IPRO It takes a team!
INTERPROFESSIONAL PROJECTS PROGRAM

IPRO 337: THE ZERO ENERGY LAB
FACULTY ADVISOR: NANCY HAMILL – GOVERNALE

I. ABSTRACT

The ultimate goal of the Zero Energy Lab is to get the fourth level of machinery hall off the electrical grid. The IPRO is moving towards transforming the space into a research space for future energy and lighting technologies. Since the end goals of the Zero Energy Lab are ambitious for one semester we are proposing to address solar hot water, a golf cart used as a mobile battery bank, and window efficiency this semester. Each member of the team was able to learn more about various technologies that we were implementing in the lab. Everyone had hands on experiences with energy efficiency and green technology. The team is a collaboration of students from various majors including architecture, political science, civil engineering, electrical engineering, mechanical engineering, and biophysics. Together we believe we were able to create a cohesive end product and worked well together along the way. The group was able to define the goals quickly and get started on the projects early on in the semester.

II. BACKGROUND

In semesters past there were various technologies implemented to take steps closer to going off the grid. A solar cell/ hydrogen fuel cell hybrid system has been developed and its purpose is to supply energy to the lab space. A passive environmentally friendly climate control system has also been researched in the past. A few other technologies previously researched are photovoltaic arrays and wind turbines for power generation, battery systems for energy storage, passive cooling and heating systems, desiccant systems, and various devices native to the laboratory environment. The Zero Energy Lab is also overall supposed to be a research space for people to collaborate with others from various backgrounds to find a solution to current issues.

Last semester's IPRO divided into three subgroups: the Lab Space group, the mobile energy station group, and the windmill team. The Lab Space group made the space a more usable and efficient Lab area. The Mobile Energy Station Team created a golf cart that is a mobile battery bank to be used within the lab space. The Windmill team built a 27 foot windmill and tested it outside. The results obtained from testing the windmill were favorable to the Chicago area due to efficient wind power.

The societal issue that is being addressed in this project is that of energy. With the varying costs for different forms of energy, the zero energy lab is supposed to not rely on any of these issues. A large goal of the team is to develop cleaner ways to live and sustain ourselves with a similar quality of life as is current. The lab will be a functioning space that will produce and use its own energy and not rely on "grid energy." Going off the grid is intended to provide a passive way to collect and use energy while also paying close attention to the environment. Throughout the IPRO, the team predicts to run into certain ethical issues and has prepared for them. With the various ways of testing, the team is prepared to take the extra steps to ensure that toxins are not being released into the environment. During various types of testing it is possible that water contamination could occur. Of course the contamination would not reach levels of danger but the IPRO team will implement various backflow and filtration systems to prevent contaminated water to enter the city's main water supply. Another obstacle predicted to occur is that of building permits. The group has committed to following all Chicago and the State of Illinois building codes. Emissions will also be handled very carefully in order to maintain the current environmental status if not a better status. Overall, since the goal of the IPRO is to improve environmental conditions, the preservation of the current conditions will be top priority.

The team had determined that the expenses for the project were very much up front with the cost of products, materials, etc; however, the payback for the systems will be sufficient enough to gain a return on the initial expenses and also will provide lower energy costs and emissions.

During initial goal setting, the team decided that it was possible for new information to be found. The group agreed that all new discoveries will be posted in the public domain, available for further research and use by outside parties.

III. OBJECTIVES

a. Ventilation Sub-group

The main goal of the ventilation sub-group is to decrease if not eliminate the need for an active cooling system. In order to achieve this, the group must look into installing a mechanical system for opening the windows.

i. The group will determine which will be best for the particular kind of windows that are currently in the space.
ii. Once all this can be determined, a mechanical system for opening the windows can be installed.
iii. Afterwards, a sensor system can be installed and programmed to open the windows given certain conditions. Budget provided, this project should be easily completed within the time allotted.
iv. Also, provided that the weather becomes warm enough, the system's effectiveness will be able to be tested in the appropriate conditions.
v. This particular group would need photographs taken and close observations be made of the mechanisms and their installation. These would aid in fixing any failures should they occur.
vi. During testing the sensor will be most observed to see if it works the appropriate way for this application.

vii. The results from testing will be reviewed to identify trends and determine if the solution is the best possible outcome for the space.
viii. If the end product is not up to par, the appropriate adjustments will be made to maximize efficiency.

b. Solar Hot Water Sub-group

One of the major problems of the lab space is that there is a lack of an efficient active heating system; there is no running hot water supply either. The solar hot water sub-group would like to implement technologies to provide the space with these two systems. The team plans to assemble a solar collector in order to address the stated problem. Currently there is a solar collecting system in place; however it is not efficient enough for the size of the space.

i. The first step is research to investigate the most economical and efficient systems for the space and the needs of the space. The sun is the main source to develop hot water for a passive heating and cooling system. Case studies will be the main source for research methods other than actual testing. Throughout the semester a strict timeline will be followed in order to find the best system to provide both hot water and the heating and cooling system. Depending on obstacles experienced in the research, testing, installation stages, time constraints, etc. if the system is not fully working, enough research will have been conducted for another party to complete the task.
ii. This sub-group expects the testing and experimentation to determine the quantity of water necessary for a certain volume of space before needing to be replaced.
iii. During research, commercial fabrications and their level of efficiency will be compared to the efficiency levels of a system assembled by the group members. The differences in installation, cost, efficiency, durability, labor efforts, and various other factors will determine which system is better for this lab space.
iv. Research of solar hot water will include but will not be limited to topics of installation, waterproofing methods, insulating methods, thermal storage methods, low emissivity/ cost effective paint options, control systems, drain back vs. antifreeze uses, closed loop vs. open loop systems, line power vs. photovoltaic power systems, differential controllers, glazing types, and series vs. parallel connections for multiple panel uses.
v. After thorough research is finished materials for a thermal collector will be purchased. These materials will allow the sub-group members to assemble, install, and use a thermal panel to gain results from testing.
vi. Also an already assembled panel will be purchased for comparison testing purposes.
vii. The final stage will be to test and record data. The testing conducted will determine various results.

