The Pressure Is On

A Piezoelectric Solution to Our Power Needs

March 7, 2014

Team Leader

Jane Colling

Mentors

Ryan Curtis -- Leo A Daly
Patrick Prososki -- Union Pacific

Student Team Members

<table>
<thead>
<tr>
<th>Seni Adekunle (12)</th>
<th>Doug Barnum (12)</th>
<th>Isabel Chavez (11)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Joslyn Jensen (12)</td>
<td>Sam Lyons (12)</td>
<td>Rachel Pruch (12)</td>
</tr>
<tr>
<td>Morgan Roth (12)</td>
<td>Chris Sheridan (09)</td>
<td>Katy Stuckey (11)</td>
</tr>
<tr>
<td>Table of Contents</td>
<td>Page</td>
<td></td>
</tr>
<tr>
<td>----------------------------------------</td>
<td>------</td>
<td></td>
</tr>
<tr>
<td>Number</td>
<td></td>
<td></td>
</tr>
<tr>
<td>I. Table of Contents</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>II. Synopsis</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>III. Team Organization</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>IV. Problem Identification</td>
<td>4-5</td>
<td></td>
</tr>
<tr>
<td>V. Recommendations</td>
<td>5-9</td>
<td></td>
</tr>
<tr>
<td>Piezoelectric Technology</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>Harnessing the Energy</td>
<td>6-8</td>
<td></td>
</tr>
<tr>
<td>Using the Energy</td>
<td>8-9</td>
<td></td>
</tr>
<tr>
<td>VI. Implementation: Costs and Funding</td>
<td>9-10</td>
<td></td>
</tr>
<tr>
<td>VII. Applied Science and Innovation: Experimentation</td>
<td>10-13</td>
<td></td>
</tr>
<tr>
<td>VIII. Innovation</td>
<td>13-14</td>
<td></td>
</tr>
<tr>
<td>IX. Solution: Summary</td>
<td>14-15</td>
<td></td>
</tr>
<tr>
<td>X. Journey</td>
<td>15-17</td>
<td></td>
</tr>
<tr>
<td>XI. Teamwork</td>
<td>17-18</td>
<td></td>
</tr>
<tr>
<td>XII. Lessons Learned</td>
<td>18-19</td>
<td></td>
</tr>
<tr>
<td>XIII. Acknowledgements</td>
<td>19</td>
<td></td>
</tr>
<tr>
<td>XIV. Appendices</td>
<td>20-24</td>
<td></td>
</tr>
<tr>
<td>XV. Bibliography</td>
<td>25</td>
<td></td>
</tr>
</tbody>
</table>
Synopsis

In today’s society, energy efficiency has become a major concern for countless organizations and businesses. The pressure to increase this efficiency is an environmental and economic issue. This is a major problem with our school, as we have the second largest electricity bill of all Omaha Public High Schools, totaling $571,424.45 for the last calendar year. We plan to solve this issue by utilizing the piezoelectric effect, defined as the production of electricity or electric polarity by applying a mechanical stress to certain crystals. By placing special cables which utilize these crystals within our school’s eight main staircases and increasing our school’s efficiency in other regards, we hope to gather enough energy to supplement our school’s electrical needs. With over 2,400 students in the building on any given day, the pads will have plenty of potential to collect electricity from their footfalls.
Team Organization

Mrs. Jane Colling

Engineering
Mentors:
Ryan Curtis
Leo A Daly
Patrick Prososki
Union Pacific

Doug Barnum
Seni Adekunle
Isabel Chavez
Joslyn Jensen
Sam Lyons
Morgan Roth
Rachel Pruch
Chris Sheridan
Katy Stuckey
Problem Identification

Electricity is a vital component of our society, coursing through the veins of all modern infrastructures. Being such a valuable commodity, organizations are constantly searching for means to conserve electricity. In this age of electrical conservation, considerable attention is being given to developing energy-efficient buildings. Increased efficiency results in both lower electricity costs and greater environmental safety.

In the Omaha Public School (OPS) District, both monetary and environmental issues are of great concern. As a massive school district encompassing a total of 96 school buildings (Appendix A), OPS must allot a considerable portion of its funding to energy. Currently, OPS is budgeting over $9 million annually to support every school building’s energy consumption. Inevitably, the larger the building, the higher the electricity consumption.

Being one of the largest contributors to OPS’ energy bill (Appendix B), Central High School uses a significant amount of energy annually. As a building which has recently celebrated its 150-year anniversary, Central is consequently less modern than other schools. As a result, our school struggles to compete with the economic and environmental efficiency of more modern buildings. This energy inefficiency results from a wide number of things. For instance, the building has a severe lack of natural light throughout its main halls and stairwells. In fact, the majority of our natural light is located in Central’s interior courtyard, which features semi-transparent roofing (see Figure 1). Unfortunately, this light fails to reach the remainder of the school. Without natural light, Central must rely on artificial sources of lighting much more than the average school building. In turn, Central’s spending totals regarding electricity are remarkably higher. In fact, according to the OPS budget for CHS, the school spends over $570,000 per year on electricity. Conversely, other schools throughout the district rarely exceed $350,000. Clearly, in a time of economic stress, this is a number which must be reduced.

Significant emphasis is currently being placed on the importance of protecting the environment. For architects and engineers, this increasing concern has translated into making buildings more energy efficient. As a part of the Clean Air Act of 1992, the United States government sanctioned the creation of the Energy Star Rating System for such buildings. This Environmental Protection Agency (EPA) program evaluates buildings based on their efficiency and environmental considerations. Using the criteria of the Energy Star System, Central High School ranks third out of seven high schools within OPS (Appendix C). Even so, Central’s Energy Star Rating is relatively low: 46 out of 100 points. Across the nation, a rating of 50 qualifies as roughly average, while a rating of 75 or better indicates Energy Star top performance. Our current rating is certainly not one to be proud of. For example, the Franklin Academies and Montessori School of New York is an 86 year-old school with a similar square footage (446,215) and an Energy Star Rating over double that of Central’s: 94. Countless similar schools exist (Appendix D). With this in mind, it is apparent that Central must take measures to drastically improve its Energy Star Rating. Central’s potential to become an energy-efficient building is impressive; in 2012, Central ranked 36, ten entire points lower than our most recent rating. Thus, it is clear that our building has certain
potential to increase its Energy Star Rating even further. Using this valuable system of measurement, we hope to take strides to improve our standing on energy usage and to save money for Omaha Public Schools (OPS). The money saved as a result of increased energy efficiency may then be directed to other programs for schools across the district. To ensure Central’s continued tradition of excellence, improving the Energy Star Rating of our building will enable Central to survive as a usable building for yet another 150 years. Indeed, raising its environmental considerations is a primary concern for Central High School.

