Abstract

BUTTERFIELD, MATTHEW PAUL. Design and Manufacture of a Second Generation Switch-Operated Window Wall. (Under the direction of Dr. Larry M. Silverberg.)

A new system of horizontal window blinds that operates by means of electrostatic induction, called the powerblind, was developed at North Carolina State University. The blinds can be opened and closed with a simple switch. An evaluation of the first-generation system was conducted to determine the features that needed improvement before a second-generation model could be constructed.

The problems inherent to the previous powerblind model were resolved after redesigning several parts. Eight new, fully operational powerblind units were assembled and installed in a boardroom of the Talley Student Center at North Carolina State University in July 2006. They replaced the defective first-generation units previously located in the boardroom. A set of instructions for all the assembly and manufacturing processes was also created to facilitate the construction of additional second-generation windows.

With the improvements made to the design and to the manufacturing process, it was concluded that commercial production would be possible at this stage of the project. The powerblind windows remain cost effective, when compared to the combination of standard window blinds and insulated glass. The ability to quickly and easily control the amount of light entering a room makes these windows desirable for many applications.
Biography

I, Matthew Paul Butterfield, was born on July 8, 1982 in Hartford, Connecticut. I grew up in Farmington, Connecticut with my parents, Paul and Ann Butterfield, and my sister, Sarah. A penchant for math and science fueled my desire to pursue a career in engineering at a young age. I graduated from Farmington High School in June 2000 and began my undergraduate studies at the University of Virginia in the fall of that year. Through my curriculum in Mechanical Engineering, I developed a particular interest in the area of robotics. Upon graduation from the University of Virginia in May 2004 with a Bachelor of Science, I enrolled in the Mechatronics graduate program at North Carolina State University. I will graduate in August 2006 with a Master’s Degree in Mechanical Engineering and a concentration in Mechatronics.
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1. Introduction

In recent years, there has been an increasing effort to harness the energy provided by the sun. With billions of dollars being spent annually on electricity to power artificial lighting, there is an enormous potential for economic gain by using natural lighting solutions. In addition to the economic benefits, sunlight has many positive effects on the human body not afforded by simulated light.

Using light admitted by windows is the most obvious way to reduce the reliance on artificial light. However, the issue of controlling light that enters a room does not have a simple solution. Today, common methods include horizontal and vertical window blinds and various types of shades and curtains. While these window coverings are adequate for small scale applications, some windows require a different solution. Conventional blinds and shades are impossible to adjust when used with windows near high ceilings. In rooms with many large windows, such as in a commercial setting, adjusting separate blinds is a tedious task. A new system of horizontal blinds has been developed at North Carolina State University, called the powerblind, which will remedy these problems.

The powerblind unit consists of horizontal window blinds sealed between two panes of glass. The blinds can be opened and closed with a wall mounted switch by means of electrostatic induction. Once the preliminary design was finalized, first-generation powerblind units were installed in a boardroom in the Talley Student Center at North Carolina State University. Unfortunately, several problems arose with these models that had to be resolved in order for the project to proceed. Work for this thesis began by identifying these problems and pursuing potential solutions. Second-generation powerblind models were
manufactured and installed in the Talley Student Center to replace the aforementioned faulty windows. These units were free of the defects present in the first-generation models.

In addition to the new windows, this thesis provides a clear and concise set of instructions for all the manufacturing and assembly processes related to the powerblind project. Prior efforts left few records of their methods and much time and effort was wasted attempting to recreate the production methods. With the instructions presented in this thesis, future fabrication of the powerblinds will be aided by precise documentation. Using the new, second-generation design modifications, fully functional windows have become a reality.
2. Background Information

The positive effects of natural light on the human body have been well documented. Sunlight helps regulate many physical and mental processes. Adequate exposure improves the body’s resistance to disease, and can aid in recover from injury and illness. Without natural light, the body does not produce enough red blood cells, which transport oxygen throughout the bloodstream. This same deficiency has been shown in the number of white blood cells, which help fight disease, and blood platelets, which facilitate blood clotting. In addition, UV rays initiate the production of vitamin D in the skin, which allows the body to absorb calcium and in turn, strengthen bones. A lack of exposure to sunlight can lead to sleepiness, decreased sexual desire, and depression, as more melatonin is synthesized by the pineal gland (Lillyquist, 70-101).

Today’s artificial lighting found in homes and offices is not intense enough to produce the same positive effects as sunlight. While these health issues have been well known for decades, the country’s ever increasing energy consumption has prompted a more urgent look at reducing the reliance on artificial light sources. In 1992, the U.S. Office of Technology Assessment reported that approximately $45 billion was spent annually on electricity used in commercial buildings alone (21). Of this total, 41 percent, or nearly $19 billion was used to provide artificial lighting (50). The most natural cost saving measure is known as daylighting, the use of sunlight to supply sufficient illumination to an interior space (“Daylighting,” 1). This technique involves placing windows in specific locations throughout a building to take advantage of the sun’s path above that particular building each day. The Office of Technology Assessment estimated that daylighting could reduce the electricity required for artificial lighting in a commercial building by up to 70 percent (57).
However, daylighting solutions are not yet commonplace in commercial or residential settings, as retrofitting buildings with the necessary technology can be quite expensive. In addition, it is difficult to precisely control the light entering a room as the angle of the sun changes. Venetian blinds provide an acceptable solution in small rooms, but because daylighting relies on many windows that are concentrated towards the ceiling, adjusting blinds is both time consuming and difficult (Kiefer, 229). The powerblind system under development at North Carolina State University is intended to solve these problems.

The basic principle behind the powerblind system is simple: use static electricity to create a switch-operated set of horizontal window blinds. Dr. Larry Silverberg began work on this idea during the mid 1990s and received a patent in 1998 (Silverberg, 1). In the years that followed, several graduate and doctoral students put the theory into practice by producing small, sample windows with a blinds system that succeeded in opening via a light switch. The speed and ease with which it was now possible to open horizontal blinds provided a solution to a large problem facing Venetian blinds in daylighting applications.

Following the production of these successful models, electromechanical and thermal analyses were developed to confirm the system’s functionality and validity as an energy saving design (Kiefer, 242). Manufacturing processes and tools were then prepared so larger powerblind units could be produced. In 2000, under the direction of master’s student Frank Gallion, work began on bringing the powerblind technology out of the laboratory and into the real world. By the spring of 2001, the first generation of powerblinds was installed in a boardroom in the Talley Student Center at North Carolina State University.
3. First Generation Powerblind System

The first generation powerblinds installed in the Talley Student Center boardroom consisted of horizontal slats, the portion of the blinds that open and close, sealed between two panes of insulated glass. The metal slats were electrically connected to an aluminum frame around the perimeter of the window by vertical “ladders.” The aluminum ladders, in conjunction with plastic “tabs,” positioned the slats appropriately between the panes of glass. The entire assembly is shown below in Figure 3.1.

