SIEMENS SUSTANABILITY PROJECT: MORE EFFICIENT WINDOWS

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Abstract

This report will explain the detailed steps we undertook during the improvement of the windows in the Penn State dorms. The goal of this project was to increase the efficiency of the windows to help cut back on heating and cooling cost by apply a coating to the windows and improving the seal to help keep heat in the building. The current windows around the campus dorms work in the fact that they help keep the bugs out, but they do not do much for the keeping the warm air in. Through collective brainstorming, our team analyzed the problems associated with the old windows. We decided which aspects needed improvement, which ones needed to be redesigned, and which ones could be left alone. Our team conducted a survey of potential customers and examined the data through various PCC and AHP charts. From the results of the survey and our team's ideas, we felt the most important features that needed to be worked on were the sealing of the windows and the amount of energy and heat they can keep in. Each of these features needed to be redesigned in order to create a more effective and low cost design. We successfully accomplished our overall goal of creating a more efficient window by modifying key aspects of the window and frame. The following report outlines the research process and development that we undertook to improve the window in the dorms, and concludes with the finished model of our more efficient windows.

1.0 Introduction

Windows have been around almost as long as man has created sophisticated buildings, and they have undergone significant advances in design and technology since their inception. With the increasing emphasis on energy efficiency, their popularity has grown and the need for more proficient windows to save on energy costs has become imperative. The windows of the dorms at Penn State are more than half a decade. And yes the windows still work to keep out pests but they are nowhere near new nor do they match the new way people think about energy conservation. Our initial mission was to improve the windows on campus in the cheapest and most efficient way possible.

To begin the redesign process, our team analysed and inspected the windows in the dorms. To make the windows more energy efficient, we began by finding where the window was weak at in terms of where the most energy escaped from. We then used this information to see what the students at Penn State wanted to do about the inefficient window problem. Next we researched some aspects of the window to help put together a survey.

In order to determine the importance of the various qualities of the more efficient window, we surveyed the student currently living in the dorms around campus and used this information to begin assessing the important attributes of our new window. Using our initial list of possible consumer needs, we then used the collected data to prioritize these needs and create charts, like the AHP Pairwise Comparison Chart, to better understand which aspects of the window we needed to focus on for our more efficient window.

1.1 Initial Problem Statement

Our team must improve upon the efficiency of the windows around the Penn State campus to help cut back on University spending on wasted heating that is lost through windows that does not keep that expensive heat in.

2.0 Customer Needs Assessment

In order for our team to properly redesign the dorm room windows, we conducted a survey through which we identified how students felt about the current windows in their dorm rooms. Each group member interviewed two/three students on Penn State's campus about the subject. The questions were aimed at determining student's thoughts on the current status of their windows, and how they felt about the inefficiency of them. The subjects interviewed are freshmen living in college residence halls on the Penn State University Park Campus. The results of this survey will aid our team in determining future design aspects in the new window and track system we are creating.

2.1 Weighting of Customer Needs

From the data collected in the survey, we created an AHP and PCC of the attributes, so that we could create a weighted customer needs chart. Weighting our customer needs was an important step because it allowed us to determine which aspects of the redesign to focus on. Table 1 lists all the criteria that our team has identified as integral in our revision process, as determined by the results of the surveys. As a group, we conducted a product analysis and determined which attributes we needed to improve. We considered our target audience and their answers to our surveys and decided that the following criteria would be necessary to revise. The weights determined from the AHP and PCC gave us better information on the importance of the different attributes.

Table 1. Initial Customer Needs List Obtained from Team Focus Group

This table lists the criteria that our group, prior to surveying our target audience, felt needed to be emphasized and/or improved. We later used this list to categorize and weight our main objectives of our redesign.

Aesthetically Pleasing
Cost
Energy Efficient
Size
Ease of Use
Quality

Table 2. Hierarchal Customer Needs List Obtained from Focus Group and Individual Interviews

This table shows how we organized our criteria into different categories to better understand the main ways in which the product needed to be redesigned. This allowed us to focus on overall aspects of the design process to improve the final product.

1.Sustainability
1.1 Cost
1.2 Energy Efficient
2. User Friendly
2.1 Aesthetically Pleasing
2.2 Size
2.3 Ease of Use
2.4 Quality

Figure 1. PCC (Pairwise Comparison Chart) to Determine Weighting for All Customer Needs

Evaulated	Aesthetically Pleasing	Cost	Energy Efficient	Size	Ease of Use	Quality		Total
Aesthetically Pleasing		-1	-1	1	1	-1		-1
Cost	1		-1	1	1	1		3
Energy Efficient	1	1		1	1	1		5
Size	-1	-1	-1		-1	-1		-5
Ease of Use	-1	-1	-1	1		-1		-3
Quality	1	-1	-1	1	1			1

This pairwise comparison chart compares the importance of each attribute. This gave us a better idea of which aspects of the redesign should take precedence over the others. The attribute got a score of 1 if it was more important than the base attribute, 0 if it was of the same importance, and -1 if it was less important.

Figure 2. AHP Pairwise Comparison Chart to Determine Weighting of All Customer Needs

Evaulated	Aesthetically Pleasing	Cost	Energy Efficient	Size	Ease of Use	Quality		Total	Weighted
Aesthetically Pleasing		0.50	0.25	1.50	1.25	0.75		4.25	0.0935
Cost	2.00		0.50	3.00	2.50	1.50		9.50	0.2090
Energy Efficient	4.00	2.00		6.00	5.00	3.00		20.0	0.4400
Size	0.67	0.33	0.17		0.83	0.50		2.50	0.0550
Ease of Use	0.80	0.40	0.20	1.20		0.60		3.20	0.0704
Quality	1.33	0.67	0.33	2.00	1.67			6.00	0.1320

The AHP takes the criteria from the PCC and gives them a weight to further evaluate the importance of each attribute.

Table 3. Weighted Hierarchal Customer Needs List Obtained from Focus Group and Individual Interviews

This table shows the weighted values of each attribute as taken from the AHP Pairwise Comparison Chart. This step is important because it emphasizes which attributes of the redesign are most important to customers and should therefore be focused on during the design process.