This excessive energy use is clearly both an issue of environmental and monetary concern. With this in mind, it is vastly important for Central to exercise all means possible to remain energy-efficient.

**Recommendations**

Our project aims to cut energy spending within the Omaha Public School District, beginning primarily with Central High School. We hope to use these more cost-efficient solutions to simultaneously become a more energy-efficient and environmentally friendly facility. In order to accomplish our goal, we analyzed a variety of alternative energy sources to use within the halls of Central. Potential options included installing cylindrical windmills across Central’s campus, placing solar panels above our parking lots and school building, or using torque produced by doors to produce energy.

Despite these many viable options, our true solution did not present itself until well into the problem-solving experience. By analyzing Central’s infrastructure, we were able to determine the ideal option. Central is a large building of 426,740 square feet which hosts approximately 2,400 students. Within Central there are four main floors, a basement, and two sub-basements, featuring a total of eight main stairwells from the basement to the fourth floor. Each day students travel around the circumference of the main building and between the floors repeatedly.

One Thursday, a team member came from the basement to the fourth floor colorfully complaining about the excessive stairs. Another member began explaining a story he read about an innovative dance floor that used piezoelectricity to harness the potential energy of the dancers. It occurred to us that, though a nuisance, these stairs are actually the very solution to our problem. By harnessing the energy of students’ traveling up and down Central’s endless stairs, the school building could potentially tap into a great store of energy.

In order to access this energy, unique methods must be used. In our particular case, our solution is the use of piezoelectric energy. These seemingly simple rocks possess a remarkable ability: to produce energy with the application of pressure. This energy may subsequently be stored and utilized for a variety of purposes.

With this in mind, we plan to use the piezoelectric technology underneath the rubber floor mats on Central’s stairs. As pressure is applied by hundreds of students daily, extra energy will be generated for the school’s use. Considering this massive amount of stairwell traffic, we anticipate that the piezoelectric technology will be able to harness this human power. This energy may then be transferred to power countless other activities throughout Central, ranging from running computers to basic lighting. In particular, we hope to use the energy generated to illuminate the lights located directly above the stairwells involved. With the introduction of piezoelectric energy, the energy costs throughout the building would decrease. Given Central’s massive student body, we firmly believe that the installation of piezoelectric pressure cable will generate a meaningful amount of electricity. As a result, we
hope the introduction of piezoelectric technology will cut expenditures in our school’s current energy budget.

**Recommendations: Piezoelectric Technology**

Originally, piezoelectric crystals were discovered by scientists Pierre and Jacques Curie during the late 1800s. As they tested various crystals, they took measurements of surface charges of specially prepared crystals. Pierre and Jacques Curie found that the application of a mechanical force to certain crystalline minerals actually polarized the crystals, thus generating a low amount of voltage. The brothers performed a series of tests in which they applied tension and compression to the crystals and exposed them to an electric field. This test demonstrated that when a force acts upon the crystal, the crystal produces a positive or negative charge. The discovery of these characteristics was dubbed the “piezoelectric effect,” derived from the Greek word “piezein,” meaning to press or squeeze.

In keeping with this, piezoelectricity is defined as a property that, when put under pressure, produces a small charge. Piezoelectric materials include special crystals, most often quartz. These crystals absorb energy and expel a reduced amount of energy in the form of electricity.

During World War I, Paul Langevin, a French physicist, and his co-worker, Constantin Chilowski, worked on ultrasonic submarine detectors. Their transducer, an object which converts energy, consisted of two steel plates with several thin pieces of quartz glued in between. The goal of this machine was to produce a high frequency sound (38 kHz) which would echo off other underwater objects, such as fellow submarines. With the quartz, the experiment was able to tap into the underdeveloped technology of piezoelectricity. Several industrial nations across the world took advantage of their findings. As scientists worldwide have continued to research this process, piezoelectricity significantly developed through the years. Now, the technology may be found in Rocket Propelled Grenades (RPG’s), quartz watches, singing cards, and lighters. Japanese inventors have used specially-crafted ceramics featuring piezoelectric crystals to make television remotes and security alarms since 1980. The success of the Japanese use of piezoelectricity sparked a rush for piezoelectricity patents in the United States. A few American examples include charging phones in a backpack by using the Piezo-effect. With this process, the backpack straps are constructed from Polyvinylidene Fluoride or Polyvinylidene Difluoride (PVDF), a substance commonly used for insulation on electrical wires. The PVDF produces energy that may be collected and used to charge phones without having to plug them into an electrical jack. Transmission devices, which eliminate the need for long, obnoxious wires, also use piezoelectricity. These important devices require sufficient power to function; unfortunately, the batteries they use wear down too quickly and are difficult to replace. With the use of piezoelectricity, the cost of running these devices would be reduced. Russia, China and India have also had a large increase in production for piezo material and applications. All of these examples showcase the endless possibilities of the piezo-effect. The search for perfect piezoelectric product is now in full swing.

**Recommendations: Harnessing the Energy**

To offset the school’s energy costs, we plan to implement piezoelectric pressure cable on each of Central High’s steps. Initially, we researched crystals, piezo-pads, coaxial cables, and PaveGen pads as potential options for capturing the energy of the stairs. Of these, the
two most viable solutions are the PaveGen pads and the coaxial cables (see Figures 2 and 3). PaveGen Pads are recycled rubber tiles which, when stepped on, produce energy. The spiral coaxial cables possess the unique ability to produce a charge proportional to the amount of stress placed upon it. Like the spiral coaxial cable, the PaveGen Pads create energy when a force is applied. The spiral coaxial cables require a battery to store energy, whereas the PaveGen tile can store up to three days of energy.