Powerblinds operate by means of electrostatic induction, in which an object charged with static electricity induces a charge in another object without contact between the objects. A power supply was connected directly to the aluminum frame, and a positive charge followed the path from the frame, through the ladders, to the slats. To complete the electrical
circuit, one pane of insulated glass had an invisible layer of tin oxide, also known as a low-e coating, which was electrically grounded. The positively charged slats were attracted towards the electrons in the tin oxide, which gravitated towards the side of the coating closest to the slats, putting the slats in an open position, as shown in Figure 3.2. The entire system was sealed with a silicone suitable for high voltage applications to isolate the electrical circuit. A simple wall mounted light switch controlled the flow of electricity. With power on, the slats would open. With power off, the slats would close due to gravity. A slight offset placed the center of gravity of each slat slightly beyond the axis of rotation, allowing them to close when electricity was not flowing.

![Figure 3.2 - Side View of Slats and Glass in Closed and Open Positions (Gallion, 10)](image)

Eight powerblind units were ultimately installed in the Talley Student Center boardroom. The following photographs show the windows shortly after completion.
Figure 3.3 - Boardroom Powerblind Units in the Closed Position (Gallion, 8)

Figure 3.4 - Boardroom Powerblind Units in the Open Position (Gallion, 8)
4. Second Generation Powerblind System

The scope of this thesis began where the first generation system in the Talley Student Center left off. While the powerblinds in the boardroom worked well as an initial experiment, they were still not ready for commercial production. In the spring of 2005, work began towards remedying two major problems inherent in the first generation design.

About six months after the units were installed in the boardroom, a hazy film became visible on the surface of the glass, which can be seen in Figure 4.1. This film was found to be the tin oxide coating beading up around the areas to which the slats were continually attracted. It became apparent that a new method of supplying a grounded glass surface was required. Instead of the low-e coating, it was determined that thin wires would be embedded in the glass to complete the electrical circuit.

![Figure 4.1 - Film on First Generation Glass](image)

Investigation into wire patterns began by simply using electrical tape to secure thin, bare wire to the outside of one pane of glass of a powerblind window. Testing conducted by previous graduate students resulted in a preferred wire pattern, coined a “sunburst.” The theory behind this pattern, depicted in Figure 4.2, was that there would be more wires crossing slats at the bottom of the window than at the top, causing the slats at the bottom to open faster than those at the top of the window. The “sunburst” pattern was the starting point
for further research into finding the ideal pattern for use in the second-generation windows for the Talley Student Center boardroom.

Figure 4.2 - Sunburst Pattern

While the “sunburst” pattern did cause the slats to open, there was no noticeable “cascading,” as was desired. Any imperfections in the window, such as slightly different slat lengths or deformed ladders, had more of an effect on the opening of the slats than the “sunburst” pattern. With this realization, it was determined that changing the wire pattern was not a valid method for cascading the blinds.

The next idea was to utilize the capacitance of the blinds in combination with a resistance to create an RC circuit that would gradually delay the opening of the blinds. The glass and slats in a horizontal position create a condition similar to a parallel plate capacitor. Estimating the gap between the glass and the open slats to be approximately 0.1 inches, the total capacitance of the window could be calculated, as shown below.

\[
d = 0.1" = 0.00254m \\
A = 34" \times 62.75" = 2133.5 in^2 = 1.3765 m^2 \\
\varepsilon = 8.84 \times 10^{-12} F/m \\
C = \frac{A\varepsilon}{d} = 4.79 \times 10^{-9} F
\]
For a simple RC circuit, the time constant, $\tau$, is given by the equation $\tau = RC$ and after $4\tau$ the charge across the capacitor will be approximately 98% of the full value.

Estimating that the time for the blinds to open completely ($4\tau$) would be 1 second, the resistance for the given window can be estimated.

$4\tau = 1$
$\tau = 0.25s = RC$
$0.25 = R(4.79\times10^{-9})$
$R = 5.22\times10^7 \Omega$

To test this theory, the wire pattern was altered to consist of only six vertical wires, cut in three places to create four separate sections of wire. Five 10-megaohm resistors were placed between each section to delay the voltage from flowing to the top of the window. This arrangement can be seen in Figures 4.3 and 4.4.
When powered, the bottom fourth of the slats opened immediately, with each subsequent section opening a fraction of a second later. This arrangement opened all of the slats in a reasonable amount of time, approximately one second. With a total of fifteen 10-megaohm resistors along six vertical wires approximately 64” (5.33 ft.) in length, a necessary resistance per foot of wire was calculated.

\[
10M\Omega \times 15\text{resistors} = 150M\Omega \\
\frac{150M\Omega}{5.33\text{ ft.}} = 28\frac{M\Omega}{\text{wire}} \\
28M\Omega \times 6\text{wires} = 168\frac{M\Omega}{\text{ft.}}
\]
Finding a common bare wire with a distributed resistance of approximately 168 MΩ per foot is not a possibility at this time. An alternative material, such as a semiconductor, may provide adequate resistance, but further investigation will be necessary. In order to stay within the schedule of the Talley Student Center project, common 30 gauge tinned copper wire was chosen to be embedded in the glass.

Without the need for a cascading effect, the simplest wire pattern that would open the blinds was pursued. Vertical wires were chosen because one wire could be “hidden” if placed directly in front of a ladder. With four ladders in each window, four vertical wires could be embedded that would be relatively unobtrusive. Four vertical wires were taped to the glass but did not open the slats completely. Additional wires were added near the ends of the slats, in order to keep them away from the main viewing area of the window. However, the slats opened even less with the extra wires. Unusual “end effects” were created by having charged surfaces, the air spacer and mutton, next to grounded surfaces, the wires. The benefit to aesthetics of having the wires near the edges of the glass was therefore not possible.

The next wire design consisted of the four wires in front of each ladder and one wire located at the center of each column of slats. With two columns of slats in each window, this produced a total of six wires, three per column. This pattern eliminated any “end effects” and divided each column of slats into four sections of approximately equal width. The distance between the ladders was roughly twice the distance from one ladder to the end of the slats, so by adding one wire halfway between each ladder, the three wires formed an aesthetically pleasing pattern.
The wire design with six vertical wires per window was chosen as the pattern for the windows in the Talley Student Center because it exposed a minimum amount of wire and because of its ability to open the blinds at a reasonable voltage. Once this decision was made, the design was sent to Arch Deco Glass in Ohio, where the wire embedding process was implemented. A wire jig was made at North Carolina State University to facilitate this process, which was also sent to Arch Deco Glass. Information on the jig can be found in Appendix 8.1.

The second major problem with the first generation powerblinds was a particular step in the manufacturing process. After the ladders were punched into the appropriate shape, one then had to insert the many plastic tabs used to support the slats into the ladders individually. Because the ladders were made of thin aluminum, they bent easily when the tabs were inserted. This deformation was plastic in nature and therefore any slight curvature resulted in a permanently misshapen ladder. If each ladder were not straight, the horizontal slats would also be misaligned. Without the proper configuration of the ladders and slats, the blinds would not open properly. This incredibly small margin for error in the assembly of the powerblinds had to be remedied in order to make the process more efficient.

