actively promote adopting renewable energy technologies, aligning with the global shift towards sustainable solutions. Importantly, transitioning to renewable energy solutions like small wind turbines often comes with tax benefits or offset expenses. Governments provide incentives to encourage businesses to embrace renewable energy sources, with various incentives available in different regions, including the U.S.

For instance, in the U.S. market, several incentives support the adoption of small and medium-sized wind turbines. The Residential Renewable Energy Tax Credit offers a 30% credit to those installing qualifying small wind power systems (100 kW or less) on their residences (U.S. Department of Energy, 2021). Similarly, the Business Energy Investment Tax Credit (ITC) provides federal income tax credits for capital expenditures in renewable energy projects, including small wind turbines (ibid).

These incentives reduce upfront costs and provide financial assistance to companies integrating sustainable energy solutions into their operations. While applying for these incentives may sometimes entail significant time and effort, particularly for small to medium-sized businesses, leveraging them can substantially offset initial investment costs and bolster the economic viability of projects.

Product Durability Goals

Our primary objective is to engineer a wind turbine that exhibits exceptional resistance to diverse weather conditions, ensuring longevity and reliability over its operational lifespan. We aim to design a turbine capable of withstanding harsh environmental elements, including strong winds, rain, and extreme temperatures, guaranteeing optimal performance and durability. We aim to achieve a product lifespan with minimal maintenance requirements, providing customers with a cost-effective and sustainable energy solution that delivers consistent performance over time. By prioritizing durability in our design and manufacturing processes, we aim to instill confidence in our customers regarding the longevity and reliability of our wind turbine technology, ultimately enhancing customer satisfaction and trust in our brand.

Marketing Strategies

The primary consumers benefiting from our wind turbine solutions are small to medium-sized businesses, including laundromats, hotels, and restaurant kitchens. These enterprises can harness our cost-effective wind turbines to produce additional power from their current exhaust systems, diminishing their dependence on the grid and cutting down on energy expenses. Moreover, our turbines can alleviate the labor and expenditure associated with battery replacements in backup power systems while conserving grid energy by charging small-scale devices using turbine-generated power.

Our marketing and sales strategy adopts a multifaceted approach to effectively reach our target audience and maximize market penetration. We implement a direct sales approach, utilizing targeted marketing campaigns for decision-makers in laundromats, hotels, and restaurants. By identifying and directly engaging with key stakeholders in these industries, we highlight the benefits of our wind turbine technology and demonstrate how it can help businesses reduce energy costs and enhance sustainability.

We also explore strategic partnerships with companies offering complementary products or services, such as security camera providers. By offering bundled packages of security cameras and wind turbines, we can provide businesses with comprehensive solutions for enhancing their security and energy efficiency. This collaboration expands our product offerings, allows us to tap into existing customer bases, and leverages synergies between different technologies.

Additionally, we establish a solid online presence through our website, social media channels, and participation in industry forums. Through engaging content, informative resources, and targeted advertising, we aim to raise awareness about our wind turbine technology, generate leads, and drive traffic to our online platforms. By leveraging the power of digital marketing, we can reach a wider audience, including potential customers who may not be accessible through traditional sales channels.

Lastly, we actively participate in relevant trade shows, conferences, and networking events within the renewable energy and hospitality industries. These events provide valuable opportunities to showcase our products, network with industry professionals, and build relationships with potential customers and partners. By engaging in face-to-face interactions and demonstrations, we can effectively communicate the value proposition of our wind turbines and establish credibility within the market.

Combining these strategies, we create a comprehensive marketing and sales approach that drives awareness, generates leads, and converts prospects into satisfied customers. Through targeted outreach, strategic partnerships, online promotion, and participation in industry events, we position our wind turbine technology as a leading solution for businesses seeking to reduce energy costs, enhance sustainability, and improve their bottom line.

Conclusion

The objective of this project was to assess the potential of small-scale wind energy harvesting with a focus on utilizing wind energy sourced from excess exhaust. This analysis was conducted in two phases: a comprehensive literature review to evaluate existing research within the field, followed by the development of a prototype to evaluate the feasibility and physical properties of small-scale wind energy systems. The literature review not only provided insight into current findings within the wind energy harvesting field but also identified potential gaps in the existing research. From these insights, we were able to extract ideas to aid in the design and construction of our prototype. This ultimately led to a focus on the structure of the system, as well as the capabilities of the turbine in terms of voltage generation and stability. Using this prototype, we were able to provide an analysis of small-scale wind energy harvesting, adding our own findings to the conversation at large.

Beyond the conclusion to this project, there are several considerations that could be made for the future development of this project. Firstly, a greater focus can be placed on the energy storage attachments for the device. While our project primarily focused on the turbine used in the system and the overall structure of the unit, further consideration of the energy storage attachments would allow for further research to be conducted on the energy storage and capture capabilities of the prototype. Additionally, improving the wind turbine design in order to enhance efficiency and reduce costs is another potential avenue for further development of this project. Taking these steps would result in a more marketable product due to its increased reliability and lower cost.

Finally, a key consideration for future developments of this project is to model how long-term and widespread implementation would impact emissions and energy consumption. Despite demonstrating the feasibility of the concept, our assessment was constrained by our relatively limited data sample, both in terms of the turbine's operational duration and in the variety of exhaust sources we utilized. In order to develop a more comprehensive analysis of the system and provide more information about the long-term impacts of the system, future iterations of this project should incorporate longer testing periods, including computer simulation and a broader array of exhaust sources.

In conclusion, we were able to utilize our resources to contribute valuable insights to the larger conversation about wind energy production. Our findings serve as a stepping stone for further exploration into the overall potential of this product and the long-term environmental, social, and economic impacts of this system on the energy grid.

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