While researching the PaveGen system we learned this is the only company that sells tiles of this nature. From a proposal from the University of British Columbia, we discovered that cost of one PaveGen tile is approximately $3,850 (600 mm by 450 mm x 82 mm). This is a per-unit cost only, so it does not include disposal, installation, maintenance, and shipping. A certified technician from the London based main offices must be present during installation. It provides twelve volts with approximately seven watts per footstep (depending on a person’s mass). These pads consume 5% of collected energy and leave the remaining 95% for other uses. Each pad lasts for approximately five years and is waterproof and indoor/outdoor compatible. If the pads were to be used within the stairwells of Central, we estimate that the building would require approximately 1800 pads for a total cost of $6.9 million dollars. Upon further analysis we decided that this option is not feasible at the present time due to the exorbitant cost. However, as this technology develops, we hope the market will grow to become more competitive. As a result, the price of the pads will likely decrease in the future, leaving this as a viable option in the years to come.

Though both feasible, we believe the spiral coaxial cables will be well suited to our purposes because it is able to be spliced and reconnected, very durable, ideal for large areas, and can support heavy loads.

Originally, we intended to simply lay the cable flat inside the pressure pad. In doing so, the pad is able to compress when someone steps on it and thereby produce a charge. Upon further consideration, we realized that arranging the cable in such a way as to promote tension (see Figure 4) would generate considerably more stress. In doing so, we would
effectively increase the pad’s electrical output.

Undoubtedly, Central’s stairwells have the potential to supply a significant amount of energy. According to our surveys, any one of Central’s thousands of students averages upwards of 426 steps daily (Appendix E). Our graph demonstrates that the majority of students take 300 to 700 steps a day (Appendix F). Thus, it is clear that the stairs in CHS have a considerable amount of potential energy available.

After investigating how to generate piezoelectricity, it was necessary to determine how to store this valuable energy. Considering that the foot traffic of Central’s stairs varies considerably depending on the time of day and year (i.e., less traffic during the evenings and summer), we determined that the ideal solution would be to store the power and use it as needed. For this, our two main options were a battery or a capacitor. Both batteries and capacitors perform the desired action: to store energy. Batteries use electrical energy storage when they are connected to a circuit. After the chemical energy stored in batteries is used, it can be replaced. Capacitors, on the other hand, discharge more quickly and cannot produce electrons as a battery is able to. With this background and advice from our Advanced Placement Physics teacher, Mr. Hammil, we selected the battery for its usage flexibility. Additionally, batteries have become widely researched in recent years, making them considerably more efficient. In our particular project, we plan to use a secondary cell battery. Secondary cell batteries are not only efficient, but they recharge as well. New technology has increased the amount of charge and discharge cycles they can withstand, increasing efficiency. Though we considered using batteries specifically designed for renewable energy sources, such as Innogy’s Polysulfide Bromine Redox system, we decided this battery was too large for our project. Indeed, the secondary cell battery serves as an ideal means for storing the piezoelectric energy. Our goal is to send this electricity straight to a secondary cell battery and use it as needed.

Recommendations: Using the Energy

Once the students’ energy is properly stored, the next matter of concern is where the energy is to be directed. As previously stated, Central severely lacks natural light. With this in mind, we hope to supplement the costs of artificial lighting throughout the building by powering it with the energy from the piezoelectricity.

In first addressing our lighting issue, we aimed to ensure that the lights throughout Central are all the most energy efficient. Two years ago, Central replaced all four-foot, classroom T12 lights with the more efficient T8 lights. The difference between these two light varieties is notable: T8 lights use 40% less electricity than T12 lights of the same size. Despite the significant amount of electricity saved, the school neglected to replace the T12 lights within the stairwells. Due to lighting code mandates, the lights in the stairwells must be on at all times. Thus, the lack of replacement in the stairwells is particularly unfortunate as this area arguably uses the most light consistently. To solve this, we propose to change all 32 of the T12 lights in the stairwells to T8 lights. By doing so, we would save 1,124 kilowatt hours each day (Appendix G).
This simple swap has incredible economic impact. The lights are active for roughly 17 hours every 258 days out of the year. With OPPD charging Central $0.06 per kilowatt hour, and the cost of replacing all 32 lights at a total of $384, we would ultimately save $63.67 annually. Installing the ballasts will cost an additional $256, but they will require little maintenance over the years and can withstand the usage of a number of bulbs. Each bulb lasts roughly 5.6 years. Considering the first pay-off term would take 5.7 years, this works out well. Since we would only have to replace the bulb after the first installation, the amount spent would be paid-off after 1.9 years (Appendix G). Once the lights are installed, we hope to further their efficiency by powering them using our piezoelectric energy.

**Implementation: Costs and Funding**

As with all engineering projects, determining the cost is vital in determining the feasibility of the endeavor as a whole. As seen in the various case studies, the abilities of piezoelectricity have clearly been shifted into global awareness. Even so, the technology has yet to be applied on a large scale within the United States. We propose placing the piezoelectric pressure pads on every stair in Omaha Central High School.

In order to implement the powers of piezoelectricity, we must renovate our stairwells. Doing so requires piezoelectric cables, batteries, wood, springs, eyelets, screws, and the like. In order to determine the costs, we chose to perform our calculations on individual stairs. On our eight main staircases, we have a total of 888 stairs from the basement to the fourth floor. By our estimates, we would need approximately 6 meters of piezoelectric cable for each stair. The cable, which costs $12.86 per meter, amounts to a total of just over $68,500.00. The total cost for springs, eyelets, and wood is $2,960, $1,110, and $7,104 respectively. While this number includes the piezoelectric power itself, it neglects to factor in the cost of storing the energy. We plan to transfer the energy directly into 6-volt batteries, of which we will need 32 for a total of $520.00. Accounting for these items, raw materials, and unforeseen expenses, the total of our first installation reaches approximately $70,000 (Appendix J).

Financial assistance. While this will certainly be a costly investment, the Central High School Foundation has proven its fundraising capabilities with its Generation C initiative, which paid for the implementation of a Wi-Fi system, more computers, SmartBoards, and, in the future, iPad devices. Another potential investor is the Peter Kiewit Foundation, which was established by a generous Central alumnus. Having founded one of the five largest engineering firms in the world, Peter Kiewit seems a promising funding option. Furthermore, a project which is based on such an emergent technology - with the potential to save a company thousands of dollars on electricity - is likely to be of interest to many potential donors.