1.Sustainability (0.65, 0.65)
  1.1 Cost (0.21, 0.323)
  1.2 Energy Efficient (0.44, 0.677)
2. User Friendly (0.351, 0.351)
  2.1 Aesthetically Pleasing (0.094, 0.268)
  2.2 Size (0.055, 0.157)
  2.3 Ease of Use (0.07, 0.20)
  2.4 Quality (0.132, 0.376)

3.0 Revised Problem Statement

Our mission is to improve the energy efficiency of the already existing windows in the dorms on the Penn State campus. According to the customer needs assessment, it is important that the windows are more energy efficient then the way they originally were. It is also important that the improved window is cost effective, so to help with costs we are keeping the windows already there and adding a film and seal to help prevent heat from escaping . Our design will fuse cost effectiveness and energy efficiency together to help save money in the long run.

4.0 External Search

To aid our rehabilitation of the windows, we collected external research regarding the type of sustainable windows and window treatments in existence currently. This included history of the campus windows, the cost of heating the dorms currently, the price of the energy-saving window treatments, and the eventual decrease in cost and heat-energy conserved. This also involved looking up different kinds of window films and different kinds of window sealers to determine which would be most cost effective and energy efficient.

4.1 Patent Search

Table 4. Art-Function Matrix for Window Treatments

This table shows the results of our patent search, including the patents for the insulating window film and for the window sealer.

FUNCTION						
	Solar / Insulating	Lightweight insulating material	Removable and transparent insulation panels	Rope Caulk	High Performance Sealant	Low Expansion Foam
Window Film	EP 0149105 B1	US 5203129 A	US 20120324806 A1			
Window Sealer				US 20090199495 A1	US 20120225983 A1	EP 1811111 A2

4.2 Product Archaeology

The U.S. Dept. of Energy estimates that during the summer up to 60% of a home's cooling energy is lost through its windows and during the winter up to 25% of a home's heating energy is lost through its windows. Insulating window films help to conserve energy by reducing amount of energy spent on heating buildings. They reflect the sun's heat in summer which helps reduce overall heat gain, and causes air conditioners to have to run less. For the winter, insulating films retain up to 55% of a building's heat. For window sealers, rope caulk is easy to add and to remove, and is an effective insulator. High performance sealant is also good for insulation, while low expansion foam is not as effective.

4.3 Benchmarking

Table 5. Benchmarking of Four Products (Qualitative)

This table shows the results of our benchmarking research: we looked up different kinds of window sealers and compared them to each other, and looked up various window films and compared them to each other. We compared costs, installation types to compare ease of installation, and materials to determine environmental-friendliness.

Feature	**'GILA' window film**	**'3m' window film**	**'Energy film'**	**'Duck Brand' Insulating Seal**	**'Osi' Window Foam**	**'MPT' High Performance Sealant**
Window film cost	$37.58 per 45 sq ft	$22.54 per 75 sq ft	$27 per 15 sq ft			
Window film material	polyester	PVC	Vinyl and plastic			
Window film installation type	adhesive	Double sided mounting tape	Adheres to any smooth surface without adhesive			
Window sealer cost				$5.94 per 42 inches	$19.97 per 22 oz	$22.35 for 8 oz
Window sealer material				EPDM rubber	polyurethane	Silicone/ PTFE

Table 6. Benchmarking of Four Products (Weighted)

This table uses the same window sealers and window films that we compared in Table 5.1 for our benchmarking research. We ranked each window film/sealer on a scale of 1 to 5 for how successful it was in each category/feature. Then we assigned a category weight to each feature, so that we could find the total score of the window treatment's success overall. This allowed us to then rank the window films and sealers (1 having the most successful features). This gave us an idea of which window sealer and which window film to implement (we ranked them separately).

Feature	**'GILA' window film**	**'3m' window film**	**'Energy film'**	**'Duck Brand' Insulating Seal**	**'Osi' Window Foam**	**'MPT' High Performance Sealant**	***Category Weight***
Window film cost	**3**	5	2				40%
Window film material	**5**	4	3				30%
Window film installation type	**4**	2	5				30%
Window sealer cost				**5**	3	1	70%
Window sealer material				**4**	2	3	30%
Total score (weighted)	**3.9**	3.8	3.2	**4.7**	2.7	1.6	
Rank	**1**	2	3	**1**	2	3	

