FINAL REPORT
Door for People with Disabilities

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ME 450 Design and Manufacturing III TEAM 15
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Project Abstract

The goal of this project is to design, build, and test an innovative door system that showcases several concepts that can make the simple act of opening and closing a door at home as effortless as possible for the aging populations of the world. The percentage of the world's population that is elderly is increasing every day, and the need for engineering solutions that increase their independence and quality of life is growing as well.

Executive Summary

The goal of this project is to design a door concept that makes it easier for the aging population to open and close doors within their own homes. Our team developed customer requirements and engineering specifications after discussion with our sponsors, Albert Shih, a professor of Mechanical and Biomedical engineering and Dr. Mark Ziadeh MD, a rehabilitation and physical therapy doctor at the University of Michigan Hospital. From these specifications, our team developed a final Alpha Design. This design featured a flexible door material that can be raised and lowered vertically by a motor attached to the spool. This system will be mounted above the doorframe and will be contained in a single unit. The door material will be guided in the vertical direction by bottom guide bar that slots into a vertical t-track system mounted on the face of the doorway. This design allows for access to the full width of the doorway by removing all doorjambs and hardware associated with a normal wooden hinged door, which was a key engineering specification. The alpha design has been fully developed and modeled, and all materials to be used in our prototype have been chosen after analyzing design parameters developed from our engineering specifications. The design was validated after performing failure analyses on our door design's predicted points of possible failure.

Once the materials were chosen and purchased, we fabricated a prototype garage-style door. We built a full-size door frame using the same dimensions and materials that are used in any standard sized doorframe. We added trim to further enhance the realism of our doorframe. This served as a base for both our motor system and the t-track system utilized in our design. When the prototype was complete, we performed validation testing in order to assess the performance of our prototype. The results of this testing is shown below in Table 1 where it is compared to our engineering specifications. Overall, our prototype met or exceeded many of our engineering specifications, and performed very well in use. However, our design would benefit from some refinements, and further work on this design would result in a better functioning door system.

Table 1. Prototype Performance Summary

Engineering Specifications	Target Requirement	Prototype Results
Opening or Closing Time	20 seconds	13 sec. (opening), 11 sec. (closing)
Useable Door Space	30 x 80 inches	30 x 80 inches
Visibility	0%	10%
Sound Dampening	38 STC	21 STC
Electrical Power Source	120 V	120 V
Footprint	12 x 48 x 12 inches	3.5 x 42 x 4 inches
System Weight	75 pounds	44 pounds
Cost	$1200.00	$594.00
Mountable on Standard Doorframe	3 inches above doorway	2 inches above doorway

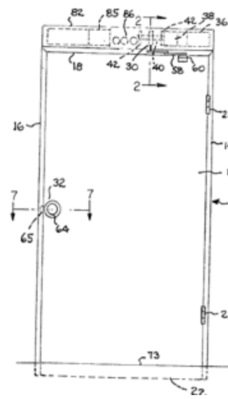
Introduction
Our project entails the design and fabrication of a door system for home use, tailored to meet the needs of elderly people. Albert Shih, a professor of both Mechanical and Biomedical engineering, is a sponsor for this project. He specializes in finding engineering solutions for elderly people. Dr. Mark Ziadeh MD, a geriatrician at the University of Michigan Hospital, has become a sponsor for our project as well. He works mainly with elderly patients, specializing in physical medicine and rehabilitation. Elderly people are becoming an increasingly large part of the population around the world, and the need for engineering solutions designed to increase the independence and quality of life for these people is growing. At first, this project was focused on designing a door system specifically for arthritic people that could be utilized in their homes. The goal of this project would be to reduce or eliminate the pain and discomfort that arthritic people experience when using a normal door and doorknob by innovating a novel door system. However, after our preliminary research revealed that this problem was almost completely solved by existing "lever-type" doorknobs, our project shifted focus towards a door system designed to meet the needs of the elderly at home. The goal of this project is to produce a door concept that makes it easier for the aging population to open and close doors within their own homes. We hope to produce a working prototype that showcases a variety of solutions that can be easily implemented in existing homes.

Information Sources
We spoke with Dr. Jeanne Riggs, a hand therapist at Domino's Farms, as well as two other groups for information, the Glacier Hills Senior Living Community and an online arthritis forum, http://www.arthritisinsight.com. We posted a survey on the online forum to try and gauge the need for assistive door devices for sufferers of arthritis (Appendix A) . The responses from both Dr. Riggs and the survey indicated there is not a pressing need for an assistive door device for arthritic people. This helped us move our project focus away from a device that assists arthritis patients exclusively and more toward the elderly population and people with various disabilities as a whole.

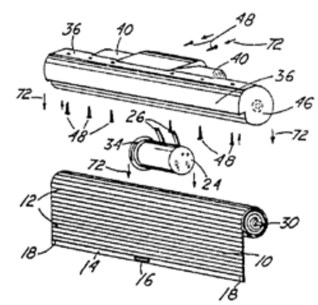
We also talked to our co-sponsor, Dr. Mark Ziadeh. He helped us to narrow down our focus and customer requirements. He pointed out several problems with standard doors that would affect people with disabilities and the wheelchair bound. Dr. Ziadeh stressed to us that our door design should be easy to use, maintain the same level of privacy as existing doors, and should be affordable. Also, he noted that many doors obstruct the full width of the doorway when opened 90 degrees, which our designs should attempt to eliminate. Due to the standard hinge configuration on most doors, the door juts into the doorway at the hinged end. While most people do not notice this small impediment, for people who use walkers or wheelchairs that inch or two can disrupt their movement through a doorway. Dr. Ziadeh also suggested that we consider electric designs to maximize the ease of use. The inclusion of electric systems increased the scope of our patent and existing product search. Our market research found that the exisiting electric door systems eliminate any difficulty in opening doors for elderly or disabled people, but do not allow for full doorframe clearance. Patents describing the systems we found are below with additional patents in Appendix B.

We found that hands-free automated door systems are the best for the disabled and elderly because it greatly reduces the effort to open the door. We also learned that roll up doors provide an advantage over other door systems by providing total door clearance, which is paramount for people in wheelchairs. However, most of the current roll up doors focus on industrial and commercial use. We also found that metallic roll up door systems are heavy and cumbersome, which is not be optimal for purposes.

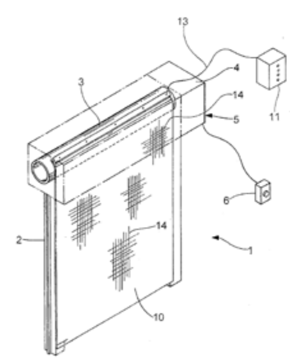
Residential Handicap Accessible Door *(US20040098915 A1)*
This design was filed on November 22, 2002 and patented on May 27, 2004. This design comprises of a low voltage power supply, an opening device comprising electric motors, light controlling apparatus, a locking and unlocking device, force limiting hardware and movable door sill. An electrical-operated power mechanism, which moves between the opening and closing position of the door, is added to the top of a door. By pressing button on the remote, the door will open automatically. This design is aimed to provide a hand-free door system to people confined to wheelchair. However, this invention does not clear the doorway completely which may present to be a problem for people on wheelchairs with standard doorframe.



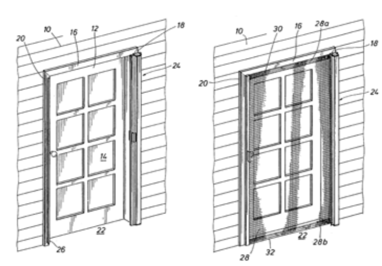
Roll Up Closet Door *(US4807684)*
This design provides a roll up closet door in a tubular housing attached to the top. It was filed on Jun 11, 1987 and patented on February 28, 1989. The design includes a compression spring and an electric motor. Therefore, it can be operated manually or with electrical assistance. This invention is designed for closet doors, but could be scaled up for home use and provide total doorframe clearance; it will also ease the door access of people with wheelchairs.



Steel Reinforced Roll-up Industrial Door Substrate Fabric *(US 5655585)*
This design incorporates a mutltilayer door closure fabric into a commercial or industrial roll-up door system. It was filed on April 25, 1996 and patented on August 12, 1997. The fabric is reinforced with conductive yarns embedded within layers of fabric. This design addresses some of the problems facing conventional metallic roll-up door systems, which are easily susceptible to denting and cumbersome to use. It also provides adequate levels of security. This design can serve as a reference for a roll-up, interior door system using fabric in for use in the home.



Retractable Covering for a Door Opening *(US 5505244)*
The design involves a retractable covering for a door. It was filed on August 8, 1994 and patented on April 9, 1996. It has a housing mounted on one side of the door and a latching strip mounted on the opposite side of the door. A roll of screen can



be pulled out of the housing across the door opening and engaged to the latching strip on the other side. This design is only the addition to the current door system and thus, cannot stand alone as a door. However, it gives a full doorframe clearance if it is installed alone on the doorframe without the door.

Project Requirements and Engineering Specifications

Our customer requirements were developed by analyzing information provided by our sponsor meetings with Albert Shih and Dr. Mark Ziadeh, our interview with Dr. Jeanne Riggs, and our visit to the Glacier Hills nursing home in Ann Arbor, Michigan. The customer requirements are listed in order of importance in Table 2 below.

Table 2: Customer Requirements

Requirement	**Description**
1. Safe operating conditions	Use and operation of this design must not worsen physical condition by introducing new injuries.
2. Minimize use and rotation of thumbs, wrists, and fingers to make door easier to open.	Patients with arthritic conditions experience pain, particularly in their thumbs, wrists, and fingers, when opening standard doors.
3. Minimize use of hands and fingers to prevent disease transmission.	Opening doors with hands spreads germs, which causes rapid transmission of sicknesses.
4. Use an assistive mechanism to aid in opening and closing the door to reduce apparent weight.	Reduces the strain and difficulty associated with walking through a door.
5. Use body parts in neutral positions	Neutral positions minimize stresses on the body and joints.
6. Provides maximum clearance	Customers with wheelchairs or walkers require more room to pass through space.
7. Privacy	Applications such as bathroom and bedroom doors require privacy which meets or exceeds current door standards.
8. Longevity	Operation must not be affected by environmental factors such as temperature and humidity.
9. Easily installed into existing doorway	Modifications to the current door frame should be avoided
10. Easy to use	Must be natural and intuitive
11. Cost effective	Must be affordable and competitive

Many of our previous engineering specifications did not apply to our selected design. With guidance from Dr. Shih, Dr. Ziadeh and the American National Standards Institute (Appendices C, D), we revised our specifications and re-evaluated our QFD to incorporate these changes (Appendix E). The QFD relates our engineering specifications and the customer requirements, and weighs the relative importance of each engineering specification with regards to fulfilling all customer requirements.

Table 3. Engineering Specifications

Engineering Specifications	Target Requirement	Supported Customer Requirements	Weighted Importance (%)
Opening time (-)	20s	1, 7, 10	9
Useable door space (+)	30 x 80in	1, 6, 10	18
Visibility (-)	0%	7	6
Sound dampening (+)	38 STC	7	6
Electrical power source (-)	120 V	2, 3, 4, 5, 8, 9, 10	37
Footprint (-)	1 x 4 x1 ft	6, 9	6
System weight (-)	75 lbs	8, 9	2
Noise level (-)	30 dB	7, 8	4
Cost (-)	$1200	11	4
Mount on standard doorframe (-)	3 inches above door	6, 9, 10	8

(+) means more is better, (-) means less is better.

As seen in Table 3, having a 120 V electrical power source is our most important specification. By itself, this specification fulfills all of our customer requirements related to physical interaction with the design. Being 120 V provides ease of use and installation since it can be plugged into a standard outlet. A useable door space of 30 x 80in gives customers in wheelchairs and walkers more clearance to maneuver through the door frame. An opening time of less than 20 seconds is a large improvement over competitors and contributes to safe operating conditions in case of emergency. Visibility of 0% and sound dampening of 38 STC, sound transmission coefficient, provide the same privacy of a household wall and a noise level of 30 dB, which is the sound level of an ambient house, further assists with privacy. Having a footprint of less than 1 x 4 x 1 ft and being able to mount within 3 inches above a standard doorframe help maintain maximum clearance and ease of installation. A cost of less than $1200 provides a cost effective alternative to competitors.

Competitor Products

After we had completed Design Review 2 and decided upon our garage door design, we found a very similar product already on the market. The Motor Door from DEL Motorized Solutions, shown below in Figure 1, is a power window blind system converted into a door. Through the use of an electric motor, the door is rolled up and down to allow entry and exit to a room. The product is marketed to people with disabilities, just like our door design. However, since this company has adapted a power window blind system for a doorway, this product has several flaws. Since window blind material is used as the door material, sound is easily transmitted through the door. When we contacted DEL Motorized Solutions about the sound dampening abilities of their door, we received an e-mail response from our contact in the company, Anshul Rastogi, who said:

> "There is extremely minimal sound dampening capabilities, and also minimal door strength. The shade will roughly roll 1 1/2" to 2 1/2" per second."

After requesting a quote for the custom order Motor Door from DEL Motorized Solutions, we found that the system would cost $1,116.00 without installation. This quote is included in Appendix F. According to our research on the product, the Motor Door also takes 32 seconds to open or close. Due to the high price, low speed, and low sound dampening abilities of this product, we decided that we can greatly improve the Motor Door product and to continue with the development of our own design. We plan to improve the sound dampening capabilities, strength, and rise time of the Motor Door with our own design, all at a much lower cost compared to the Motor Door.

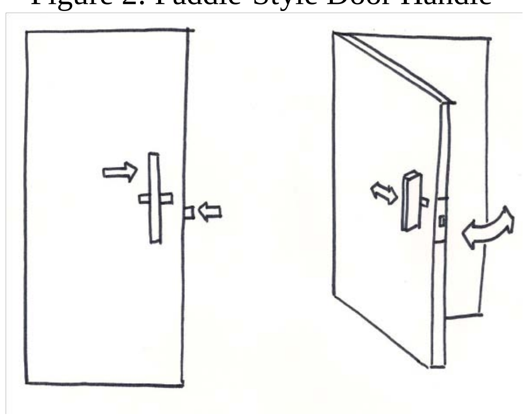
Figure 1: The Motor Door

Concept Generation

As a team, we developed several potential concepts designed to address our customer's requirements while meeting our engineering specifications. After we compiled our ideas and concepts, we found that they could be organized into three main categories, doorknob designs, foot-actuated designs, and novel door systems.. We chose the six best concepts for further analysis. This section will discuss the rationale behind each of the six main designs, organized by category.

The first category includes designs that focus only on the doorknob itself. Designs that fit within this category are located in Appendix G, complete with basic visuals and explanations of how they work. Many of our concepts in this category attempted to make doors easier to enter and exit by optimizing the doorknob mechanism, and many relied on no hand contact whatsoever. The best concept developed within this category was a paddle-style door handle that could be actuated by pressing it with either a shoulder or an elbow in a side-to-side motion, as shown in Figure 2.