Yet another source of funding may be found with Central’s energy provider, OPPD. As a customer of this utility provider, the school is eligible to participate in the "Innovative Energy Efficiency Project (IEEP) Incentive Program." Through the IEEP Program, customers may receive rebates for the cost of an energy study - in our case, the implementation of the piezo pressure pads. The program donates 50% of the cost, up to $10,000, to research and another $400 per kW of demand reduced as a result of implementing the measures suggested by the energy study. Clearly, this is a promising avenue of funding, as it applies directly to our project focus.

Fortunately, our project qualifies for a large host of other grants as well. Through Walmart’s Community Grants Program, OPS is eligible for grants up to $2,500. The Energy
Innovations Small Grant Program allots a maximum of $95,000 for hardware projects and $50,000 for modeling projects for research purposes which aim to “establish the feasibility of new, innovative energy concepts.” In 2009, the U.S. Department of Energy created a similar grant, titled the American Recovery and Reinvestment Act, with a total of $92 million to support “cutting-edge research programs that will enhance the nation's use and production of energy.” These funding opportunities may become a huge helping hand to our efforts with our proposed renovations to Central.

Applied Science and Innovation: Experimentation

Like the work of Pierre and Jacques Curie, our proposal is truly innovative. Initially, we could only find a few case studies that related to our goal. We hoped to turn to professional help instead; however we experienced trouble finding an experienced engineer for this highly specialized field. As a result, we were forced to discover the way that these crystals functioned on our own. Following in Pierre and Jacques’ footsteps, we designed our own experimental tests.

During the first stage of our project, we considered growing our own crystals. The very first step in this process was to accumulate “seed crystals.” These seed crystals are placed in a sodium bicarbonate solution and left to develop overnight. The following day, the largest of the resulting “seed crystals” are removed from the original solution. This step is necessary, as the “seed crystals” compete for electrons in the original solution. Thus, by removing the largest, most competitive crystals, the smaller crystals are also able to develop. Once the largest crystals are accumulated, they are attached to one end of a fishing line. The other end of the fishing line is tied to a pencil and inserted into the new solution of potassium bitartrate. Upon entering the new solution, the crystals are left to grow for over two weeks without interference. Though this option was feasible, we decided it would be easier and faster to buy a piezoelectric disc online.

Initially, we began our research of the Piezo-effect by attempting to crush quartz crystals to create electricity. Although relevant, this test yielded relatively inconsequential results. We crushed the crystals into small pieces and applied pressure. Unexpectedly, the quartz rocks did not react to the pressure applied. Though this test did not function as we thought it would, it helped us realize the complexity of our project. In summary, we discovered that quartz rock is not easily breakable. Unfortunately, our data from this miniature experiment may be inaccurate: the supposedly “quartz” rocks were purchased from the Smithsonian gift shop. Not being the most reputable of all quartz providers, it is possible that the rocks tested may not be true quartz, therefore skewing our results. Even so, we were disappointed by the lack of reaction from the quartz. Though seemingly a setback, this step in our journey encouraged us to look into new avenues of research.

Our next (and slightly more scientific) experiment consisted of creating a circuit with a battery. Using our physics textbook, *Physics* by Serway & Faughn, we explored series and
Team members disassembling grill

parallel circuits. From this, we learned that electricity requires a complete loop in order to function. Series circuits also have more voltage than parallel circuits, but if one resistor blows the entire circuit goes down. To form a conceptual basis, we connected a light bulb in a series circuit using wires and alligator clips and added 5 Volts with a power supply. We succeeded in lighting a 4.8 V (volts), 0.5 A (amp) miniature light bulb. Afterwards, we performed the same trial again using a quartz crystal. Unfortunately, our attempt did not work. Assuming that perhaps the light was too large for the small amount of energy generated, we decided to try using a 5mm red LED light with 1.8 volt and 20 mA, as it is one of the smallest voltage LEDs available. This LED light was attached to two copper wires with alligator clips while the Smithsonian crystals were attached to the other end. Using a hammer, we tapped the quartz crystal to see if it would cause the LED light to illuminate. However, this resulted in no reaction. Returning to batteries, we managed to light up the LED using two D batteries. This series circuit of ours was designed similarly to a telegraph machine, based on the concept that repeated tapping results in the desired deformity. Even though we were able to illuminate the red light, we were unable to discover any voltage reading with a voltmeter. Upon further research we learned that voltmeters need to be connected in a parallel circuit, thereby explaining our previous failure. After attempting a parallel circuit, our experiment worked yet again and we lit up our LED light. Through these multiple experiments, we learned about circuits which helped further our conceptual understanding of electricity.

Our next quartz investigation provided us with considerable information. In this experiment we disassembled a grill lighter, a tool which utilizes the piezoelectric technology, to understand the concepts of the piezo-effect. Using this knowledge, we attempted to create a simple piezoelectric prototype. To do so, we assembled a spring-powered rod, tongue depressor, duct tape, and copper cylinder to try to create our own electricity. In this test, the piezoelectric pad was taped to the bottom of the cylinders. The pad was then struck by compressing the rod and releasing it. Every time the free rod hit the plate, a bit of electricity lit up the small LED bulb attached to the piezoelectric pad. A negative side effect of this experiment was the metal rod, which conducted static electricity, left the user with a small numbing shock. This experiment was remarkable; we were ecstatic that we finally succeeded in producing a small amount of piezoelectricity.
Afterwards, we purchased three 27 mm Piezo-elements with leads for further experimentation from C. B. Gitty Crater Supply. We later attempted stepping on these discs with our feet. However, the size of our shoes far overpowered the surface area of the small piezoelectric device, inhibiting our experiment. Next, we tried stacking the three piezoelectric pads on top of each other, which had no effect. Later, we designed a spring-loaded device using the inside section of a toilet paper handle. By pushing with one finger, we were able to generate a maximum spike in voltage, .3 V, with only one pad in a parallel circuit. We then established a series circuit generated with 0.15 V using direct current. Placing the voltmeter parallel to the circuit, we generated another 0.3 V. With more application, we were able to spike at 0.4 V. Given the small amounts of voltage generated, we concluded that this pad was not intended for pressure testing.

