

Cary Hairfield
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Professor David Dethier
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Harnessing Kinetic Energy from Humans

Introduction

Energy is everywhere and this semester I have learned many different ways in which energy can be harnessed and utilized. Beginning with a study of coal I learned that in 2002 “coal [was] used to generate more than 50 percent of the Nation’s electric energy” (Groat, 61). This was mostly due to the fact that coal is abundant in the U.S. thus relatively inexpensive (Schweinfurth, 65). Coal is an example of a raw material being removed from beneath the earth’s surface in order to generate electricity. Other types of raw materials that can also be used for this purpose include petroleum and natural gas. Figure 1 illustrates that as of 2011 coal was used to generate 20 percent of our nation’s electric energy, natural gas was used to create 26 percent and petroleum was used to generate 36 percent (U.S. Energy Information Administration/Annual Energy Review 2011).

Using raw materials to generate electric energy, however, creates an abundance of other issues that our society is left to grapple with. In fact, “critical issues in public and political affairs of human society ultimately have an energetic basis” (Odum, 34). One of the issues with using coal, petroleum, and natural gas is that they emit greenhouse gases into our environment that increase global warming. In an effort to halt this increase, new ways in which energy can be harnessed are being invented. These different types of methods are called renewable energy sources because they do not emit greenhouse gases in order to produce electric energy.

I have always been most interested specifically in renewable and sustainable sources of energy. In fact, renewable and sustainable energy sources will be imperative as the world population continues to grow and create more waste. Some of the types of renewable energy sources we have studied this past semester include solar power, wind energy and hydropower. All three of these methods extract energy from nature. However, unlike raw materials, nothing has to be removed from the earth. These technologies are harnessing energy by converting energy that already exists into electric energy. These methods though are not without their own set of flaws. One of the largest issues with solar power, wind energy and hydropower is that to a certain extent they are unpredictable. For example, at a certain point hurricanes are predictable. However, hurricanes can only be predicted once they have come to be. There is no way to predict every hurricane that will occur in the future. This idea has motivated me to look into renewable types of energy that can more easily be predicted. For this project I will explore the ways in which energy can be harnessed from the kinetic movements of humans and converted into electric energy.

1. Piezoelectricity

Discovered by French physicists Jacques and Pierre Curie in 1880 (Ultrasound), piezoelectricity is the accumulation of electric charge in certain solid materials. For example, most notable materials include different types of crystals, however certain ceramics and biological matter can have piezoelectric qualities as well. Examples of biological matter with piezoelectric qualities include bone, tendon, wood, DNA and multiple different proteins (Principles of Instrumental Analysis). Examples of crystals with piezoelectric properties are tourmaline, berlinite, quartz, topaz, cane sugar and Rochelle salt. Quartz (Figure 2) and Rochelle salt exhibit the most piezoelectricity.

A working definition of piezoelectricity is “the generation of electricity or of electric polarity in dielectric crystals subjected to mechanical stress, or the generation of stress in such crystals subjected to an applied voltage” (The Free Dictionary). In other words, for a material to have piezoelectric properties it must not only generate electricity when a force is applied to it, but also change shape when high voltage is applied to it. This is called the converse piezoelectric effect. The Curies did not discover the converse effect, however, it was mathematically deduced from fundamental thermodynamic principles in 1881 by Gabriel Lippmann (Lippmann, Principles of the Conservation of Electricity). The Curies took Lippmann’s discovery and went on to obtain quantitative proof of the complete reversibility of electro-elasto-mechanical deformations in piezoelectric crystals.

2. The Math behind Piezoelectricity

Piezoelectricity is the combination of two main factors: Hooke’s Law and the electrical behavior of the material in question. Hooke’s Law states that $S = sT$ where S is strain, s is compliance and T is stress. The electrical behavior of the material can be derived using the equation $D = \epsilon E$, where D is the electric charge density displacement, ϵ is permittivity and E is the electric field strength.

3. Piezoelectricity Implemented in Everyday Life

Piezoelectricity is a source of high voltage, thus power. Some substances, such as quartz for instance, can create potential differences of thousands of volts of electricity. An example of piezoelectricity being implemented in everyday life is the electric cigarette lighter. As Figure 3 illustrates, by pressing the button on the top of the lighter a spring-loaded hammer is caused to hit a piezoelectric crystal. This application of mechanical stress on the piezoelectric crystal produces a sufficiently high voltage electric current. The current then flows across a small spark gap, which heats and ignites the gas within the lighter. “Approximately 46.6 million U.S. adults smoke cigarettes,” which means that at least this many people are using piezoelectricity on a regular basis (Centers for Disease Control and Prevention).