1. Actual cost will also be determined upon completion of assembly and installation of both types of panels. Manufacturing and shipping time will be determined upon receiving the units.
2. The required labor and skills of assembly and installation will be determined.
3. The temperature and flow rates achieved by the thermal collectors will be measured and recorded.
4. Also, the major discovery that will be determined will be which system, the self assembled system or the pre-assembled system, is more efficient and suitable for this particular application.

viii. A possible outcome that is predicted by the team is that the self-assembled system will be the better application because it will be less cost even though the labor will outweigh the pre-assembled system.

ix. The group will also determine the best working system for the needs of the space. The sub-group will be able to record data for a working prototype, create installation and assembly instructions that were beneficial in this application, and also experiential feedback. These discoveries will be recorded in the form of deliverables made available to the IPRO office.

c. Energy Conversion Cart Sub-Group

The last issue being addressed in this IPRO is the lack of electrical power. Currently the space is being run off of AC power from Commonwealth Edison. The goal is to harness the sunlight through the use of photovoltaic panels to create power for the space. There are solar panels on the roof of machinery hall charging a bank of four batteries. The current battery storage bank is inefficient. The power from the solar panels is in effect being wasted. Storage of the electric energy will be in battery banks and a controller will be installed to provide feedback and to manage the balance of the batteries. There is an electric cart that is used as a mobile carrier for the battery bank. That battery bank is inverted to supply 120 volts AC where needed on the fourth floor. The current problem is that the batteries are being charged through Commonwealth Edison. The batteries need to be charged using the photovoltaic panels on the roof instead so that the panels will not be gathering wasted energy.

i. The first task will be to gather all of the specifications of the current battery charging system. The critical components will be the inverter, battery charger, controller, batteries, and solar panels.

ii. Once the components are known and their limitations are well defined, a schematic can be made. This will serve well in future projects.

iii. The next major task is to research possible solutions or systems that can be implemented as an upgrade to the existing conditions.

iv. Using the specifications, schematic and budget limitations, appropriate components can be ordered.

v. The next task will be to safely install the devices.

vi. Finally the system can be tested and the actual improvements documented.

IV. METHODOLOGY

a. Ventilation Sub-Group

During last semester, Zero Energy Lab Fall 2008 team conducted research on the wind conditions outside the energy lab. It was found that generally, there existed a steady wind from the south. Linking this with current research, it was found that a steady wind from this direction onto the building (the windward side of the building) would create an area of lower pressure outside the roof windows. This, linked with a potential temperature difference between the inside and outside of the building would cause both stack (created by temperature differences) and wind driven (created by pressure differences) ventilation. This would remove warm air from the Zero Energy Lab space. The air conditioning that exists on the lower levels of the building would then create of flow of air up and out of the building. This should adequate ventilate the Zero Energy Lab.