Our next experiment involved discovering potential energy and power. A member of our team, Doug, weighed himself at 145 pounds, which we converted to kilograms as 65.77 kg. Next we measured the height of a step at Central (0.155 meters) and counted 31 steps between the third and fourth floors. Finally, we timed Doug walking from the third floor to the fourth floor in 18 seconds. Using the following equations for potential energy, we were able to determine Doug’s energy.

\[
\text{Potential Energy} = (\text{mass})(\text{acceleration of gravity})(\text{height})
\]

\[
PE = mgh
\]

\[
PE = (65.77 \text{ kg})(9.8 \text{ m/s}^2)(0.155 \text{ m})
\]

\[
PE = 99.90463 \text{ Joules}
\]

X 31 steps from the 3rd floor to the 4th floor

\[
\text{PE} = 3097.04353 \text{ Joules}
\]

With this equation, we were able to determine the potential energy which Doug generated by escalating merely one flight of stairs. Since power is equivalent to work divided by time, we were also able to determine the amount of power generated by Doug’s movements.

\[
\text{Power} = \frac{\text{Work}}{\text{time}}
\]

\[
\text{Work} = \text{change in PE}
\]

\[
\text{Power} = \frac{\text{PE}}{\text{time}}
\]

\[
\text{Power} = \frac{3097.04353 \text{ J}}{18 \text{ s}}
\]

\[
\text{Power} = 172.0579739 \text{ W} (\text{Watt} = \text{J/s})
\]

With a single person generating 172 W from only a single flight of stairs, this experiment demonstrated the potential of the stairwells. Compounded with Central’s approximately 2,500 students simultaneously using the flights of stairs, our team believes we may generate a significant amount of power (Appendix H).

Our final experimental trial involved creating a prototype of a piezoelectric pressure pad. We decided to create a floor mat to absorb the mechanical energy of people walking across it in order to create electrical energy. This goal may be accomplished by placing piezoelectric materials inside the matt or in conjunction with the matt. For our experiment, we aimed to generate enough energy with our matt to power a small LED. To do so, we
purchased two meters of piezoelectric coaxial cable. We placed the piezoelectric coaxial cable in a box-like apparatus such that, when stepped on by a student climbing the stairs, tension is placed onto the cable (Figure 4). Above this apparatus, we placed a matt material, preventing individuals from damaging or altering the wiring. This prototype demonstrated how the energy will be harvested within our stairs.

**Innovation**

Unfortunately, technology for using these pads is relatively new and under-developed. Currently, quartz crystals are most commonly used for their ability to resist change in shape and operate at sufficiently low power. This function, combined with either conical or plated designs, powers numerous devices today, including quartz watches and lighters. Even singing birthday cards use this technology to operate. Another new use for piezoelectricity is piezoelectric paper, which is specially processed to condense its cellulose. The cellulose may then be used to create energy with the Piezo-effect. Using these properties, the manufacturer may then form this unique paper into various items, such as paper speakers. Unlike our project, however, all of these examples have limited energy requirements.

Recently, piezoelectricity has been gaining popularity throughout the world. In Singapore, scientists have developed a dance floor which is powered by the movements of the dancers themselves. In another instance, the Japan East Railway Station chose to invest in the revolutionary piezoelectric energy to help power its busy, growing population. To do so, the company installed new stone tiles featuring piezoelectric technology and improved the layout of the mechanisms to more efficiently collect the energy which is generated by the pedestrians. The entire area covers roughly 25 square meters and is expected to obtain over 1,400 kilowatts per day. This energy will be used to power the ticket gates throughout the business.

MIT students James Graham and Thaddeus Jusczyk collaborated to “harvest” piezoelectric energy in a competition sponsored by the Holcim Foundation for Sustainable Construction. Their process, which they dubbed “crowd farming,” has been implemented within a train station in Torino, Italy. What sets this project apart is the idea, similarly to ours, to collect energy from the vibrations caused by people’s movement. Through their experimentation, this project was able to collect energy from people walking throughout the station in order to power a passenger train. Graham and Jusczyk’s project is an example of the increasing interest in different forms of energy. This project utilized the same idea which powers our project: harnessing human kinetic energy. These students placed pads under sheets of flooring which released energy when a force was applied. Each time a depression is made on the surface, negative charges are emitted on one side, while the opposite side releases positive charges to be collected by a battery. This energy was then transferred to a dynamo, a generator which converts mechanical energy into electrical energy. The project focuses primarily on collecting the steps of pedestrians throughout the train station. However, during their experimentation, the scientists developed a small prototype using a chair which collected energy as people sat. The pressure from the people illuminated LED lights underneath the chair. Given this experiment, the scientists have proven that piezoelectric energy may be created with a wide variety of movement and pressure.
Another railroad company, Innowattech of Israel, has also implemented similar piezoelectric power. Previously, highways throughout Israel have used piezoelectricity, a concept which they hope to expand. This company plans on installing the piezoelectric pads on each of their railways to generate energy. Innowattech plans on substituting 32 normal railway pads with piezoelectric ones of their own design. Along with generating electricity, the new Innowattech Piezo-Electric Generator (IPEG) pads are capable of measuring the size of the wheels, speed, and weight of the vehicle that passes over it. The Technion University and Israel Railways installed a prototype of the energy generating system to prove the benefits of having it on the railways. They found that a track which was frequented by ten to twenty trains with ten cars each is capable of producing as much as 120 kWh. This energy may be used to power signs and lights, while the excess energy may be placed into the country's power grid to help power other things.

A case study in London, England directly parallels our concepts. Scientist Laurence Kemball-Cook recently invented the innovative “PaveGen” pads. These tiles are constructed from recycled rubber and harvest kinetic energy from the impact of people stepping on them-all by using piezoelectricity. These slabs are designed to compress five millimeters with each step, and are able to store up to three days of energy. The pads utilize an on-board battery, which does not emit power to an external device. In the experiment, twenty PaveGen pads were scattered randomly at the central crossing between an urban mall during the 2012 London Olympics. The producers expected roughly thirty million people for foot traffic—enough to power half the outdoor lights in the mall. Given the success of this minor endeavor, Kemball-Cook has expressed hopes that these tiles will be integrated into dense areas of human traffic such as city centers, underground stations, and school corridors. Already, the inventor has orchestrated two other projects in Paris and Singapore. Schneider Electric, the company which wired the PaveGen pads, hopes to continue this green concept during their next four years of sponsorship and promote piezoelectric materials throughout the world. These case studies show the feasibility of the world utilizing the human population to promote energy use for the betterment of future generations.