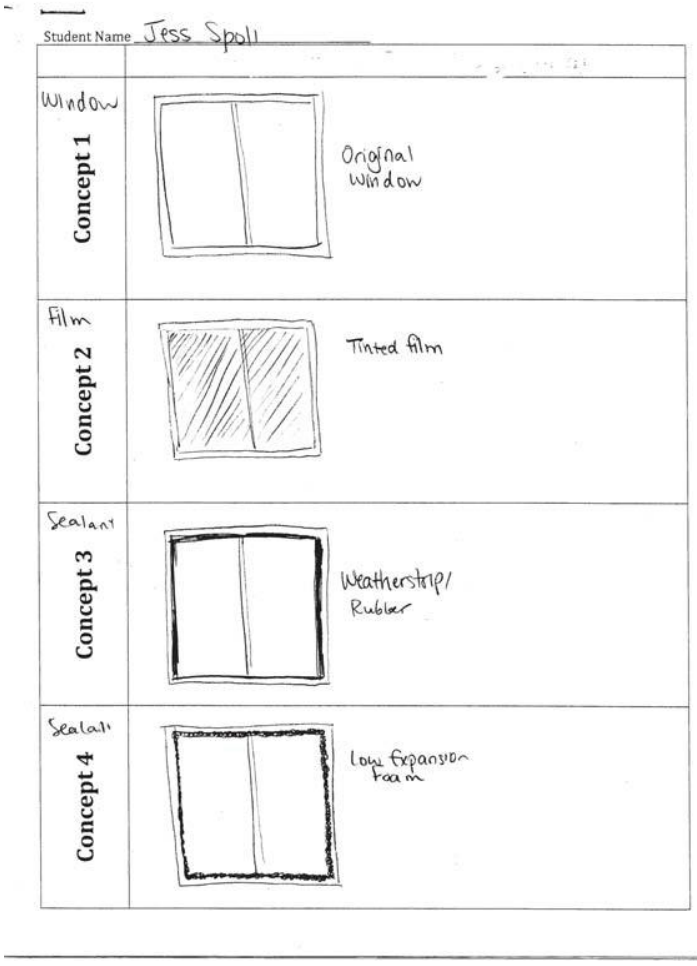
4.4 Design Target

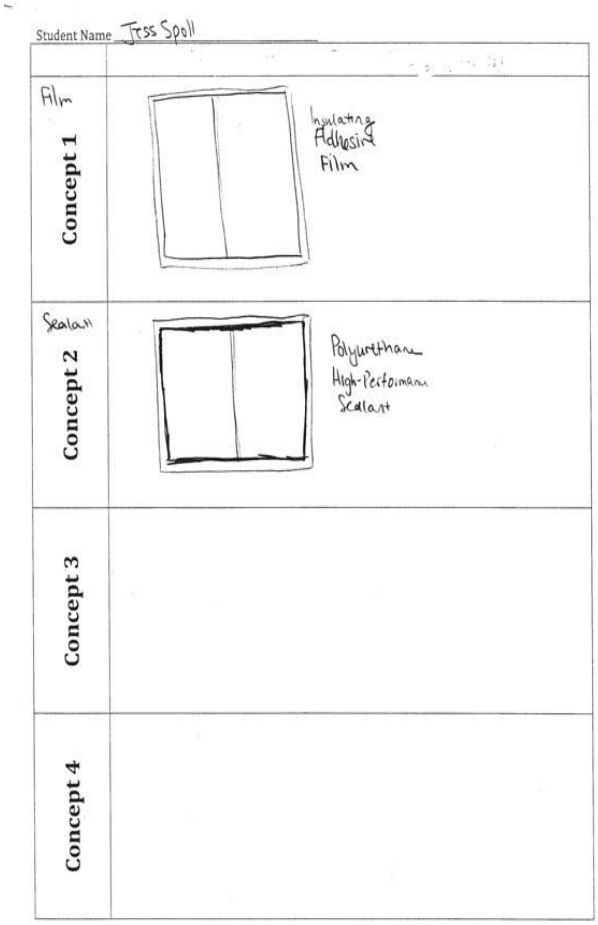
Our team's target design is a viable update to the windows that is cost effective and saves energy by reducing the amount of heat lost. This led us to adding insulating materials to the window such as a window film and an insulating window sealer. The external research gave us ideas and more information about what kind of window film to use and what kind of window sealer to use. We want our plan to be relatively inexpensive, simple to implement, and effective in reducing energy use and expense.

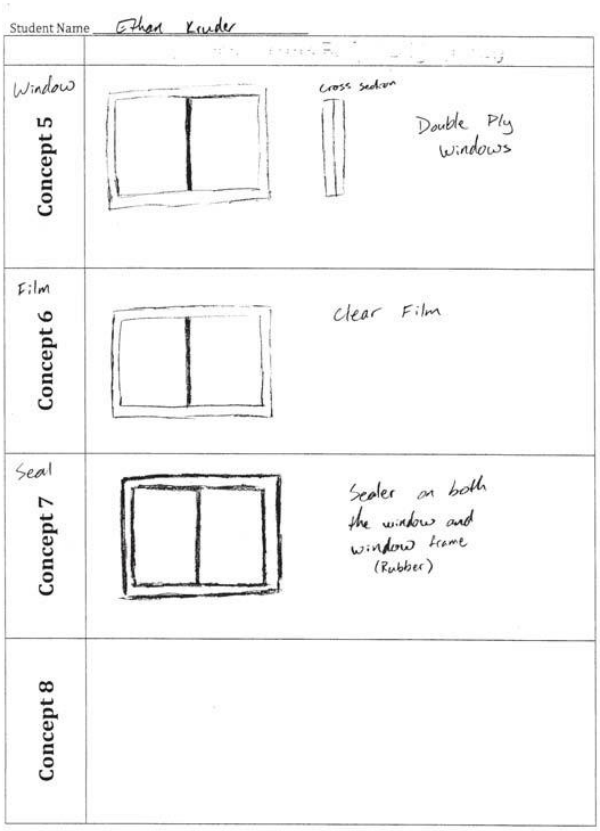
5.0 Concept Generation

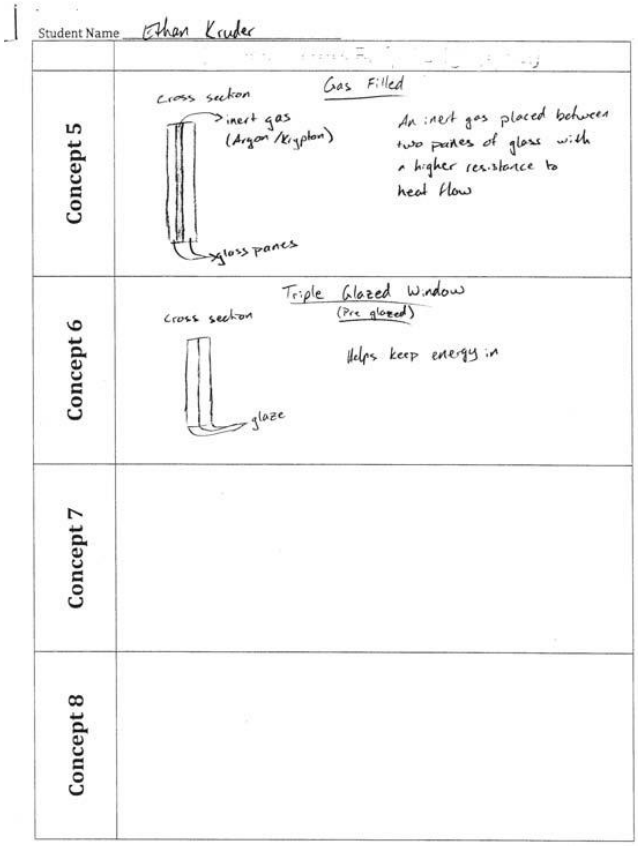
Before beginning the concept generation process, we gathered all the research we conducted previously from the product archaeology, patent research, and survey to aid us in the process. Using the research we conducted and previous knowledge we brainstormed ideas within our group that addressed the problems we found with the current window situation. The survey we conducted helped our group target which aspects needed improvement and what qualities were important to consumers, or in this case, Penn state students. Our goal was to generate several concepts for window design, window sealant, and window film, in order to create a more sustainable and consumer-friendly window.

