Siemens Sustainable Campus Project

4.29.13

Crowd Power

SIEMENS

EDSGN 100
Section 020

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Summary

The Hetzel Union Building (HUB) at University Park, Pennsylvania, used 11.88 Million kWh of electricity in 2012 from non-renewable resources. Our team's goal was to analyze the environmental impact and economic feasibility of implementing Pavegen tiles on the central HUB stairway. After analysis, we have determined that implementing Pavegen tiles would generate 11.1% of the HUB's energy demand, and would pay for itself in 4.28 years. The success of Pavegen tiles in the HUB could lead to additional energy-saving upgrades across campus.

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Introduction

As we progress further into the 21st century, sustainability is becoming more of an issue than ever before. As scientists warn us of the impending consequences of climate change, companies are taking unprecedented steps to become more efficient and green. As undergraduate students at Penn State, we aim to make University Park a more sustainable campus.

The HUB building at Penn State is one of the university's biggest consumers of energy. Last year, the HUB used 11,879,309 kWh of energy, and has averaged 11,104,633 kWh over the past four years. Currently, all of the energy used to power the HUB is from nonrenewable sources, and thus is unsustainable. The HUB is the central building on the Penn State campus, and making it a greener building would go a long way towards building the image of Penn State as a world leader in sustainability. This is the problem that we will address and propose a solution for in our report.

We define sustainability as the effort and actions by society to preserve the natural resources of the earth for future generations. By making the HUB more sustainable, we hope to reduce Penn State's carbon emissions and make our university a leader in green energy.

Concept Development

As our team began to brainstorm potential ways to make the HUB more sustainable, we realized that there was many ways we could approach this problem, depending on the technology and methodology we wanted to apply to the HUB. As a result, each team member researched a specific green technology, including Pavegen tiles, vertical axis wind turbines, body heat, and even sound, and looked into the feasibility of implementing each of these into the HUB.

Pavegen tiles are a relatively new product that is produced by Pavegen Systems. They are floor tiles that can be installed in high traffic areas, and generate energy by converting the kinetic energy of a step to electric potential energy

through the compression of a piezoelectric material. Our team thought that these tiles could be very effective in the HUB due to its central location on campus and its resulting high volume of traffic. We researched and determined many features of Pavegen tiles, including its cost, size, lifespan, and power output. This research is explored further in the detailed concept development section.

Vertical axis wind turbines are a relatively new method being used to harness wind energy. After much research, we learned that vertical axis wind turbines require considerably less space than horizontal axis wind turbines, and can generate electricity at lower wind speeds than their horizontal counterparts. In addition, vertical axis wind turbines are bird-friendly, can be mounted closer to the ground, and are quieter than traditional wind turbines. Our team looked into the possibility of installing these turbines on the roof of the HUB.

Using the additional body heat generated from a crowded room is another way to create green energy. This excess heat can be used to heat water, creating steam that spins a turbine. Based on our research, our team determined that generating electricity from this body heat is still a very raw way of producing energy and is still in experimental stages. The conversion from heat to energy is an inefficient process, and more efficient ways to create usable electricity from excess body heat is being researched.

Finally our group looked at the potential to generate energy from sound waves in the HUB. After some research, it was clear that although harnessing the energy from sound is feasible on a small scale, it is extremely inefficient on a large scale.

After completing an AHP matrix, shown in Table 1, we determined that the three most important features our design concept needed to have were its potential to generate significant amounts of power, its affordability, and reliability. We analyzed our four potential energy sources in a selection matrix, shown in Table 2, based on what we determined was our most important design features.