Eventually, we believe this technology has the capacity to be implemented throughout the world. Potentially, the powers of piezoelectricity may be placed within the streets, generating energy as individuals walk, bike, and drive. Thus, the energy expended by the millions of individuals during their travels will be transformed and reused. With the expansion of piezoelectricity, the potential for our reliance on fossil fuels to decrease becomes a strong possibility. As a result, implementing piezoelectricity within our society may help reduce the global energy shortage.

**Solution: Summary**

To reduce the expenses of electricity within our building, we plan to use the energy being exerted by the student body on the several flights of stairs in the building. Using the remarkable powers of piezoelectricity, we will be able to utilize the kinetic and potential
energy of the student population. Throughout the world, this technology is being developed in countless other avenues, which we hope to emulate in our school. We hope to utilize this remarkable and innovative technology within the stairwells of Central. Using piezoelectric cable, a durable product suitable for covering large areas, we will place the power of piezoelectricity underneath our stair boards. Energy harvested inside the piezoelectric matt will be transferred to an energy storage station and used to power the T8 light bulbs in the stairwells. By our estimates, using this natural and unusual source of energy will enable the school to power all of the stairwell lighting. Given the world’s current energy concerns, the importance of piezoelectricity – and in turn, our project- becomes remarkably valuable. We hope to set a strong example of innovative power sources for many other buildings and organizations across the world.

**Journey**

Our journey began quite early last April during Omaha Downtown Cleanup. As a team building activity, the club was assigned an area surrounding Central High School, roughly eight blocks total, to collect litter. As we picked up trash, our team discussed various ideas for the upcoming year’s project. By August, the team again united to finally select a project and further plan the year. We discussed various ideas that interested team members and decided to meet every Thursday from 3 pm to 4 pm, as with previous years. Project topic ideas varied widely. Debates featured ideas such as:

- Rebuilding the Civic Center to use as a sports complex for Central
- Putting a garden in our courtyard or on our roof
- Installing solar panels on Central’s roof
- Placing wind generators on the school’s lawn
- Replacing the doors with revolving doors

Though these ideas were quite viable, our true project did not present itself until well into the project. A member came to the club excited about reading an article on piezoelectric energy generated from people dancing on a special floor. Given Central’s large amounts of floor space and steps, the group quickly latched onto the idea. Once we selected this avenue of research, we discussed the many ways in which it could be applied within our school. We saw opportunity for placing piezoelectric pressure pads on the outdoor track, stairs, and parking lots.

Once we began truly looking into our project, it became apparent how little we knew and understood about piezoelectric energy. Consequently, we began researching the history of piezoelectric energy and searching for articles regarding how this energy may be generated (Appendix I). Admitting our lack of knowledge of electricity in general, we also decided to request a lesson on circuits and began setting up our own circuits for a better conceptual understanding. Still not quite comfortable with our knowledge of piezoelectricity, we sent out several SOS messages to various engineers and composed a long list of questions to ask (Appendix J). Unfortunately, no engineer ever responded, leaving us to continue our research independently. Therefore, we spent the next several months trying to generate
piezoelectric energy on our own. With research, one team member discovered that piezoelectric technology was utilized within common grill lighters. We then tore apart a lighter and practiced pushing on it to get a spark, following the instructions of a helpful YouTube tutorial. The success of this experiment encouraged discussions of building various prototypes. In the meantime, we researched the average step count of students within Central.

October found us taking a slight break from investigating piezoelectric energy by attending workshops at PKI. Team members Morgan and Seni attended the model building session in which they learned how to present the models, use detail, and work with different materials and designs. While at the seminar, they participated in activities such as building small version of a hotel out of a box, chip-board, and glue which helped solidify their model-building experience. Morgan also went to the presentation skills workshop, where she learned to avoid using hands while speaking, referencing note cards, and walking while speaking. Other tips were to keep hands behind backs and practice in front of others. Meanwhile, Seni attended the sustainability workshop. To be sustainable, she learned that our project needed materials natural to the geographic region and to explain how the project can help others and the ecosystem. Sam took part in the REVIT seminar. Being the only student present, he received one-on-one mentoring specifically for our project. During the hour-and-a-half period, Sam was able to build a model of Central’s staircases, resulting in precise statistics for our prototype. The proctor was able to give Sam plenty of advice and drilled him with questions about the project. Though this revealed Sam’s lack of knowledge (at that point in time), he learned that research is considerably easier when we have questions established. All in all, it was a fantastic lesson, made all the more informative by the fact that it was completely custom-made for our project.

Our goal this year was to incorporate sustainable energy with our school’s outdated technology. Our mentor, Ryan Curtis, gave us a tour of his offices in the Leo A. Daly building, a LEED-Gold Certified structure. The tour contained vital information on sustainability, a major part of our project. We discussed the ability of the facility’s lights to dim or brighten depending on the time of day, how the window frames reflect sun away from the building, and how the paint helps cool the building. Visiting this incredibly sustainable building reinforced the idea that little things truly have a significant impact. To further our knowledge of sustainability, Patricia Rooney gave us a tour of the National Park Service Building. The building was built using several methods to keep the building green and served as an excellent example of how to improve Central’s sustainability in the future. Some of the main features are a limestone wall designed to help heat and cool the building, low emission paints and carpets, and special ponds to help capture and use rainwater. Additionally, the structure’s internal offices are located on the east side of the building, maximizing heating and cooling efficiency since the sun does not directly hit them during the workday. In our project, we hope to utilize this green philosophy to increase Central’s sustainability.

Another break from lab research occurred during November, as our team wrote a short nomination for our mentor, Ryan Curtis, as an awesome mentor. With our letter, we hope to recognize Ryan for his incredible help with our team projects throughout the years and praise his effort to consistently “help above-and-beyond.” We are very grateful for his knowledge and understanding of engineering which continuously aids us in our quest to learn. This year in particular, Ryan was an invaluable asset in helping with the math portion of our project, an area we consistently struggle with. To finish off the first semester, the
engineering club worked together to assist with the removal of outdated science textbooks as a team building activity.