To solve this problem, a new ladder material was selected. The material had to be a metal, so as to retain the ability to conduct the necessary static electricity. It also had to be highly elastic, so when the plastic tabs were inserted, any bending of the ladder did not result in permanent deformation. The most promising material was a shape memory alloy, or “memory metal,” called nitinol, which is a mixture of titanium and nickel. The attractive property of nitinol was its superelasticity, which is the ability to deform reversibly under high stresses. With nitinol ladders, the stresses created by the insertion of the plastic tabs would
no longer have a permanent effect. The drawbacks to the use of nitinol were its cost and machining requirements. Nitinol was more expensive than the aluminum used in the first generation ladders. It also could not be punched by hand, so a more expensive process, laser cutting, was employed. While the cost for a small number of experimental ladders was high, once in production, the added expense of nitinol ladders would not increase the overall cost of a window by an excessive amount. This small increase in cost was outweighed by the ability to adhere to the tight tolerances required of the manufacturing process.

Unfortunately, the relatively small amount of nitinol required for the eight windows in the Talley Student Center was not enough for any nitinol suppliers to perform a custom run at the required size. Instead, a more readily available material, spring steel, was selected. Spring steel was still a vast improvement over aluminum because it had a much larger elastic range. The thickness of the material was also doubled for added strength. While nitinol would theoretically be preferable to spring steel, it was simply impractical to use it in such a small, experimental setting.

The changes to the electrical conductor in the glass and to the ladder material and manufacturing method, along with other minor changes that will be explained in subsequent chapters, produced a more consistent and reliable second-generation system.
5. Instructions

This chapter acts as a detailed instruction manual for any future persons working on the powerblinds project. Included is a discussion of individual parts and their manufacturing, as well as assembly and installation instructions.

5.1. Parts and Materials

Many of the parts and materials used in the powerblind units are identical to those used by the insulated glass (IG) industry in standard windows. The following table provides a brief overview of the parts that make up a switch-operated window. Each part is discussed in greater detail in subsequent sections. For information regarding the ordering of parts and materials, as well as related contact persons, see Appendix 8.3.

Table 5.1: Overview of Powerblind Components (Gallion, 9)

<table>
<thead>
<tr>
<th>Part Name</th>
<th>Function</th>
<th>Production Method</th>
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<tbody>
<tr>
<td>Air Spacers</td>
<td>Provides structural spacing between glass panes and support for sealant. Provides a path for high voltage actuation signal to hooks, ladders, and slats.</td>
<td>Commercially produced for IG industry. Cut to size with miter saw in lab. Holes for hooks and mutton keys punched and drilled in lab.</td>
</tr>
<tr>
<td>Aluminum Foil</td>
<td>Provides a low resistance path for high voltage electricity between segments of air spacer and mutton.</td>
<td>Commercially produced for HVAC industry.</td>
</tr>
<tr>
<td>Electrically</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Conductive Tape</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corner Keys</td>
<td>Connect air spacers to form the rectangular shape of the window.</td>
<td>Commercially produced for IG industry.</td>
</tr>
<tr>
<td>Desiccant</td>
<td>Placed inside air spacers to absorb any residual moisture in the sealed window.</td>
<td>Commercially produced for IG industry.</td>
</tr>
<tr>
<td>Hooks</td>
<td>Connect the ladder, slat, and tab assembly to the top air spacer. Provide a path for high voltage actuation signal to ladders and slats.</td>
<td>Manual die punch in lab.</td>
</tr>
</tbody>
</table>
### Table 5.1 (continued)

<table>
<thead>
<tr>
<th>Part Name</th>
<th>Function</th>
<th>Production Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Insulated Glass (with embedded wire)</td>
<td>Wire embedded within the IG attracts slats to open position with induced charge. Seals the inside of the assembly, provides insulating air space.</td>
<td>Commercially produced for IG industry. Specific wire pattern embedded by glass company.</td>
</tr>
<tr>
<td>Insulated Glass (without wire)</td>
<td>Seals the inside of the assembly, provides insulating air space.</td>
<td>Commercially produced for IG industry.</td>
</tr>
<tr>
<td>Insulated Wire</td>
<td>Provides an insulated path for high voltage signal from the power supply to the air spacer.</td>
<td>Commercially produced for high voltage power supply industry.</td>
</tr>
<tr>
<td>Ladders</td>
<td>Locate and support slats in air space. Provide an electrical path for high voltage actuation signal to slats.</td>
<td>Laser cut.</td>
</tr>
<tr>
<td>Mutton Keys</td>
<td>Connect muttons to top air spacers.</td>
<td>Commercially produced for IG industry. Cut to size with miter saw in lab.</td>
</tr>
<tr>
<td>Muttons</td>
<td>Provide a separation between columns of slats in larger windows.</td>
<td>Commercially produced for IG industry.</td>
</tr>
<tr>
<td>Sealant</td>
<td>Seals the inside of the assembly, provides insulating air space.</td>
<td>Commercially produced for high voltage power supply industry.</td>
</tr>
<tr>
<td>Slats</td>
<td>Rotate to either block or transmit light.</td>
<td>Commercially produced for venetian blind industry. Hole for ladders produced with manual die punch in lab. Cut to length in lab.</td>
</tr>
<tr>
<td>Tabs</td>
<td>Locate and support ladder and slat assembly between panes of glass.</td>
<td>Manual plastic injection molder used in lab.</td>
</tr>
<tr>
<td>Uninsulated Wire</td>
<td>Embedded in one pane of glass (see &quot;Insulated Glass (with embedded wire)&quot;).</td>
<td>Commercially produced for electronics industry.</td>
</tr>
</tbody>
</table>

#### 5.1.1. Air Spacers, Corner Keys, Desiccant, Insulated Glass (without wire), Mutton Keys, and Muttons

These parts are all donated by Arch Aluminum and Glass, located in Youngsville, NC. The insulated glass can be ordered to any specified dimensions and can be tinted upon request. The thickness used for the windows in the Talley Student Center is 1/8”. The air
spacers used in the powerblinds are 3/4” wide, and the muttons are 5/8” wide. Both are modified in the lab at North Carolina State University to fit the window being constructed. Corner keys and mutton keys are made to fit the corresponding air spacers and muttons. The desiccant comes in a granular form. Figure 5.1 shows some of these parts from Arch Aluminum.

![Image of air spacer, corner key, mutton key, mutton](image)

Figure 5.1 - Air Spacer, Corner Key, Mutton Key, Mutton (clockwise from top left)

5.1.2. Aluminum Foil Electrically Conductive Tape

The aluminum tape is 1/2” wide and can be ordered from Electron Microscopy Sciences for $28 for a 54-foot roll. Free samples can be obtained from 3M sales representative Larry Yates. It should be noted that standard aluminum foil tape from home
improvement stores cannot be used for this application because it does not have the electrically conductive adhesive of the 3M tape.