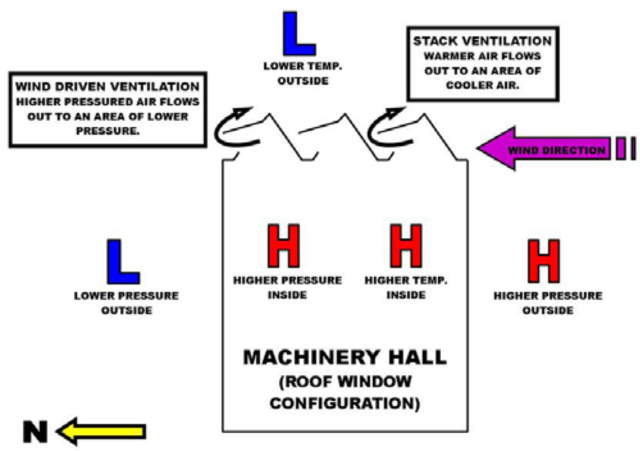


Diagram Showing Wind Direction in Relation to the Building

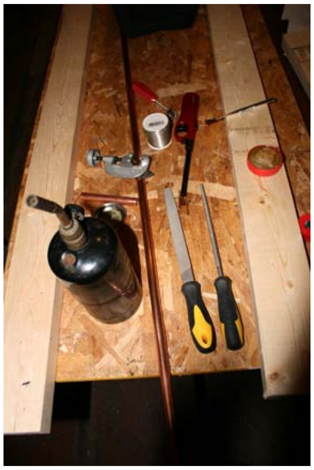
Current Window Conditions

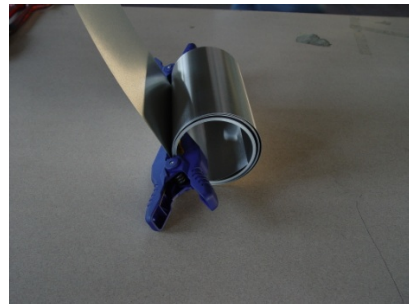
The ventilation sub-group began by researching natural ventilation methods in order to determine its effectiveness under the current particular circumstances. Then, a mechanical system for opening the windows was designed, keeping in mind current design of the windows. The Sub-group them completed research on what conditions the windows should be opened and closed for optimum ventilation. This involved looking at the parameters of similar designs and looking at the mechanics of natural ventilation. Also, research needed to be completed on what parameter values would indicate rain. The group then created a program which would tell the actuator when to open and close the windows based on the inside temperature as well as outside temperature, dew point, and barometric pressure. Lastly, the group analyzed cost of installation of a natural ventilation system in comparison with the cost of cooling in order to determine the cost benefits. Lastly, a model was constructed of the proposed window system.

Construction of the Window Model

b. Solar Hot Water Sub-group

The solar hot water sub-group's main objective was to build a solar thermal collector that could be used as a model for further research and development of passive heating and running hot water. The group began by researching the most efficient and cost effective systems that had been built by everyday people rather than a manufacturing company. Once a design was chosen for the solar collector a list of needed materials was assembled.





Tools and Materials Acquired and Used

Materials were specified based on cost and quality. Enough materials for a 4’ x 8’ solar collector were acquired and the decision to make 2 collectors for transportation reasons was made. Once the materials were acquired construction began on a 2’ x 8’ collector. The assembly consisted of cutting the copper pipes to size, cutting the wood to size, soldering the copper pipes together to ensure no leakage would occur in the collector, the wood was both applied with caulking and screws to ensure strong fastening, aluminum sheets were placed over the copper pipes and screws were drilled through the aluminum into the wood backing to keep the pipes from moving and also to ensure a better efficiency and conductivity rating.

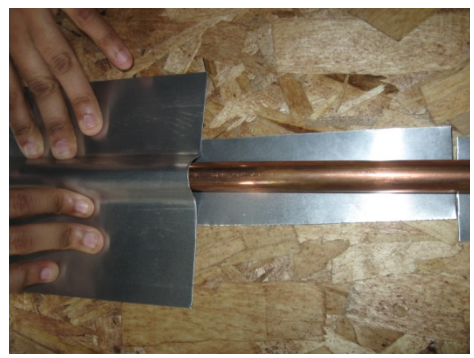
Soldering of the copper pipes

Caulk was used for fastening the wood to itself

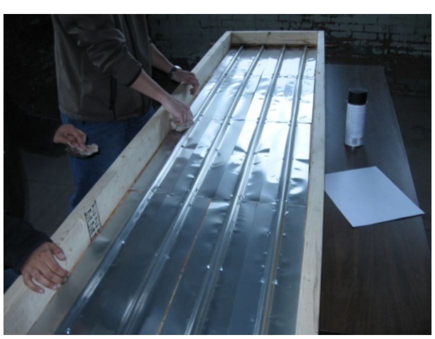
Attaching Plywood Backing

Solar Collector Prior to Aluminum Sheets being installed

Bending of Sheet Aluminum to fit around copper pipe



Fitting Aluminum Sheets around copper pipe prior to drilling screws



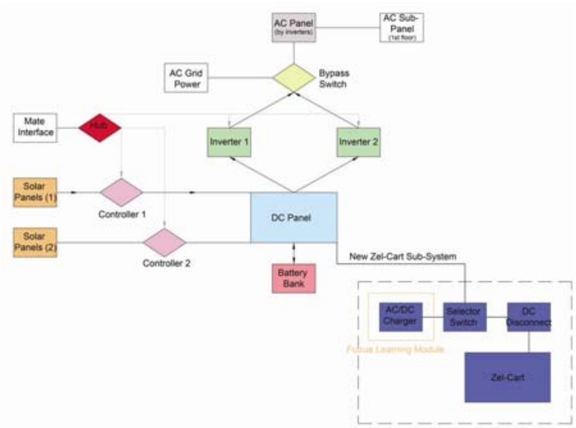
Collector prior to Black Painting

Spray Painting collector

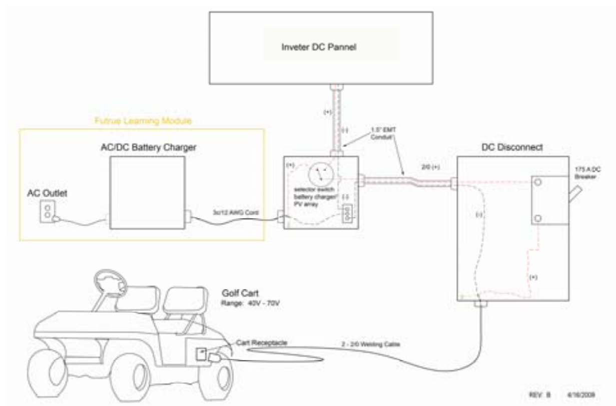
This was followed by painting the entire collector black to provide better absorption rates. Next, insulation was attached to the back of the collector to insulate it. Lastly, the solar thermal collector was placed on the roof of Machinery Hall and tested.

c. Energy Conversion Cart Sub-Group

The Energy conversion cart sub-group began by analyzing and documenting the existing system because nothing had been done like this previously. Next, they reviewed the hardware and met with the lab technician, Geno. They then talked with various suppliers, distributors, and manufacturers about the current situation. Documentation was created that clearly communicated the understanding of the system in terms anyone could understand. The group then designed the subsystem which can be seen in the following diagrams.