	Cost	Aesthetics	Reliability	Ease of Installation	Lifespan	% Hub Power generated	Total	Weights
Cost	1.00	3.00	1.00	6.00	2.00	0.50	13.50	23.10
Aesthetics	0.33	1.00	0.50	3.00	0.50	0.25	5.05	8.65
Reliability	1.00	2.00	1.00	4.00	2.00	0.33	10.33	17.70
Ease of Installation	0.17	0.33	0.25	1.00	0.25	0.17	2.16	3.70
Lifespan	0.50	2.00	0.50	4.00	1.00	0.33	8.33	14.30
% Hub Power generated	2.00	4.00	3.00	6.00	3.00	1.00	19.00	32.60
						Grand Total:	58.37	

Table 1: AHP Matrix

Concept	Power output	Affordability	Reliability
Pavegen tiles	4	3	5
Vertical axis wind turbines	2	3	3
Body heat	1	2	2
Sound	1	2	2

Table 2: Section Matrix

When comparing power output, affordability, and reliability, Pavegen tiles score much higher than all the other energy sources. Vertical axis wind turbines show some promise, but both body heat and sound generate minimal electricity at a high cost. We quickly determined that using either body heat or sound was not a realistic option, as neither would generate a significant amount of energy. Due to the relatively open design and layout of the HUB, there would not be enough body heat to boil water and create steam, and thus no electricity could be produced. As previously stated, current technology does not efficiently convert body heat to energy, and as a result, we eliminated the possibility of using body heat as an energy source. We dismissed sound as a potential energy source after realizing that sound cannot generate electricity on a large scale. As a result, we decided to do additional analysis on the potential of installing Pavegen tiles on the main HUB stairway, and installing vertical axis wind turbines on the HUB roof.

Detailed Concept Development

In order to see the potential of using Pavegen tiles at Penn State, we needed to find data to analyze their effectiveness in the HUB. During the week, we counted the number of people going one way down the stairs for fifteen-minute intervals during morning, lunch, and late afternoon periods, and both during and between classes for each of these periods. We did this separately for a Monday, Wednesday, or Friday, as well as for a Tuesday or a Thursday. This takes into consideration that some people only have classes these days. After obtaining this data, we were able to calculate the number of people using the stairs both ways in a given hour using the rates we obtained. This data is shown in Table 3.

Monday/Wednesday/Friday	**Time Periods**	**Measured (One way)**	**Per hour (Both Ways)**
Morning during classes	10:20-10:35	61.00	488.00
Morning between classes	9:55 - 10:10	215.00	1,720.00
Lunch during classes	12:25 - 12:40	315.00	2,520.00
Lunch between classes	1:10 - 1:25	580.00	4,640.00
Late	4:40 - 4:50	115.00	1,380.00
Tuesday/Thursday			
Morning during classes	10:45 - 11:00	152.00	1,216.00
Morning between classes	10:05 - 10:10	28.00	672.00
Lunch during classes	12:25 - 12:40	530.00	4,240.00
Lunch between classes	1:10 - 1:25	623.00	5,056.00
Late, after most classes	5:35 - 5:45	170.00	2,040.00

Table 3: Observation Data

After this data was calculated, we needed to determine how many people would use the stairs in a given day. During the morning and lunch sections of the day (8 a.m. – 3 p.m.), we knew there would be two time periods: between classes

and during classes. We assumed that 25% of an hour during this period would be between classes for most people traveling through the HUB, while 75% of the hour was during classes. During the late time period (3 p.m. – 6 p.m.), we assumed that the rates remained constant throughout the entire late period. For late nights and early mornings (6 p.m. – 8 a.m.), we assumed the total for both of these periods per day would be approximately a quarter of the total number of people for the rest of the day. For the weekend days, we assumed that each day would have about half of the traffic of an average weekday. With these assumptions and calculations completed, we found the data shown in Table 4.

Monday/Wednesday / Friday	**Times**	**Break(0.25 hour)**	**During (.75 hour)**	**Totals Each period**
Early Morning	12:00-8:00	none	2,675.43	2,675.43
Morning	8:00-11:00	1,290.00	1,098.00	2,388.00
Lunch	11:00-3:00	4,640.00	7,560.00	12,200.00
Late	3:00-6:00	none	4,140.00	4,140.00
Late Night	6:00-12:00	none	2,006.57	2,006.57
Total of day				*23,410.00*
Tuesday/Thursday	**Times**	**Break**	**During**	**Totals Each period**
Early Morning	12:00-8:00	none	3,876.57	3,876.57
Morning	8:00-11:00	504.00	2,736.00	3,240.00
Lunch	11:00-3:00	5,056.00	12,720.00	17,776.00
Late	3:00-6:00	none	6,120.00	6,120.00
Late Night	6:00-12:00	none	2,907.43	2,907.43
				33,920.00
Saturday/Sunday	**Total Number of People for a 5 Day Week**	**Average per Week Day**	**Average People during Weekend**	
All Day	138,070.00	27,614.00	*27,614.00*	