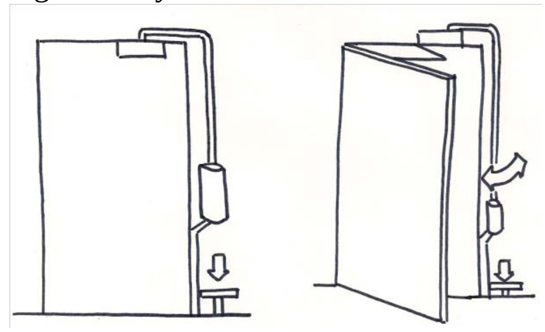
Figure 2: Paddle-Style Door Handle



The second category of concepts includes all of our designs that rely on foot actuation. By utilizing the customer's feet, the goal was to reduce stress on the upper body, eliminate hand contact and disease transmission, and take advantage of the weight of the user in order to open or close a door. As before, the designs that fit within this category are located in Appendix G, complete with basic visuals and explanations of how they work. There were two distinct concepts that best represent this category, a hydraulic foot-actuated door and a foot-actuated door bolt.

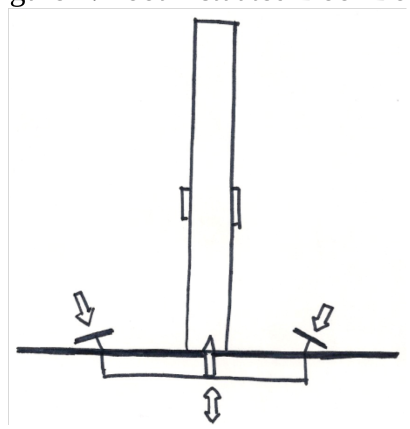
The hydraulic foot-actuated door will utilize the user's body weight to transmit hydraulic fluid through a closed system, transferring this hydraulic pressure into the rotational motion of a door opening or closing, as shown in Figure 3. The user would simply step (or roll their wheelchair) onto a small, wall-mounted pedal and the door would open. This design would feature a holding mechanism in order to keep the door open long enough for an elderly person to pass through the doorway, even if they were in a walker or a wheelchair.

Figure 3: Hydraulic Foot-Actuated Door



The foot-actuated door bolt would eliminate the door handle altogether, instead relying on foot pedals to un-bolt the door, as shown in Figure 6 below. This is accomplished this by moving the door bolt from the side of the door (and the doorframe) to the floor (and the bottom of the door). When the user steps on the foot pedal, the door bolt would retract into the floor (and out of the bottom of the door), freeing the door to swing open. This concept also incorporated a double swinging door design, so that the door could be pushed open from both sides. The user would simply step on the foot pedal, push open the door, and walk through the doorway. The door would automatically re-bolt as the door closes.

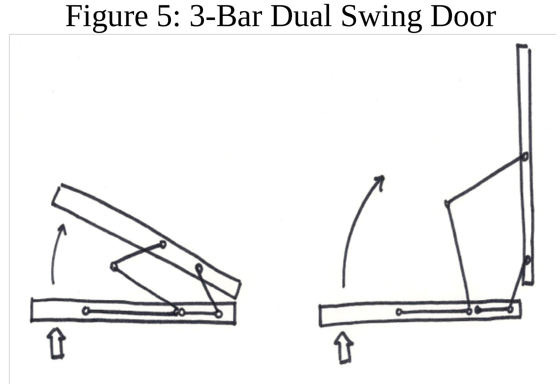
Figure 4: Foot Actuated Door Bolt



The third category of concepts consists of all designs that attempt to reinvent the door. Almost all of these designs eliminated normal hinges altogether, and some utilized electric power. The general goal of these concepts was to eliminate the "pulling" motion required to open a door from one direction. The designs that fit within this category can be found in Appendix G, along with basic visuals and an explanation of how each one works.

The first design within this category is a dual swing door that utilizes a three bar mechanism mounted between the top of the door and the top of the doorframe, as shown in Figure 5. This design attempted to eliminate the door clearance problem posed by normal doors so as to benefit customers who are wheelchair or walker bound. It does so by swinging in a slightly outward arc, so that when the door is opened 90-degrees, it is offset from the doorframe. This leaves the full width of the door

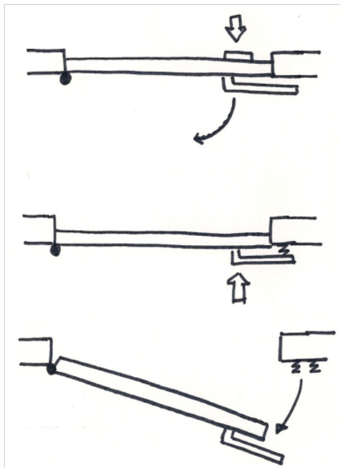
Figure 5: 3-Bar Dual Swing Door



available to the user. As a dual swing door, it could be pushed open from both sides, and would have an auto-close feature provided by a torsion spring mounted in the three bar mechanism.

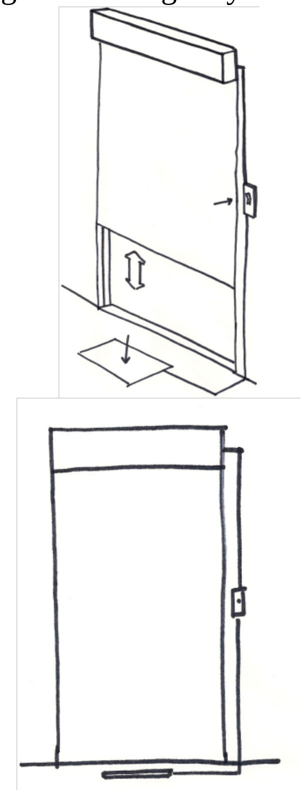
The second design within this category was a spring-loaded door concept, as shown in Figure 6. This design attempted to build off of existing doors within the home by adding a spring-loaded mechanism to one side of the door. The side of the door that is pushed open would remain unchanged. However, on the pull-side of the door, a small set of springs would be mounted on a bracket at the top of the door. There would also be a slight gap between the door and the doorjamb, allowing the door to be pushed slightly from the "pull" side of the door. When the customer wants to go through the door from this direction, instead of pulling the door open, they would push the door in. This would compress the springs on the bracket against the wall, and when the door is released, it would pop back towards the customer, allowing them to open the door without any difficult pulling motions. This design works very much like many cup holders found in today's cars.

Figure 6: Spring-Loaded Door



The final concept within this category is a garage style door adapted for use in the home, as shown in Figure 7 below. This design would operate very much like the protective metal shutters that roll down over storefronts when they close up for the night. The door would be pulled upwards and rolled up above the doorframe. This design would utilize an electric motor system that plugs into the wall to provide the lifting force necessary to open this type of door. This design was created to eliminate the door clearance issue and provide the easiest possible way to pass through a doorway with the maximum level of privacy. The door itself would be made out of a strong yet flexible material that provides adequate levels of soundproofing. The bottom of this door would be weighted to maintain tension in the material, and ball bearing supported rollers would be mounted to each side. These rollers would slot into a track mounted to each side of the doorframe to keep the door traveling straight up and down, and to maintain a level of privacy. The entire system could be activated by a remote control, a wall mounted switch, or a floor mounted pressure sensor. Since this design is electric powered, a fail-safe must be added in order to facilitate easy egress in the event of a power outage.

Figure 7: Garage Style Door



Concept Selection Process
We set out to select the best overall design by comparing and scoring our designs using a scoring matrix. We listed our customer requirements and scored each of our top six designs from 1 to 5 based on how well it accomplished the requirement. A few customer requirements were omitted from the overall score calculation because they were met by all the designs. For example, all of the designs were safe to operate and minimized joint rotations, so there was no need to list these. The "doorframe clearance" category was rated by awarding either a 0 or a 5, because the door either cleared the doorframe or did not. We also weighted each category with weights from our QFD, which were then multiplied by individual scores given. The overall scores are listed in Table 4.

Table 4. Concept Scoring Matrix

	Weight	**Paddle Door Handle**	**Foot Actuated Hydraulic Door**	**Foot Actuated Floor Bolt**	**3-bar dual swing**	**Spring-loaded door**	**Garage Door**
Hands Free	10/10	4	5	5	3	4	5
Assistive mechanism	9/10	1.8	4.5	1.8	1.8	3.6	4.5
Doorframe Clearance (0 or 5)	8/10	0	0	0	4	0	4
Privacy	8/10	4	4	1.6	1.6	4	1.6
Easily installed	7/10	3.5	.7	0	1.4	2.8	1.4
Easy to use	6/10	1.8	0	2.4	2.4	1.2	3
Cost	5/10	2.5	1.5	1	1.5	2.5	0
Total	**-**	**17.6**	**15.7**	**11.8**	**15.7**	**18.1**	**19.5**

The paddle style doorknob's main advantage was the its hand free design. It is operated by sliding the paddle with an elbow or a shoulder, which means someone without full use of his or her hands could use it. It can also fit existing doorways easily and without extensive installation because it doesn't use any specialized hinges. However, it is a single swing design, which means it must be pulled open from one direction. Because this design does not feature an assistive opening mechanism, there is not a good way to pull it open without a handle. Due to its use of standard hinges, it does not fully clear the doorframe. This design is not ideal for people in wheelchairs or walkers, as the sliding paddle could be awkward in those positions.

The foot actuated hydraulic door excelled in its hands free design and assistive opening without requiring pulling in any direction. Pushing down on the pedal would fully open the door, however, this did not lead to an easy to use design. Either a single, forceful pedal press or multiple pumps would be required to operate it, which can be difficult, especially for elderly people in wheelchairs and walkers. It also required extensive installation on both sides of the door. The foot actuated floor bolt design also excelled in the hands free category as well as ease of use. Unlike the hydraulic foot design, people in wheelchairs or using walkers could easily operate this door system. It also features a double swing design, which eliminates the need to pull the door open. However, the main disadvantage of this design is the extensive installation necessary. The pedals and bolt are built into the floor, which is not easily accessible in most houses. There are also potential safety and centering issues. When the pedal is released, the bolt pops back out from the floor, which could create a tripping hazard. Also, if the pedal on the other side is pressed down as the door swings back, the door could overshoot the doorframe and hit someone following closely behind.

The 3 bar door system's main advantage is the fact that it full clears the doorway, something most of the other designs do not accomplish. This 3 bar design also means that it can swing both directions, which eliminates the need to pull the door and makes it wheelchair and walker friendly. However, the 3 bar system requires more extensive installation than traditional hinges and like other double-swinging doors, has reduced privacy due to the lack of a door jam.

The spring-loaded door doesn't require hands to operate, as it can be pushed by an elbow or shoulder. The door is easy to open in most situations due to the lack of a doorknob and can be activated by pressing almost anywhere. However, it is still a single-swing design and requires some pulling force once popped open. Even though the opening is assisted by the springs, this is not meant to fully open the door. This design can be difficult for people in wheelchairs and walkers to operate because they must maneuver all the way up to the door, pop it open, and then move backwards to pull it open. The door also doesn't clear the doorframe, so moving through it once the door is open could also be difficult.

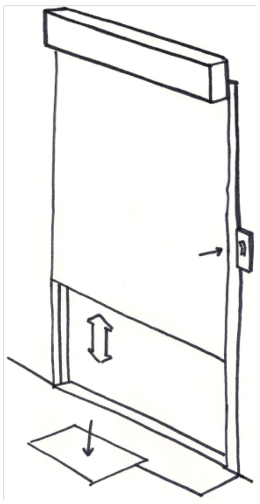
The garage door met many of the customer requirements and as a result, scored highest in our concept selection matrix. The automatic design means it is hands free and very easy to operate. It also solves the door clearance issue by retracting into the ceiling, which results in another advantage we didn't originally foresee. In smaller rooms such as bathrooms, open doors can take up a significant portion of the floor space and make navigating the room difficult, which the garage door design eliminates. Cost and installation are the main disadvantages of this design. It is the most expensive of our designs because it features an electric motor, and comparable systems on the market cost about $200. Installation involves mounting the motor assembly above the door and installing a track in the doorframe, which is not as simple as some of the other designs.

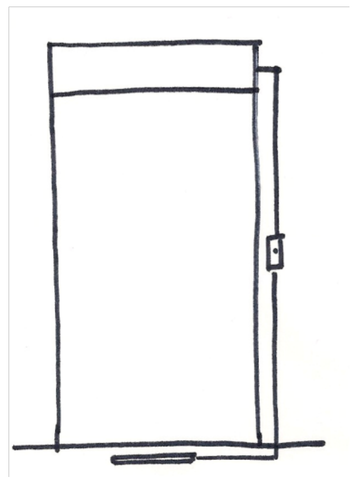
In the end, the garage door scored highest overall by best meeting the design requirements. Although we originally intended to keep the design purely mechanical, our analysis and meetings with Dr. Ziadeh and Professor Shih revealed that it would be very difficult to match the convenience and ease of use of an electric door. Cost is the main drawback of the design, which means it may not be economically feasible for a customer to install these throughout their house, but we think that the advantages of the system far outweigh the disadvantages and feature a significant improvement over existing door systems.

Final Alpha Design Description

We chose the garage style door adapted for use in the home. For reference, Figure 8 shows our final design, as seen in the Concept Generation section. The door itself will consist of a thick, flexible material that can be rolled up vertically to allow the user to pass through the doorway. Some type of reinforced acoustical foam with 100% opacity that will provide sufficient sound dampening while being resistant to tearing, ripping, cutting, and other damaging effects would be preferable. The door will be raised and lowered by an electric motor. When activated, the motor will pull up the door material and roll the material onto a spool hidden in a unit mounted over the top of the doorframe. The motor can either be activated by a pressure sensor installed on the ground on both sides of the door, a wall-mounted switch, or by remote control.

Figure 8. Alpha Design





In order to ensure that the fabric door remains taut and only moves in the vertical direction, a metal bar will weigh down the bottom of the fabric door. This will keep the fabric taut and help to unroll the door from the spool when the motor operates in reverse to lower the door. Attached to this metal bar on each side will be ball bearing supported rollers that will line up with a track mounted in the doorframe. This track system will keep the door from moving in any direction except up or down and help to seal the door, providing the same level of privacy as a normal door. This track will be mounted next to the doorjambs in existing doorways. This keeps the track somewhat hidden from view, and maintains the full width of the doorway for easy ingress and egress for customers who are wheelchair or walker-bound.