System Diagram



Overall Diagram

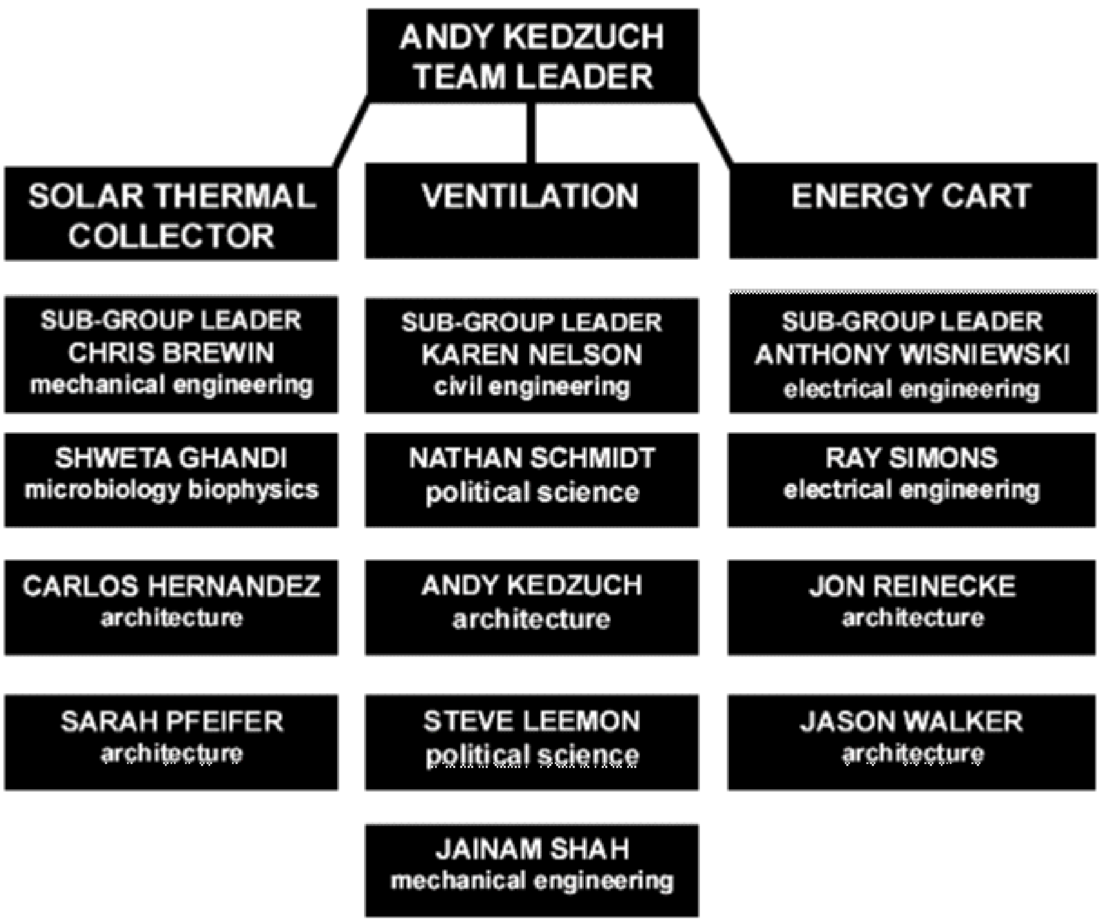
The subsystem was then connected into the DC panel of the outback. It is currently being run through a selector switch to allow future additions of an alternate charger. The system was run through a 175 amp circuit breaker and utilized an Anderson Power product SB connector after consulting with the MFR. The cart's battery bank was then rewired to include a 2/0 cable to accommodate a potentially high current. The system was then fully installed in 66 man hours. The installation was then tested and proved to be in working condition.

Photovoltaic Panels on the roof of Machinery Hall

System Prior to installation

V. TEAM STRUCTURE AND ASSIGNMENTS

a. Team Structure



b. **Individual Assignments**

i. **Ventilation Sub- Group**

1. Karen Nelson (3rd year civil engineering) was the leader of this sub-group. She researched the feasibility of the window/ ventilation system. She also determined the parameters for the window program. She was also in charge of making the final presentation power point slide show.
2. Nate Schmidt (4th year political science) conducted ventilation research. He also helped with the brainstorming of the window design and code criteria. He conducted the actuator research and acquired the appropriate actuator for this application. He was part of the construction team on the window study model.
3. Andrew Kedzuch (5th year architecture) was the overall IPRO team's leader. He was in charge of the window linkage. He also helped with the window electronics and code design. He helped with the construction of the window. He also contributed various images and renderings for the deliverables.
4. Steve Leemon (4th year political science) conducted ventilation and systems research. He also helped with design schematics and the final decision of the team. He purchased the lumber and other design components of the window study model. He was in charge of transporting the window to and from the Herman Union Building for IPRO Day.
5. Jainam Shah (3rd year mechanical engineering) conducted research for the ventilation team. He was also the head of designing the electronics for the code design.

ii. **Solar Hot Water Sub- Group**

1. Christopher Brewin (3rd year mechanical engineering) researched different designs of solar thermal collectors. He also helped design and assemble the collector. He helped with the midterm presentation and also the final presentation.
2. Shweta Gandhi (2nd year molecular biochemistry/ biophysics) was in charge of taking meeting minutes each week. She helped assemble the solar thermal collector as well. She worked on the

brochure with other team members and took pictures throughout the semester as documentation.