5.1.3. Hooks

The hooks are punched in the lab at North Carolina State University from an aluminum sheet that is 0.016” thick. The aluminum can be ordered from McMaster-Carr. A 12” x 12” sheet costs $2.78. One hook is required for each ladder. Figure 5.2 shows a sample hook.

![Figure 5.2 - Hook](image)

5.1.4. Insulated Glass (with embedded wire) and Uninsulated Wire

The wire embedding process is provided free of charge by Arch Deco Glass in Ohio. As with the glass from Arch Aluminum, any dimensions can be accommodated. To make new wire embedded glass, Arch Deco Glass must receive a wire pattern, the corresponding wire jig, and the uninsulated wire that is to be embedded. The wire used in the second generation of windows is bare, tinned copper, 30 gauge wire from Anixter. A 1000-foot roll can be purchased for $58. The wire is sealed between two panes of glass, each 1/8” thick.
5.1.5. Ladders

The ladders are laser cut from sheets of 0.032” thick blue tempered spring steel. The spring steel can be ordered from Industrial Spring Steel, which has a $130 minimum order. For the eight windows at the Talley Student Center, one sheet was ordered to fit 32 ladders side by side. It should be noted that each ladder is 0.1917” wide and between 1/8” and 1/4” of extra material must be left between each ladder to accommodate the laser cutting process. For 32 ladders, each 64” long, sufficient material was purchased for the minimum order amount.

The spring steel is shipped directly to Advanced Laser to be cut. Cutting services for the 32 ladders was approximately $1200. The bottom portion of a finished ladder can be seen in Figure 5.3 below.

5.1.6. Sealant

The GE high voltage sealant comes in a five-gallon bucket and in 10-ounce caulk cartridges. The sealant in the bucket (RTV5812) is white, while the sealant that comes in cartridges (RTV5818C) is clear. Both can be purchased from Hisco, with the clear variety selling for $10-12 per tube, depending on the quantity ordered. The white and clear sealants differ only in color, as they are chemically equivalent. The caulk cartridges were used for the
second-generation windows because of the easier application process. The clear sealant is simply applied with a caulking gun. When purchasing the sealant, note that one cartridge is required for approximately 100” of air spacer length.

5.1.7. Slats

   Slats are purchased from AAA Blind Manufacturing and can be ordered in various lengths and colors. Approximately 2250 slats were ordered for the eight windows at the Talley Student Center, which cost $500. Slats are cut to length and holes for the ladders are punched in the lab at North Carolina State University. Several slats can be seen in Figure 5.4 below.

![Figure 5.4 - Slats](image)

5.1.8. Tabs

   Tabs are manufactured in the lab at North Carolina State University by means of a plastic injection molding machine. The polypropylene pellets used in the injection molder are donated by Aimet Technologies in Raleigh. Several tabs are pictured in Figure 5.5 below.
5.2. **In House Manufacturing**

Some parts require modification in the lab, while others are manufactured entirely at North Carolina State University. Related instructions are provided in the following sections.

An important tool that helps in determining the necessary quantity of parts and their sizes is a preexisting excel file. By inputting the desired window size, glass width and height, the excel file automatically computes the number of slats, the lengths of the muttons, air spacers, and slats, as well as the positions of various holes that must be punched. The glass sizes used in the Talley Student Center can be found in Appendix 8.1.

5.2.1. **Air Spacer and Mutton Modification**

<table>
<thead>
<tr>
<th>Materials Required:</th>
<th>Aluminum air spacers</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Aluminum muttons</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Primary Tools Required:</th>
<th>Miter saw</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Drill press (with 5/64” and 1/4” drill bits)</td>
</tr>
<tr>
<td></td>
<td>Air spacer punch</td>
</tr>
</tbody>
</table>

Air spacers and muttons must first be cut to the length dictated by the size of the window using the miter saw in the lab. The appropriate lengths are given by the excel worksheet. For the second-generation powerblinds, the muttons were cut 1/8” shorter than the length of the opening to allow them to hang freely when attached to the top air spacer.
This eliminates a potential failure mode because everything inside the air spacers now hangs freely, and therefore parallel, decreasing the chances of contact between the slats and the mutton.

While muttions must only be cut to length, the air spacers require further modification. The top air spacer of each window has to have holes from which to hang the ladders and any muttions. It is important that all holes are punched or drilled on the correct side of the air spacer. One side is smooth, while the other side, the side where the holes should be, has a series of indentations along the centerline.

The ladders are attached to the top air spacer by aluminum hooks. The hook holes are punched with the air spacer punch, shown in Figure 5.6 below, at distances dictated by the excel worksheet. The nature of the ladder design requires that the hook holes be offset from the centerline of the air spacer. The punch accounts for this offset, which can also be seen in the air spacer in Figure 5.6.

Figure 5.6 - Air Spacer Punch and Offset Hook Hole
There is another offset present in the punch design. The distance between actual cutting piece and the edge of the punch housing is one inch. This means that if one were to slide the air spacer to the edge of the punch housing, as in Figure 5.7, the hook hole would be punched exactly one inch from the end of the spacer. Therefore, to punch a hole, for example, four inches from the end of the air spacer, one would mark the spacer at three inches, slide the spacer until the line is at the edge of the punch housing, and punch the hole.

![Figure 5.7 - Air Spacer in Punch](image)

The muttons are attached to the top air spacer by a mutton key. Holes are drilled in the air spacer to accommodate the two-pronged end of the mutton key, which can be seen in Figure 5.8. The excel spreadsheet provides the location of the mutton holes in relation to the end of the air spacer, but it does not specify the location of the holes along the width of the spacer. The distance between the two prongs of the mutton key is 1/2”, while the spacer is 3/4” wide. This leaves 1/8” from the center of each prong (and the center of each hole) to the outer edge of the air spacer.
When drilling the mutton holes, use the drill press in the lab with a 5/64” drill bit. The holes will be slightly smaller than the diameter of the prongs, so an awl should be used to enlarge them just enough to allow the prongs to be press fit in the holes.

One final hole must be drilled in the air spacer, directly opposite the two mutton holes, on the smooth side of the spacer. This hole, shown in Figure 5.9, is 1/4” in diameter and is centered along the width of the spacer. It is used to insert a small amount of sealant into the air spacer during the assembly process to secure the mutton key.
5.2.2. Hook Fabrication

Materials Required: 0.016” thick sheet of Aluminum
Primary Tools Required: Arbor press
Hook die

Hooks are manufactured in the lab at North Carolina State University. The press in Figure 5.10 is used in conjunction with the hook-shaped die shown in Figure 5.11 to cut the aluminum hooks.