With the help of Ryan, our team tackled the issue of calculating the amount of money our project will save in January. Again, team members Morgan, Rachel, Chris, and Isabel attended a series of workshops on engineering occupations at the Peter Kiewit UNO building. The session was a wonderful opportunity available to those considering pursuing engineer as a career. Our members were able to meet and interact with local engineers from a wide variety of fields. Towards the end of the seminar, the students engaged in hands-on activities which built reasoning and teamwork skills. Later, Morgan and Chris attended the civil engineering workshop. Here, they were able to meet civil engineers and learn about the process of becoming an engineer. They also did a short activity on finding a solution to a traffic problem in Lincoln. Next, Morgan and Rachel attended the architecture workshop. Once again, the presenters discussed their experiences as engineers and the process of becoming an engineer. Within the seminar, Morgan and Rachel were challenged to construct an object from paper which connected two people’s feet together, and experiment which was both challenging and fun. For the February SMP Career Workshops, Doug attended the computer and robotic engineering sessions. The computer seminar was presented by Jay Knapp, a programmer from the firm 42 based in Lincoln. The robotics engineering session was hosted by Duane Sages of Valmont and Mike Baldino, the retired owner of Kelly Klosure. Each went over how their respective companies have incorporated robotics into their everyday use. After their presentation, Doug moved to a lab room at PKI and witnessed a hands-on demonstration of the university’s robots.

While compiling the final report our club met every day after school and on Saturday for two weeks in mid-February. Using pizza, donuts, pop, junk food in general and a massive amount of caffeine from Starbucks, we were able to finalize our research and complete our written proposal.

Teamwork

Our team unfortunately faced multiple issues throughout the year. Being a small club, our group only met after school once a week for an hour. This being so, the majority of the work for our project was completed individually outside of school. Time spent with the group was used mainly for collaboration. Having such a limited amount of united time truly inhibited the group’s ability to achieve much together. This difficulty was further intensified by the inability of many group members to attend each Thursday meeting. With a variety of after-school clubs, activities, and sports, team members were spread remarkably thin throughout their multiple involvements. Thus, it became exceedingly difficult for all members to meet at once. Even so, the team used many other methods to encourage constant communication. Through a shared Google Drive, group text-messaging and contact during school, our team was able to communicate effectively and develop our project. Utilizing Google Drive to host our project was invaluable, as it provided each group member with access to the project at all times. Information regarding all upcoming meetings, trips, and useful notices was sent out over a group message. These various technologies were significant contributors to our project’s success, interconnecting the group.
To promote community service and teamwork, we volunteered to move outdated science books. Using carts, we transported numerous books from the third floor to the loading dock at the basement level. We had a lot of fun pretending we were on the Titanic and flying through the wind in front of the cart of books. Working together, we were able to lift heavy textbooks and properly stack these books to prevent them from falling. This process required patience, cooperation, and remarkable teamwork. The activity even helped generate new ideas to try for our lab activities the following week. As a result of working together (and maintaining our good humor), the entire experience made us feel closer as a team.

Chris later suggested another fun team project which enabled us to see piezoelectricity in an unexpected way: through candy. With the experiment, we placed a mint lifesaver in our mouth and chewed them (in a dark room) in front of a mirror. While we chewed, we noticed that the candy actually created little blue sparks within our mouths. As Chris later explained, lifesavers contain small amounts of quartz which cause the candy produce piezoelectricity. As a fun (and tasty) experiment, our team was very pleased by the unexpected results.

Finally, to promote an environment of team unity, our “Engineering Club Family” invented with nicknames for each team member. The names were based on our individual skill sets and nuances. Our teacher, Mrs. Colling, was nicknamed “Caterer” due to her constant supply of snacks and treats. Ryan Curtis, our engineer and mentor, was nicknamed “Father”, because he recently became the loving parent of twin baby boys. Patrick Prososki, who was unable to attend meetings due to his busy schedule, was dubbed our “Ghost Engineer” since he checked in solely via e-mail. Doug Barnum is referred to as “Mr. President” due to his slightly bossy but organized manner. Katy Stuckey, who has an aptitude for editorial work, became our team’s “Editor in Chief.” Morgan Roth is our “Translator”, since she condensed science terminology to something that actually resembles the English language. Joslyn Jensen is our “Support Editor.” Chris Sheridan is our “Mad Scientist”, since he continually came up with innovative designs and investigations; as well as having a tendency to get his fingers smashed and shocked. Sam Lyons is our “Prototype Designer”, because he created our final prototype. Seni Adekunle, Isabel Chavez and Rachel Pruch are our “Researchers #1, #2, & #3” since their talents gravitated towards discovering new information. Each of the team members has strong skills which were fully taken advantage of. It took a team effort by every member working together to finish our written proposal.

Lessons Learned

Throughout the project’s development, we learned countless valuable life lessons as a team. Undoubtedly, our team learned the important lesson of perseverance. Considering that
the technology and research of piezoelectricity is fairly limited, it became necessary to experiment and research to gain an understanding of this largely untapped field. Though discouraging at times, our team managed to work together and continue learning. This proved remarkably beneficial, as we gained valuable knowledge from studying the process. Overall, our research was invaluable to the success of the project. The more exploration we did of the Piezo-effect, the better we became at comprehending new information and piecing it together to create a unified understanding of its benefits.

Our Engineering Club represents the embodiment of teamwork which was hugely influenced by the project this year. Our club only meets once a week for an hour while some schools have a class for the SMP program and others have club meetings more than once a week. We were all assigned a job according to our strengths in order to get the project going. We had to depend on each other, while contributing our own part to complete the project. A huge part of what makes our group function as superbly as it does is that we have set a strong foundation. As everyone has to go their own ways for the different sports, employment commitments, and other activities we had to find a way to be able to communicate. The invaluable lesson of collaboration clearly permeated our entire project experience.

Throughout the process, we also learned the value of communication. Indeed, without the ability to constantly interact with one another, our project would have inevitably faced failure. In order to accomplish this, all files were hosted on Google Drive to allow everyone simultaneous access to our report. This solved our communication issues and brought us closer together as a team, ensuring everyone was able to contribute. Truly, the importance of full group contribution was emphasized while we worked on our project.