The motor and spool assembly will be mounted above the top of the doorframe on the wall. A box will surround the entire assembly for aesthetic purposes. The spool will be mounted to brackets that attach to the wall, and the spool will be ball bearing supported for smooth and quiet operation. The motor will be mounted to the wall, with a gear reduction to the spool in order to turn the spool to raise or lower the door. The fabric may be attached directly to the shaft or on larger diameter discs, depending on the gear ratios that optimize motor performance. A torsion spring will be attached to the shaft as a safety precaution that will open the door in case of motor failure or power loss.

Parameter Analysis

The purpose of this analysis is to determine parameters that dictate the selection of any components we purchase or fabricate for our door design to ensure that our engineering specifications are met or exceeded while satisfying our customer requirements. Many of our parameters will be dictated by the motor we choose for our design, since the motor's specifications will determine the weight of the door material itself, the speed at which the door is raised or lowered, and the voltage requirement of our system. The door material itself also influences certain aspects of our design, since its thickness determines the maximum diameter of the motor and spool assembly when the door is fully rolled up, which dictates how far the system needs to be spaced off of the doorframe. The door material's properties also determine the forces on the screws holding it to the motor spool, and whether or not the screws will tear through the material. Once these materials are chosen, we need to ensure that the door studs will be able to support the weight of the system on the wall.

A major concern when choosing the motor system is the amount of space it will occupy, since this door system is designed for use in the home where large and obstructive systems mounted above doorways are undesirable. Therefore, we sought to find a motor system that was as compact as possible and preferably programmable so that we could dictate how far the motor had to spin in either direction (up or down). As laid out in our engineering specifications, the system must take up less space than a one-foot by four foot by one-foot volume above the doorframe. As previously stated, the motor's specifications will dictate the door material we use for our system. The motor's torque or overall load rating will be key for this. Our door material must be approximately 3' wide by 8' tall, and weigh less than the maximum load rating for our motor system. The door material must also be able to block sound as effectively as a standard wooden interior door found inside an average home or in other words have an STC rating of around 30. There may be a trade off here however, since sound-dampening materials can get expensive as their sound dampening abilities increase. A balance between affordability and sound dampening ability will have to be made. Once the door material and motor have been chosen, the rise and fall time of the door system can be calculated. Using the length of the door material *L* in inches, the initial diameter *D* of the spool in inches, and the speed *S* of the motor in RPM, the rise time in seconds can be found using Equation 1 below. This is a conservative estimate of the rise time, since it assumes the diameter of the spool remains constant, when in reality, the spool's diameter will increase as the material is rolled onto it. This will result in the spool rolling more material onto itself with each successive turn, which should result in a lower actual rise or fall time.

$$Rise\ Time\ (\text{seconds}) = \frac{L \times 60}{\pi \times D \times S} \qquad \text{(EQ. 1)}$$

Since the spool will accumulate door material on itself, when the door is fully rolled up the spool's diameter should be considerably larger than when the door was fully rolled down. This final spool diameter will determine how far off of the wall the spool system needs to be mounted. The first step is to find how many turns it takes the spool to fully roll up the door material. This is calculated in Equation 2 below, where *L* is the length of the door material in inches and *D* is the initial diameter of the spool in inches.

$$N\ turns = \frac{L}{\pi \times D} \qquad \text{(EQ. 2)}$$

This is again a conservative estimate, as it assumes the spool diameter remains its initial diameter. Once the number of turns it requires the spool to roll up the material is known, one can then calculate the final diameter of the spool (again, an overestimate, since the number of turns is itself an overestimate) using Equation 3, where *D* is the initial diameter of the spool in inches, *N* is the number of turns it requires the spool to fully roll up the material, and t is the thickness of the material in inches.

$$D_{final} = D + N \times (2 \times t) \qquad \text{(EQ. 3)}$$

Once the final diameter is known, the spool can be mounted an adequate distance away from the wall in order to ensure sufficient clearance between the fully rolled up door material on the spool and the wall.

We also performed a failure analysis for several components of our design. To ensure that the door studs could adequately support the maximum weight of our system according to our engineering specifications, a failure analysis on the vertical door studs was performed. This analysis was an absolute worst-case scenario analysis, assuming that the entire load of the system is borne by just one bracket. In reality, two brackets will split this load, but if just one bracket can hold the entire load with an acceptable safety factor, it should be more than fine with two. The motor brackets are modeled as simple beams, with a load on one end (the system weight) and fixed at the other where it is mounted to the door studs. The result of the weight of the system is an internal moment on a concentrated point on the vertical door stud. This analysis can be found in its entirety in Appendix H.

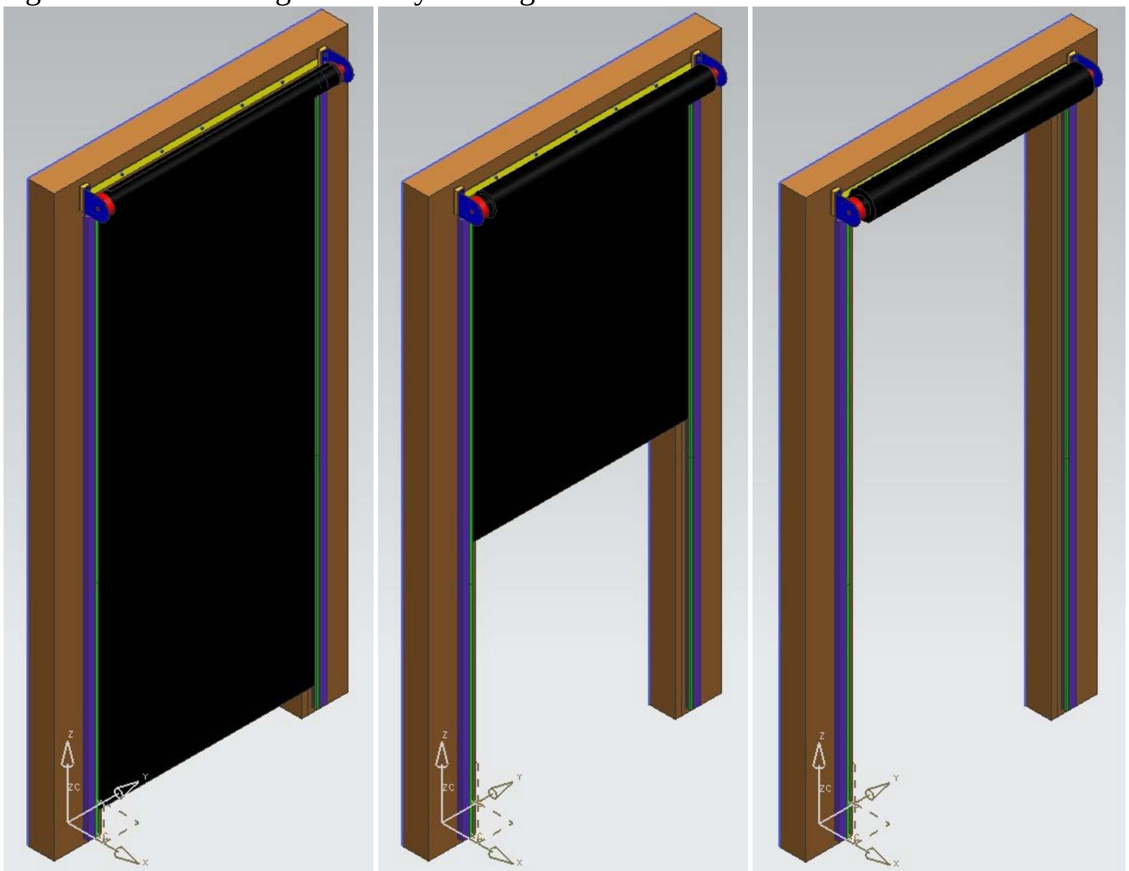
Another point of failure would be the interface between the door material and the spool that it is mounted to. In our design, the door material would be mounted to the spool via threaded screws and a pinch bar. To ensure that the screws would not tear through end of the door material, a bolt tear-out analysis was performed on the door material to ensure that it was adequate for our design. Also, to ensure that the screws holding the door material to the motor spool would not fail under the load of the door material, a failure analysis was performed on the screws themselves. These analyses can also be found in Appendix H.

After these analyses were performed, our design was validated from a failure analysis standpoint, with the door studs easily handling the maximum load our system could impart upon them, the screws holding the door material to the motor spool not even coming close to failure, and the door material being able to resist the effects of bolt tear-out.

Final Design Description

Our final design is very similar to our alpha design, the garage style door for the home. A door constructed from a sound dampening fabric is rolled up and down by a motor and spool system mounted above the doorway. By rolling up vertically, the full width of the open doorway would be available to the user, which is very advantageous to those confined to wheelchairs or walkers. The door is guided by a track system mounted vertically on each side of the doorway. This track system not only guides the door, but also slightly encapsulates the door material on each side of the door, which prevents light from passing through the door as well as increasing the sound dampening abilities of the door. The entire system can be activated by a remote, a wall-switch, or a pressure sensor mounted in the floor. The result is shown below in Figure 11. The door itself will consist of sound dampening material sandwiched between an aesthetically pleasing material that would also protect the door from moisture.

Figure 11: Final Garage Door Style Design

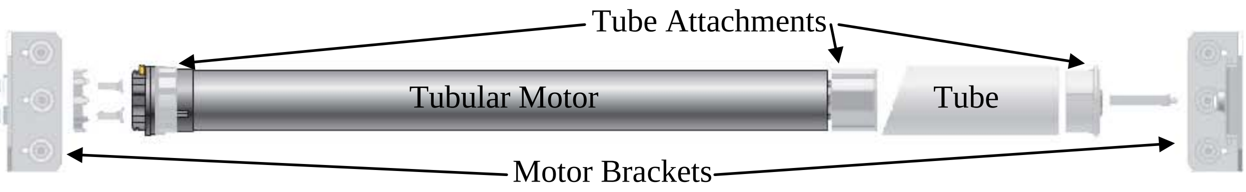


We decided on the Quiet Barrier MD (Appendix K), a flexible, high-density composite consisting of vinyl and polyether foam. This material offers the sound dampening characteristics we desire, while being flexible enough to be rolled onto a tube. According to our calculations, the door material will weight under 21 pounds for our application. This calculation was based on the 3’ wide by 8’ tall dimension, which is slightly larger than is necessary for our design and the density and thickness of the material. This door would roll up onto the combined motor and tube assembly to allow entry through the door.

Once we chose the door material, the biggest challenge was finding an electric drive system for our electric garage style door. After careful research, tubular electric motors were deemed to be the best solution for our design. These tubular motors are designed to fit within a roller shade tube, and consequently they are very low profile, and help to keep the footprint of our design small and unobtrusive. We chose to use the Somfy Sonesse ST50 RTS roller shade motor. The motor and tube assembly is pre-manufactured and designed to be sold as a system. This system consists of a tubular motor, spool, motor brackets, and the proper spool attachments to fix the motor in the spool. This assembly is shown in Figure 12. The motor brackets will be mounted onto the existing door frame above the door opening. This motor has an operating voltage of 120 VAC, with a current draw of 0.95 amps. It has a torque rating of 2.86 foot-pounds, which gives a lifting capacity of 28 pounds. The weight of the door material (21 pounds) is well within the load range of this motor. The motor spins at 32 RPM and according to our calculations (Equation 1) provides a theoretical rise time of 18 seconds for our design. This motor is programmable via an

RF remote. The user can program the travel of the door, including where the door will stop when it is fully down, and how far up the door will stop when the door is fully open.

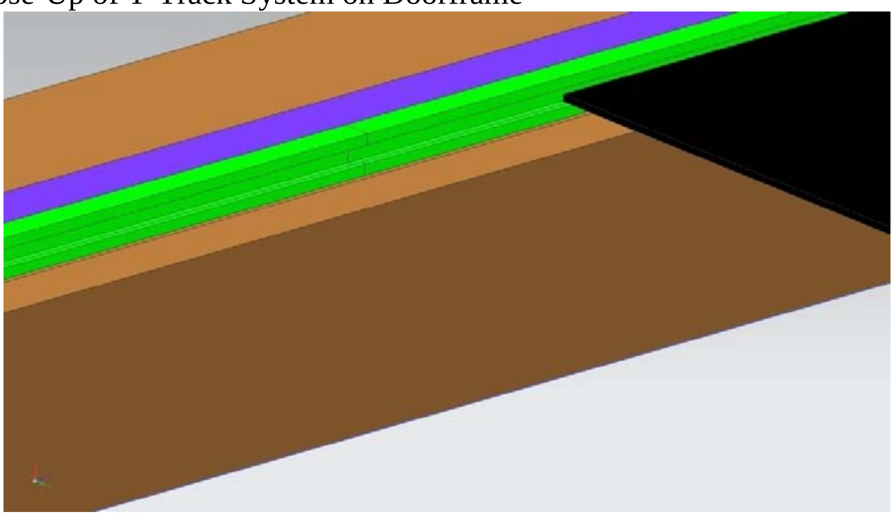
Figure 12. The Somfy Sonesse LT50 Motor, Tube, and Bracket Assembly



Using Equations 2 and 3 in the Parameter Analysis section, we calculated the total diameter of the motor and tube assembly when the door was fully raised and the door material was fully rolled onto the tube. We found this diameter to be approximately 4.25”. The brackets specific to our motor are fairly shallow and therefore we need to fabricate spacers to position the combined motor and tube further away from the wall to give enough clearance for the largest possible diameter of the motor and tube assembly, 4.25”. The spacers will have the same dimensions as the smaller face of the motor brackets, and will be constructed from one-inch sections of two by fours. This will give ample clearance between the wall and the fully rolled up material on the motor and tube. The entire system will be mounted to the vertical studs on each side of the doorframe with 3-inch long wood screws.

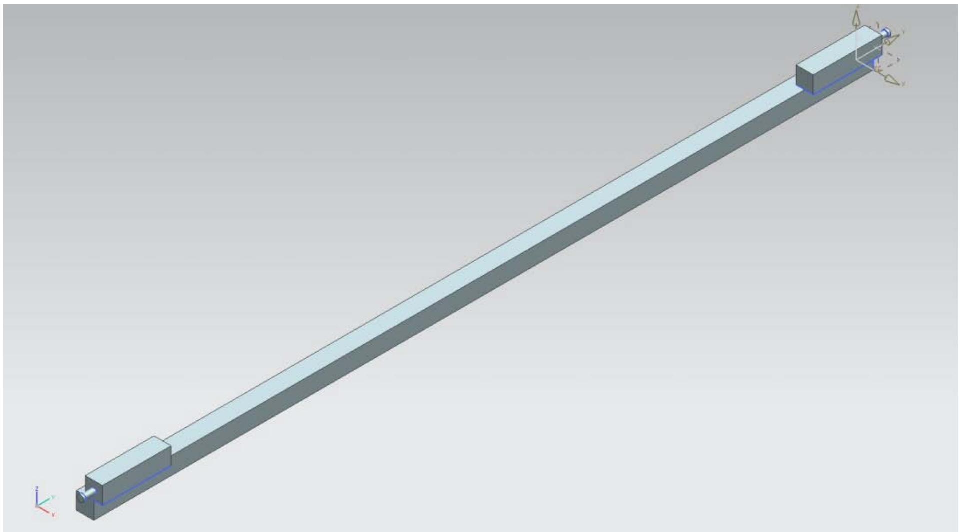
Below the motor and tube assembly, there will be t-track mounted vertically on each side of the door, starting at the floor and ending four inches below the motor and tube system. This t-track will guide the door material, keeping it aligned in the vertical direction, as shown in Figure 13.