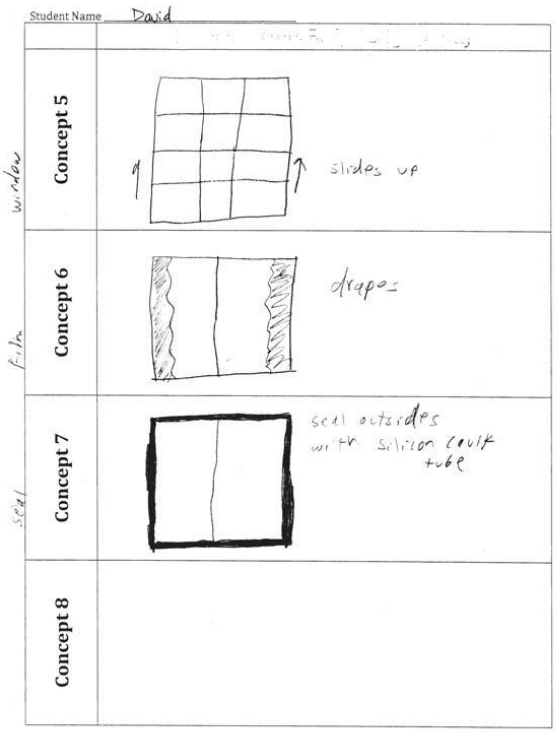
Figure 5.1: Concept Generation Charts











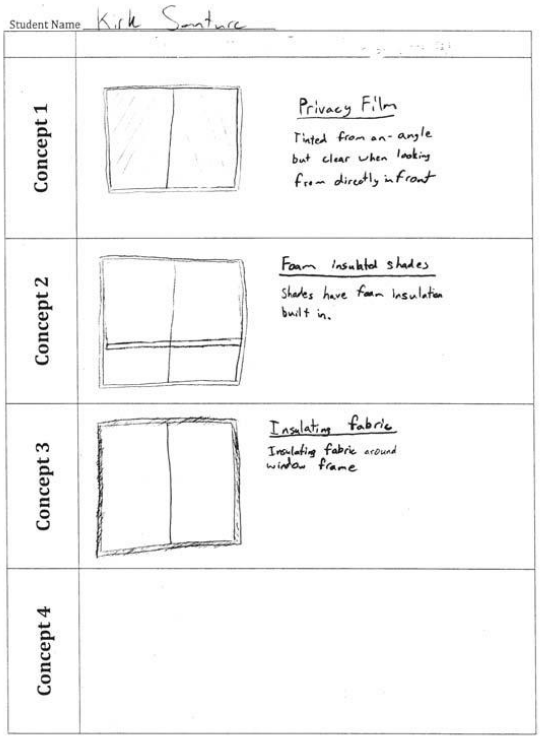
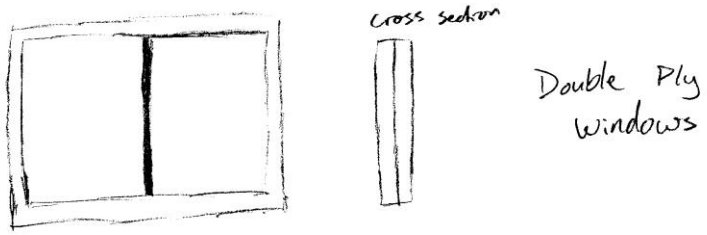
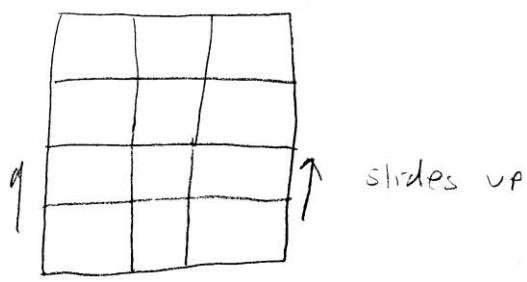
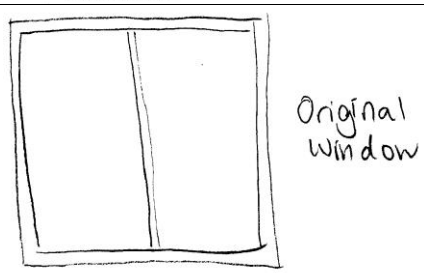
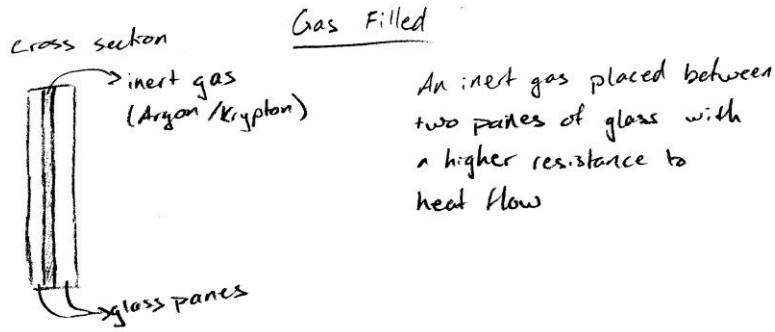


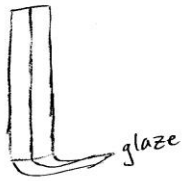
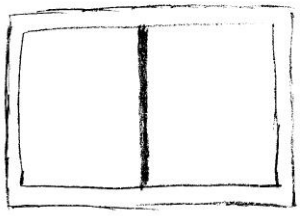
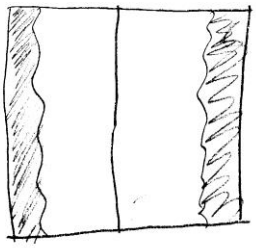
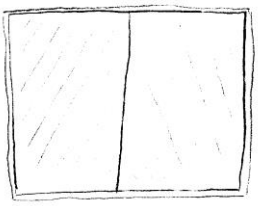
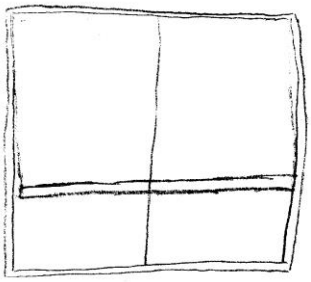
Figure 5.1 shows the concepts we generated.