4. Piezoelectricity Harnessing Human Movement

Humans do not always understand the ways in which they are a part of an energy cycle. In order to maintain a healthy lifestyle the average person is supposed to walk 10,000 steps a day. In other terms, the average person should be traveling five miles by foot every twenty-four hours (Parker-Pope, New York Times). This equates to a lot of human motion. In fact, in order for the average adult to be capable of transporting himself this far he is supposed to eat about 2,000 calories. However, depending on the person's basal metabolic rate, amount of physical activity and thermal effect of food, this number is subject to change (Discovery, Fit and Health). Their bodies virtually function as energy converters but instead of converting solar energy into electric energy for instance, they are converting energy from food into kinetic energy. The kinetic energy can be harnessed; much like some hydropower technologies harness water movement.

A way to convert this kinetic energy into electric energy is through piezoelectricity. By applying a mechanical stress to a piezoelectric crystal or material an electric current will be created and can be harvested. The Defense Advanced Research Projects Agency is an agency of the United States Department of Defense that researched a way in which battlefield equipment could be powered by piezoelectric generators embedded in soldiers' boots. The project was called Energy Harvesting and was not successful, however, it is a good example of how people are trying to implement piezoelectric materials in order to harness kinetic energy as a renewable energy source.

A more successful example of piezoelectric materials creating energy can be found at Bar Surya. Named as the world's first eco-nightclub, it is powered by solar panels and a wind turbine. A large energy generator, however, is the dance floor. Made of crystals according to Andrew Charalambous, the club's owner, the dance floor generates the energy that runs the club's air-conditioning system (Kannampilly, ABC News).

5. Another Way of Harnessing the Kinetic Movement of Humans

In 2007 two graduate students at MIT's School of Architecture and Planning, Thaddeus Jusczyk and James Graham, wanted to harvest the energy of human movement in urban settings such as commuters in a train station. Jusczyk explains why harvesting human movement is significant when he emphasizes the importance of "people [understanding] the direct relationship between their movement and the energy produced." These two graduates designed what they called "A Crowd Farm" to be implemented in Boston's South Station railway terminal. The design included a sub-floor system made up of blocks that would respond to the weight of humans and depress slightly under the force. Installed beneath the station's main lobby, the slippage of the blocks against one another as people walked would generate power through the principle of the dynamo. The dynamo is a device that directly converts the energy of motion into electric energy. To put this movement into context, a single human step can only power two sixty-Watt light bulbs for one flickering second. In comparison, however, 28,527 steps can create enough energy to power a moving train for one second (Wright, MIT News).

A company called Energy Floors has designed and patented an installable floor with the exact same technology that Jusczyk and Graham investigated. The company was

founded in 2005 in an effort to create a sustainable dance club. Much like Charalambous' Bar Surya, the goal of these creators was to use dance to power a club. The difference between Bar Surya's floor and an energy floor, however, is that the former use piezoelectricity and the latter do not. In fact, based on the results from extensive research, the company decided to develop an electro-mechanical system since the potential power output was calculated to be much higher when compared to other systems such as piezo and hydraulic systems.

To create electricity the Sustainable Dance Floor will compress up to 10mm when it is stepped on. This slight compression is enough to activate an internal generator beneath the floor that can produce up to 25 Watts of sustained output per module. Each module is 75 x 75 x 20cm large.

The earliest model of the Sustainable Dance Floor was showcased in September 2008 when Club WATT was opened in Rotterdam as the first ecological dance club. Since then, however, Energy Floors has grown as a company and now sells and rents out not only Sustainable Dance Floors, but also Sustainable Energy Floors. Sustainable Energy Floors are a more cost effective, efficient floor for large-scale applications.

Sustainable Energy Floors convert human footfall into electrical energy with an efficiency of 50%. With a design different from the Sustainable Dance Floor, Sustainable Energy Floors need little vertical movement to create about 5 Watts per step. This means that it requires less effort to create energy, for example, walking is enough. The modules are smaller with a measurement of 50 x 50cm, thus easier to install. Sustainable Energy Floors focus on efficiency, low cost and low maintenance (Sustainable Dance Club).

6. Harnessing Kinetic Energy at Williams College in Williamstown, Massachusetts

For this project I am trying to deduce whether or not a Sustainable Dance Floor would be economically feasible for Williams College in Williamstown, Massachusetts at this point. A small, liberal arts college located in the Berkshires, Williams College is extremely invested in not only lessening its energy use, but also exploring different renewable energy sources. Currently, the college utilizes solar panels during the late spring, summer and early fall. The majority of the school's annual energy use, however, comes from natural gas.

Setting

I am investigating Goodrich Hall as a potential location for the implementation of a Sustainable Dance Floor. Located near WCMA between the eyes and Lasell Gym, Goodrich Hall enhances student life by providing members of the Williams Community with programmable space. The two-story building is mainly an open area with a stage at one end. Optimal for parties, dances, small musical events, workshops and lectures, I decided that this space would be an interesting one to look into because of its versatility. I also wanted to study this space because of its floors. Goodrich Hall has hardwood flooring that is often subjected to massive amounts of moisture as well as heavy wear and tear (Figure 4). Because of the poor environmental factors for the current flooring, I thought that the next time Goodrich's floors needed to be completely re-done the school should look into installing a Sustainable Dance Floor instead.

Data/Information/Narrative

Goodrich Hall's main floor is 45ft x 45ft and its stage area is 18ft by 30ft. Every two years the floor is sanded and a new finish is applied. It costs \$3 per square foot to sand and reapply finish, thus the floor costs a total of \$7,685 every two years. The floor is completely replaced though every 10-20 years. It costs \$15 per square foot to replace the floor, thus the floor costs a total of \$38,475 every 10-20 years. It is safe to say that hardwood floors in this space have a definitive expiration date.

Since the Sustainable Dance Floors come in 75 x 75 x 20cm modules, for this investigation I needed to convert the space into square centimeters. There are 30.48 centimeters in every foot. The equations for the main floor then are as follows.

$$\begin{aligned}45 \text{ ft} \times 30.48 &= 1,371.6 \text{ cm} \\1,371.6 \text{ cm} \times 1,371.6 \text{ cm} &= 1,881,286.56 \text{ cm squared} \\75 \text{ cm} \times 75 \text{ cm} &= 5,625 \text{ cm squared} \\1,881,286.56 \text{ cm squared} / 5,625 \text{ cm squared} &= 334.45\end{aligned}$$

In order to fully retrofit the main area we would need about 334 modules. The equations for the stage are as follows.

$$\begin{aligned}18 \text{ ft} \times 30.48 &= 548.64 \text{ cm} \\30 \text{ ft} \times 30.48 &= 914.4 \text{ cm} \\548.64 \text{ cm} \times 914.4 \text{ cm} &= 501,676.4 \text{ cm squared} \\75 \text{ cm} \times 75 \text{ cm} &= 5,625 \text{ cm squared} \\501,676.4 \text{ cm squared} / 5,625 \text{ cm squared} &= 89.2\end{aligned}$$

In order to fully retrofit the stage area we would need about 89 modules. Thus, in total, we would need to purchase 423 modules from Energy Floors. In addition to this cost, the school would need to pay for shipping as well as the company to come install the floors because only trained professionals are allowed to install the panels.

In terms of energy production, the Sustainable Dance Floors are capable of producing 25 Watts per module. If we were to have 423 students all bounce on an individual module then we would be able to create 10,575 Watts of energy. In comparison to the studies that the MIT graduate students conducted, this means that we would be able to produce enough energy to light 176 60Watt light bulbs for an hour.

Ignoring the spike of electricity usage during breakfast, Goodrich Hall uses roughly around 8.5 Kilowatts per hour (Figure 5). In the context of the building's overall energy use, if 423 students all bounced 20 times on an individual module then we would be able to create enough energy, 204,000 Watts, to power the entire building for 24 hours. This is a substantial amount of energy, however in the context of Williams College it is a very small amount.

Discussion/Conclusions/Recommendations

All of the data presented in this essay is extremely promising, however, realistically, in the context of Williams College, it would not make sense to implement a Sustainable Dance Floor unless it cost less than \$150,000. Unfortunately, Energy Floors never got back to me regarding my inquisition about the price of each individual module, so this figure is a rough estimation that I came up with. It costs \$111,483 every twenty years to maintain Goodrich Hall's floor. The pros of purchasing a Sustainable Dance Floor would be that the floor could create some of the energy that the building uses (especially the energy used during dances), the floor would not be affected by moisture (thus would not have to be repaired every two years) and most importantly, the college could teach its students about renewable, clean energy. The cons of purchasing a Sustainable Dance Floor would be that the college would have to pay a lot of money all at once, just because the floor wouldn't need yearly inspection does not mean that it would not require maintenance that only a trained professional could provide, and most importantly, in the context of the entire school's energy usage, the floor would not create that much energy.

In conclusion, I would not recommend that the college purchase a Sustainable Dance Floor for Goodrich Hall. I do, however, recommend that the college look into a Sustainable Energy Floor for the Paresky Student Center. Paresky is the location that has the most amount of student foot traffic and because Sustainable Energy Floors cost less money than Sustainable Dance Floors maybe they would be worth purchasing in an effort to educate the campus' students about clean, renewable energy created from harnessing the kinetic energy of humans.

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Image Sources

Figure 1- U.S. Energy Information Administration/Annual Energy Review 2011

Figure 2- <http://www.fanpop.com/clubs/diamonds-and-crystals/images/704863/title/clear-quartz-photo>

Figure 3- <http://global.kyocera.com/fcworld/charact/elect/piezo.html>

Figures

Renewable Energy as Share of Total Primary Energy Consumption, 2011

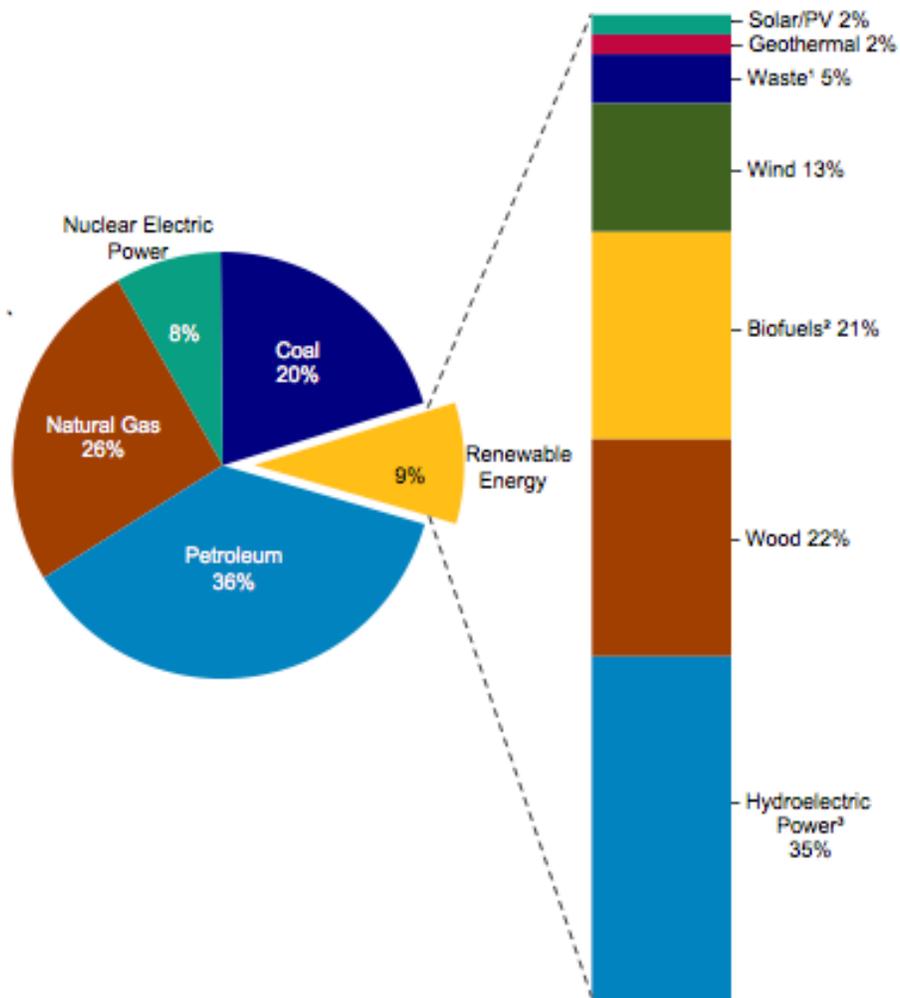


Figure 1. Different types of energy used throughout the United States in 2011 and their individual distributions. (U.S. Energy Information Administration/ Annual Energy Review 2011)



Figure 2. Clear Quartz (Fanpop)

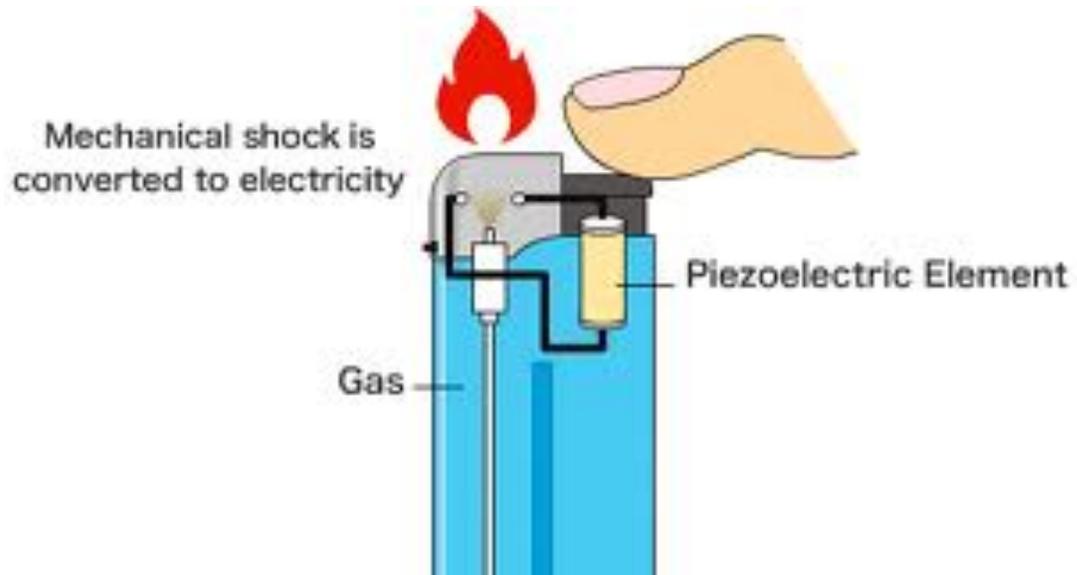


Figure 3. A diagram depicting how pressing the button on an electric lighter causes a spring-loaded hammer to hit a piezoelectric crystal, which produces a sufficiently high voltage electric current that flows across a small spark gap that heats and ignites the gas within the lighter. (Fine Ceramics World)

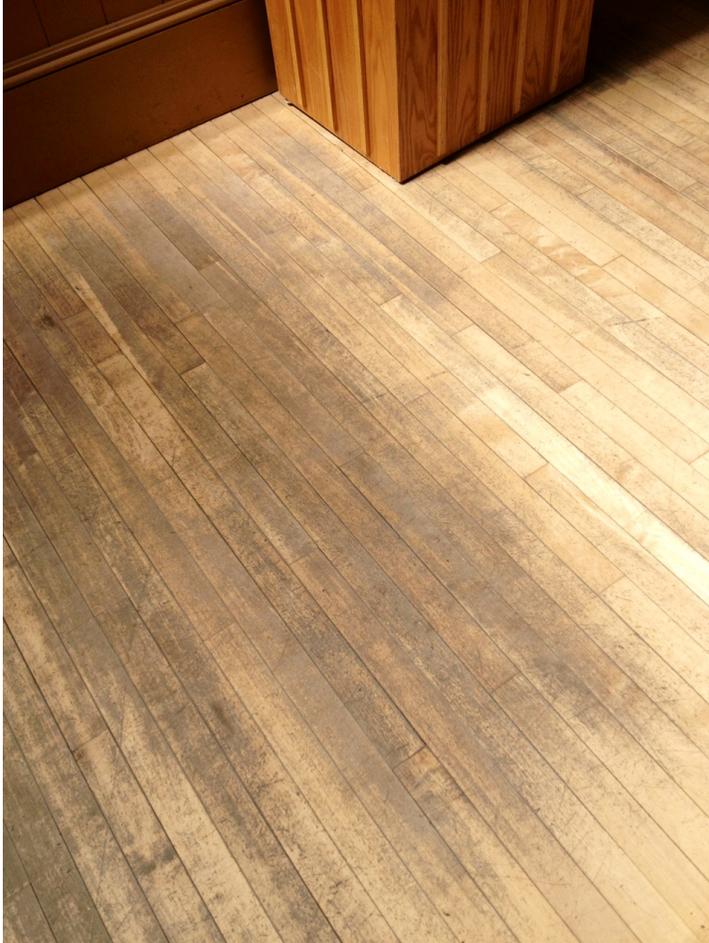


Figure 4. An image I took of Goodrich Hall's floor. This is just a small example of a much larger scale issue. The wear and tear on these floors does not go unnoticed.

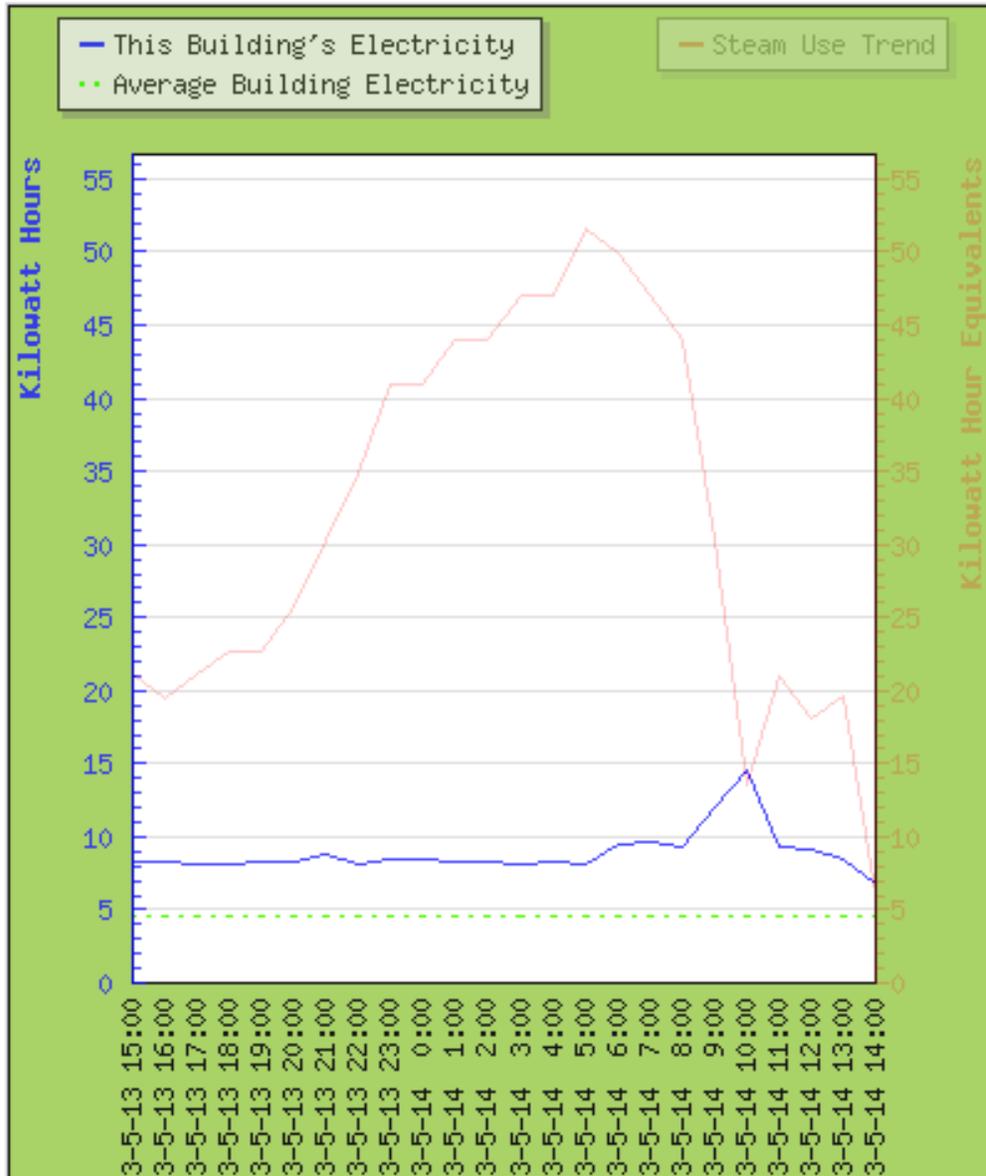


Figure 5. This is a graph of Goodrich Hall’s electric energy usage over a 24-hour period. Usage is measured in Kilowatts per hour.