3. Carlos Hernandez (4th year architecture) helped with researching of solar thermal collector case studies. He also helped assemble the solar thermal collector. Carlos helped assemble to brochure and he was also in charge of taking pictures throughout the semester as documentation of what was achieved.
4. Sarah Pfeifer (4th year architecture) helped with research of solar thermal collector designs. She also put together the deliverables for the team. She helped assemble the solar thermal collector as well. Lastly, she helped taking pictures as documentation during the semester.

iii. Energy Conversion Cart Sub- Group

1. Anthony Wisniewski (4th year electrical engineering) was the leader of the energy conversion sub-group. He worked with the vendors of the materials used and also helped a great deal with the installation of the system. Anthony also faced a tragedy in the 10th week of the semester and decided to minimize his participation in the IPRO for personal reasons. He was responsible for various research conducted about the system and also for the midterm presentation slide show.
2. Raymond Simons (4th year electrical engineering) was the one to take over after Anthony left. He was responsible for sourcing the materials that were needed for the project. He worked with the product vendors to find out more about making the system more efficient for this use. He helped installing the system and also was the speaker for the sub-group in the final power point presentation.
3. Jon Reinecke (4th year architecture) was responsible for documenting the electrical systems. He helped with the installation of the system as well. Lastly, he created various graphics based on the system for the deliverables.
4. Jason Walker (4th year architecture) helped Jon to document the electrical systems. He also helped with the installation of the system. He helped with the final abstract and provided graphics for the deliverables.

VI. BUDGET

a. Ventilation Sub-Group

Materials	Company	Cost
Arduino USB Board	www. Sparkfun.com	$29.95
Breadboard Mini Self-Adhesive Black	www. Sparkfun.com	$3.95
Solar Cell Large	www. Sparkfun.com	$34.95
SCP 1000 Gasket	www. Sparkfun.com	$0.95
USB Weather board	www. Sparkfun.com	$124.95
Humidity and Temperature Sensor	www. Sparkfun.com	$41.95
Lumber	Home Depot	$50.00
TOTAL:		**$276.70**

b. Solar Hot Water Sub-Group

Materials	Company	Cost
AL roll 6” X 50'	Home Depot	14.19
2” X 4” X 8'	Menards	8.95
10' X 1/2” M copper pipe	Home Depot	47.52
Poly insulation 4' X 8'	Menards	13.79
Copper connectors and tees	Menards	15.68
Plastic connectors and hose	Menards	13.89
OSB	Menards	11.18
Silicon caulk	Menards	19.88
Pump	Sidewinder Computer	68.75
Polycarbonate 2' X 8'	Lowe's	29.24
Screws	Menards	12.77
Soldering supplies	Menards	24.28
Paint	Home Depot	9.49
Tax		20.76
TOTAL:		**310.37**

c. **Energy Conversion Cart Sub-Group** (All costs of this sub-group were reimbursed by the TGI Grant from previous semesters)

Materials	Company	Cost
Various	Advanced Electrical Supply Company	$656.47
Disconnect Box	Affordable Solar	$190.00
APP SB Connector Repair	Crown Forklift	$32.00
Total		**$878.47**

VII. CODE OF ETHICS

The IPRO Team expected each team member to be punctual in class attendance, punctual in assigned tasks, appropriate levels of completeness of assigned tasks, conscientiousness of ethical issues, respect within the group and with other consultants. The team did abide by IIT's code of conduct regarding research and experimentation and gave credit to those deserving. In a case an issue arose within the team, the appropriate action was taken. The issue was addressed within the subgroup. If the problem was not solved at that level of command it continued to the command of all of the sub-group leaders. If still then the problem persisted, the faculty advisor would be brought in to help.

The team took careful steps to ensure the decisions and actions were ethically sound. The solar hot water sub-group made sure to assemble the collector in the proper environment to ensure no unnecessary emissions were emitted into the atmosphere. Also the proper safety precautions were taken while working in the model shop, spray painting, and soldering. The ventilation group made sure they did not go beyond their knowledge by taking the existing windows apart without realizing the windows needed professional help. The energy conversion cart sub-group had to deal with losing the leader at the end of the semester and had to pick up the extra work he had left for them to complete. Anthony was able to come in for their milestone day of installing the system however. Also the entire team had to deal with a very limited budget. Sticking to the proposed financial assistance from the IPRO office was an ethical task as well. The initial proposed budget was five times the amount provided and the IPRO team made sacrifices and other arrangements for the project plan in order to keep the spending below the amount given.