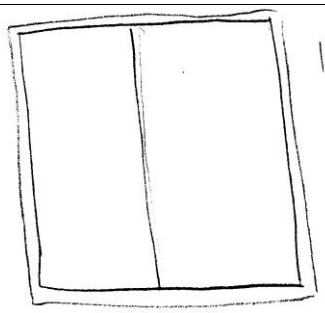
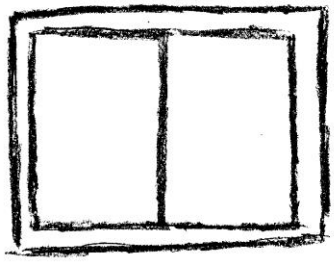
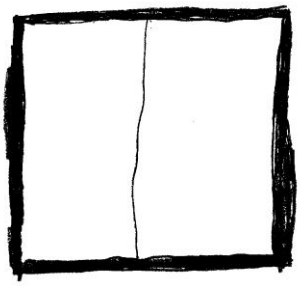
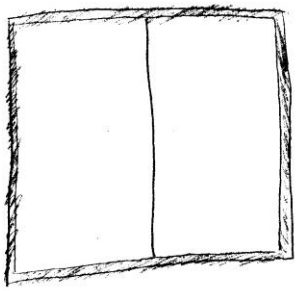
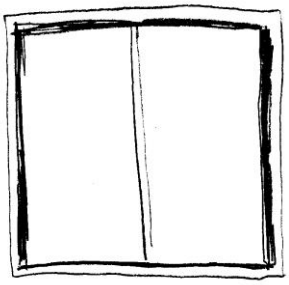
5.1 Morphological Chart

We generated concepts for each of the four main divisions of the design: (1) window design, (2) window sealant, (3) and (3) window film. We organized our concepts in the morphological chart below (see figure 5). Our final design will contain the best concept from each of the three categories in order to provide the highest quality and most sustainable windows for the dorms.

Figure 5.2: Morphological Charts

Concept #	Window Options
1	
2	
3	
4	

5	Triple Glazed Window (Pre glazed) Cross section  Helps keep energy in
Concept #	Film Options
1	 Clear Film
2	 drapes
3	 Privacy Film Tinted from an-angle but clear when looking from directly in front
4	 Foam Insulated shades Shades have foam insulation built in.

5	 Insulating Adhesive Film
Concept #	Sealer Options
1	 Sealer on both the window and window frame (Rubber)
2	 seal outsides with silicon caulk tube
3	 Insulating fabric Insulating fabric around window frame
4	 Weatherstrip/ Rubber

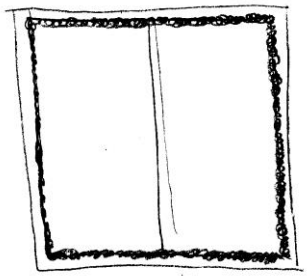
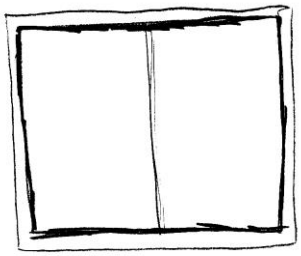
5	 Low Expansion Foam	
6	 Polyurethane High-Performance Sealant	

Figure 5.2 is a morphological chart containing our group's generated concepts for the three categories: window, window sealant, and window film. These are possible concepts that could be implemented in our final design.

6.0 Concept Selection

Figure 6.1: Window Design Pugh Chart:

Iteration 1						Iteration 4					
		Sustainability	User-Friendly	Sum	Rank			Sustainability	User-Friendly	Sum	Rank
	Weighting	0.650	0.350				Weighting	0.650	0.350		
Concepts						Concepts					
	1	-	-	0	4		1	-1	0	-0.65	4
	2	-1	-1	-1	5		2	-1	-1	-1	5
	3	**1**	**0**	**0.65**	**1**		**3**	**1**	**0**	**0.65**	**1**
	4	1	0	0.65	1		4	-	-	0	2
	5	1	-1	0.30	3		5	0	0	0	2
Iteration 2						Iteration 5					
Concepts						Concepts					
	1	**1**	**1**	**1**	**1**		1	-1	1	-0.3	4
	2	-	-	0	5		2	-1	-1	-1	5
	3	**1**	**1**	**1**	**1**		**3**	**1**	**1**	**1**	**1**
	4	**1**	**1**	**1**	**1**		4	0	0	0	2
	5	**1**	**1**	**1**	**1**		5	-	-	0	2
Iteration 3											
Concepts											
	1	-1	0	-0.65	2						
	2	-1	-1	-1	4						
	3	-	-	**0**	**1**						
	4	-1	0	-0.65	2						
	5	-1	-1	-1	4						

Figure 6.1 displays the Pugh Chart for the window design. The concept selected for final design was Concept 3: the original window; not changing the actual design of the window from the dorm windows. This fits customer needs because it saves money and is still aesthetically pleasing and functional.