Figure 13: Close-Up of T-Track System on Doorframe



At the bottom of the door material, there will be a guide that attaches to the bottom of the material and slides into the t-track keeping the material in line. This bottom guide bar can be seen in Figure 14 below. The t-track is approximately half an inch deep on each side, which will encapsulate some of the door material on each side of the doorway, preventing light from passing through the sides of the door. This also increases the sound dampening ability of the door.

Figure 14. Bottom Guide Bar



Our final design includes several options for activating the door, including a remote control, a wall switch, and pressure sensors mounted on the floor on each side of the door. An electronic locking mechanism will be incorporated into our final design as well, allowing the user to “lock” the door for extra privacy. A battery backup system would be installed between the motor system and power source to allow for a seamless transition to battery power in the event of a power outage. Our final design includes several aesthetic additions to help boost acceptance of our concept for home use. Wood trim would be added on each side of the door to cover the track system, and this trim could be painted or stained to match the existing doorway. A plastic cover would be fabricated to hide the upper assembly, including the motor, spool, and brackets from view. This cover could also be fabricated from wood so that it too could be stained or painted to match the existing doorway. This design makes the removal of the old door, hinges, and doorjamb possible, which in a standard doorway will provide approximately an extra one-inch of door width. A complete Bill of Materials (BOM) is included in Appendix K.

Prototype Description

Functionally, our prototype is very similar to our final design. It features the same motor, tube, brackets and sound dampening material to be used in the final design. However, since the goal for our prototype is to simply demonstrate the functionality of our final design, certain aspects of the final design were not fully developed for the prototype. The design features that were omitted from the prototype are not essential for demonstrating the validity our final concept. Our prototype only features one activation method, the RF remote, instead of the three explained in the final design description. The remote supplied with the Somfy Sonesse ST50 motor was used to easily activate the motor and set the start and stop points. The other two activation methods, the pressure pad and wall switch, simply involve other methods of activating the wireless signal, which is not necessary to show the overall capabilities of the final design. While our prototype will not feature an emergency backup system, this would be a necessary feature in our final design to ensure the door does not become inoperable in the event of a power outage. Lastly, our prototype does not feature any aesthetic enhancements, including motor and tube enclosures or door fabric coverings. The covering for the sound dampening material would be important in real world usage because it would protect the material (for example, from humidity in a bathroom), however, since our prototype will not be used for long term operation in these types of conditions, it is not a necessary feature.

The prototype we eventually produced had several components, the first of which was the full size doorframe complete with trim that we fabricated. Constructed to mimic a real standard doorway exactly, down to the dimensions and the materials used, the doorframe provided a mobile platform onto which we could mount our door system. The t-track system was then mounted to vertical wood strips, which were then installed on the front of the doorframe. Once the doorframe was built, we then mounted the Somfy Sonesse motor in the aluminum tube along with the requisite hardware. The brackets for the motor system were mounted on spacers above the doorframe, and the complete motor and tube system was then installed to ensure that the brackets were mounted properly. The QuietBarrier MD sound dampening material was mounted to the motor tube with a combination of machine screws and a steel pinch bar. The bottom bar was then attached to the bottom of the door material, and the door material and bottom bar was then slotted into the t-track. The prototype was then complete, and it can be shown in action in Figure 15 below. Any changes in our prototype design that occurred between Design Review 3 and the writing of this report are outlined in Appendix L.

Figure 15. Completed Prototype in Action

Fabrication Plan

The components we purchased for our prototype include the Somfy Sonesse ST50 motor, a 2.5-inch tube, a drive adapter, a crown adapter, a head motor bracket, an idler bracket, and a remote control for our motor. Our prototype will also require wood for constructing a doorframe, and wood screws for constructing the doorframe and attaching our prototype to the doorframe.

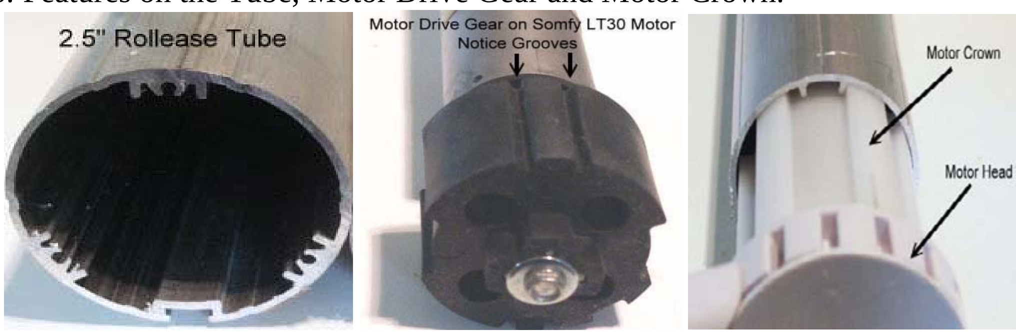
Step 1: Cutting the Tube
The 2.5-inch aluminum tube we bought is 4 feet in length. It needs to be cut to reduce the length to 35 inches. The tube will be cut using the band saw in the machine shop.

Step 2: Fitting the Motor into the Tube
After cutting, we will then fit the motor into the tube. As we purchased a 2.5-inch tube, a drive adapter and a crown adapter are needed. We put the adapters on both the motor drive gear and the crown. These components are shown in Figure 16. Steps are shown as below:

1. Align the grooves on the motor drive gear adapter with the internal ribs of the tube.
2. Push the motor further into the tube until the flange of the motor crown is touching the tube.
3. Install the idler at the crown side.

Detailed instructions are can be found in Appendix J.

Figure 16: Features on the Tube, Motor Drive Gear and Motor Crown.



Step 3: Attaching Sound Dampening Material to the Tube
For the prototype, we will only use the sound dampening material as the door fabric. We will cut the door fabric into desired dimensions (34” x 90”). Then, we will drill and tap eight evenly spaced holes into the tube for 10-24 machine threaded screws. The same holes will be drilled into a 1/8 inch thick, 1 inch wide, and 34 inch long, steel strip. The top end of the door material will then be sandwiched between the tube and the steel strip, and the door material and the strip will be attached to the tube with half inch long 10-24 machine screws.

Step 4: Fabricating the Doorframe
We will construct a full-size doorframe upon which we will mount our door assembly. Six 96-inch long two by four wall studs will be cut down to a length of 84 inches to be used for the vertical studs on each side of the doorframe (three on each side). Two 96-inch long wall studs will be cut down to a length of 41 inches long to be used for the top of the doorframe. These wood pieces will be cut to length using a table saw. To help the frame stand, we will add diagonal legs to the front and back of the bottom of each side the doorframe. These legs will be constructed of the same two by four wall stud pieces of wood. All of the pieces of wood are to be fastened together using two inch long wood screws. After this is complete, the wood trim will be cut to length and installed. This involves cutting two 96-inch long strips down to 81 inches long, and one 96-inch strip down to 32 inches long. The longer strips will be attached to each side of the inner part of the doorframe, with the short piece being placed on the bottom of the upper wall

studs. Two more 84-inch-long sections will be cut and installed vertically on each side of the front of the doorframe, with one 32-inch long section being added horizontally directly above the door opening on the front of the doorframe to complete the door trim. The door trim will attached to the doorframe using standard wood nails.

Step 5: Fabricating the Motor Bracket Spacers
The motor bracket spacers will be fabricated from one inch sections of two by fours. A cutting saw will be used to cut the spacers to one inch lengths using leftover wall stud two by fours.

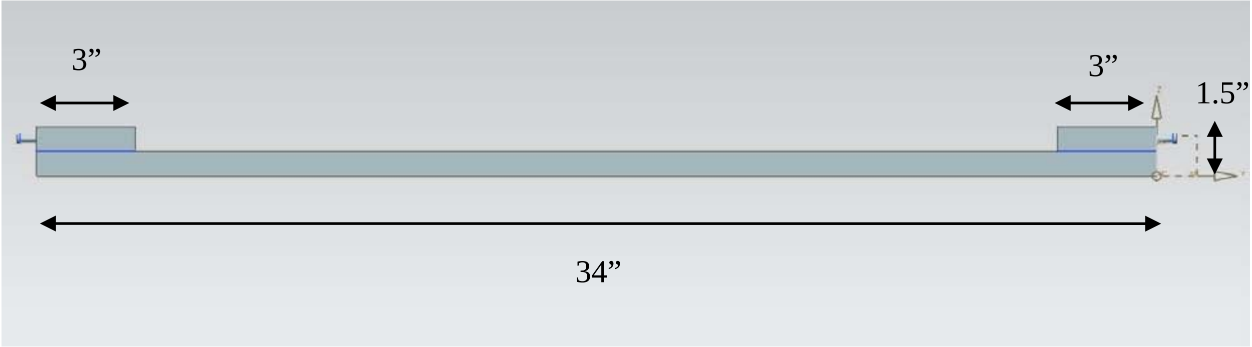
Step 6: Mounting the Motor Brackets
The motor brackets need to be mounted on top of the door opening. The brackets will be mounted 39 inches apart and the top of the brackets will be 4 inches above the door opening. We will line up the brackets and bracket spacers and drill pilot holes with a hand drill. Then we will secure them in place with wood screws.

Step 7: Placing the Motor and Tube in the Brackets
The idler side of the tube needs to be placed into the idler bracket. Then the tube needs to be pushed into the bracket allowing free space to move the motor head into the motor head bracket. Then push the tube and motor head bracket together and the motor will snap in place.

Step 8: Installing T-Track to the Doorframe
Two, 7-foot long wood strips, with a 1” by 1” cross section will be installed vertically on each side of the doorframe. One 48” and one 36” length of t-track will then be mounted on these wood strips on each side of the doorframe using wood tacks.

Step 9: Fabricating the Bottom Guide Bar
The bottom guide bar will be made of ¾ inch by ¾ inch cross section wood, one 34-inch long piece and two 3-inch long pieces, as shown in Figure 17. Attach these pieces together using nails. Screw one wood screw into the outer facing edge of each of the three inch long pieces of wood, and these will be used as the t track guides.

Figure 17. Bottom Guide Bar Dimensions



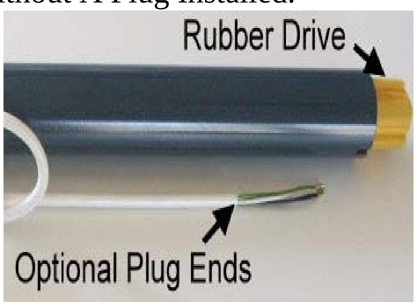
Step 10: Attaching the Bottom Guide Bar
The bottom guide bar will be attached to the bottom of the door material using wood tacks along the longer pieces of the guide bar. Once the bottom bar is attached to the door material, the material and bottom bar can be slotted into the t-track system. Slots will need to be cut out of the

bottom corners of the door material to accommodate the shorter pieces of wood on the guide bar, as shown below in Figure 18.

Figure 18. Bottom Bar Detail

Step 11: Performing Wiring to Connect Motor Assembly to Power Source
The motor we ordered does not come with a plug, as shown below in Figure 19. Therefore for our prototype, we will utilize an easy-to-wire plug, which only requires us to connect the wires (positive, negative, and ground) to their respective leads on the plug.

Figure 19. The Motor Wiring Without A Plug Installed.



Step 12: Activating the Motor and Placing the Guide Bar into the T Track
The motor is activated by pushing both the up and down buttons on the remote simultaneously until the motor jogs up and down. Roll the material all the way up and slide the guide bar into the t track. The material should now be guided by the track while being rolled up and down.

Step 13: Calibrating the Motor Travel
The motor can be programmed using the remote control. We will set the lower limit and upper limit of door's travel after everything is assembled.

We minimize the need to use the machine shop in our prototype fabrication and require only basic operations such as cutting and drilling to be performed in the machine shop.

Validation Testing and Results

Tests were conducted to confirm that our design meets or exceeds our engineering specifications. We measured the opening time, visibility, system weight, noise level, and the sound dampening abilities of our design. A description of each test is provided below, along with the results. All of our other engineering specifications did not require testing for validation, and therefore are not listed in this section. These include the specifications regarding useable door space, electrical power source, footprint, cost, and the ability to be mounted on a standard doorframe.

Opening Time: We used a stop watch to measure the amount of time the door took to roll down and up once the motor was activated.
Results: 13 seconds up, 11 seconds down

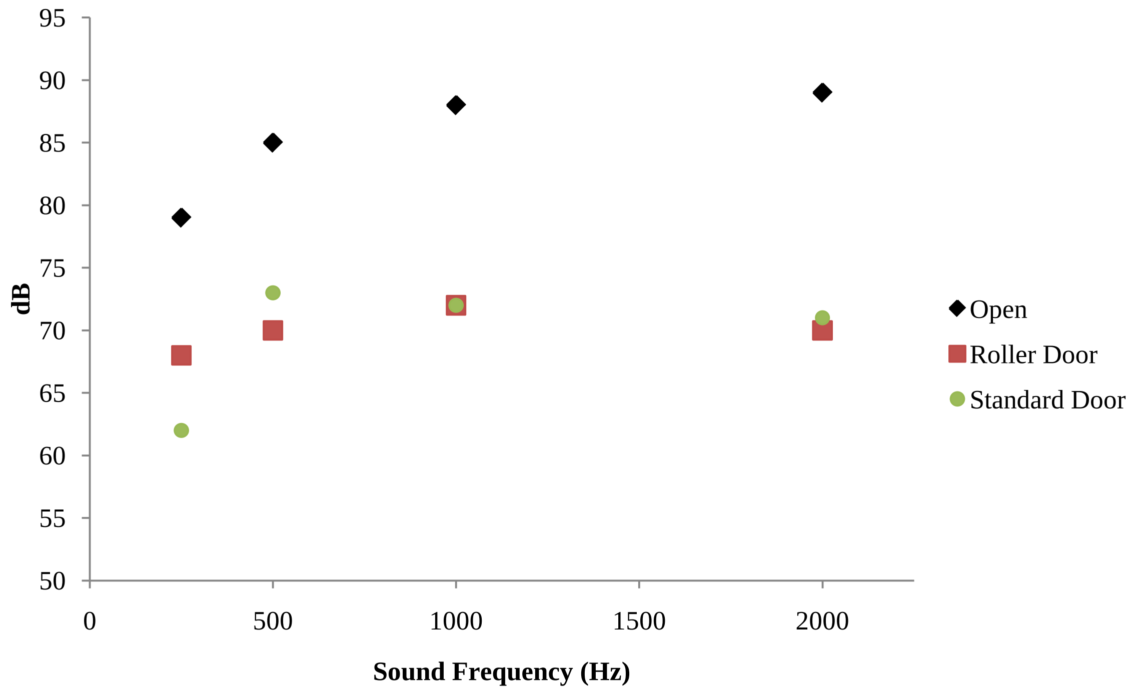
Visibility: We turned off the lights in a room. Then we took a flashlight and shined it at the door, observing is any light passed through.
Results: 10% visibility, calculated by using a rough estimate of the area where light escaped through openings compared to the total door area. The engineering specification of 0% was not met but could have been by adding a shield over the motor assembly.