Before operating the press, the sheet of aluminum is cut into strips wide enough to accommodate one hook. A box cutter and a straight edge will suffice for this procedure. Next, one strip of aluminum is placed in the die and the press handle is lowered. After the hook is punched from the strip, excess aluminum remains caught on the die. It can be removed with a pair of pliers.

Figure 5.10 - Arbor Press for Hook Fabrication
Figure 5.11 - Hook Die
5.2.3. Slat Modification

- **Materials Required:** Slats
- **Primary Tools Required:** Slat end punch, Slat hole punch

Two modifications must be made to the slats before they are ready for assembly. First, they must be cut to the appropriate length given in the excel worksheet. The slat end punch, pictured in Figure 5.12 below, trims and rounds the ends of the slats. The guide on the punch is used to provide a mechanical stop for the slat at a fixed distance away from the cutting tool. It is important to trim both ends of each slat so both are rounded. Therefore, the guide should be set to half the length of the amount to be trimmed. For example, if a particular slat is 18” long, and the desired length is 16”, the guide should be set to trim 1”. Then, both ends of the slat will have 1” removed and both will have rounded ends.

![Figure 5.12 - Slat End Punch](image)

The second step in the slat modification process is punching the ladder holes. The slat hole punch, seen in Figure 5.13, functions in the same manner as the slat end punch. A guide can be positioned to provide the mechanical stop for the slat at any point. The distance from the end of the slat to the slat hole center can be found in the excel spreadsheet. Once the guide is locked at the appropriate location, both holes can be punched using that position by rotating the slat 180 degrees because the slat is symmetrical.
5.2.4. Tab Fabrication

Materials Required: Polypropylene pellets
Primary Tools Required: Plastic injection molding machine
Air compressor
Tab mold

The plastic injection molding machine pictured in Figure 5.14 melts polypropylene pellets in a heated chamber before a plunger is lowered into the chamber, pushing the liquefied pellets into the tab mold, seen below in Figure 5.15. The mold has two holes, with each producing five tabs.
To begin the fabrication process, the injection molder is plugged into an outlet and into an air compressor. This allows the operator to control two parameters: temperature of the chamber and pressure of the plunger. Optimum temperature and pressure have been found to be approximately 500 degrees Fahrenheit and 60 psi, respectively. The chamber is immediately filled with pellets to prevent any burning. Once the appropriate temperature is
reached, the operator purges the chamber in order to eliminate any leftover burnt and
discolored plastic by holding the control button for the plunger until clear plastic flows from
the injection molder.

At this point, the mold is opened and the inside is sprayed with a silicone mold releaser. The mold is then closed and placed in the vise of the injection molder, with one of
the holes of the mold aligned with the exit nozzle of the injection molder. To position the
mold directly beneath the nozzle, pieces of metal are used as spacers behind the mold. Care
must be taken to ensure that the vise is as tight as possible to prevent leakage of the plastic
within the mold. Next, the operator holds the plunger control button until a small amount of
plastic seeps out of the hole on the mold. The mold is then moved so that the other hole can
be filled. To remove the completed tabs, the mold is reopened and needle-nosed pliers are
used to pull the tabs from the mold. Excess plastic can sometimes seep out from the mold
and must be trimmed to produce acceptable tabs. Keeping the mold clamped tightly in the
vise will limit this problem.

When repeating this process, the silicone mold releaser should be sprayed on the
mold before each batch of ten tabs. The operator should also refill the pellet chamber
completely after each batch. Tab quality will improve as the temperature of the mold
increases through repeated use.

5.3. Assembly

The following is a step-by-step list of instructions for assembling one powerblind
unit. Before beginning, make sure all parts are in hand, as dictated by the aforementioned
excel spreadsheet. Clean the work area thoroughly. It is important that no dust or debris be
accidentally sealed inside the window. If possible, have a previously constructed powerblind unit present with which to compare during the assembly process.

Frame Assembly:

Required Parts:
- (4) Aluminum Air Spacers (of appropriate lengths)
- (1) Insulated Wire (approximately three feet long)
- (4) Corner Keys
- Muttons (if necessary)
- Mutton Keys (if necessary)
- Aluminum Foil Tape
- Desiccant
- Sealant

1. Strip about two inches of insulation off one end of the wire.

2. Wrap the bare end of the wire around one corner key, as shown below. This will establish an electrical contact between the wire and the top air spacer.

![Wire Wrapped Around Corner Key](image)

3. Insert the end of the corner key with the bare wire into one end of the top air spacer, as pictured below. Push the corner key all the way into the air spacer. Be sure the air spacer is oriented correctly. The series of indentations along the centerline, as well as the hook and mutton key holes, should be along the smooth side of the corner key.
4. Connect the remaining aluminum air spacers and corner keys to form the rectangular frame, as depicted below. Be sure the sides of the air spacers with the indentations all face toward the center of the frame. During this process, completely fill the two vertical air spacers with desiccant.

5. Apply aluminum foil tape around the outside corners of the frame, electrically connecting all four air spacers, as shown below.
6. If a mutton is necessary (see excel spreadsheet), insert a mutton key into one end of the mutton in the manner shown in the picture below.

![Figure 5.21 - Mutton Key Inserted into Mutton](image)

7. Insert the other end of the mutton key, the two-pronged end, into the predrilled holes in the top air spacer, as shown below. The mutton key will be press fit, and the prongs should be pushed completely into the air spacer.
8. Apply aluminum foil tape, as depicted below, to electrically connect the top air spacer with the mutton. Place a piece of tape on both sides of the mutton.

9. Using a caulking gun, fill the hole on the opposite side of the air spacer with a small amount of sealant, as shown below. Use enough sealant to completely cover the prongs of the mutton key, securing it in place.
Blind Assembly:

Required Parts:
- Ladders
- Slats
- Tabs
- (2) Guide Blocks

- (1) Slat Divider
1. Place the two guide blocks side by side, with the “T” towards the top of the ladder and the “B” towards the bottom. Clamp the guide blocks to the edge of the table where the assembly is taking place.

2. Place 2 slats in each horizontal groove of the guide blocks, as shown below. The slats should span both guide blocks, with the slat holes lining up with the ladder groove.

3. Slide a ladder along the ladder groove of each guide block, passing it through the aligned slat holes, as illustrated in the figure below.
4. Insert a tab into each corresponding opening in the guide blocks. Part of the tab will pass through the holes in the ladder. Use a hammer and a nail set or punch, similar to the one pictured below, to ensure the tab is secured to the ladder. DO NOT insert a tab into the top set of ladder holes. These holes will be used to attach the ladder to the top air spacer using a hook.

![Figure 5.30 - Tab Secured to Ladder with Nail Set](image)

![Figure 5.31 - No Tab Inserted into Top Set of Ladder Holes](image)

5. Carefully remove the ladder/slat/tab assembly from the guide blocks. For windows with ladders longer than the length of the guide blocks, place the tabs that were removed from the bottom opening of the guide blocks into the top opening and repeat steps 1-4 as needed. Instead of inserting the slats into the horizontal grooves of the guide blocks first, align the ladders in the ladder grooves and then slide the appropriate number of slats onto the ladders from the bottom. At this point, the slats can be placed in the horizontal grooves as described in step 2.