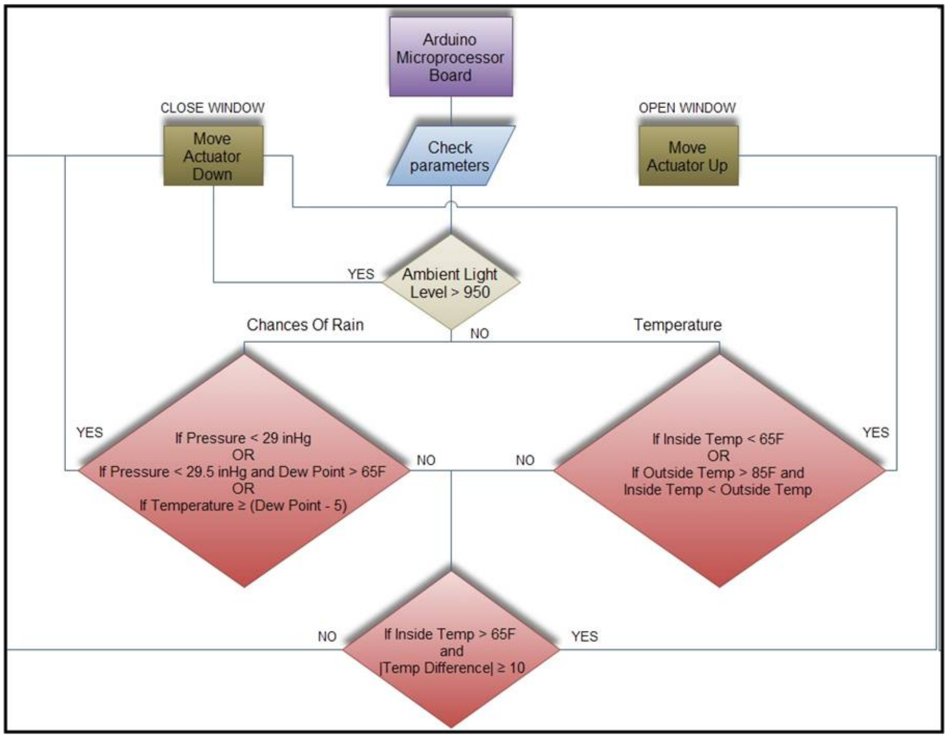
VIII. RESULTS

a. Ventilation Sub-Group

Cost Estimate of Window System

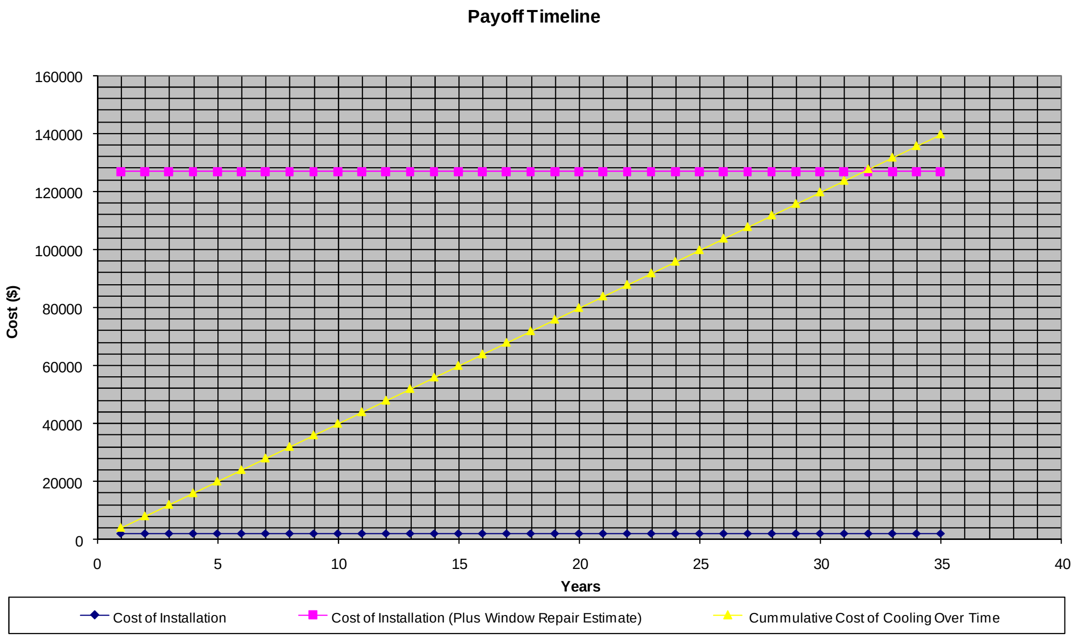
COST OF INSTALLATION		
Item	**Item Type**	**Price**
Arduino USB Board	Inside Unit	$29.95
Breadboard Mini Self-Adhesive Back	Inside Unit	$3.95
Humidity and Temperature Sensor - SHT15 Breakout	Inside Unit	$41.95
2xbees (Wireless Upgrade)	Inside/Outside Unit	$20.00
xB Shield (Wireless Upgrade)	Inside Unit	$20.00
Solar Panel (Wireless Upgrade)	Outside Unit	$30.00
Solar Cell Large	Outside Unit	$34.95
USB Weather Board	Outside Unit	$124.95
SCP1000 Gasket	Outside Unit	$0.95
Actuator	Mechanical Unit	$125.00
Motor Controller	Mechanical Unit	$48.00