System Weight: Before the system is installed and or put together, we will weigh all the components and add them up to confirm a total system weight of less than 75 pounds.
Results: The system (not including the doorframe itself) weighed approximately 44 pounds.

Noise Level: Using a sound level meter, we will measure and record the sound output from the entire system while the motor is activated. Sound output should be less than 30 dB.
Results: According to the motor manufacturer, the sound levels from the motor alone are less than 30 dB, and we could barely hear it while it was in operation. However, the high-friction t-track system produced a lot of noise. Unfortunately our sound meter was unable to read the decibel levels of our system because they were too low. However, due to the noise level of the t-track alone, we estimate that our system is louder than 30 dB.

Sound Dampening: We detached the motor spool and sound dampening material from the finished prototype and held it over a real door frame. We placed a speaker 5 inches from the doorframe on one side and a digital sound level meter 5 inches from the doorframe on the other side, and played test tones at frequencies of 125, 250, 500, 1000, 2000, and 4000 Hz since we have the respective dB reduction values for our sound dampening material (see material technical data sheet in Appendix I). We played these frequencies with a standard door open, closed, and open while holding our material over the door frame.
Results: A graph of the data table is shown below in Figure 20. Data from frequencies of 125 and 4000 Hz could not have been measured due to insufficient sound output by the speaker. The data recorded for the roller door does not match the data on the material technical data sheet or meet our engineering specification. However, with an average reduction of about 20 dB, the roller door’s sound reduction ability matches that of the standard door, which suggests that our customer requirement was not quantified correctly.

Figure 20. Sound Dampening Characteristics Comparison



Design Critique

The door system design that we developed this semester met or exceeded almost all of our engineering specifications. Our prototype was a convincing proof of concept. The door opened in 11 seconds, closed in 13, both times exceeding our engineering requirements. According to our testing, the door was able to mimic the sound dampening abilities of a standard wooden door, and was very compact and lightweight. However, our design was not perfect, and there is room for improvement in several key areas. Given more time and ability in the area of electrical systems, we would have liked to have used a more powerful electric motor with a proprietary motor and remote control system, similar to the one found in our tubular motor that we purchased. The Somfy Sonesse ST50 motor was adequately powerful for our application, but it was fairly expensive. One of our main goals was to beat the existing Motor Door product on price, which we did, but further price reductions would be possible by utilizing a custom motor design with custom electronics and controls. As stated before, the Somfy motor was adequately powerful, endowing our door with lower than expected rise and fall times. However, a motor with higher torque ratings could more easily handle thicker and heavier sound dampening material, or the existing sound dampening material with some aesthetic covers added to conceal the rather ugly bare sound dampening material. A more powerful motor could also potentially lower the rise and fall times even further, while being able to consistently open and close without risk of overheating.

Our team universally agreed that some sort of safety release should be added to this system so that the door remains operable in the event of a power outage. Adding a power backup system between the motor system and the wall outlet can solve this problem. There are many stand alone products on the market today that perform this task, and they are designed to immediately sense a power outage and then provide power from batteries within the backup system. While this sort of product would ensure consistent door operation in the event of a power outage, if the motor were to malfunction, the user would be stuck. Therefore, we also agreed that a purely mechanical safety release should be added to the system as well. If a more powerful motor were added to the system, the spool onto which the door material is accumulated could have a torsion spring inside that would be tensioned every time the door was lowered, and a simple physical switch could release the spring from tension, thus rolling the door up. This is just one option for solving this problem, and there could be even better solutions. Adding sensors along the bottom bar to detect if someone is in the doorway as it is closing would prevent injuries to the user from the door itself. The sensor would detect and obstruction and automatically retract the door material upwards.

Another issue with our design was the “t-track” system and the bottom bar attached to the door material that slotted into this track system that we employed to guide the material up and down. As we found out when we tested our prototype, this was a very high friction system. The interface between the t-track and the bottom bar was a wood screw that slotted into the t-track. While this system worked admirably, it was chosen mostly for budgetary purposes, since it was fairly inexpensive, and we had already pushed our budget with the big motor purchase. Ideally, a roller track system would be used instead, which would be a much smoother, lower friction system. This would result in lower track noise, smoother operation, and less load on the motor during operation. It would also eliminate any binding in the system as the door material is lowered. When the door material on our prototype was lowered, the screws in the t-track would bind slightly, causing the door material to lower unevenly. This was mainly due to the friction in the t-track system and the fact that our door system relied on gravity to unroll the door material and lower the door. When there is little or no friction in the track system, gravity is sufficient for unrolling the door, since the sound dampening material was fairly heavy at around 22 pounds. Roller track systems are fairly expensive, and they don’t solve the issue of door flexion. Any door material used in our door system would have to be flexible in order to be rolled up on the spool. However, while this flexion is an advantage in the vertical direction, it is a hindrance in the horizontal direction. When the door material flexed in this direction, it could easily be pushed off the track system and deformed. Adding horizontal bracing across the door material would add lateral strength to the material while still allowing the material to flex in the vertical direction and roll onto the spool. These horizontal braces would be strips of metal or sturdy plastic, and would slot into any track system used in the door system. This way, if someone were to push on the door, it would not be able to be pushed off the track system, since these horizontal braces would slot into the track system along with the door material. These braces would be placed at 8-inch to 1-foot increments along the door material. As long as they are fairly flat and low profile, they will easily roll onto the spool along with the door material.

We would also improve would be the aesthetic quality of our prototype. Our design was ugly, and almost nobody would want to install our prototype in his or her home as it stands today. The addition of a box to cover the motor and spool system above the doorframe would go a long way towards making our prototype more visually appealing as well as blocking all light transmission through the top of the doorway via the gap between the motor and spool assembly and the doorframe itself. Covering our door material with an aesthetic layer of a different material would increase the visual appeal of our design as well as providing a protective layer for our sound dampening material. The sound dampening material is easily torn, so adding some type of tear-resistant nylon or some other tough fabric on each side of the door will increase the wear resistance of our door system, as well as providing moisture protection for the door (allowing it to be used in bathroom applications). Also, redesigning the bottom bar to work with a new roller track system and to increase its visual appeal would help as well. A thorough analysis of a universal mounting system would also help make our prototype into a more finished product. We installed our system on a doorframe that we built ourselves, with bland door trim that made our installation very easy. Adjusting the design to work with a variety of door sizes, door trims, and mounting locations would give the prototype more mass appeal.

Recommendations

As previously stated in the Design Critique section of this report, we have singled out a few key aspects of our design for improvement.

1. The t-track that we used for our prototype has proven to be a very high friction system. The interface between the door material and the track is just a screw head, which results in friction between the steel screw head and the aluminum track. It sometimes caused the door material to bind in the t-track when the door was unrolling, stopping the door altogether. This friction also places an unnecessary load on the motor. Therefore, we recommend switching the track to roller track system, which has much lower friction, is much quieter and involves less maintenance.

2. The QuietBarrier MD sound dampening material that we used for our door is easily damaged and not waterproof. We recommend adding a layer of stronger fabric (such as polyester or PVC) on both sides of the sound dampening material to protect the sound dampening material and provide some aesthetic appeal for our system. This will also avoid direct contact of air moisture with the sound dampening material, allowing it to be used for bathroom door applications. By adding the fabric layers, it will allow the door to last longer by reducing the risk of tearing as a result of wear and tear or if someone accidentally runs into the door.

3. We recommend adding some rigidity to the door material by adding several strips of thin metal sheet horizontally across the door. Spaced every eight to ten inches along the door height and buried underneath the layer of stronger fabric suggested above, these strips would prevent the door material from being pushed off of the track system, since they would slot into the track system along with the door material itself. The metal sheets have to be thin, preferably with the same width of the door material, and small enough to allow the smooth rolling process of the door material. Since our current door material is only fixed at the top of the door to the motor tube and at the bottom to the support bar, the material is easily pushed off of the t-track.

4. Generally increasing the aesthetic appeal of our door system is another recommendation that we have. Adding a box like structure to cover the upper motor and tube assembly would greatly improve the visual appeal of our design, and help prevent light transmission through the top of the doorway. With the gap that we currently have between the motor assembly and the doorframe (even when door material is fully rolled up), the light passes through from above which reduces the ability of our door system to shield light. Redesigning the bottom bar to be more visually appealing would help as well.

5. We also recommend implementing a more powerful motor system. While the existing Somfy motor does an adequate job of lifting the door material, it can't handle much more weight than what we have put on the system. It is also an extremely expensive motor system. By utilizing an original motor and control system, the price of our prototype could be reduced even further, and the added power of the motor could allow for heavier sound dampening material to be used, or for aesthetic layers to be added to the existing door material without risk to the motor. The door could also open and close even faster than it does now.

6. The addition of a purely mechanical safety release in conjunction with a backup power supply system would ensure that this electronic door system could operate during a power outage and in the event of motor failure. Also, adding a sensor that detects when someone is underneath the door as it is closing would prevent injuries to the user. The sensor would detect an obstruction and automatically retract the door material upwards.

7. While we designed our system to work on our ideal doorframe, it might not work on every doorframe that exists. Redesigning the system with universal installation capabilities would allow this system to be mounted on all types of doorways, and easily installed with common hand tools.

8. We did not have enough time to conduct the light test on our door system except to eyeball it. Therefore, we recommend a proper light test to be taken to examine the ability of the door material to shield light.

Conclusions

The door design that we created this semester was tasked with improving the mobility of elderly and disabled people throughout their own homes. Despite several setbacks at the beginning of the semester, we were able to overcome these disadvantages and create a functioning prototype that met or exceeded many of our engineering specifications. Table 5 below outlines the performance of our prototype compared to our initial engineering specifications is shown below. While our design achieved many of our initial goals, it is not quite a final design yet, and with further refinements, could truly be a life changing device for elderly or disabled people who live or want to continue to live at home alone. By providing the full width of the doorway for those who are walker or wheelchair bound, eliminating door opening or closing effort altogether, and doing so with a compact, unobtrusive design that provides the aesthetic and sound dampening levels of a normal door for a relatively reasonable cost, countless elderly or disabled people could continue to live a life of independence at home.

Table 5. Prototype Performance Summary

Engineering Specifications	Target Requirement	Prototype Results
Opening or Closing Time	20 seconds	13 sec. (opening) 11 sec. (closing)
Useable Door Space	30 x 80 inches	30 x 80 inches
Visibility	0%	10%
Sound Dampening	38 STC	21 STC
Electrical Power Source	120 V	120 V
Footprint	12 x 48 x 12 inches	3.5 x 42 x 4 inches
System Weight	75 pounds	44 pounds
Cost	$1200.00	$594.00
Mountable on Standard Doorframe	3 inches above doorway	2 inches above doorway

Acknowledgements

We would like to show our gratitude for the following people for their contributions and valuable input throughout this semester:

Dr. Jeanne Riggs, for providing valuable information on the difficulties arthritis patients face.

Dr. Mark Ziadeh, for his guidance and information on patients with disabilities.

Professor Albert Shih, for his guidance and feedback on our project.

Dan Johnson, for his guidance and advice throughout this semester.

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Appendix A
Survey Questions and Answers

1. On a scale of 1 to 10 (10 being the worst / most severe), how would you rate your arthritis pain on a day to day basis?

2. Where is the pain the worst / most severe? (For the purpose of the project, we are mainly concerned with body parts involved in opening a door, such as the hands, wrists and arms.)

3. Do you find opening a traditional, circular doorknob challenging or painful?

4. What in particular is challenging or painful?

5. What motions are painful? (i.e. pulling / pushing, grabbing, twisting, etc.)

7. Do you / have you used a "door knob gripper", such as the one shown on this website? (http://www.greatgrips.com/)

8. If so, what are your experience with these? Are they effective in reducing pain when opening a door?

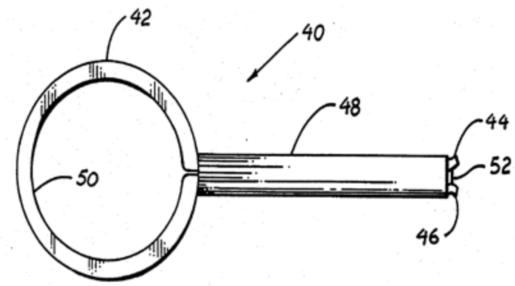
9. What changes would you make to the product?

10. Would you be willing to buy a device or new doorknob if it was effective in reducing pain? At what price?

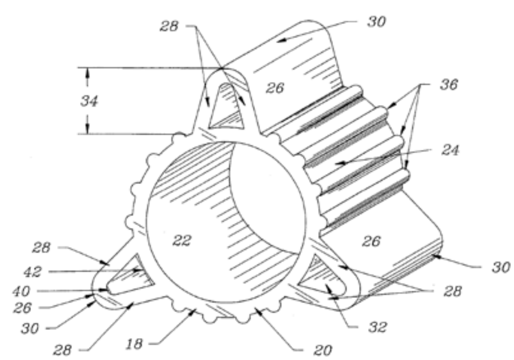
Appendix B
Patents

For purely mechanical solutions, we found several patents for products that aim to make opening and closing household doors easier. We have compiled a list of them below, along with a short description of each product. The patent diagrams for each of these products can be found in Appendix G.

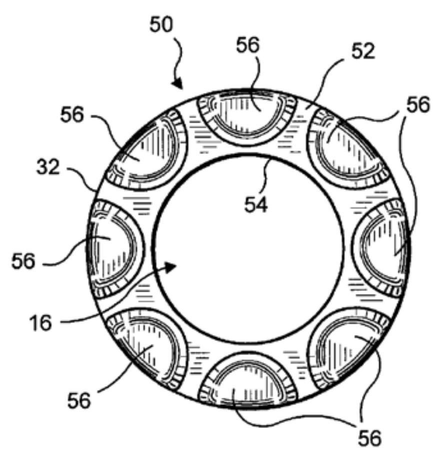
Lever Assists for Door Knob *(US4783883)*
This design addresses the limited ability of elderly people to turn a doorknob. It was filed on February 2, 1987 and patented on November 15, 1988. It intends to fit a lever attachment onto the conventional round doorknob. The lever device provides increase leverage to provide easy turning. It is clamped to the existing doorknob, secured by a threaded fastener. The lever solution presents an alternative for eliminating the need to twist and turn a doorknob and utilizing other body parts for opening door, which may be incorporated into our designs.