6. Set the ladder/slat/tab assembly in the slat divider, separating the slats so that one slat rests in each slot of the slat divider, as in the figure below.
7. Turn both ladders 90 degrees counterclockwise, so that the slats rest properly on the ladders, as illustrated below.

Attach Blind Assembly to Frame:

Required Parts:
- (1) Insulated Glass (with embedded wire)
- (1) Insulated Glass (without embedded wire)
- Hooks
- Sealant
1. Place the piece of insulated glass with wire on a clean table. Clean the surface of the glass facing up (which will be on the interior of the unit) with glass cleaner.

2. Center the previously assembled frame on the piece of glass. The insulated wire should be at the top of the window. The hook holes in the top air spacer should be located on the side of the centerline furthest from the piece of glass with the embedded wire, as pictured below.

![Figure 5.34 - Frame Positioned on Glass](image)

3. Attach a hook to each ladder as shown below. The lower tab of the hook is inserted through the ladder hole closest to the air spacer and is bent around the ladder.

![Figure 5.35 - Hook Attached to Ladder](image)

4. Remove the ladder/slat/tab assembly from the slat divider and place it on the piece of glass with embedded wire. The top of the ladder, where the hook is attached, should
be positioned at the top of the window. Insert the upper tab of each hook into the appropriate hook hole in the top air spacer, as pictured below.

Figure 5.36 - Hook Before Being Inserted into Hook Hole

Figure 5.37 - Hook After Being Inserted into Hook Hole

5. Clean the piece of glass without the embedded wire with glass cleaner and then place it on top of the frame. Using a combination square, square the two pieces of glass so the edges of both pieces are even, as seen below. Be sure the frame is still centered on the glass.

Figure 5.38 - Squaring Both Pieces of Glass
6. Clamp the unit together using spring clamps, as seen below. Test the unit to be sure it is functioning properly.

![Figure 5.39 - Unit Clamped Together with Spring Clamps](image)

7. Using a caulking gun and putty knife, apply sealant around the entire perimeter of the unit, as illustrated below. Be sure to use the putty knife to fill the entire area between the air spacer and the edges of the glass. Do not leave any air pockets.

![Figure 5.40 - Sealant Applied with Caulking Gun](image)  ![Figure 5.41 - Sealant Spread with Putty Knife](image)

8. Allow the sealant 48 hours to dry.
5.4. Installation

The following are instructions for installing a powerblind unit in the Talley Student Center boardroom at North Carolina State University. While some of the information is specific to that particular application, installing a powerblind unit elsewhere follows the same basic procedure.

Note on the electrical wiring in the boardroom:

The switch by the main door of the boardroom operates all eight powerblind units. There is a box above the ceiling tiles directly above the switch that controls the 110 V AC. A relay plugs into this box, providing an easy way to kill the power to the blinds. The 110 V AC runs across the room to an outlet above the ceiling tiles near the rightmost window. A variable high voltage power supply, which is also mounted near the rightmost window, runs off of the 110 V outlet. This power supply provides the high voltage electricity used to open the blinds. The optimum voltage for the boardroom was found to be 3.75 kV. There is a junction box installed above each powerblind unit. One positive and one ground wire run from the power supply to the nearest junction box. Another set of positive and ground wires runs from that junction box to the next in line. This arrangement repeats through the series of eight junction boxes.

1. Remove any existing glass and framing material.

2. Set the powerblind unit in the exterior window frame. Place thin, foam padding around the perimeter of the powerblind unit so it does not rest on the metal window frame.
3. Feed the positive wire connected to the aluminum spacer frame through the hole in the exterior window frame, as shown below. Do the same with one end of the horizontal wire embedded in the top of the glass, which acts as a ground.

![Wires from Powerblind Fed Through Exterior Window Frame](image)

**Figure 5.42 - Wires from Powerblind Fed Through Exterior Window Frame**

4. Secure the powerblind unit in place with the appropriate framing material.

5. Feed the two wires from the powerblind unit into the junction box above the window. Connect all three positive wires (one from the junction box to the right, one going to the junction box on the left, and one from the powerblind unit) inside the box with liquid electrical tape and a wire nut. Do the same for the three ground wires. The junction box is pictured below.
6. Put the cover on the junction box. Return any ceiling panels that were moved during the installation.

Below are photographs of all eight powerblind units installed in the Talley Student Center boardroom.
Figure 5.45 - Second Generation Units in the Open Position
6. Conclusions

The ultimate goal of the powerblinds project was to produce a cost effective method to quickly and easily control large-scale window blinds. By relying predominantly on preexisting parts from the insulated glass industry, the windows were quite economical. A complete price list can be found in Appendix 8.2. Work on the second-generation system focused on incorporating several improvements to the final design.

One major change was using thin, embedded wire to facilitate the electrostatic induction, rather than the tin oxide coating from the first-generation windows. This eliminated the possibility of the film reappearing in the new units. A particular wire pattern was chosen to minimize the appearance of the wire, while still providing sufficient electrostatic force to open the slats completely.

The other critical modification implemented in the second-generation powerblinds was the use of a new ladder material and a new process for manufacturing the ladders. The requirements for this material were that it conduct electricity and deform elastically. Ultimately, spring steel was chosen for the ladders. The original ladder punch in the lab was designed to cut the ladders from aluminum, and therefore could no longer be used to punch the spring steel ladders. Laser cutting provided an accurate method of manufacturing the ladders from the spring steel. The spring steel ladders did not deform permanently at all during the assembly process and relatively little care had to be employed when handling these new ladders.

Several other minor changes were made to the manufacturing and assembly processes that improved the end product. In the first generation windows, the ends of the slats were not cut with the slat end punch, which was designed for the second-generation blinds. The slat
end punch not only trimmed the slats to length, but also rounded the edges of the slats slightly. This curvature can be seen in Figure 5.4. Rounding the edges prevented the slats from sticking to the vertical air spacers or muttons when making contact with them in the window.

The first generation windows were also assembled without the aid of the guide blocks or the slat divider. Instead, the tabs were inserted individually, by hand, into the appropriate holes in the aluminum ladder. Because of the nature of the aluminum, the insertion of each tab would have caused the ladder to deform locally. Without the slat divider, each slat had to be carefully positioned to allow the 90-degree rotation.

All of the aforementioned improvements not only led to a superior set of windows, but also greatly reduced the production time. Frank Gallion, the master’s student in charge of the first generation system, noted that two workers assembled the final unit in two hours (Gallion, 6). The final second generation unit was assembled in approximately one hour by two workers.