Table 4: HUB Traffic Calculations

From this data, we were able to acquire the average number of people that use the main HUB stairs during an average week during the semester. We also needed to make assumptions about traffic during the summer, since there are still people who use the stairway during this time. We made the assumption that weekly summer traffic on the HUB stairway would be 10% of the total weekly traffic during the semester. We also needed to take breaks into consideration, when almost all students are required to leave campus and go home. Therefore, for breaks, which are 4 weeks of the year, we assumed no one uses the stairs, since the amount of people who will actually use the stairs will be insignificant.

After calculating these numbers, we determined that thirty steps would be needed walk up or down the stairs and to cross the stair landing. We multiplied the amount of people who use the stairs during a week by thirty in order to find the total amount of steps taken during a given week during a regular semester and a summer semester. Our calculations are seen in Table 5.

Total Number of People for a Regular Semester Week	**Total Number of Steps Taken for a Regular Semester Week**
165,684.00	4,970,520.00
Total Number of People for a Summer Week	**Total Number of Steps Taken for a Regular Summer Week**
16,568.40	497,052.00
Total Number of People for a Break Week	**Total Number of Steps Taken for a Break Week**
0	0

Table 5: Weekly Steps Taken Calculations

After finding this data, we were able to determine the number of kilowatt-hours that can be generated yearly if these tiles were to be installed. The tiles are rated to produce approximately 7 watts of energy per step taken (1). Therefore, by multiplying the steps taken in a regular and summer week by the number of watts per step and the number of weeks for each respective time period, we were able to find the total number of watts produced. We divided this number by 1000 in order to find to find the total number of kilowatts produced. We then determined that

every kilowatt of energy currently costs approximately 13.2 cents for Penn State to generate, so we were able to calculate the amount of money these tiles would save (2). Also, using the average yearly amount of energy used in the HUB for the past 4 years, which is 11,104,633.25 kilowatts per year (3), we were able to calculate the percentage of the total electricity used by the HUB that these tiles could produce. We assume that no energy is lost in the transition from the power generated by the Pavegen tile to usable electricity for the HUB. This data is seen in Table 6.

Time Period	**Watts Produced (Wh)**	**Kilowatts Produced (kWh)**	**Money Saved**		
Semester Weeks (34 weeks)	1,182,983,760.00	1,182,983.76	$156,153.86		**Total Money Saved per Year**
Summer Weeks (14 weeks)	48,711,096.00	48,711.10	$6,429.86		$162,583.72
Breaks (4 weeks)	0.00	0.00	$0.00		
		Total kWh Per Year		**Percentage of Electricity of HUB**	
		1,231,694.86		11.09%	

Table 6: Energy Calculations

This would save a significant amount of coal from being burned to power the HUB. Every kilogram of coal burned generates 8.13 kWh of power. By generating 1,231,694 kWh of green energy every year, our design solution would save 151,500 kg of coal from being burned every year. Over the course of the tiles' five-year lifespan, 757,500 kg of coal would not be burned as a result of our design solution.

After we figured out the amount of money that the tiles could save Penn State on energy costs in the HUB, we needed to determine the amount of money that the tiles would cost and the break-even point, or how long it would take for them to pay for themselves. In order to do this, we had to find out the amount of tiles that would

need to be installed. We counted the number of stairs, and found there to be 21 steps with a larger middle landing. We also decided to put tiles at the top and bottom of the stairs that were about the same size as the middle landing, maximizing the amount of energy that could be produced from people using the stairs. Our design solution also includes installing a digital display at the top of the stairs that displays how many kilograms of coal that have not had to be burned thanks to the green energy produced by the Pavegen tiles.