Adapter	Mechanical Unit	$10.00
TOTAL COST OF PARTS:		**$489.70**



Final Code Diagram

Final Model of Window Design Mock-Up

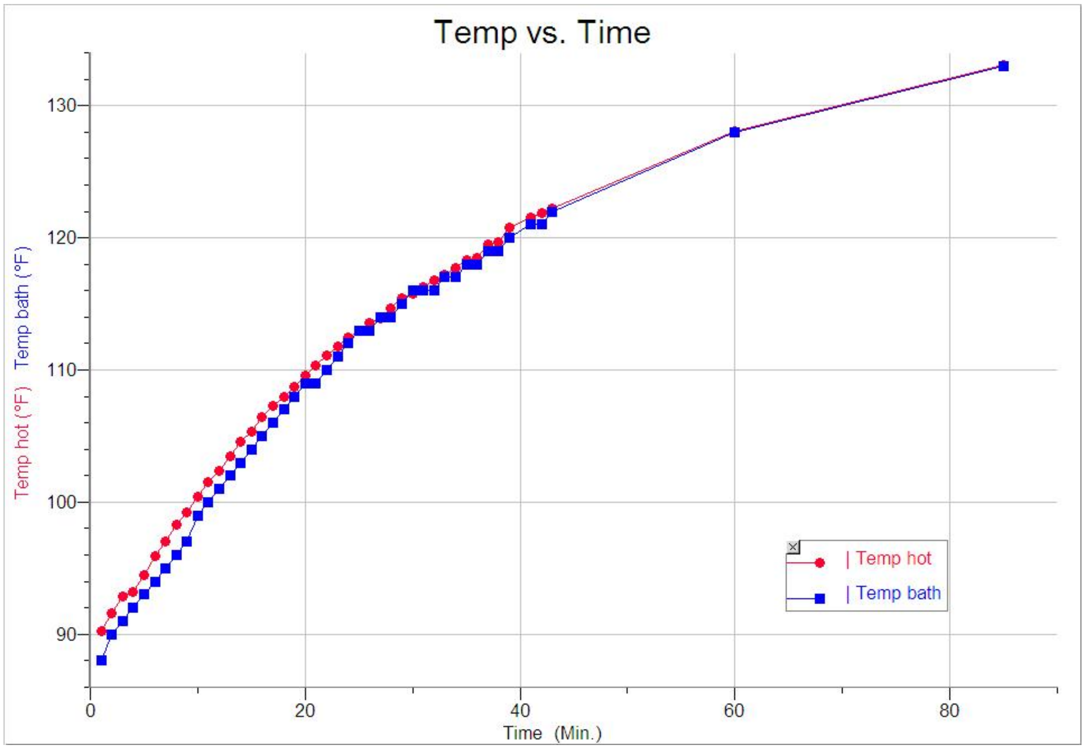


Benefit Cost Analysis

b. Solar Hot Water Sub-Group

The Solar Hot water group was able to test the efficiency of the collector. The water in the collector got up to 330 watts of heat at 115°F. The collector overall has a thermal efficiency of 26%. Also the collector ended up costing less than $100.

Testing the Collector on the roof of Machinery Hall



Graph of Results of Solar Thermal Collector

c. Energy Conversion Cart Sub-Group

Installation and Connection of Battery Bank

End Product after installation and connection

The installation of the new system proved to be very beneficial for future users. By connecting the cart, the system's energy storage was doubled from 96 am hours to 192 amp hours. There was no anticipation of needing to accommodate higher current. This necessitated the addition of the 2/0 wiring and researching connectors.

Anderson Power Products was consulted with often and were able to come into the lab space for a visit. Budget constraints prohibited the purchasing of the addition of new batteries and so the existing batteries were integrated into the system. Research was conducted to find an appropriate replacement battery in the future.

IX. OBSTACLES

a. Ventilation Sub- Group

i. The windows sub-group began the semester without any previous research on ventilation and wind studies around the area. With further time, they were able to find few diagrams about wind from previous semesters. The disorganization of past IPRO files was an obstacle for the group.

ii. Another obstacle faced by the ventilation sub-group was the fact that the windows are not operable at the moment. The initial design was going to implement the actuator on the current window system. The current system however, is covered with corrugated acrylic to protect against leaking making the windows inoperable.

iii. Another obstacle was to determine and define the parameters for opening and closing of the windows. This task was difficult because no previous research was found within IPRO and also public case studies were not easy to come by in this particular subject.

b. Solar Hot Water Sub- Group

i. The solar hot water group had a very big obstacle in the budget. The initial objectives called for purchasing the materials to build a solar collector and also to purchase an already manufactured solar collector. The intentions were to test which collector was more efficient in comparison to its cost. The sub-group had to limit their purchases to the materials to build their own collector and not purchase a manufacture collector anymore.

ii. The sub-group was required to find the most economical materials that would work for the application and not compromise the end results. Also finding a location that was easily accessible and would deliver quickly was a task.

iii. Another obstacle for the sub-group was to acquire the materials. Many of the students did not have any other transportation other than that of the CTA and the mass of the materials would make that impossible to travel via public transit. This called for the sub-group leader to acquire the materials on his own. The sub-group did pitch in to transport the materials from his car to the zero energy lab space.

iv. The initial design called for a collector measuring 4' x 8'. This proved impractical with travel. Testing the collector required for it to be taken to and from the roof space frequently. The solution to this problem was to minimize the design to a 2' x 8' collector. The materials for another collector at the same size were also purchased and could be used in future IPROs.

v. Testing design was another obstacle experienced. Time did not allot for much testing however there was some done. The collector yielded better results than expected, however, more research and testing should be done to ensure appropriate results.

c. Energy Conversion Cart Sub-Group

i. The energy conversion sub-group had difficulty with the unanticipated high current design issues.

ii. The inter-connect design of the cart was difficult to understand as appropriate documentation was not made from previous IPROs.

iii. The constraints of the budget were also an obstacle to overcome. This particular project within the IPRO had previously received grant money that was used throughout this semester to help with their project.

iv. Lastly, the loss of the sub-group leader during week 10 was a very difficult obstacle to overcome. Anthony was very hard working and knew a lot about electrical engineering.