One problem did arise upon installing the second generation units. Random slats experienced a slight “flutter,” or shake at higher voltages. The power supply in the boardroom was set to 3.75 kV to eliminate this activity. However, a higher voltage, such as 10 kV, is preferable, as the slats would open faster, but the fluttering motion was too distracting at voltages above 3.75 kV. Various external sources are potential causes of this problem. The frame of the powerblind is completely separated from the outside environment by the high voltage sealant and the pane of wire embedded glass is grounded. However, the other pane of glass is not protected. Small differences in potential between the ground of the
embedded wire and the ground of the surroundings could cause the slight fluttering effect. It is also possible that the steel window frames need to be grounded.

Once this issue of fluttering is addressed, it is expected that the powerblinds project will have reached a point in which commercial production is possible. The two major defects of the first-generation windows have been remedied and it may be that further improvements would be best completed in industry.

First, spring steel may not be the definitive solution to the problem of deformed ladders. While it is a tremendous improvement, nitinol remains a more elastic material. It was not financially possible to use nitinol in such small quantities in this experimental setting, but if the powerblinds were in commercial production, nitinol could be purchased to the desired specifications. However, the cost of nitinol is approximately ten times that of spring steel in small quantities. Unless there is a significant discount for ordering a large amount of nitinol, spring steel may still be the most practical option in production.

Second, if a manufacturer wanted to pursue the cascading effect of the slats, the research already presented could be used to find a wire with the appropriate distributed resistance. The same pattern used in the Talley Student Center windows could still be used, replacing the 30 gauge tinned copper wire with the resistive wire.

In addition to potential commercial production, variations of the rectangular, vertical powerblinds are currently being researched at North Carolina State University. Adaptations for atypical window sizes, such as half rounds, are being examined. Skylights, both horizontal and angled, also have the potential for modification to house powerblinds.

Another area of future research is the automation of the system’s operation. Currently, the blinds can be either fully opened or fully closed with the flip of a switch.
However, electromechanical and heat transfer analyses have been performed that have shown that automation is possible. A control algorithm for the slats could be implemented to optimize daylighting and heat transfer (Kiefer, 231-241).

With the advent of automated slats, a project on a grand scale is highly encouraged. For example, preliminary brainstorming on a geodesic dome that uses powerblinds has been ongoing. The automated powerblinds would control the light entering the dome throughout the day. Successful implementation of these blinds in a geodesic dome would provide a major advancement in the study of daylighting.
7. Works Cited


8. Appendices
8.1. Wire Jig Information

The following instructions relate to the eight windows built for the boardroom at the Talley Student Center.

Items Shipped to Arch Deco Glass:

- 4’x 6’ MDF (3/4” thick) with 32 holes drilled for roll pins
- roll pins
- molding to protect roll pins
- wire to be embedded in glass

Wire Jig Assembly Instructions:

The jig contains 32 predrilled holes in the piece of MDF. The holes have been drilled to allow slightly less than ¼” of the roll pin to stick out of the MDF, as requested. The roll pins have not been inserted into the MDF in order to protect the jig during shipping. The roll pins are easily inserted into the holes with a rubber hammer. They can be removed with a pair of pliers.

Glass to be used:

Eight pieces of glass embedded with the included wire are needed. There are two different sizes of glass required. The dimensions are given below:

- 34” x 63 ¾” (6 pieces needed)
- 35 3/8” x 63 ¾” (2 pieces needed)
Wiring Instructions:

Please see attached drawings for wire layout.

Due to the different dimensions of the glass, the wiring of each size is slightly different. When wiring the bigger glass, only insert roll pins in the holes that have been circled with blue marker. An outline of the four corners of the bigger glass has also been drawn in blue marker on the MDF to show where the glass should be placed. Once the roll pins and glass are in place, the wire can be strung. The vertical wires should be run on the left side of the roll pins and the horizontal wires on the bottom side of the roll pins, as shown in the attached drawings. When the wiring is complete, the included molding can be placed next to the roll pins, with the lip overhanging the pins for protection. Use the two longer pieces of molding on the top and bottom of the glass (the shorter dimension) and place the four small pieces so that they cover each of the four roll pins used to string the horizontal wires. This process is repeated for the smaller glass using the red markings instead of blue. Also, please leave about an inch of wire sticking out of the glass everywhere after it is removed from the oven.

Important:

- Run **vertical** wires on **left** side of roll pin
- Run **horizontal** wires on **bottom** side of roll pin
Wiring Diagram (not to scale)
**Jig Information:**

- ¾” MDF (medium density fiberboard)
- 1/8” diameter, 5/8” length roll pins (also called spring or tension pins)
- holes in MDF are slightly deeper than 3/8”, leaving slightly less than ¼” of roll pin sticking out of MDF, as requested by glass manufacturer
- Wire should also be sent to Arch Deco Glass

Ship MDF to Arch Deco Glass at NCSU shipping and receiving located at 3240 Ligon Street. Talk to Sherwood at 919-515-9464.
## 8.2. Price List for Talley Student Center Windows

<table>
<thead>
<tr>
<th>Part/Process</th>
<th>Amount of Material (if applicable)</th>
<th>Estimated Cost</th>
</tr>
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<tbody>
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<td>Ladder material</td>
<td>65'' x 12 3/8'' x 0.032'' sheet</td>
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<tr>
<td>Ladder fabrication</td>
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<tr>
<td>Window sealant</td>
<td>24 tubes</td>
<td>$329.49</td>
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<tr>
<td>Hooks</td>
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<tr>
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<td>Wire to be embedded in glass</td>
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<td>Medium density fiberboard and hardware for wire jig</td>
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<td>$90.66</td>
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<tr>
<td>Slats</td>
<td>~2200 slats</td>
<td>$500.00</td>
</tr>
<tr>
<td>Wire embedding</td>
<td>free</td>
<td>free</td>
</tr>
<tr>
<td>Polypropylene pellets for tabs</td>
<td>free</td>
<td>free</td>
</tr>
<tr>
<td>Corner Keys</td>
<td>free</td>
<td>free</td>
</tr>
<tr>
<td>Mutton Keys</td>
<td>free</td>
<td>free</td>
</tr>
<tr>
<td>Aluminum air spacers</td>
<td>free</td>
<td>free</td>
</tr>
<tr>
<td>Muttons</td>
<td>free</td>
<td>free</td>
</tr>
<tr>
<td>Glass</td>
<td>free</td>
<td>free</td>
</tr>
<tr>
<td>Desiccant</td>
<td>free</td>
<td>free</td>
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<tr>
<td><strong>Total</strong></td>
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<td><strong>$2,355.93</strong></td>
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8.3. Contact Information