We measured the total area of the stairs to be roughly 432 square feet. With each tile being 2.93 square feet, we were able to calculate the number of tiles needed to be 147.44 (1). With each tile costing $3850, our total cost for the materials, which does not include shipping, installation, maintenance, or disposal, would be $567,645.05 (4). The tiles will need certified workers to install them, so money must be spent on labor costs. Since they are not easy to install and require technical knowledge, we assumed it would cost $75 an hour for labor, with each tile taking an hour to install. Our total labor cost came out to be $11,058.02, and this would include any cost associated with shipping, installation, maintenance, or disposal. A general and administration cost would need to be considered, which would be approximately 20% of the tile and labor cost combined, or $115,740.61. We assume that we could use a flat screen television to display the kg of CO_2 saved, which would cost approximately $1300 (5). With these four costs, the grand total of expenses would come out to be $695,743.69. These numbers and assumptions that were made can be seen in Table 7.

Pricing per Tile	**Labor Cost**	**General and Administration Cost**	**Digital Display Cost**
Assumption: Does not include shipping, installation, maintenance, or disposal.	Assumption: Each tiles takes an hour to install.	Assumption: G&A cost is approximately 20% of the tile price and labor total	Assumption: We use a 55'' flat screen TV.
$3850 per tile	$75/hour per tile		
Price for Staircase	**Price for Staircase**	**Price for Staircase**	**Price for Display**
$567,645.05	**$11,058.02**	**$115,740.61**	**$1,300**
	Total Cost of Stairs		
	$695,743.69		

Table 7: Pavegen tile installation cost

With the total expenses and yearly returns found, the payback time of these tiles can finally be determined. By dividing our total expenses by the return per year, we found a payback time of 4.28 years. With the usage life of the tiles being rated for approximately 5 years, a time less than its lifetime means that Penn State will end up earning a profit from these tiles. A summary of our expenses, returns, and payback time can be seen in Table 8.

Payback Time	
Expenses	$695,743.69
Returns	$162,583.72
Payback Period (Years)	4.279294912

Table 8: Payback period of investment

The data in Table 8 is shown in a graph in Figure 1. This graph represents the initial investment of approximately $700,000 as the y-intercept, and the payback period of 4.28 as the x-intercept. The slope of the line is the money saved per year.