In researching, experimenting, and writing this report, everyone gained an understanding of the requirements for writing a professional proposal. This experience gave all team members insight into future careers and provided us with a sample of what a career in the engineering or architectural fields would entail. In fact, all of our senior members plan to pursue a career in engineering or a related science field. Our experiences have been essential to developing most of the member’s future goals. Engineering club has been undeniably influential - especially in a year filled with life-changing decisions.

Acknowledgements

We would first like to thank Jane Colling, our sponsor, who has been a great moral support. Next we would like to thank Ryan Curtis, who is the main engineer who helped us with our research for this year’s project. Ryan established a tour of Leo A. Daley which enabled us to learn about the work life of engineers and to research sustainability. We would also like to thank Patrick Prososki, another mentor who provided encouragement by e-mail. We would also like to thank Patricia Rooney who gave us a tour of the National Parks Service and Fred R. Clough, Fire Safety Specialist from OPS, when helped us with stair codes. Along with them we would also like to thank Jill Best, who was very helpful with budget information. Finally, thanks go to Central High School’s head engineer, Deb Bolis, who was helpful with building facts. Math teacher Molly Jensen, a former engineer, also gave us ideas on different projects to explore. AP Physics C teacher Matt Hamill helped with information on batteries. Paul Nielson provided a color printer to print off our written proposal. Finally, our principal Dr. Ed Bennett was helpful in providing budget information.
### Appendix D

**Other high schools standings around the country that compare to Centrals size:**

<table>
<thead>
<tr>
<th>Energy Star Rating</th>
<th>Square Feet</th>
<th>Year built</th>
</tr>
</thead>
<tbody>
<tr>
<td>Downey High School, CA</td>
<td>100</td>
<td>368,027</td>
</tr>
<tr>
<td>Monroe High School, NY</td>
<td>86</td>
<td>321,293</td>
</tr>
<tr>
<td>Central High School, NE</td>
<td>46</td>
<td>426,740</td>
</tr>
</tbody>
</table>

### Appendix E

Survey given to randomly selected classes; used to estimate approximate number of daily steps per student

- What floor is your class on?
  - 0 ____ 5th ____
  - 1st ____ 6th ____
  - 2nd ____ 7th ____
  - 3rd ____ 8th ____
  - 4th ____ 9th ____
Appendix F

**Number of Steps Taken Daily**

<table>
<thead>
<tr>
<th>Number of Steps</th>
<th>Number of Students</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-200</td>
<td>5</td>
</tr>
<tr>
<td>2-300</td>
<td>20</td>
</tr>
<tr>
<td>3-400</td>
<td>25</td>
</tr>
<tr>
<td>4-500</td>
<td>30</td>
</tr>
<tr>
<td>5-600</td>
<td>25</td>
</tr>
<tr>
<td>6-700</td>
<td>10</td>
</tr>
</tbody>
</table>

Appendix G

Total usage of lights:

Total wattage saved per light:

\[
\frac{32 \text{ lights} \times 17 \text{ hours}}{\text{day}} = \frac{544 \text{ hours}}{\text{day}}
\]

[Image of bar chart showing number of steps taken daily]

\[
\frac{544 \text{ hours}}{\text{day}} \times 6 \text{ watts (saved)} = \frac{4352 \text{ wathours}}{\text{day}} = 4.352 \frac{\text{kilowathours}}{\text{day}}
\]

Light usage per year:

\[
\frac{258 \text{ days}}{\text{year}} \times \frac{4.352 \text{kWh}}{\text{day}} = 1,123.82 \frac{\text{kWh}}{\text{year}}
\]

Amount Saved:

Cost to replace:

- Lights - $4.00
- Ballasts - $8.00

\[
$4 + $8 = $12 \text{ to replace each light and ballast}
\]

\[
$12 \times 32 \text{ lights} = $384 \text{ to replace lights and ballasts}
\]

\[
\frac{$384}{67.37} = 5.7 \text{ years}
\]

Pay-off after light and ballast replacement:
Pay-off after light replacement:

\[
\frac{\$128}{\$67.37} = 1.9 \text{ years}
\]

Appendix H

The potential energy and power lab helped us figure cost another way.

\[
Cost = \frac{172.0579739 \text{ W}}{1000 \text{ W}} \times \frac{1 \text{ kW}}{1 \text{ kWh}} \times \frac{1 \text{ h}}{36000 \text{ s}} \times 0.06 \text{ cents}
\]

Cost = $0.000002868

By dividing the cost by 31 steps (from the above activity) and multiplying this result by
the 400 steps Doug takes in a day, he generates $0.004126 per day. Furthermore, by
multiplying this by 170 days in a school year, it would give the school $0.70141 a
year. Multiplying this by Central’s 2,400 students, our team finds that a 145 pound person
would produce approximately $1683.38 per year.

Appendix I

History of Piezo Crystals

- Piezo crystals
  - First published experiment in 1880 (piezo.com)
  - Human power
  - Piezein is Greek for “subjected to pressure”
- Direct Piezo-effect
  - Means electricity from applied stress
- Converse Piezo-effect
  - Stress in response to applied electric field
- Pierre and Jacques Curie experimented
  - Quartz, topaz, cane sugar, rochelle salt - subject to mechanical stress
- 1920 - 1940
  - General applications with natural crystals
  - Classic App
    - Microphones
    - Accelerometers
    - Ultrasonic transducers
  - Materials available
    - Often limited device performance
    - Commercial exploitation
- 1940-1965
  - Powerful sonar
  - Piezo ignition systems
  - Sensitive microphones
  - Snap action relays
- 1965-1980
  - Japanese Developments
    - Smoke alarms
    - Tele remotes
- Intrusion alarms
  - 1980-Present
    - The search for high volume markets
    - Phenomenal rise in piezo patents by the U.S. patent office

Appendix J
Questions for Engineers
1. How does piezoelectric energy work?
2. How can we harness piezoelectric energy?
3. How do we convert the energy put off by the quartz into electric energy?
4. What would be the simplest way to transfer the electricity generated into the school or city grid?
5. Would wireless work better? How does wireless work?
6. How many watts are needed to power the lights?
7. How would we connect the pads to the lights?
8. How long does piezoelectric energy last?
Bibliography: