Sustainable Penn State Residence Hall

by Team Name

EDSGN 100

Section 21

Submitted to: Professor Smita Bharti

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**Our Prototype:**

The exterior of our residence hall shows the area of our photovoltaic system, 9,000 square feet. In addition to this, our prototype illustrates the sloping of each of these tiles. These tiles will be mounted at an angle and will be able to rotate to different degrees in order to absorb the maximum amount of sun during each season. For instance, in the winter months the panels will be 26 degrees from the vertical, in the spring and fall months the panels will be 49 degrees from the vertical, and in the summer the panels will be 72 degrees from the vertical. Beaver Residence Hall has the most amount of windows directed towards the south, and therefore can participate in passive solar heating. One can also view the three windmills that are located on the top of our building to provide us with 111,448 kWh/year.

The interior of our residence hall is accounted for and can be viewed when removing either the roof or everything above the ground floor. When viewing the ground floor one can see the space where elevators are located, the location of vending machines, common areas, and also storage spaces. On the other side of the cut out tunnel area is the computer lab. This will appear as an open box in our model and is surrounded by other storage space. One can also view the floor plan of each floor by removing the roof piece. Only the 8th floor was modeled because each floor is exactly the same. It is important to note that the floor plans of Beaver Residence Hall were not altered for this project, and that our target sustainability measurements were still met.
Executive Summary:

The goal of this project was to redesign a campus building at the Pennsylvania State University, University Park Campus to make it more sustainable both now and in the long run. Our building had to follow a few requirements provided by our professor. Of those, the most important include: having reasonable remodeling costs, using pre-existing parts of the original building, and also using pre-existing technology and methods. Our building fulfilled all of these requirements but in no way is perfectly sustainable.

Introduction:

Mid Semester, Team Name was asked to redesign a building on the Penn State University Park Campus making it much more sustainable than it previously was. Before even selecting our building of choice, we found it necessary to define sustainability. To us, sustainability is using resources at a level that can be maintained for a long period of time. Our Group decided that a residence hall would be best to accomplish this because there are many changeable aspects than can be altered to make it run more efficiently. After consulting with all of the group members, we decided that Beaver Hall would be the best residence hall to choose from because many of our group members had easy access to the building and was a building they saw daily, and it is among the most complicated of Residence Halls. If we are able to make one of the largest residence halls sustainable, then all of the other residence halls could definitely follow these steps as well.

This project also required that we set target specifications. These specifications included cutting down energy usage and water usage by means of both behavioral and structural changes to the building. To determine these targets we compared the average use figures in Beaver Hall to other residence halls, and roughly estimated how much we could save by implementing the measures we are proposing. Most of these changes cut about 50% of what is being used now. Another target specification regards recycling. When beginning this project we planned to raise the current 58% recycling rate to 75% of what is coming out of our building.
Clearly Defined Problem:

The initial problem here is that Penn State could be made much more sustainable than it is now. Following the desires of the Siemens Project we realized that it necessary to research ways in which college students can practice sustainable behaviors and live in an overall sustainable environment. From conducting a student survey most people feel that we are going to run out of fuel eventually even if it does not cause a direct threat to us now. They also seem to agree that although sustainability is relevant, it is usually more talk than action. These students suggested to us that we could begin recycling more, make efforts to conserve, use sustainable materials, and use sustainable sources of energy. Taking these into consideration we also incorporated the use of behaviorally saving energy, recycling, producing less trash, limiting water usage, and eating more sustainably. Although these changes were brought up to us, and we were told that the masses realize it is a problem, few people seem willing to make changes. It is necessary that we, as a group of project engineers in this case make it easier for people to follow steps to sustainability, and make it almost a requirement to be sustainable when living in the on campus residence halls.

In order to correctly make changes that would not negatively impact the students here it was necessary that we follow a few constraints for the customer needs, which include: Making the building sustainable, using sustainable energy sources within the building, incorporating sustainable transportation options both to and from campus and within campus, using sustainable food and water systems, having a sustainable means of handling waste, using participatory schemes to maximize the use of sustainable technology, and using the campus as a “classroom” for sustainable living.

External Research (Step 2 of the Design Process/Concept Generation):

Following the steps of the design process we began research on other sustainable buildings to see how they managed. It is important to point out, however, that we have already done a substantial about of research on sustainability techniques to design our first project, the Zero-Energy Home, so we took some concepts for this project from our prior work. One of the first sources that drew our attention was that of the University of Minnesota. The University of Minnesota has focused much of its efforts on trying to make residence life sustainable. For example, they have already developed recycling programs, installed low-flow shower and toilet features, initiated the use of water and energy-saving laundry facilities, and recycled materials in hall offices. With these enhancements within the residence halls, they realize that college students are still not willing to make much of an effort. Because of this they have developed a “Live Green Games” program that educates residents on how to live more sustainably and conserve resources whenever possible.
The desire to participate in these games are fueled by the reward of being treated to a “Sustainable Study Break” during finals, something I am sure everyone can use during finals. Setting up a friendly competition reminds students that it is not hard to be sustainable if one simply alters some of their everyday habits. They have also instructed residents on how to be sustainable which we have considered to be very important in our project. Switching out a reusable water bottle instead of buying bottled water, shutting off the tap when doing dishes or brushing your teeth, only doing full loads of laundry, turning off the lights and other electronics when you leave the room, and utilizing the recycling bins in the residence hall are just a few things that Minnesota has done that we have merged into our project as well.

In addition to using design features from our previous project, and researching potential solutions for residence hall designs, we also had to do research on the appliances for Beaver Hall. Considering that one of our group members lives in Beaver Hall, we understand as a group what makes these wasteful behaviors possible. For instance, we now have faucets that can be turned on and off allowing students to keep the tap running when it is not necessary. To fix this we will replace these faucets with motion sensors that will only run when your hands are directly underneath the spout. We have also decided that the showers can be fixed by replacing the showerhead with one that is low-flow to increase sustainability by decreasing water usage. Also, to convince residents to use reusable water bottles we will replace the old, poorly working water fountains, with new water coolers. Other appliances that play a vital part in residence life are washing machines and dryers. After much research we found that the washing machines already existing within Beaver Hall, are Energy Star quality and to save money, we will not be replacing those. We will also not be replacing the dryers that function off of natural gas within Beaver Hall now. Another aspect that affects water use is the use of toilets and urinals. There are two options that exist for making these more sustainable: adding flush valves, or replacing the entire appliance. The cheaper solution, considering the amount of these appliances existing within the residence halls is adding flush valves to each that restrict the amount of water used with each flush, and thus is the option we are going with. This list only touches on the appliance changes we intend to make, and all other appliances will be discussed in the Concept Generation and Concept Selection portions of this report.
**Concept Generation:**

With most of our concepts previously discussed, our team took many other steps in our generation process. After brainstorming new ideas for the building, we selected many passive and active features that could improve the building's sustainability. Alongside these possible changes, certain parts of the building would remain that already run efficiently.

To start, our passive features could change by:

- Replacing single-pane windows with argon-filled double-paned
- Thermal mass in common area (bottom floor, room with most south-facing window area)
- More/more efficient insulation
- Plant trees

Alongside our possible passive changes, we developed a list of active features that will help our building's total sustainability as well. We came up with four main categories of Active features that will make our building a better, and more sustainable place.

These Active Features would include:

**Electricity**
- Solar panels
- Windmill(s)
- Motion sensors in common areas
- Wi-fi
- Fluorescent light bulbs instead of personal lamps
- Power strips and meters for appliances

**Heat**
- Heat pumps
- Individual room heating controls
- HVAC heat exchange
- Addition of Valve on a Radiator
- High-Efficiency Insulation
- Double-Paned Argon Filled Windows

**Water**
- Graywater system
- Rainwater Collection
- Low-flow showerheads
- Low-flow motion-sensing faucets
- Flush valves on Toilets and Urinals
Behavioral
- Increased recycling
  - Individual recycling bins in each room
  - Pictures of landfill on trashcans
- Decreased elevator use
- Promotion of reusable water bottles
- Decreased water use (shorter showers, etc.)
- Turning off/sleep mode appliances/devices
- Donating old items
- Using reusable dishes instead of disposable
- Only full loads in washers
- Several sizes of washer
- Green custodial supplies

Concept Selection:

How we worked towards our target specifications:

Water Usage in Beaver:

One of our target specifications was to cut our overall water consumption by almost half. Beaver Hall is one of the largest consumers of water on campus, so there is much room for improvement. The first and biggest system that we decided should be added to Beaver Hall was a gray water system. A gray water system collects the water that has already been used in certain processes (mainly showers, sinks, and washing machines) and recycles it for use in other systems (toilets and urinals being the main users).

Currently in Beaver Hall, potable water is used for all processes, including flushing the toilets. Water that could otherwise be used for showers, drinking, and washing clothes is immediately being used to wash away waste, rendering it largely unusable. The water from the toilets is mixed with water from the showers and sinks, rendering that water unsafe for any use as well. In the end, all systems use drinkable water and dispose of it directly into the public sewer system.

The gray water system allows the water that is no longer potable but still safe for other uses to be reused. Water that once flowed through the showers may no longer be drinkable, but it can still be used to flush toilets. If water from the showers, sinks, and washing machines were used to flush the toilets, the toilets no longer would require a constant supply of tap water. Less water is used overall, and less sewage output is created. If the system is tuned correctly, water usage could be cut by half with just a gray water system alone.
However, rarely do gray water systems achieve 50% savings all of the time. What if the demand for gray water exceeds production? Or what if the showers are producing more water than the toilets can use? The result is still wasted water. In order to achieve our goal, other systems had to be installed or upgraded to drop the water usage by 50%.

One such system we decided to incorporate in our design was the rainwater collection system. Currently, rainwater that falls on the roof of Beaver Hall enters a storm drain and goes unused. We decided that if we could collect and purify that water, then we could offset the usage of tap water even further. State College gets about 40 inches of rainfall every year. When the area of Beaver Hall’s roof is calculated in, almost 300,000 gallons of rainfall pass through the roof’s drains every year. If we could harness this water, we could add it to the gray water cycle, either by purifying it and adding it to the tap water, or using it to supplement gray water production.

The third major way to save water we decided on was to upgrade some of the fixtures in the hall. Currently in Beaver Hall, the shower heads are not low-flow. Upgrading to low-flow shower heads could cut shower water usage by a third or more. The current shower heads are very low quality and are quite unpopular with the residents, so almost any change to the current shower system would be welcomed, rather than protested. Other fixtures that could be upgraded include the toilets installed in the halls. The toilets, including the standard toilets and urinals, have very long flush cycles. Some toilets flush for longer than 20 seconds, shutting off long after the waste has been purged. Simply changing out the flush valves for ones with shorter cycles could save much water, at no loss of cleanliness. The toilets themselves wouldn’t even need to be replaced.

With a combination of the above mentioned systems, Beaver Hall could definitely cut water usage and sewage output by half. If all systems work as designed, Beaver Hall could go well beyond a 50% reduction of usage, and at no loss of quality of living.

**Energy Usage in Beaver:**

Another goal we had in mind while updating Beaver Hall was to significantly reduce the amount of energy use in Beaver Hall. There are two sources of energy being supplied to Beaver for domestic use: Electricity and natural gas. The natural gas in Beaver is only used to heat the clothes dryers; it has no other uses. Electricity is the main source of energy for Beaver. Electricity not only supplies energy to power lights, appliances, and consumer goods in Beaver Hall, it is used to heat the building. From what we could tell, the current system uses heat pumps to heat water used in a liquid water radiator system. Heating is by far the biggest consumer of electricity in Beaver Hall.

Since heating was the largest consumer of energy, we decided to focus on improving the heating system as our primary method of reducing electricity waste. Currently in Beaver Hall,
the heating system is extremely inefficient. Almost no insulation exists in the walls, and all windows and doors have a single, large pane of glass. On even mildly cold days, a noticeable draft comes from the windows and walls. The walls and windows are cold to the touch. What little insulation exists is not well-distributed, and is largely ineffective at insulating the building. So to compensate for the uneven heat loss, the heating system produces an excess of heat, which is then distributed around the building, regardless of the temperature of that area. As a result, some sections remain cold while others become quite hot. And to compensate for the excess heat, the residents open windows, even on the coldest days, letting even more heat escape from the building.

So to improve the heating system we decided that two steps were needed. First, insulation had to be upgraded. Reducing heat loss to the exterior reduces the amount of heat needed to keep the building warm. Second, improvements had to be made to the heat distribution system. Overly heated rooms lead to open windows, which lead to heat loss.

To address the first step, we decided that two main types of building insulation needed to be upgraded. First, the insulation on the walls needed to be significantly upgraded. However, with the current architectural design, very little wall space is available for insulation to be added. To compensate for this, we decided that the current brick façade needed to be removed in order for the insulation to be upgraded. Once the insulation was in place, the brick façade could be rebuilt around the newly insulated walls. The new façade would probably end up about a foot further out from the building than it already is. So instead of cinder block being attached directly to the redbrick exterior, a foot thick layer of insulation and façade support elements would be put in place. With the upgraded walls, much less heat would be lost through the walls.

The second type of building insulation upgrade involves replacing the windows and exterior doors on the building. The current windows have little to no insulation value, and serve only as a barrier to weather. We decided that it would be important to install double-paned argon-filled or even triple-paned windows in place of the current windows. We have selected double-paned argon-filled windows, as they are more cost efficient than triple-paned windows. The new windows, although significantly more expensive, would reduce the amount of heat loss by a large fraction. Long-term energy savings help offset the cost of initial installation.

To address the second step, we decided that a method was needed for residents to shut off the heat to their own rooms. With the current radiator system, there is no way to access a shutoff valve without opening up the whole unit. And because the radiators are so old, most of the valves have become rusted open. We decided that a simple way to remedy this would be to install valves on each radiator that could shut off the water flow. The valves would need to be easily accessed by the residents as well as easy to turn off/on. These valves would allow
residents to keep their rooms at a reasonable temperature without having to open a window, yet prevent them from abusing the heat (the residents would not be able to crank the heat higher than the radiator system currently provides).

To further reduce electricity usage, we decided that it would be wise to install single-outlet electric meters in each room so that the residents not only can see how much energy is being used, but also be fined for overly excessive energy use. Only the people who used extremely large quantities of energy would receive the fine, however, the limit still exists as a way to encourage people to use less. If the limit is in people’s minds, even if they are nowhere near it, the thought about using too much would still be more prevalent.

We decided that there was not much we could save in the way of appliances, because most of the university-owned appliances are already energy-efficient. For example, the washers and dryers are already low energy machines, and most of the lighting in the building is fluorescent or another type of non-incandescent source.

Overall, the biggest way to reduce the electricity usage involves upgrading the insulation and heating system. The metering of individual residents’ energy usage is more of a method to encourage energy conservation.

However, we also decided that Beaver Hall should try to make up a significant portion of its remaining energy use through non-grid methods. We set a goal of trying to reduce the remaining power usage by at least 50%. Our first idea was to produce as much as possible using solar panels. However, Beaver does not have enough roof area to supply all the energy needs through solar. So we decided that in order to achieve the goal of generating 50% of remaining power use through non-grid methods, we would need another method of generating electricity. So to supplement the energy produced by a solar array, we decided that installing a wind turbine or two would be an easy way to supplement solar energy production. In the end, we actually settled upon the addition of three wind turbines. Because of Beaver Hall’s height, a wind turbine would not need to be elevated far above the roof. The top floors of Beaver get a significant enough amount wind that elevation would not be a problem. Doing research on how others have done this, we are sure that this addition is extremely safe and very sustainable.

With all systems and improvements in place, Beaver Hall could reduce its overall energy consumption by 75% or more. It all depends on how the systems are installed and how the residents and staff of the university react to them

**Design-Energy Analysis:**

Current total water use:
- 8,895,150 total gal/year

Using percentages above:

- Shower: 1,494,000 gal/year
- Faucet: 1,397,000 gal/year
- Toilet: 2,375,000 gal/year
- Leaks: 1,219,000 gal/year

Current efficiency:

- Shower: 2 gpm
- Toilet: non-standard; 3.2 gpf
- Faucet: 1.5 gpm

New efficient rates:

- Shower: 1.5 gpm
- Toilet: 1.6 gpf
- Faucet: 0.5 gpm

Save:

- 25% of shower water
- 50% of toilet water
- 66% of faucet water
- In addition, major pipe work will reduce leaks; est. by 50%

Total water savings:

- 3,093,000 gal/year from appliance replacement alone

Reduce water use by roughly 1/3 from fixture replacement alone

- This doesn’t take into account behavioral changes; shorter showers, faster handwashing, etc., that can reduce use even more
- Also doesn’t take into account rainwater or greywater systems, which should also increase efficiency greatly

Take into account greywater/rainwater:

- Greywater/rainwater goes into toilets
- Originates in showers, faucets, washing machines
- 297,000 gal/year from rainwater
- 3,512,000 gal/year from greywater (washing machines, showers, taps)
- Toilets use 1,188,000 gal/year
- Therefore, no water needs to be drawn from pipes to supply toilets; all water for toilets can come from building

New total water savings:

- 4,281,000 gal/year without behavioral changes
- 48% savings
- Reasonable to assume that behavioral changes (shorter showers, faucets not on) can account for remaining 2%
- **TARGET MET-YEAH WE’RE GOOD**

Cost:

- Faucets: \(10 \times 2 \times 8 \times $388.60 = $62,176\)
- Toilets: \(5 \times 2 \times 8 \times $111.51 = $8,920\)
- Showers: \(5 \times 2 \times 8 \times $27.75 = $2,220\)
- Greywater system: \(\sim $500\) for residential system -\(\sim $50,000\) for Beaver

Total costs (minus labor/installation costs):

- **$123,000**

One of the main ways Beaver Hall with become more sustainable is by reducing its water usage. Currently, Beaver Hall uses roughly 8,895,000 gallons per year, or roughly 16,000 gallons per resident per year. As part of our project, we aimed to reduce these figures by 50% as part of our overall push towards sustainability. We accomplished this goal primarily through two ways.

One of the main ways we reduced water usage was an overall investment in new, water-saving water fixtures. Chief among these were the showerheads, the bathroom faucets, and the toilets. Our reasoning behind this was simple. According to the American Water Works Association Research Foundation, these three fixtures on average account for 59.2% of each individual’s total water usage. By significantly reducing the water use from these three fixtures, we were able to significantly reduce the total water use. We elected to not include a new clothes washer, as the current ones are already very water-efficient, and not cost-effective to improve on.
Our other significant investment was a greywater system covering all of Beaver Hall. Greywater systems essentially reuse water used in things such as showers, sinks, and washing machines for uses such as toilet flushing. These systems can result in large water savings, especially when paired with a rainwater collection system. Since Beaver Hall has a large, flat roof, ideal for catching rainwater, we decided to include a rainwater system as well.

The water savings of these two systems are significant. Currently, the fixtures in Beaver Hall are fairly inefficient. The toilets use roughly 3.2 gallons per flush, the showers use roughly 2 gallons per minute, and the faucets use about 1.5 gallons per minute. These figures can be easily improved on. After some research, we located fairly affordable fixtures that were enormously more efficient. The new toilets will use 1.6 gallons per flush, the new showerheads will use 1.5 gallons per minute, and the new faucets will use 0.5 gallons per minute. In addition, the new faucets are motion-triggered. This means that they are impossible to leave running without anyone there, greatly reducing wastage. With these new fixtures, we are able to reduce shower water use by 25%, toilet water use by 50%, and faucet water use by 66%, not including any behavioral changes. When this is factored into the original water-use figures, we save about 2,484,000 gallons per year purely from fixture replacement.

The water savings from the greywater system, while not quite the same, are still significant. As seen in the water system diagram below, the greywater system uses water that has already been through certain fixtures, including the sinks and showers, as toilet water. In addition, rainwater is collected from the roof for use as greywater. State College gets a fair amount of rainwater each year, with Beaver Hall specifically getting roughly
297,000 gallons per year on the roof. This is added to the water used by the sinks, showers, and washing machines, for a total of 3,512,000 gallons of greywater available. Since the toilets use roughly 1,188,000 gallons per year, there is clearly a large excess of greywater available. The entire water use of the toilets can be easily supplied by the greywater system, and so the toilets incur no net water cost. In addition to the water directly saved, the greywater system also produces some indirect savings. As seen in the previous chart, 13.7% of the water used by residents goes to leaks. Installing the greywater system will necessitate major work on the pipes of Beaver Hall, which will likely reduce the loss to leakage significantly as new pipes are installed. Though this is difficult to calculate, we decided it is reasonable to assume that this will cut loss to leaks by about 50%, or roughly 609,000 gallons.

Adding both the water saved by the greywater system and the water saved from fixture replacement, Beaver Hall will save roughly 4,281,000 gallons per year. When compared to the original water use of 8,895,000 gallons per year, Beaver Hall will see its water use drop by 48%. However, this is somewhat under what the total water savings will be. This does not take into account behavioral changes that will be promoted as part of the sustainability effort. It also does not take into account unseen changes due to the new technology, specifically the motion-activated water faucets. Again, these effects are difficult to calculate or quantify, but we estimate that they will be sufficient for us to exceed our target of 50% water savings in Beaver Hall due to our upgrades.
A major consideration in making these upgrades is the cost. As it is highly difficult to calculate labor costs, we are not taking them into account when making our cost estimate, and thus our estimate will be significantly lower than the “real-world” costs. Beaver Hall has eight floors, with two bathrooms per floor. Each bathroom has 5 showers, 5 toilets, and ten faucets. We were able to find faucets for $388.60 each, toilets (actually filters which reduce the amount of water per flush) for $111.51 each, and showerheads for $27.75 each. The cost of the greywater system is harder to determine, as they are more customized. Materials for a residential greywater system of the capabilities we are looking for cost roughly $500, so we simply scaled it up to get a rough estimate of the total cost. The total cost of materials for the upgrades to Beaver Hall is about $123,000.

Electricity Use

Current Use (from grid):
- 700,288 kWh/year

Target Use:
- 350,000 kWh/year

4 main methods:
- Solar power system
- Wind power system
- Upgraded heating system (as Beaver only uses electricity for heat)
  - Includes new windows
- Behavioral things

Solar system:
- 9000 ft^2
- Produces 9 W/ft^2 (solarelectricityhandbook.com)
- 9000 ft^2 * 9 W/ft^2 * 5 hours/days * 365 days = \[118260\text{ kWh/yr}\]

Wind system
- 3 turbines
- 10kW per turbine -> 37,000 kWh/yr per turbine = \[111,000\text{ kWh/yr}\]
  - Assume avg 7 m/s winds; state college has avg winds of 7.67 m/s
Heating System

- Windows: upgraded windows, 2-pane argon-filled
- Heating: HVAC system
- New insulation on outside of building
- Savings
  - Heating accounts for about 50% of electricity use
  - Heating upgrades save approx. 50% of heating bill
  - \( 700288 \times 0.5 \times 0.5 = 175070 \text{ kWh/yr} \)

Behavioral changes

- Turning lights off when leaving room
- Individual room controls for heating

Total savings:

- 404,230 kWh/yr
- 58% of original electricity use

Costs

- Solar: $34,800 for 19100 W system; wholesalesolar.com
  - For 81000 W system, goes to roughly $147,600
- Wind: Winforce 10kW system $49,000 per turbine ; pacifictoolcompany.com
  - For 3 systems, $147,000
- Windows: $500/room window, $5/in
  - Total: $192865
- HVAC: $4000 for 2000 ft^2 home
  - For ~115000 ft^2, roughly $230000
- Insulation: $1.28 per ft^2 * 60260 ft^2 of insulation = $77,300

The other main area Beaver Hall will become more sustainable is in its electricity use. Last year, Beaver Hall used 700,288 kWh/yr of electricity. In order to make this more sustainable, we aimed to cut the amount of electricity that Beaver Hall draws from the grid by 50%, for a final annual use of 350,000 kWh/yr of electricity. We managed to accomplish and exceed this goal, both through significant savings in efficiency and adding new green sources of electricity to the building.

To cut down on the amount of power Beaver needs to draw from the grid, we installed two power-producing systems. The first main system we added was a solar power system.
Beaver has a large, flat roof, ideal for hosting solar panels. We calculated that the roof has about 9,000 ft^2 of available area to install solar panels. Since an average solar panel in this climate zone produces about 9 W of power per square foot, we determined that our system would be able to produce 81 kW of power, or 118,260 kWh/yr. The second main system we added was a wind power system. Beaver is well-placed for wind power, as it is the tallest building in the immediate area and therefore any windmills on its roof will feel the full force of the wind. We planned to install three Winforce 10 kW windmills. These are rated to produce about 37,000 kWh/yr of power, given an average wind speed of 7 m/s throughout the year. Luckily, State College has an average yearly wind speed of 7.67 m/s, so the windmills should perform to their rated specifications. In total, these three windmills will produce about 111,000 kWh/yr.

In addition to adding new sources of power, we also planned to upgrade the building’s efficiency significantly so it will use less power. The main area we focused on was the heating system, as Beaver Hall uses electricity for its heat. There were three main systems we propose to upgrade the heating system. First, we plan to replace all of the windows in Beaver Hall with new, double-paned, argon-filled windows. This will significantly reduce heat loss through the windows, and enable residents to use the heat less. For a similar effect, we plan on installing new, high-efficiency insulation in the outer façade of the building as our second main system, further reducing heat loss. In order to take advantage of this reduced need, we plan to install individual room temperature controls, allowing residents to control when the heat is on in their rooms. This will allow us to significantly reduce energy use, as the heat is often on unnecessarily and residents have no choice but to open the windows and let the heat bleed out uselessly. Finally, to make the whole system more efficient, we plan to install a new HVAC heating system, allowing the whole system to use less electricity. It is difficult to calculate the effects of these changes on total energy use, but we estimated that they could reduce the total energy use due to the heating system by 50%. Since the heating system currently uses roughly half of the total electricity use of the building, this means that we can save about 175,070 kWh/yr from the insulation, HVAC, and new windows.

When all of these savings are added together, we can reduce Beaver Hall’s total energy use by 404,230 kWh/yr, or 58% of the original electricity use. Considering our original goal was to cut electricity use by 50%, we have easily exceeded our original goal. As with the water savings, however, these figures likely understate the total savings. These figures do not take into account the savings from behavioral changes, most significantly the individual room temperature controls. Unfortunately, it is nearly impossible to calculate how much these changes will save us given the resources we had to work with, and so we chose to leave it out of our calculations.
While the figures we have produced are impressive, we must consider how much they cost. The heating system has the two most costly single items, the HVAC system and the new windows. Determining the cost of these large systems was difficult, as most of these haven’t been applied to large buildings like Beaver Hall yet. We based most of our cost estimates on scaling up systems originally designed for residential use. The HVAC system is a prime example of this. Estimates for the costs a HVAC system for a 2,000 square foot home are generally about $4,000; scaled up to a 115,000 square foot Beaver Hall, the cost of the HVAC system comes to about $230,000. This was our most expensive system. The new windows were the next most expensive. Argon-filled, double-paned windows cost roughly $5 per inch of window. This comes to about $500 per standard room window, which is installed in each of the 35 room in eight floors. In addition to those windows, there are a number of differently-sized windows on the other floors, and so the total price of the windows comes to $192,865. This does not include installation costs. We found an estimate for the cost of a solar system of $34,800 for a 19.1 kW system. Scaled up to our 81 kW system, the cost of the solar system comes to $147,600. The windmills were the easiest to estimate. Winforce 10 kW windmills cost $49,000 to install, so three of them cost about $147,000. The insulation costs $1.28 per square foot to install. Given that 60,260 square feet of insulation must be installed, the total cost of the insulation comes to about $77,300. In total, the cost of the electricity upgrades to Beaver Hall is about $794,800.

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<th>Description</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solar System</td>
<td>$147,600</td>
</tr>
<tr>
<td>Wind System</td>
<td>$147,000</td>
</tr>
<tr>
<td>HVAC System</td>
<td>$230,000</td>
</tr>
<tr>
<td>Windows</td>
<td>$192,865</td>
</tr>
<tr>
<td>Water Fixtures</td>
<td>$73,000</td>
</tr>
<tr>
<td>Greywater System</td>
<td>$50,000</td>
</tr>
<tr>
<td>Insulation</td>
<td>$77,300</td>
</tr>
</tbody>
</table>

A breakdown of the costs of the project.
Chipboard Model:

Our scale model has a 1/8 inch to 1 foot scale. To produce our scale model we used 3-ply chipboard as the exterior walls, roof, base, and flooring to provide for a sturdy structure. We then used 2-ply chipboard for the interior walls which actually represent the difference in thickness between interior and exterior walls of the real plans. In addition to the use of chipboard we also used the band saw, hot glue, and a dowel rod. After scaling, measuring, and cutting the walls and floor, the hot glue was used to secure all pieces in their place. The dowel rod was utilized as the post for the wind turbines located on top of the building. Although windows and doors are not drawn onto the model, you can see in our calculations and plans how large they are, and where they would be located. The roof and its components were again constructed from chipboard, and the solar panels were attached at the perfect angle to enable the capturing of the maximum amount of the sun’s rays in the current month, 49 degrees from the vertical. One can see both the floor plan of a common floor, as well as the ground floor through our model. Also, we have incorporated the computer lab that is located across from the ground floor elevators in addition to the supplemental rooms existing on each floor.

Conclusion:

Making Penn State University a sustainable campus really would not be that hard if a few structural changes were made and even more behavioral changes were implemented into each student’s lifestyle. Most of the changes we have made are simple and actually not very costly, especially considering the scale of the building we worked on. The simple addition of fixtures such as low flow showerheads, water efficient faucets, and flush valves on toilets and urinals make a huge difference in the efficiency of Beaver Hall. If only those people who realized that something needs to be done were willing to make small lifestyle changes towards sustainability, Beaver Hall could be completely self-sustainable. Hopefully, with the programs, appliances, and other sustainable technologies we have included in our plans, Beaver Hall will be on its way to sustainability. We have managed to make this Residence Hall sustainable, while simultaneously maintaining the comfortable lifestyle of a college student and meeting our target specifications. Team Name is very proud of our work and would like to make an impact on the sustainable community existing within Penn State, and as always we would also like to thank Professor Bharti and EDSGN 100 for giving us the opportunity to create this model and project.

Resources:
Sustainablesupply.com
Plumberssurplus.com
 solarelectricityhandbook.com
Wholesalesolar.com
Pacificoolcompany.com
Homewyse.com
Housing.umn.edu

*We also used the Excel Spreadsheet of Water Usage supplied to us by our Professor and the floor plans obtained from a member of the Penn State faculty.