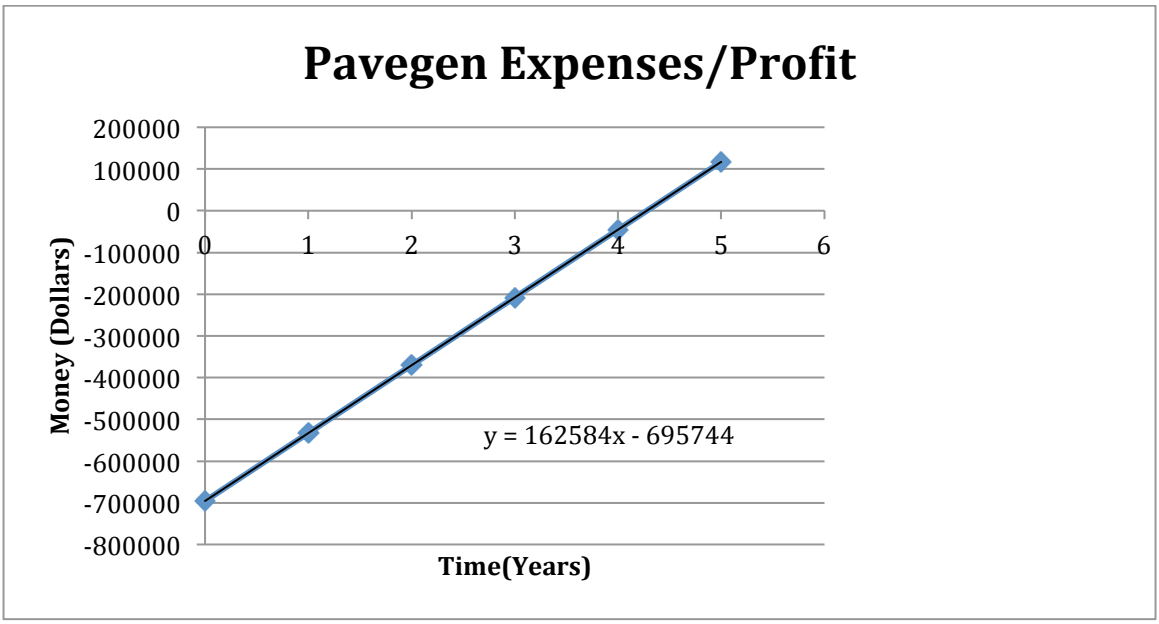

Figure 1: Payback Time Graph

After the reduced energy costs have paid off the initial investment in the Pavegen tiles, 0.72 years are left during which Pavegen tiles are saving Penn State money on

energy costs. After 5 years, the projected lifespan of these tiles, Penn State would end up saving $117,174.91.

Potential of Wind Energy

Along with our Pavegen tile analysis, we also investigated wind energy possibilities at the HUB. We looked at the possibility of installing vertical axis wind turbines on the roof of the HUB that would harness any wind that occurs over the HUB. However, after researching the average wind speeds at Penn State, we found that they only ranged from 6 to 9 miles per hour, with an average of 7.5 miles per hour during the year. This data is seen in Figure 2.

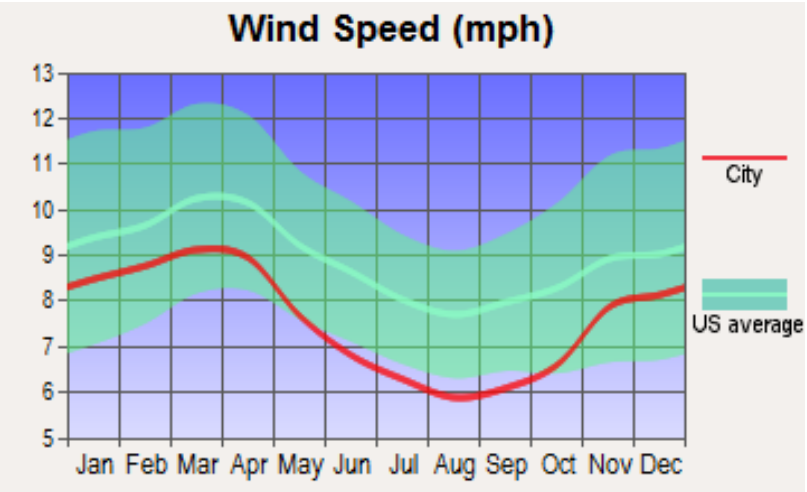

Figure 2: Wind Speeds at State College, PA
Image source:
http://www.city-data.com/city/State-College-Pennsylvania.html

With these relatively low wind speeds, we questioned whether or not these would be efficient for running a wind turbine. We choose to look at Aeolos turbines, as Aeolos is a major manufacturer of vertical axis wind turbines. However, we found that State College's wind speeds do not meet the needed running speed for a 5kW wind turbine. The start up speed for this type of turbine was only 3.4 mph. Penn State does have these kinds of wind speeds. However, the rated wind speed, or the wind speed needed for the turbines to have maximum power output, was 22.3 mph,

far above the yearly average of wind speed (6). Therefore, since these wind speeds would cause the wind turbines to run below their rated power output, we dismissed the idea since they would not produce practical amounts of energy for the HUB.

After analysis, we have determined that our final design consists of installing Pavegen tiles on the HUB's main stairway, and installing a digital display at the top of the stairs that displays how many kilograms of coal have not been burned thanks to the green energy produced by the stairway. We would install tiles on each stair on the stairway, the main landing, and extending five additional feet at the top and bottom of the stairs. The stairs with Pavegen tiles would look similar to the stairway shown in Figure 3, but would be applied on the HUB stairway, shown in Figure 4. The digital display would show an individual that using the stairs is taking pollution out of the atmosphere, and that they are actively being green. In this way, the user feels like they are being environmentally friendly and encourages them to replicate this behavior in other areas of their life.