X. RECOMMENDATIONS

a. Ventilation Sub-group

i. The window group faced some very difficult obstacles with the less than ideal current condition of the windows. However, they were able to create what they envisioned in the space for the ideal ventilation.

1. The sub-group advises for more research on climate conditions be conducted to improve the operating parameters of the window.

2. Another recommendation would be to research another additional energy-efficient cooling method that would link in well with the proposed window system.
3. Lastly, the sub-group advises that the repairing or replacing of the windows occur in order to install the proposed system.

b. Solar Hot Water Sub-group

i. The solar hot water group made giant leaps forward in regards to this idea of hot water in the space. As previously mentioned the space has no means of hot water or a heating system and the solar hot water group attempted to remedy the issue. Further steps are recommended for this project and those are as follows:
   1. A large thermal storage capacity: Time did not allow the sub-group to develop an efficient storage system for the sun heated water. The recommendation is to assemble a storage system instead of purchasing an already made one. This would in turn allow the group to determine the more efficient of the two, pre-manufactured or self-assembled.
   2. Another recommendation for this sub-group if it were to continue is to develop the use of hot running water by using the solar thermal collector. This would of course call for a purification system of some sort.
   3. The group also encourages the development of a means of solar air conditioning. With the correct alterations to the system, solar air conditioning could also be used.
   4. Design backup system is also very important especially in a place as Chicago with its ever changing climate. Due to a number of colder or cloudy days the water in the collector could possibly not work to its full potential which in turn provides for less than the best results for water temperature. This prohibits from being able to heat the space as usual. With an alternative heating system, the cloudy days would not be as inconvenient. The system would have to be just as energy efficient as the solar thermal collector as well.

c. **Energy Conversion Cart Sub-group**

   i. The energy conversion cart faced many obstacles as well. Initially, understanding the current system was a task unto itself but when the sub-group understood the system they were able to quickly make efficient decisions for the application.
      1. The sub-group advises to continue to improve and increase the battery storage.
      2. Another recommendation is to add a DC/AC inverter to cart which would prove the cart to be even more useful.
      3. Lastly, the group would like to see an addition of uses be made to the existing system so that the stored energy can be used throughout the lab space.

XI. References

a. **Ventilation Sub-Group**

   i. Wind: http://www.met.utah.edu/jhorel/html/wx/climate/windavg.html
   ii. The Fluid Mechanics of Natural Ventilation: P.F. Linden, Department of Applied Mechanics and Engineering Sciences, University of California, San Diego

b. **Solar Hot Water Sub-Group**

   i. http://www.builditsolar.com/Experimental/WallStorage.pdf
   ii. http://www.builditsolar.com/
   iii. http://www.builditsolar.com/Projects/LowTechCol/LowTechCollectorR2.pdf
   iv. http://www.builditsolar.com/Experimental/CopperAlumCollector/CopperAlumCol.htm

c. **Energy Conversion Cart Sub-Group**
   i. Anderson Power

XII. Resources

a. **Ventilation Sub-Group acquired their materials from the following**

   i. Lumber and hardware: Home Depot

ii. Window: Nancy Hamil-Governale
iii. Actuator (http://www.firgelliauto.com/product_info.php?cPath=76&products_id=3)
iv. Power Adapter http://www.firgelliauto.com/product_info.php?cPath=99&products_id=103
v. Controller (http://www.dimensionengineering.com/SyRen10.htm)
vi. http://www.sparkfun.com/commerce/product_info.php?products_id=8257
vii. http://www.sparkfun.com/commerce/product_info.php?products_id=8311
viii. http://www.sparkfun.com/commerce/product_info.php?products_id=8925
ix. http://www.sparkfun.com/commerce/product_info.php?products_id=7840
x. http://www.sparkfun.com/commerce/product_info.php?products_id=8803
xi. http://www.sparkfun.com/commerce/product_info.php?products_id=666

b. **Solar Hot Water Sub-Group acquired their materials from the following**

i. Home depot
ii. Menards
iii. Sidewinder Computer
iv. Lowe's

c. **Energy Conversion Cart Sub-Group acquired their materials from the following**

i. Advanced Electrical Supply Company
ii. Affordable Solar
iii. Crown Forklift

d. The team as a whole spent about the same amount of time per person on the project. Some students were able to spread out their efforts for the duration of the whole semester while others spent their time all at once. This was due to the experience levels and specialty areas of each individual. As a whole, each student contributed about 25 hours per week for the project. This allowed for good results to come out of the IPRO in the various areas. Most of the materials were acquired from local hardware stores such as ACE Hardware and Home Depot.

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f. Outback Power Systems, Arlington WA
g. Sun Xtender Batteries, West Covina CA
h. Manuel Garcia, IIT Facilities, Electrician
i. Ray DeBoth, Retired Engineer
j. Bridget Ford, IO Lighting
k. David Lavan, Elara Engineering