Figure 6.2: Window Sealant Pugh Chart:

Iteration 1						Iteration 4					
		Sustainability	User-Friendly	Sum	Rank			Sustainability	User-Friendly	Sum	Rank
	Weighting	0.650	0.350				Weighting	0.650	0.350		
Concepts						Concepts					
	1	-	-	0	2		1	**0**	**0**	**0**	**1**
	2	-1	1	-0.299	3		2	-1	0	-0.65	2
	3	**1**	**0**	**0.65**	**1**		3	-1	-1	-1	3
	4	0	0	0	2		4	-	-	**0**	**1**
	5	-1	-1	-1.001	4		5	-1	0	-0.65	2
	6	-1	-1	-1.001	4		6	-1	0	-0.65	2
Iteration 2						Iteration 5					
Concepts						Concepts					
	1	1	-1	0.299	2		1	**1**	**0**	**0.65**	**1**
	2	-	-	0	3		2	0	-1	-0.35	3
	3	-1	-1	-1.001	5		3	-1	-1	-1	4
	4	**0**	**1**	**0.351**	**1**		4	**1**	**0**	**0.65**	**1**
	5	-1	1	-0.299	4		5	-	-	0	2
	6	-1	1	-0.299	4		6	0	0	0	2
Iteration 3						Iteration 6					
Concepts						Concepts					
	1	**1**	**1**	**1.001**	**1**		1	**1**	**0**	**0.65**	**1**
	2	1	0	0.65	2		2	0	-1	-0.35	3
	3	-	-	0	4		3	-1	-1	-1	4
	4	1	1	1.001	1		4	**1**	**0**	**0.65**	**1**
	5	1	0	0.65	2		5	0	0	0	2
	6	1	-1	0.299	3		6	-	-	0	2

Figure 6.2 displays the Pugh Chart for the window sealant. The concept selected for final design was Concept 4: the rubber weatherstripping around the window, covering the gap between the window and the frame/casing. This fits customer needs because it is cheap but functional in keeping the window tight and not letting air through, which in turn saves energy.

Figure 6.3: Window Film Pugh Chart:

Iteration 1						Iteration 4					
		Sustainability	User-Friendly	Sum	Rank			Sustainability	User-Friendly	Sum	Rank
	Weighting	0.650	0.350				Weighting	0.650	0.350		
Concepts						Concepts					
	1	-	-	0	2		1	0	1	0.35	2
	2	-1	-1	-1	5		2	0	1	0.35	2
	3	-1	0	-0.65	4		3	-1	1	-0.3	5
	4	0	-1	-0.35	3		4	-	-	0	4
	5	**1**	**0**	**0.65**	**1**		**5**	**1**	**1**	**1**	**1**
Iteration 2						Iteration 5					
Concepts						Concepts					
	1	**1**	**1**	**1**	**1**		1	-1	0	-0.65	2
	2	-	-	0	4		2	-1	-1	-1	3
	3	0	1	0.35	3		3	-1	-1	-1	3
	4	0	-1	-0.35	5		4	-1	-1	-1	3
	5	**1**	**1**	**1**	**1**		**5**	**-**	**-**	**0**	**1**
Iteration 3											
Concepts											
	1	1	0	0.65	2						
	2	0	-1	-0.35	5						
	3	-	-	0	4						
	4	1	-1	0.3	3						
	5	**1**	**1**	**1**	**1**						

Figure 6.3 displays the Pugh Chart for the window film. The concept selected for final design was Concept 5: the clear, adhesive insulating film. This fits customer needs because it is relatively cheap, it does not impede vision through the windows, it goes on easily, and it saves energy.

7. Concept Improvement through Creativity Methods

Figure 7.1: EMS / Black-Box Model of Window

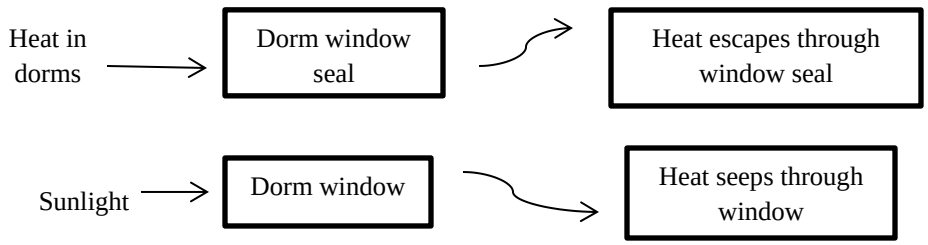


Figure 7 shows the EMS model for the window system. The dorms are heated, and this heat escapes through the window seal, which is a problem with the current windows in the dorms because they have to use more energy to continue to keep the buildings heated. During the warmer months, the sunlight from outside hits the windows and can provide unwanted heat to the building.

Figure 7.2: Solutions EMS Model

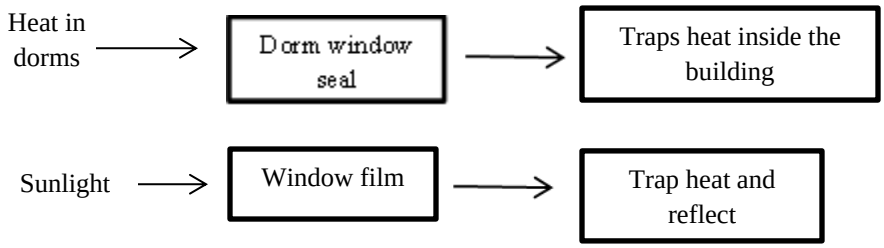


Figure 7.2 shows the EMS model for the desired result of the design. The film we are adding should reflect the sunlight and keep the building cooler and trap heat. The seal we are adding should work to keep the heat inside the building and improve energy efficiency for the dorm.

Table 7: TRIZ Technical Contradictions

This table shows the technical contradictions using TRIZ, based on the design problem. The principles are the ones given by the TRIZ matrix. Essentially we wanted to improve the heat efficiency of the dorms without wasting energy or using a wasteful amount of substance: both resulting in extra expenses. The goal of using TRIZ was come up with solutions to this problem of energy efficiency.

Triz Design Principles:
Design Problem 1: Temperature vs. Waste of Energy Design Principles: 21, 17, 35, 38
Design Problem 2: Temperature vs. Amount of Substance Design Principles: 3, 17, 30, 39

Table 8: TRIZ Implementation

Table 7.2 shows the results of using the matrix to find the principles related to the problem's contradictions. We took these and came up with the general design solutions, using the principles, with the contradictions in mind. We found a film with chemical properties that would be energy efficient without wasting heat or energy, and we found a film that wasn't very much material and that would be easy to apply.

Feature to Improve	Contradiction	Principles	Design Solutions
Temperature	Waste of Energy	21 Rushing through 17 Moving to another dimension 35 Physical or chemical properties 38 Strong oxidants	Use a film for the window with chemical properties that trap heat and preserve energy.
Temperature	Amount of Substance	3 Local quality 17 Moving to another dimension 30 Flexible films or membranes 39 Inert environment	Use a thin substance/film that will trap heat to improve the windows, without being bulky or hard to adhere.