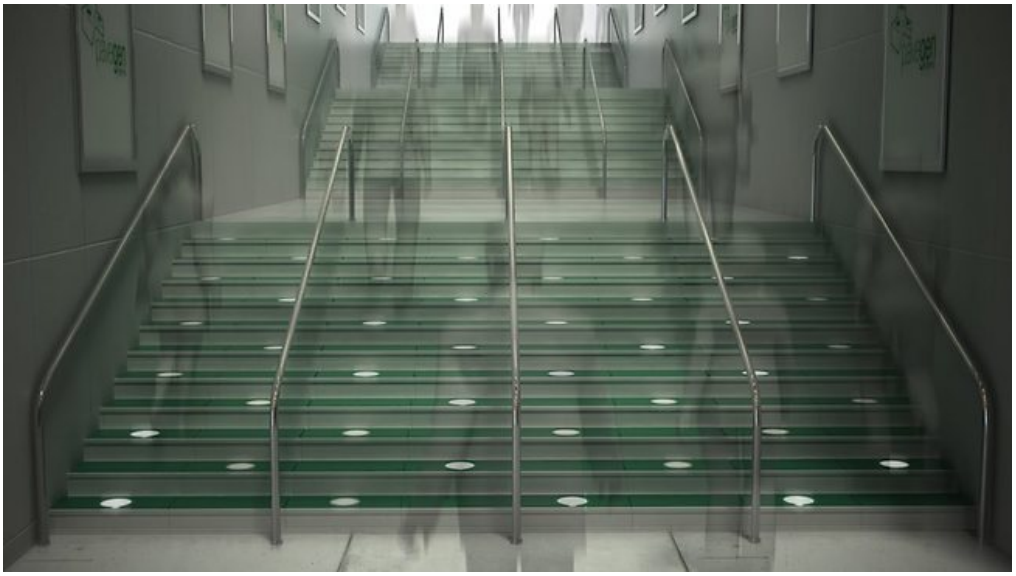

Figure 3: Stairs covered in Pavegen Tiles
Image source:
http://resources3.news.com.au/images/2011/10/14/1226166/710527-pavegen-stairs.jpg

Figure 4: Main HUB Stairway
Image source:
http://news.psu.edu/sites/default/files/styles/photo_gallery_large/public/4947644718.jpg

We created a prototype that would generate electricity similarly to a Pavegen tile. In our prototype, shown in Figure 5, we used springs to hold two parallel wooden boards apart from each other. In between the boards, we attached a magnet to the top board, and centered it above a coil of wire. When the board is "stepped" on or pushed on, the springs are compressed, and the magnet is pushed into the middle of the coil of wire. This changing magnetic flux generates an induced electric current in the wire. Using a voltmeter, we measured the voltage difference in the wire ends to be around 0.08 mV, as seen in Figure 6.