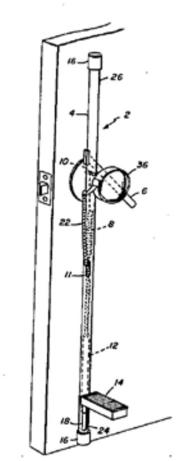
Knob Turning Device and Method *(US5495641)*
This design aims to eliminate the need to grasp the doorknob for people with hand disabilities. It was filed on April 8, 1994 and patented on March 5, 1996. The design involves a round knob cove made of a resilient material, with multiple levers protruding from the knob cover. These levers allow a closed fist to engage and push the levers down, which turns the doorknob. This design eliminates the need for grasping and twisting doorknobs.



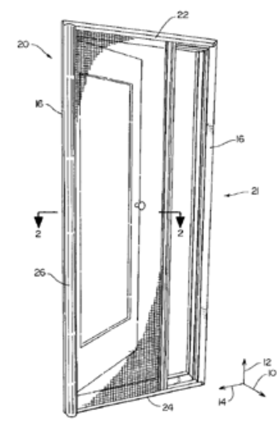
Gripper Adapter for Doorknobs *(US6154928)*
This design focuses on redesigning the inner surface of the door gripper to make it easier to install the device on the doorknob. It was filed on December 30, 1998 and patented on December 5, 2000. This design has a tubular member with an outer gripping surface and an inner surface-defining bore. The design is able to fit onto different sized doorknobs. This design does not lower the effort involved in opening or closing a door.



Portable Foot Operated Door Opener *(US4621848)*
This design was filed on February 7, 1985 and patented on November 11, 1986. It is comprised of an elongated tubular member attached to the current doorknob with a foot pedal positioned at the lower end of the tubular member. The downward vertical motion of the foot activates the foot pedal. The resulting pressure causes the doorknob grip to rotate and release the door latch. While this design is acceptable for most people, the foot pedal is located a few inches off the floor, which is not accessible by people on wheelchairs.



Retractable Flexible Door Method and Appatus *(US 6478970B2)*
This design and method was filed on December 6, 2000 and patented on November 12, 2002. It comprises of a retractable screen with bracketing components with slideways mounted on the top and bottom portion of the door. The screen is attached with a handle. As the screen retracts, it slides along the slideways of the top and bottom bracketing components to the housing installed on the side of the door. This design utilizes a lightweight material and provides total clearance of the doorways. However, a screen door does not provide enough privacy, which is a main focus of our design.



Appendix C
ANSI Power Operated Pedestrian Doors Standard

BHMA builders hardware manufacturers association Standards at a GLANCE

ANSI/BHMA A156.10-1999
American National Standard for Power Operated Pedestrian Doors

Standard ANSI/BHMA A156.10-1999 establishes requirements for power operated pedestrian doors, which open automatically when approached by pedestrians, some small vehicular traffic or by a knowing act. It includes general information, definitions, required dimensions and provisions to reduce the chance of user injury or entrapment.

Note: This standard does not apply to power assist and low energy power operated doors. For those, refer to ANSI/BHMA A156.19.

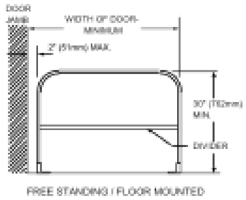
Tests and required performance levels in this standard include:

- Control Mat Performance
- Break Away Egress
- Salt Spray

The following are partial descriptions of test values. Please see the complete standard for additional tests:

Entrapment Protection	The force required to prevent a stopped power operated swinging door from moving in the direction of closing shall not exceed a 40 lbf (180 N) applied 1 inch (25 mm) from the lock edge of the door at any point in the closing cycle.
Sensors	Motion sensors shall detect a 28 inch (710 mm) minimum high person or equivalent and moving at a rate of 6 inches (150 mm) per second minimum toward the center of the door within the detection areas described. Presence sensors shall detect a stationary 28 inch (710 mm) minimum high person or equivalent within the detection areas described.
Signage	All swinging, sliding and folding doors shall be equipped with signage visible from both sides reading, "AUTOMATIC DOOR" with letters 1/2 inch (12.7 mm) high minimum. The sign described in 11.2.3 shall be permitted to be used to satisfy this requirement.

Sample Illustration:



GUIDERAIL ELEVATIONS.

To purchase a copy of any BHMA Standard log on to www.buildershardware.com or call 800.699.9277.

Note: This document is not to be used as a substitute for the standard. Users should refer to the entire standard for complete requirements and details. For further information go to www.buildershardware.com.

Appendix D
ANSI Power Assist Standard

BHMA builders hardware manufacturers association — Standards at a GLANCE

ANSI/BHMA A156.19-2002
American National Standard for Power Assist And Low Energy Power Operated Doors

Standard ANSI/BHMA A156.19-2002 establishes requirements that apply to power assist doors and low energy power operated/open doors for pedestrian and small vehicular use. Included are provisions intended to reduce the chance of user injury or entrapment.

The following are sample requirements. Please see the complete standard for additional requirements:

Signage	Doors shall be equipped with (a) sign(s) visible from either side, instructing the user as to the operation and function of the door. The signs shall be mounted 50" +/- 12" (1270mm +/- 305mm) from the floor to the center line of the sign. The letters shall be 5/8 inch (16 mm) high minimum.
Force to Prevent Closing	The force required to prevent a swinging door from closing shall not exceed a 15 lbf (67 N) applied 1 in (25 mm) from the latch edge of the door at any point in the closing cycle.
Power Failure	In the event of power failure to the operator, doors shall open with a manual force not to exceed a 15 lbf (67 N) to release a latch, if equipped with a latch, a 30 lbf (133 N) to set the door in motion, and a 15 lbf (67 N) to fully open the door. The forces shall be applied at 1" (25 mm) from the latch edge of the door.

Sample Illustration:

To purchase a copy of any BHMA Standard log on to www.buildershardware.com or call 800.699.9277.

Note: This document is not to be used as a substitute for the standard. Users should refer to the entire standard for complete requirements and details. For further information go to www.buildershardware.com.

Appendix E
Quality Function Deployment (QFD)

++ Strong positive relation
+ Positive relation
- Negative relation
-- Strong negative relation

#	Engineering Specification	1	2	3	4	5	6	7	8	9
1	Opening time (-)									
2	Useable door space (+)	-								
3	Visibility (-)									
4	Sound dampening (+)									
5	Electrical power source (-)									
6	Footprint (-)		--							
7	System weight (-)	++			-					
8	Noise level (-)	--								
9	Cost (-)	--	-		--				--	
10	Mount on standard doorframe (-)		-				-			

Engineering Specifications

(+) more is better
(-) less is better

#	Customer Needs	Customer Weights	Opening time (-)	Useable door space (+)	Visibility (-)	Sound dampening (+)	Electrical power source (-)	Footprint (-)	System weight (-)	Noise level (-)	Cost (-)	Mount on standard door frame (-)
1	Safe operating conditions	10	9	9						1		
2	Minimize use and rotation of thumbs, wrists, and fingers to make door easier to open	10					9					
3	Minimize use of hands and fingers to prevent disease transmission	10					9					
4	Use an assistive mechanism to aid in opening and closing the door to reduce apparent weight	9					9					
5	Use body parts in neutral positions	8					9					
6	Provides maximum clearance	8		9				1				3
7	Privacy	8	1		9	9				3		
8	Longevity	7					9		3	3		
9	Easily installed into existing doorway	7					1	9	1			9
10	Easy to use	6	3	9			9					1
11	Cost effective	5									9	
		Raw score	116	216	72	72	457	71	28	55	45	93
		Relative Weight	9%	18%	6%	6%	37%	6%	2%	4%	4%	8%
		Rank	3	2	5	5	1	7	10	8	9	4

	Opening time (-)	Useable door space (+)	Visibility (-)	Sound dampening (+)	Electrical power source (-)	Footprint (-)	System weight (-)	Noise level (-)	Cost (-)	Mount on standard door frame (-)
Technical Requirement Units	s	in	%	STC	V	ft	lb	dB	$	in above door
Technical Requriement Targets	20	30 x 80	0	38	120	1 x 4 x 1	75	30	1200	3

Appendix F
The Motor Door

DEL Motorized Solutions
(866) 44MOTOR - (215) 639.3880
Fax: (215) 639.3920
WWW.MOTORIZEDSOLUTIONS.COM

10/21/2010
Job#: 10769
Michael Locher

Thank you for the opportunity to provide a proposal for window treatments. Window treatments provide beauty and function to any room.

Option 1. Manufacture (one) AC Powered Motor Door including fascia and side channels:
Shades can be programmed to stop at favorite preset positions. There are many choices of fabric between Sheer and Blackout. Shades will have the ability to run individually, as a group, and all at once.

The shade rolls up and disappears into a small valance that has a clean, sleek look, which is available in white, stainless, and bronze (it can also be painted to match walls) when not in use. Each time the shade is used to clean itself (3" and 4" fascia's have a small hidden brush). The material is flame resistant.

We can create 100% blackout of your windows with our optional components. We have an option for side channels (the fabric slides in the channel to eliminate light from penetrating from the sides), top back cover (installs behind (at the top) the shade and eliminates any light that can penetrate from the rear, and sill angle (installs on the window sill to eliminate light from uneven sills).

Please refer to the diagrams in the back...
Motor Door - 1 AC Roller Shades Blackout(s) :**Item Cost:** **$1,116.00**

Electronic Components
1 - IR Remote: $100.00

Option 2. Manufacture (one) Battery Operated Motor Door including fascia and side channels:
Shades can be programmed to stop at favorite preset positions. There are many choices of fabric between Sheer and Blackout.

Our Battery-Operated Shades are far superior to our competition. The electronics in our shades allow the long life batteries to last an average of 1 to 3 years (other companies average less than 1 year), easy to change when needed.

The shade rolls up and disappears into a small valance that has a clean, sleek look, which is available in white, stainless, and bronze (it can also be painted to match walls) when not in use. Each time the shade is used to clean itself (3" and 4" fascia's have a small hidden brush). The material is flame resistant.

Please refer to the diagrams in the back...
Motor Door - 1 Battery Roller Shades Blackout(s) :**Item Cost:** **$739.00**

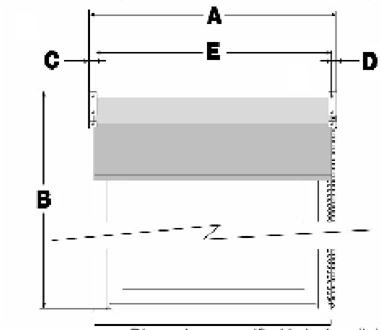
Electronic Components
1 - RTS Remote: $100.00

Showroom:
2075 Byberry Road
The Atrium, Suite 108
Bensalem, PA 19020

Factory:
111 Buck Road
Buck Road Business Plaza Unit 900
Huntingdon Valley, PA 19006

Line Item(s): 1
Product Family: **Roller**
Operator/Tube: Clutch V16/2" Aluminum
Clutch Color: Black
Chain Side: TBD - Right side shown
Chain Type: TBD
Mount Location: TBD - Outside mount shown
Drop: Regular
Hembar: 3/16x1" Sealed (Standard)
Top Trim: 4" Fascia/4" Top-Back Cover
Metal Finish: TBD - Standard Color
Fabric Code: BP-TBD
Fabric Type: Blackout (Dual Sided)
Fabric Name: Phifer SheerWeave 7000 Blackout 0%
Fabric Color: TBD
Fabric Side: Dark Side Away From Glass (Standard)

Drawing Not To Scale. For Reference Only.



Dimensions specified in inches (in)

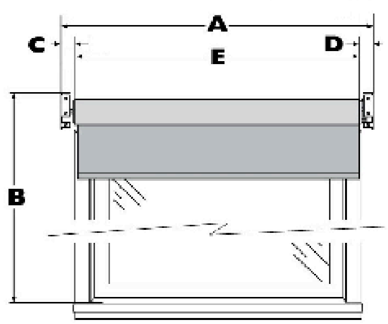
Line Item	Room Mark	Qty.	B to B Width (A)	Fabric Width (E)	Shade Height (B)	Left Light Gap (C)	Right Light Gap (D)	Seam(s)	Batn	RailR	Side Channel	Sill Angle	Chain Drop
1	Motor Door	1	36	34 5/8	84	0 5/8	0 3/4	None	N	N	2.5x1"	None	84

Notes:

Line 1: {Sealed hembars show the face of the fabric on both sides of the shade. On dual-sided fabrics with a different color backing, this may create an inconsistent look between the fabric on the hembar and the color on the back of the shade.}
Some final selections may not be compatible with configurations using TBD options. Please verify compatibility before final selection is made.

Line Item(s): 2
Product Family: **Roller**
Operator/Tube: AC 120v Tub. LT Drive/2.5" Aluminum
Drive Side: TBD - Right side shown
Mount Location: TBD - Outside mount shown
Drop: Regular
Hembar: 3/16x1" Sealed (Standard)
Top Trim: 4" Fascia/4" Top-Back Cover
Metal Finish: TBD - Standard Color
Fabric Code: BP-TBD
Fabric Type: Blackout (Dual Sided)
Fabric Name: Phifer SheerWeave 7000 Blackout 0%
Fabric Color: TBD
Fabric Side: Dark Side Away From Glass (Standard)

Drawing Not To Scale. For Reference Only.



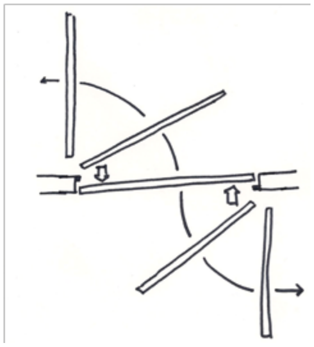
Dimensions specified in inches (in)

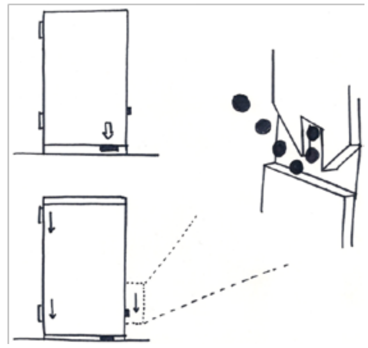
Line Item	Room Mark	Qty.	B to B Width (A)	Fabric Width (E)	Shade Height (B)	Left Light Gap (C)	Right Light Gap (D)	Seam(s)	Batn	RailR	Side Channel	Sill Angle
2	Motor Door	1	36	33 1/2	84	1 3/8	1 1/8	None	N	N	2.5x1"	None

Notes:

Line 2: {Sealed hembars show the face of the fabric on both sides of the shade. On dual-sided fabrics with a different color backing, this may create an inconsistent look between the fabric on the hembar and the color on the back of the shade.}
Some final selections may not be compatible with configurations using TBD options. Please verify compatibility before final selection is made.

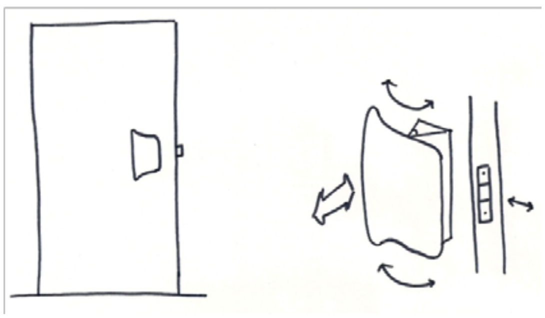
Appendix G
Other Designs

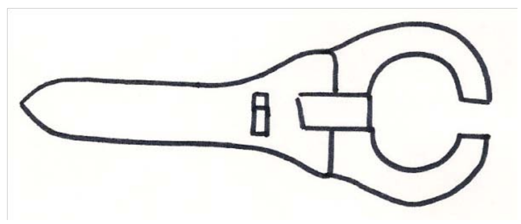




“S” Door

Foot Pedal Design





Push/Pull Handle

Adjustable Grip

The “S” door was a ceiling track system that was could be pushed from either side. The door would follow grooves in the ceiling that would move it in an “S” pattern where it would fully clear the doorframe and rest flush against the wall. It features two door jams on opposite sides that would have provided a centering position as well as privacy.

The foot pedal design had a larger than usual gap beneath the door. The bottom of the door featured a fixed foot pedal that would slide the entire door down a few inches when pushed down. This would slide a bolt down and out of a channel, allowing the door to swing freely. It also was a double swing design, allowing you to push the door open with your foot for easy operation.

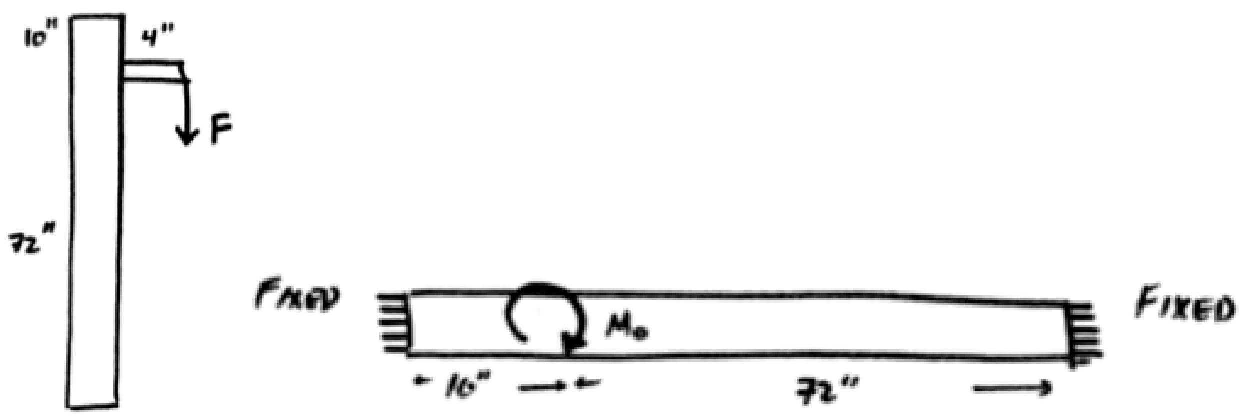
The push/pull handle was designed to give flexibility to the user. The handle could be pushed or pulled in order to unlatch the door. The primary benefit to this design is that no twisting of the wrist would be required like in traditional doorknobs. However, the user would still need to pull the door open in one direction.

The adjustable grip design allows a traditional doorknob to be turned into a lever-style doorknob. This design was adjustable, allowing it to fit securely to nearly any sized doorknob. This looked to improve on similar designs currently on the market that feature stretchable rubber which is considered “one size fits all”.

Appendix H
Failure Analysis Calculations

First we found the moment about the fixed end of the four-inch long bracket. This was done using a simple moment equation about the fixed end. The moment was found to be equal to *4F* (lb/in^2), where F is the weight of the system in pounds. Since the bracket will be mounted onto the vertical stud with three-inch long wood screws, this moment about the fixed end of the four-inch long bracket is assumed to translate directly as an internal moment within the vertical stud beam equal to *4F* (lb/in^2). The result of this assumption is shown in at left below.

System Model and Wall Stud Model



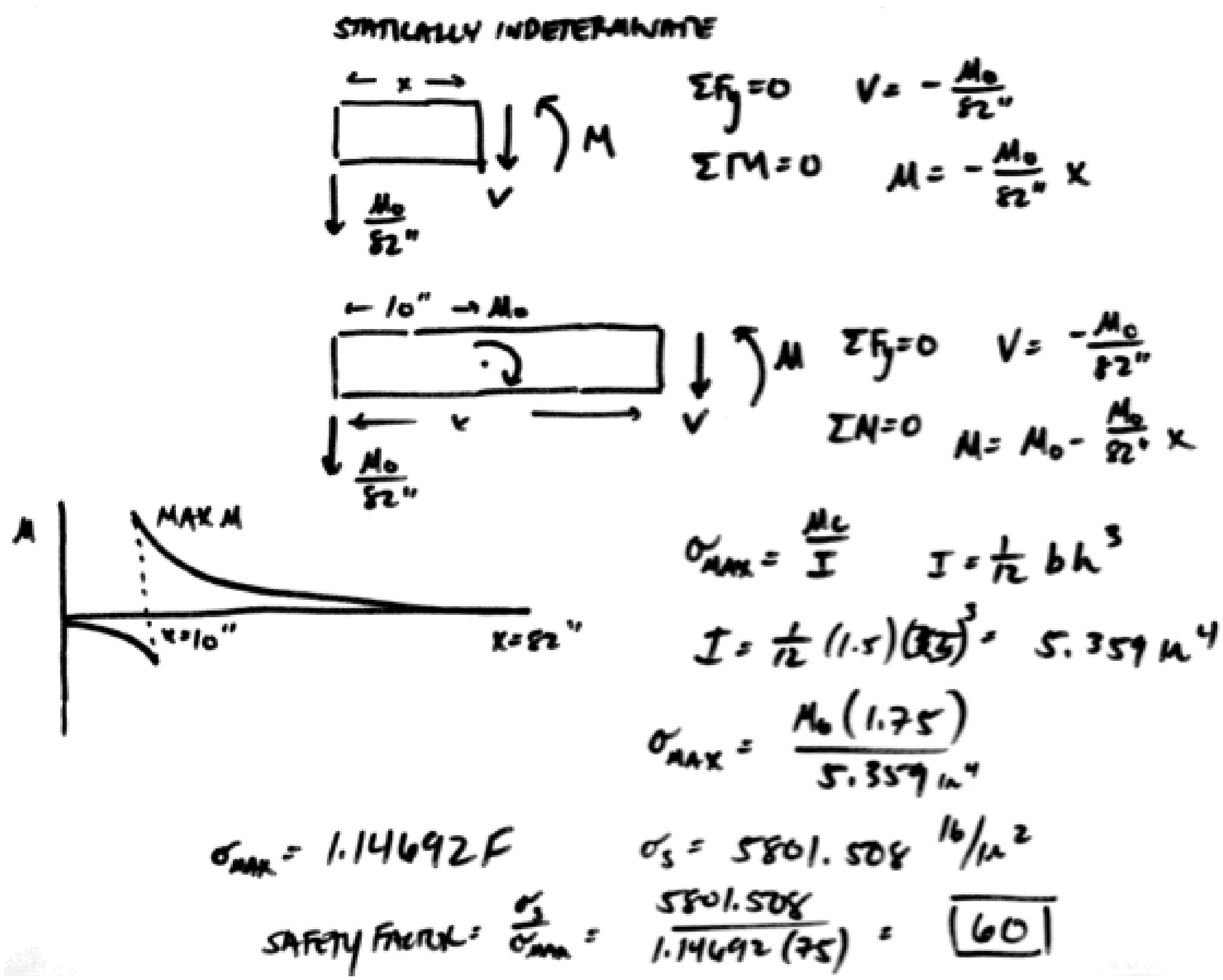
Once the internal moment is determined, we found functions for the internal moment of the beam as a function of length, and from there were able to determine the maximum internal moment experienced by the beam. The maximum internal moment is then used along with the moment of inertia and the thickness of the beam to determine the maximum internal stress experienced by the vertical stud, using Equation 1 below.

$$\sigma_{MAX} = \frac{Mc}{I} \qquad \text{(EQ. 1)}$$

The yield stress of common pine wood is approximately 40 MPa, which translates to 5801.51 psi. The safety factor of our design can be found using Equation 2 below, where σ_S is the yield strength of pine wood, and σ_{MAX} is the maximum stress experienced by the vertical stud.

$$Safety\,Factor = \frac{\sigma_S}{\sigma_{MAX}} \qquad \text{(EQ. 2)}$$

Taking the weight of our system to be 75 pounds (the maximum allowed by our engineering specifications), we found the maximum stress experienced by one vertical stud to be 97.96 psi, yielding a safety factor of 60. This safety factor is assuming an absolute worst case scenario for our system, including the entire system weight being supported by one bracket on one vertical stud, with the maximum allowed weight of our system according to our engineering specifications. Any system weight less than 75 pounds will not even come close to breaking any vertical wall studs, especially when the load is evenly distributed between two brackets and two vertical studs. The full calculations for this failure analysis are shown below.



For the analysis of the interface between the door material and the motor tube, we performed three analyses: one analysis on the normal force exerted on the screw and its threads, the shear force on each screw, and the bolt tear-out effects of the screws on the door material itself. In order to determine if the screws could withstand the weight of the door material without stripping or deforming their threads, we assumed the entire weight of the door material was being held by just one of the eight screws we used to attach the door material to the motor tube. The equations and calculations for this analysis are shown below. This worst case scenario proves that the machine screws used in our design are not even close to deforming.

EFFECTIVE EXTERNAL THREAD SURFACE AREA (IN ALUMINUM TUBE)

$$A_S = \pi n L_e K_{n_{MAX}} \cdot \left(\frac{1}{2n} + 0.57735 \left(E_{S_{MIN}} - K_{n_{MAX}} \right) \right)$$

EFFECTIVE INTERNAL THREAD SURFACE AREA (MACHINE SCREW)

$$A_n = \pi n L_e D_{S_{MIN}} \cdot \left(\frac{1}{2n} + 0.57735 \left(D_{S_{MIN}} - E_{n_{MAX}} \right) \right)$$

$K_{n_{MAX}}$ = MAXIMUM MINOR DIAMETER OF INTERNAL THREAD = 0.1818

$E_{S_{MIN}}$ = MINIMUM PITCH DIAMETER OF EXTERNAL THREAD = 0.1586

L_e = FASTENER THREAD ENGAGEMENT = 0.25

n = NUMBER OF THREADS PER INCH = 24

$E_{n_{MAX}}$ = MAXIMUM PITCH DIAMETER OF INTERNAL THREAD = 0.1619

$D_{S_{MIN}}$ = MINIMUM MAJOR DIAMETER OF EXTERNAL THREAD = 0.1890

ALL VALUES CORRESPOND TO 10-24 MACHINE SCREWS WITH 0.25" OF ENGAGEMENT!

$\sigma = \frac{F}{A}$ AFTER PLUGGING IN VALUES: $A_S = 0.02549 \text{ in}^2$

$A_n = 0.12996 \text{ in}^2$

$F = 22 \text{ lbs}$

$\sigma_S = \frac{F}{A_S} = \frac{22}{.02549} = 863.084 \text{ psi}$ $\sigma_{ALUMINUM} = 30{,}000 \text{ psi}$ $\sigma_{ALUM} >> \sigma_S$

$\sigma_n = \frac{F}{A_n} = \frac{22}{.12996} = 169.283 \text{ psi}$ $\sigma_{SCREW} = 60{,}000 \text{ psi}$ $\sigma_{SCREW} >> \sigma_n$

The machine screws were then analyzed for failure due to shearing. These calculations are shown below. Again, just one screw was assumed to hold the entire load of the door material. And again, the screw was well within the safe range of loading.

SHEAR STRENGTH OF MACHINE SCREW $\approx (0.6) \cdot$ TENSILE STRENGTH

$\approx 0.6 \cdot 60{,}000 \text{ psi}$

$\approx 36{,}000 \text{ psi}$

$\frac{F}{A} = \sigma = 36{,}000 \text{ psi}$

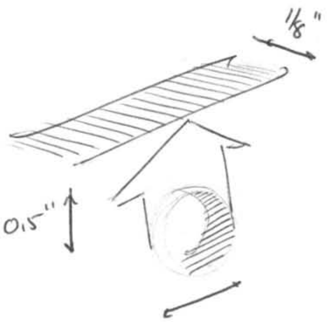
$F = 22 \text{ lbs}$

$A = (0.14") \times (0.125") = 0.02375 \text{ in}^2$

⟶ CROSS SECTIONAL AREA OF SCREW IN DIRECTION OF SHEAR STRESS

$F/A = 22/.02375 = 926.3 \text{ psi} << 36{,}000 \text{ psi}.$

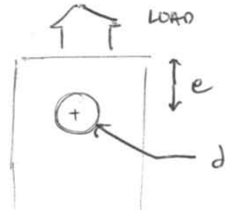
Finally, a bolt tearout analysis was performed to determine if the weight of the material would be enough to rip itself off of the machine screws holding it up. These calculations are shown below, and the results show that the material is well within its limits and should not tear itself off of the machine screws holding it on.



BOLT TEAROUT CALCULATIONS

CONCENTRATED LOAD ON HOLES 1/2" FROM EDGE OF DOOR MATERIAL.

EFFECTIVE SURFACE AREA = $2 \cdot (e - d/2) \cdot t$



$e = 0.5"$

$d = 0.19"$

$t = 0.125"$

$A = 2(0.5 - .045) \cdot .125 = 0.10125"$

$F = 22 \text{ lbs}/8 = 2.75 \text{ lbs/HOLE}$

$\sigma = 2.75/.10125 = 27.1605 \text{ PSF} \cdot .125 = 3.395 \text{ lbs/INCH}$ (THICKNESS)

TEAROUT STRENGTH OF DOOR MATERIAL: 77 lbs/INCH

$3.395 << 77 \text{ lbs/INCH}$

Appendix I
Quiet Barrier MD

American Micro Industries, Inc.