8.0 Final Design

With our final design we decided to keep the old window and frame to help save money and go with the film and sealer to save energy. Due to the high cost of the new windows that are filled with the inert gas it was seen to be too much money so we went with the original window and frame. The film is an energy saving see through film that will adhere to the window and can be cut to fit any window.

Figure 8.1: Final Window Design

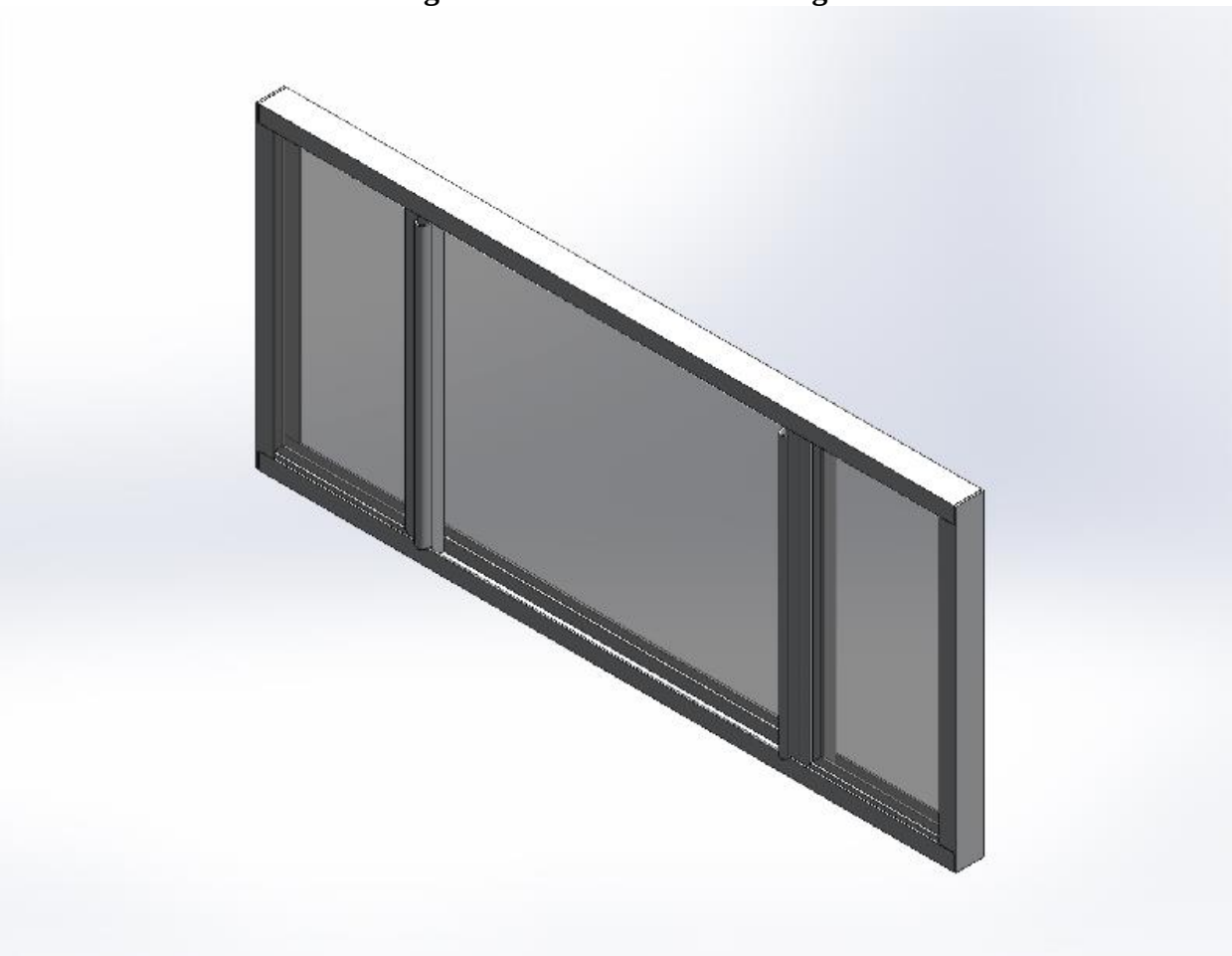


Figure 8.1 shows one of the typical windows that you might see if you go to the East Dorms in SolidWorks.