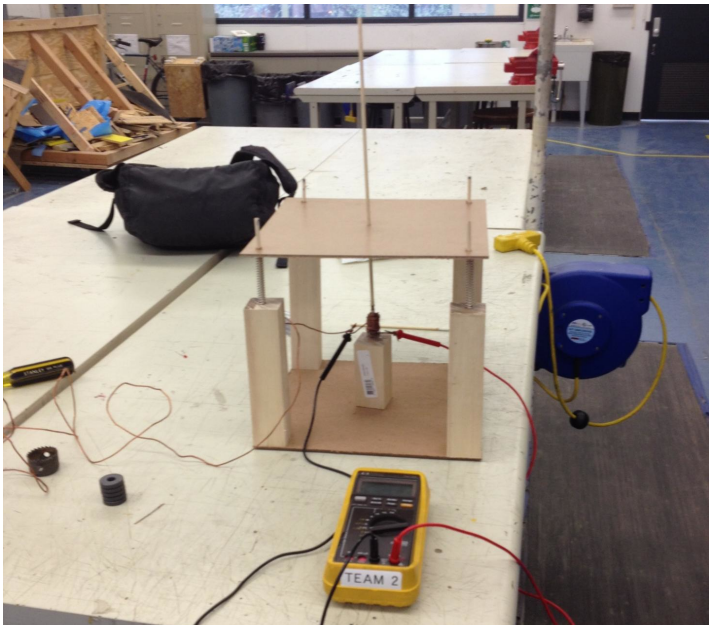

Figure 5: Photo of Prototype

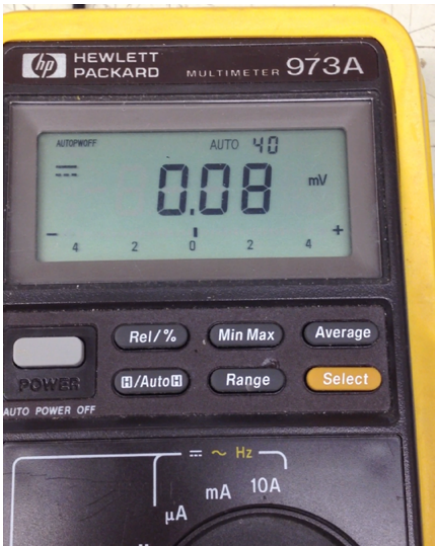

Figure 6: Voltmeter Reading

Due to budget constraints, our prototype cost around $20 to build. As a result, we could not generate a large current in the wire, as our magnets were not as strong as we would have preferred, and thus the changing magnetic flux was very small. Actual Pavegen tiles convert the mechanical strain on a piezoelectric material to create a larger voltage output and much higher electric current than our prototype does. Although our prototype utilizes a different concept than Pavegen tiles to generate energy, it shows how easy it is to convert the kinetic energy of our step into electric potential energy.

Conclusion

Installing Pavegen tiles on the main HUB stairs brings countless benefits to Penn State and the environment. Our team believes that the percentage of power the energy source can generate is the most important feature that our design solution should have. We calculated that installing Pavegen tiles on the HUB stairway would generate over 11% of the HUB's total energy demand. Unlike the other options we considered, this is a significant amount of energy that could have a big impact on the way future buildings at Penn State are designed.

Our team found that the economical feasibility of implementing the proposed design is another vitally important feature of our solution. Although Pavegen tiles are initially expensive to install, the amount of energy produced by these tiles would save Penn State over $160,000 per year on electricity costs in the HUB. The quick payback time ensures that Penn State actually makes money by installing these tiles.

Additionally, we believe that it is critical for the design solution to be a reliable source of energy. Unlike wind energy, which depends on unpredictable changes in weather, Pavegen tiles would take advantage of the potential energy that can be generated from everyday life. No behavior would need to change for Pavegen tiles to generate significant amounts of electricity during the school year. By crowdsourcing our energy, we can produce electricity from someone's daily actions.

Finally, it is important that Pavegen tiles are truly an environmentally friendly alternative to burning coal for energy. We calculated that Pavegen tiles would save 757,500 kg of coal from being burned to produce non-green electricity over their five-year lifespan. By replacing 11% of the coal needed to meet the HUB's energy demand, installing Pavegen tiles would have a significant effect on Penn State's carbon footprint. Pavegen tiles are also constructed with over 80% recycled materials. This reduces the damage to the environment associated with the building and disposing of these tiles. After use, Penn State can safely and responsibly dispose of the Pavegen tiles. By including a digital display that shows how many kilograms of coal have not been burned as a result of using the stairs, it is likely that our solution will encourage additional environmental awareness among Penn State

students, and may even encourage more people to use the HUB stairway, increasing the projected benefits gained. It is clear that the energy generated by Pavegen tiles is just as environmentally friendly as other alternative energy sources.