<table>
<thead>
<tr>
<th>Company</th>
<th>Contact Person</th>
<th>Phone Number</th>
<th>Fax Number</th>
<th>Address</th>
<th>Email/website</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>3M</td>
<td>Larry Yates</td>
<td>512-984-5458</td>
<td></td>
<td></td>
<td><a href="mailto:layates@mmm.com">layates@mmm.com</a></td>
<td>Larry is a sales rep for 3M and can provide samples of the electrically conductive tape (Part # 1120 or 1170, 1/2&quot; wide)</td>
</tr>
<tr>
<td>Arch Deco Glass</td>
<td>Mike Blankenship</td>
<td>614-876-1057</td>
<td>614-351-0211</td>
<td>2395 Setterlin Drive Columbus, OH 43228</td>
<td><a href="mailto:mblankenship@amglassmith.com">mblankenship@amglassmith.com</a></td>
<td>makes wire embedded glass</td>
</tr>
<tr>
<td>AAA Blind Manufacturing</td>
<td>Manny Montoya, Polly</td>
<td>919-380-0898</td>
<td></td>
<td>955 N. Harrison Ave. Cary, NC 27513</td>
<td><a href="mailto:mblankenship@amglasssmith.com">mblankenship@amglasssmith.com</a></td>
<td>supplies slats in various lengths and colors; ~$500 for 2250 slats</td>
</tr>
<tr>
<td>Advanced Laser</td>
<td>Lester Gragg and Rick</td>
<td>408-436-7240</td>
<td>408-441-8834</td>
<td>1707 Rogers Avenue, Unit A San Jose, CA 95112</td>
<td><a href="http://www.adv-laser.com/info@adv-laser.com">www.adv-laser.com/info@adv-laser.com</a>, <a href="mailto:alrickl@aol.com">alrickl@aol.com</a></td>
<td>provides laser cutting services for ladders (~$1200 for 32 ladders, 64&quot; in length)</td>
</tr>
<tr>
<td>Aimet Technologies</td>
<td></td>
<td>919-876-9340</td>
<td>919-876-9760</td>
<td>4200-121 Atlantic Avenue Raleigh, NC 27604</td>
<td><a href="http://www.aimet.com/">http://www.aimet.com/</a></td>
<td>supplies polypropylene pellets for plastic injection tabs</td>
</tr>
<tr>
<td>Anixter</td>
<td>Pete</td>
<td>919-380-3290</td>
<td>919-463-1093</td>
<td>120 Trans Air Drive Morrisville, NC 27560</td>
<td><a href="http://www.anixter.com">www.anixter.com</a></td>
<td>supplies wire that is embedded in glass from Arch Deco Glass; bare, tinned copper, 30 gauge, $58/1000 feet</td>
</tr>
<tr>
<td>Arch Aluminum and Glass</td>
<td>Gerald Ashley</td>
<td>800-830-2044</td>
<td>800-934-6296</td>
<td>400 Park Avenue Youngsville, NC 27596</td>
<td><a href="mailto:gashley@archaluminum.net">gashley@archaluminum.net</a></td>
<td>supplies glass without wire, air spacers, muttons, corner keys, mutton keys, desiccant</td>
</tr>
<tr>
<td>Company</td>
<td>Phone 1</td>
<td>Phone 2</td>
<td>Address</td>
<td>Website</td>
<td>Notes</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Electron Microscopy Sciences</td>
<td>919-465-2399</td>
<td>919-465-9438</td>
<td>424 Airport Boulevard Morrisville, NC 27560</td>
<td><a href="http://www.emsdiasum.com/microscopy/products/sem/conductive.aspx#77800">Website</a></td>
<td>supplies electrically conductive tape (Part #77799) 1/2&quot; wide, 54 feet long, $28</td>
<td></td>
</tr>
<tr>
<td>Fastenal</td>
<td>919-465-9438</td>
<td></td>
<td>424 Airport Boulevard Morrisville, NC 27560</td>
<td><a href="http://www.fastenal.com/web/products/detail.ex?sku=64077">Website</a></td>
<td>supplies roll pins (1/8&quot; diameter, 5/8&quot; length) $0.03 each</td>
<td></td>
</tr>
<tr>
<td>Hisco</td>
<td>Jim Danku</td>
<td>Rick Etters</td>
<td>5243 Capital Blvd Raleigh, NC 2933 S. Miami Blvd Durham, NC 27703</td>
<td><a href="http://www.hiscoinc.com/">Website</a></td>
<td>supplies sealant; RTV5812 (5 gallon bucket, white) or RTV5818C (10 oz cartridge - $12 each, clear)</td>
<td></td>
</tr>
<tr>
<td>Industrial Spring Steel</td>
<td>215-426-7000</td>
<td>215-426-7003</td>
<td>2656 N. Salmon St. Philadelphia, PA 19125</td>
<td><a href="http://www.industralspringsteel.com">Website</a></td>
<td>supplies spring steel for ladders (0.032&quot; thick sheets, $130 minimum order)</td>
<td></td>
</tr>
<tr>
<td>K.A.M. Tool and Die</td>
<td>919-269-5099</td>
<td>919-269-5709</td>
<td>530 Industrial Drive Zebulon, NC 27597</td>
<td><a href="http://www.kamtool.com">Website</a></td>
<td>made die for 1st generation ladders</td>
<td></td>
</tr>
<tr>
<td>McMaster-Carr</td>
<td>404-346-7000</td>
<td></td>
<td>6100 Fulton Industrial Blvd. Atlanta, GA 30336</td>
<td><a href="http://www.mcmaster.com">Website</a></td>
<td>supplies aluminum sheet metal for 1st generation ladders and hooks; 0.016&quot; thick, part # 8973K16 (comes in 12&quot;x12&quot;, 12&quot;x24&quot;, 24&quot;x36&quot;, 36&quot;x48&quot;, 36&quot;x96&quot;)</td>
<td></td>
</tr>
<tr>
<td>NCSU Shipping and Receiving</td>
<td>919-515-9464</td>
<td></td>
<td>3240 Ligon Street Raleigh, NC</td>
<td></td>
<td>ships MDF to Arch Deco Glass</td>
<td></td>
</tr>
<tr>
<td>NDC - Nitinol Devices &amp; Components</td>
<td>510-498-1877</td>
<td>510-623-6995</td>
<td>47533 Westinghouse Drive Freemont, CA 94539</td>
<td><a href="http://www.nitinol.info">Website</a></td>
<td>potential nitinol supplier for ladders</td>
<td></td>
</tr>
<tr>
<td>Talley Student Center</td>
<td>Marie Ministero, Randy Colby, Evelyn Reiman</td>
<td>Marie (office): 919-515-1091 Marie (cell): 919-255-0676 Randy: 919-513-3451 Evelyn: 919-515-7117</td>
<td>Marie: <a href="mailto:mmminist@gw.fis.ncsu.edu">mmminist@gw.fis.ncsu.edu</a> Randy: <a href="mailto:rrcolby@gw.fis.ncsu.edu">rrcolby@gw.fis.ncsu.edu</a> Evelyn: <a href="mailto:eqreiman@gw.fis.ncsu.edu">eqreiman@gw.fis.ncsu.edu</a></td>
<td>Marie is in charge of maintenance for Talley. Randy is in charge of the scheduling of the board room.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>