Figure 8.2: Dimensioned Window

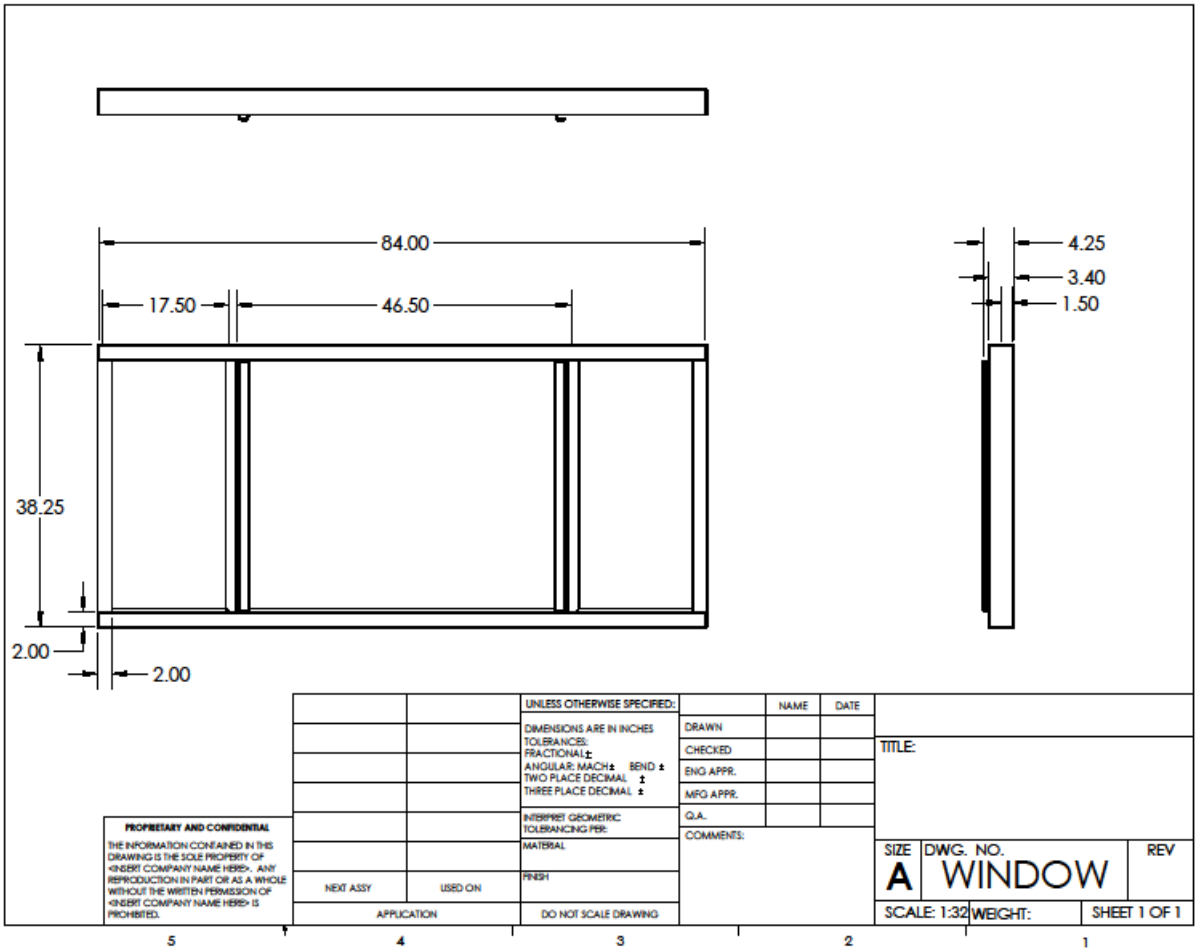


Figure 8.2 shows the dimensions of the common window in East.

8.1 Materials and Material Selection

We came up with the materials selection using our benchmarking tables:

Table 9. (6). Benchmarking of Four Products (Weighted)

This table uses the same window sealers and window films that we compared in Table 5.1 for our benchmarking research. We ranked each window film/sealer on a scale of 1 to 5 for how successful it was in each category/feature. Then we assigned a category weight to each feature, so that we could find the total score of the window treatment's success overall. This allowed us to then rank the window films and sealers (1 having the most successful features). This gave us an idea of which window sealer and which window film to implement (we ranked them separately).

Feature	**'GILA' window film**	**'3m' window film**	**'Energy film'**	**'Duck Brand' Insulating Seal**	**'Osi' Window Foam**	**'MPT' High Performance Sealant**	***Category Weight***
Window film cost	**3**	5	2				40%
Window film material	**5**	4	3				30%
Window film installation type	**4**	2	5				30%
Window sealer cost				**5**	3	1	70%
Window sealer material				**4**	2	3	30%
Total score (weighted)	**3.9**	3.8	3.2	**4.7**	2.7	1.6	
Rank	**1**	2	3	**1**	2	3	

Using these benchmarking results, we decided to use the GILA window film and the Duck Brand insulating seal for our windows. We used these results to come up with a materials list and information about cost of our project.

8.2 List of Materials

Table 10. List of Required Materials and Components

This table shows the materials we need to purchase for our design along with the vendors for each material and the total cost of all the components.

Quantity	Description	Catalog Number	Vendor	Cost
1 per 2 windows	GILA 36-in W x 180-in L Heat-control Window Film	LES361	www.Lowes.com	37.58
2 per window	Duck Brand Premium Silicone Weather-strip Seal	1299528	www.Walmart.com	19.88
Total Cost				38.67

Table 11. Contact Information for Suppliers of Required Materials

This table shows where you can contact the vendors to purchase the materials needed to construct the prototype. Since they can be bought at commercial chain stores, the website is the only necessary contact information.

Lowes: www.lowes.com
Wal-Mart: www.walmart.com

8.3 Cost & Life Cycle Cost

The costs to implement our design changes are only going to require a down payment upfront for the materials and the cost of labor to install them. The E-film is very easy to apply so it doesn't require any special skills or machinery; it's just a roll on adhesive film that any janitor can install. In addition, the weather strip has an epoxy resin adhesive strip that allows for simple instillation. A large benefit to our project is we have completely eliminated life cycle costs up until the 15 year life expectancy of the E-film. The Duck™ Weather Strips come with a lifetime warranty. Upfront costs per window would be $20 for the insulating E-Film and $20 for the Duck™ Weather Strips bringing the total to $40 per room. With such a low cost to implement our design changes we can expect to see our rate of return within the first few years and we would be saving hundreds of thousands of dollars each year thereafter.

9.0 How Does It Work & Conclusions

Our initial idea was to improve energy efficiency and make the dorms more sustainable by improving the windows. We initially thought of changing and replacing all the windows, but ultimately found that this would be much too expensive to be viable. Our customer needs and survey results showed that people would be unwilling to change their whole window, so we generated ideas and benchmarking to come up with different solutions. We came up with the concept to add an insulating film to the window and a seal around the window. This met the customer needs because it was very efficient and kept consumers with the windows they wanted. Also, it was an extremely cost effective solution. Our solution would cause the university to save over a million dollars in the film's 15 year life expectancy, in addition to being very sustainable and using less heat, therefore saving energy.

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Appendix

We created a questionnaire of open ended questions to perform a customer needs assessment. Each team member asked about 5 people the following questions, and we then used the results of the questionnaire to garner information about our project.

Customer Needs Survey:

1. On a scale of 1-10 (10 being the highest) how satisfied are you with the current status of your dorm room windows?

2. On a scale of 1-10 (10 being the highest) how energy efficient do you believe your dorm room windows are?

3. On a scale of 1-10 (10 being the highest) how important is it to you that your room is at a comfortable temperature?

4. On a scale of 1-10 (10 being the highest) how important is it that your windows are energy efficient?

5. Is there anything about your windows that you would like to see changed? If so, how important is it that it gets changed?

6. If the school could save hundreds of thousands of dollars every year on heating/cooling, where would you like that money to be spent?