Penn State should implement our design solution, as it makes sense both environmentally and economically. By utilizing the HUB's traffic to produce energy, our design solution creates green energy from the routine actions of Penn State's student body. Installing Pavegen tiles in the central building on the Penn State campus would be a display of Penn State's commitment to building a more sustainable campus. We calculated there to be a break-even point of 4.28 years, which is shorter than the Pavegen's rated lifespan of 5 years. This means that Penn State will save approximately $120,000 if they implemented our design solution. Penn State should adopt our design solution due to its potential to output significant amounts of power, economic feasibility, reliability, environmental friendliness, and its potential to encourage additional green behavior among Penn State students.

One thing we learned while working on the Siemens Sustainable Campus Project project was that thinking outside the box can often yield great results. We had each member in our group individually look up different ways that we could make the HUB more environmentally friendly, and many of the ideas that were thrown around were very generic, such as wind turbines or solar panels. However, Pavegen tiles utilize an energy source that is very predictable and is always present (during the school year). Crowdsourcing our energy is an idea that is just as efficient as other green energies such as solar or wind power, but is much more predictable. We would never have thought of implementing Pavegen tiles if we did not step back and think of unique and unconventional methods that we could use to generate energy.

Another lesson our team learned is that you get what you pay for. We tried building a prototype of the way Pavegen flooring would be utilized in the HUB. The actual Pavegen tiles that we would purchase are around thirteen hundred dollars per square foot; while our model was twenty dollars per square foot. As a result, we weren't able to generate enough energy to light up an LED light. While our model served its purpose of demonstrating that people stepping on a tile can generate

power, it did not generate a reasonable amount of energy. Thankfully, Pavegen tiles are of a higher quality than our prototype and will generate much more energy.

One of the most important things our team took away from this project was the importance of sustainability. Since there is currently no perfect, sustainable solution for the world's energy demand, engineers must solve the problem in smaller steps, by changing their designs to become more efficient and pollution-free. Although our design solution won't generate nearly enough clean energy to meet Penn State's vast energy demand, it still has a significant and important impact on Penn State's carbon footprint. Preserving the world for future generations is a task that we as engineers are responsible for. Incorporating sustainable aspects in any applicable engineering project should be a priority for the engineers of today and the future.

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(3) File name All_UP_Buildings_4_years-1.xlsx, created by Amy Frantz, OPP, provided by Andy Lau
(4) https://circle.ubc.ca/bitstream/handle/2429/42973/Cramm_J_et_al_SEEDS_2011.pdf?sequence=1
(5) http://www.bestbuy.com/site/olstemplatemapper.jsp?id=pcat17080&type=page&qp=cabcat0100000%23%234%23%23wu~~cabcat0101000%23%237%23%236d~~cabcat0101001%23%230%23%233j~~nf519%7C%7C2431323530202d202431343939&list=y&nrp=15&sc=TVVideoSP&sp=-bestsellingsort+skuid&usc=abcat0100000
(6) http://www.windturbinestar.com/5kwv-v-aeolos-wind-turbine.html

Appendix 1 – Area of tiles (ft^2) calculation

Area of Tiles(in millimeters)
600mm x 450mm x 97mm
Area of Tiles(in feet)
1.9869 ft x 1.476 ft x 0.3182 ft
2.9326644
2.93 ft^2

Appendix 2 – Area of Stairs (ft^2)/Tiles needed calculation

Stairway	**Dimensions**	**Area (in ft^2)**
21 steps	1 ft deep x 12 ft wide x 21 steps	252
1 middle landing	5 ft deep x 12 ft wide	60
2 top and bottom landings	5 ft x 12 feet wide	120
Total Number of Tiles Needed		
147.440273		
Total Area (in ft^2)		
432		

Appendix 3 – Break-even graph data

y=162583.72x-694443.69	
Time	Expenses/Profit
0	-695743.69
1	-533159.97
2	-370576.25
3	-207992.53
4	-45408.81
5	117174.91

Appendix 4 – HUB Energy usage

	HUB Robeson Electricity Usage (kWh)
2009	9,768,877.00
2010	10,291,933.00
2011	12,478,414.00
2012	11,879,309.00
All 4 Years	44,418,533.00
Average per year	11,104,633.25