PRODUCT DATA SHEET: ECONO BARRIER™

DESCRIPTION:
ECONO BARRIER™ is a flexible, high density material with a smooth surface designed to reduce noise transmission between two spaces. ECONO BARRIER™ is available with a pressure sensitive adhesive (PSA) for an easy 'peel and stick' application.

APPLICATIONS:
ECONO BARRIER™ is an economical approach to reduce the transmission of noise through walls, ceilings, and floors. This product can be applied directly to the backside of drywall or attached to the studs/joists prior to the application of drywall. Because ECONO BARRIER™ is not UV resistant, it should be shielded from exposure to sunlight. Applications include, but are not limited to; common walls, ceilings and floors between condo units, walls between office spaces and manufacturing areas, multi media rooms, industrial facilities, and machine enclosures (i.e. compressors, pumps, air conditioning units, etc.).

PRODUCT AVAILABILITY:
- 4 x 8 ft. sheets (Part #: MLVB14X8)
- 4 x 8 ft. sheets with PSA (Part #: MLVB14X8PSA)
- 4.5 x 20 ft. roll (Part #: MLVB120)
- 4.5 x 30 ft. roll (Part #: MLVB130)

TECHNICAL DATA:

PROPERTIES

Physical Property	Value	Test Standard
Color	Black	n/a
Thickness	Approx. 0.125" (1/8)	n/a
Surface Mass	1.0 lbs/ft²	n/a
Density	96 lbs/ft³	n/a
Elongation	120%	ASTM D-412
Tensile Strength	407 PSI	ASTM D-412
Tear Strength	77 lbs/ 1"	ASTM D-624
Temperature Range	-40°F to 255°F	n/a
Hardness	90 Durometer, Shore A2	ASTM D-2240
Specific Gravity	1.80	ASTM D-798
Stiffness	19.60 mega pascal	ASTM 749
Flammability	Meets	UL 94 HF-1
	Meets	MVSS 302

SOUND TRANSMISSION LOSS

Freq. Hz	125	250	500	1000	2000	4000	STC
(dB)	14	14	23	29	34	37	27

ECONO BARRIER ™

American Micro Industries, Inc.
440 Ramsey Avenue, Chambersburg, PA 17201
Phone: 800-558-2058 Fax: 717-261-9161
e-mail: sales@americanmicroinc.com
http://www.soundproofoam.com

PDS7/14/05

Appendix J
Shade Mounting Instructions

Shade Mounting Instructions

Please read all of the instructions prior to mounting your shades. It is also best that you get familiar with you shade components and brackets prior to proceeding. Note that the brackets are different for the each end of the shade.

What Do I Need: We've found it easiest to use screws (rather than nails) to mount the shades and pre-drilling the holes makes things easier. You will need a drill, screw driver, tape measure or ruler, and a bubble level. We strongly recommend having 2 people handle the shades. The longer shades can be quite awkward.

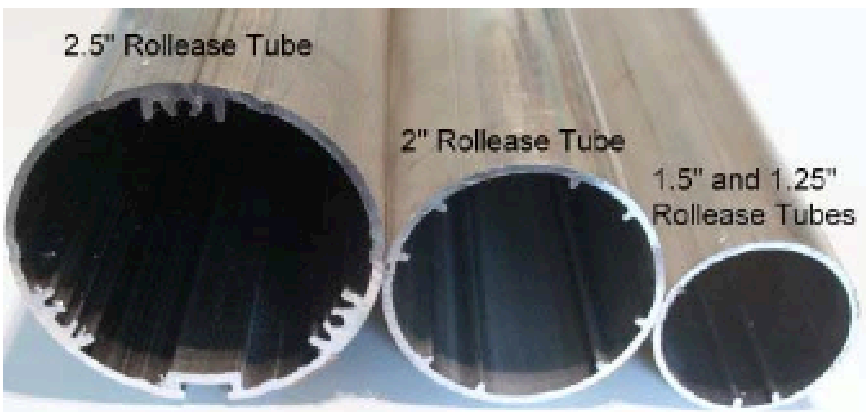
Installation and Preparation

1) Install Motors - Skip this step if your shades came with the motors, springs or clutch installed.

Shade motors are shipped outside of the tube to protect the motor. The Motors will need to be installed. This is true for the Following motorized shades.

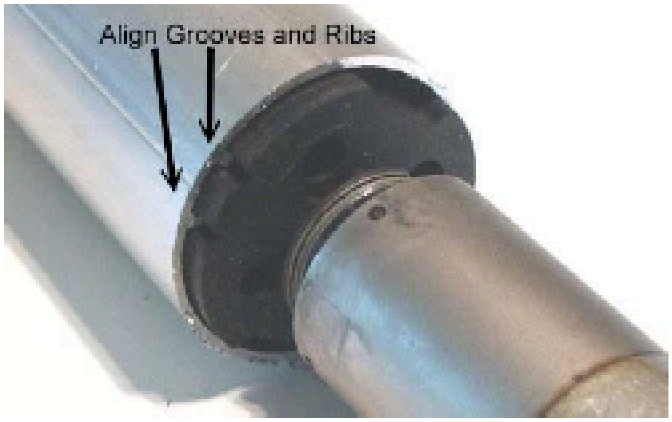
- Somfy LT30 IR or RTS Motors with 1.25" and 1.5" Rollease Tubes
- Somfy Sonesse 30 (ST30) with 1.5" Rollease Tubes
- Somfy Sonesse 50 (ST50) or LT50 Motors with 2.5" Rollease Tubes

a) Observe the internal rib pattern of the tube being used.

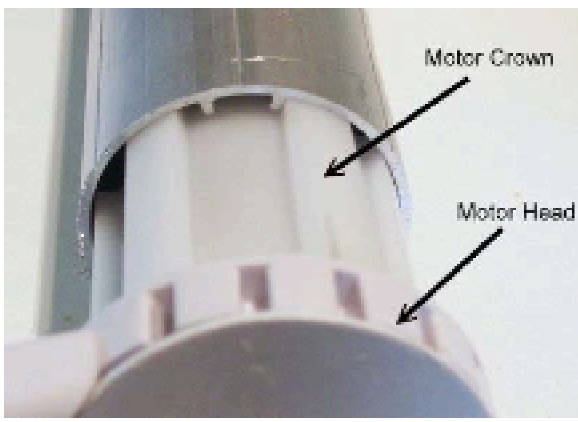


b) Observe the motor drive gear. There should be grooves or notches present that match the rib pattern.

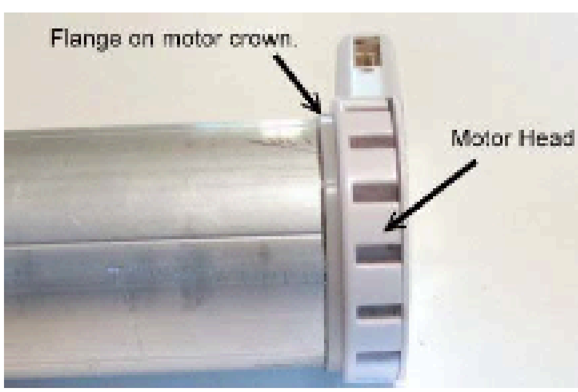
c) Align drive gear grooves with internal ribs of the tube.
NOTE: There are 2 sets of narrow grooves in the rubber drive. They look the same but one set i narrower than the other. The wider set of grooves should be used.



d) Push the motor into the tube. Rotate the crown of the motor to align with the internal ribs of th tube.



e) Push the motor into the tube until the flange of the crown is touching the tube. Generally the crown is a tight fit so some resistance may be felt here.



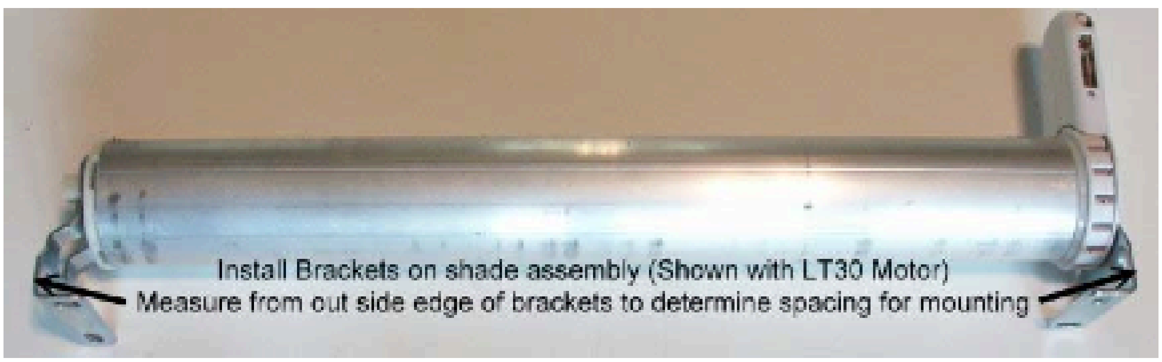
2) Evaluate your shades and mounting area before mounting!!!! Use the appropriate screws for the weight of the shade and mounting area. Most windows have a wood header and framing surrounding them so using wood screws of drywall screws will suffice for most. Shades being mounted into metal frames should be done with self tapping sheet metal screws.

3) Determine the bracket spacing.

a) Shades ordered as Inside Mount - Typically shades specified for inside mount use the entire width of the mounting location. Bracket placement will be at the extremes of this area or simply place the brackets at the extremes of the shade dimensions as ordered. If you ordered a shade that is 24" wide tip to tip or inside mount than the outside edge of the brackets should be at 24"

b) Shades ordered as Outside Mount or Tip to Tip Measure - If you have multiple shades being placed in a continuous back of shades or if you have shades for outside mount of the window frame, simply place the brackets at the extremes of the shade dimensions as ordered. If you ordered a shade that is 24" wide tip to tip or inside mount than the outside edge of the brackets should be at 24"

c) Shades ordered as Specified Material Width: We recommend putting the brackets on the shades prior to mounting and measuring the overall length to find the Tip to Tip measure for the bracket placement.



4) Check for appropriate gaps between roller and walls. In some cases the roller tube with material on it may be larger in diameter than the bracket foot print. We recommend comparing the roll thickness to the bracket foot print to ensure proper clearance of walls and obstacles. We recommend having a ¼" clearance gap.

a) If the bracket foot print is larger than the roll thickness you can put the bracket almost anywhere and the shade should fit. If you are installing over molding you might need to shim the brackets up or use a bracket with a larger projection so that you clear obstacles.

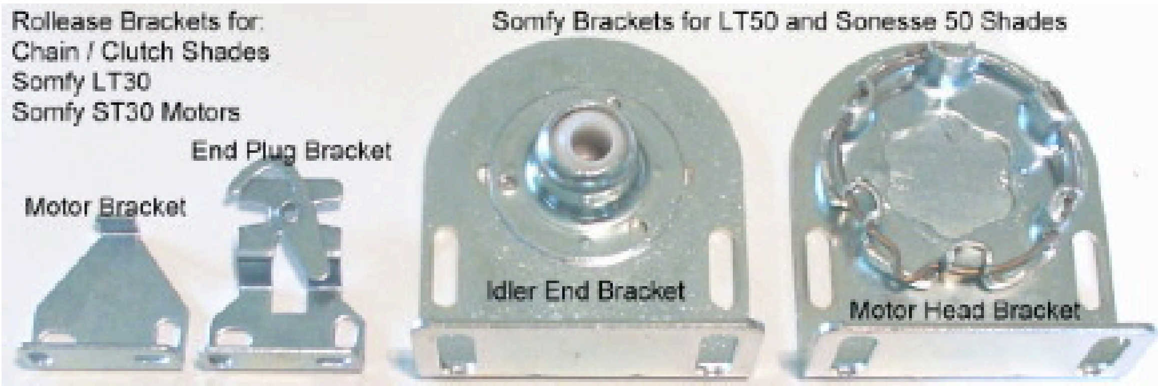
b) If the roll thickness is larger than the bracket footprint you will need to be more careful in bracket placement so there is enough clearance for the roll thickness. We like to have a ¼" gap between the roll and any surface. Since brackets and tube vary so much there is no easy formula for this.

5) Mount your brackets.

a) Mark the locations for you bracket locations with a pencil using the bracket spacing as outlined above. In most cases you will have 2 slotted screw holes in the brackets. Make lines through these locations for the screw positions. Be sure to put the marks at the center of the slots so that you have room to adjust the bracket at a later time.

b) Pre-drill your holes at the marked locations. For smaller shades it is possible to only use one of the mounting holes initially. This will provide easier adjustment for leveling the shade assembly.

c) Mount your brackets with the appropriate screws. Be sure to use the correct bracket for the side of the shade. Motor end and idler / end plug ends use different brackets. Do not over tighten screws. This may result in the sheetrock being compressed and the shade not fitting properly.



6) Install your shade.

Chain Driven Shades and Somfy LT30 or Sonesse 30 motorized shades.

Due to the weight and size of these types of shades we strongly recommend 2 people handling the shade during installation.

a) Insert the motor head end of the shade assembly onto the tab of the motor bracket.

b) Place the end plug into the opposite bracket and make sure you use the V-Groove on top of the bracket rather than the one on the bottom. If you use the bottom V-Groove the shade may fall.

c) Flip the finger lever over on the end plug bracket to protect the shade from being inadvertently knocked off the brackets.

Somfy Sonesse 50 (ST50) and LT50 Shades

Due to the weight and size of these types of shades we strongly recommend 2 people handling the shade during installation.

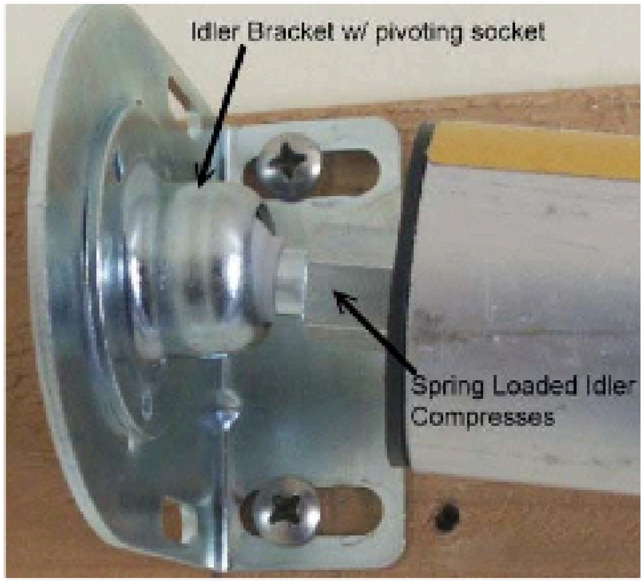
a) Rotate the retaining clip on the motor head bracket so that the opening in the clip is positioned to allow for the proper power cord position.

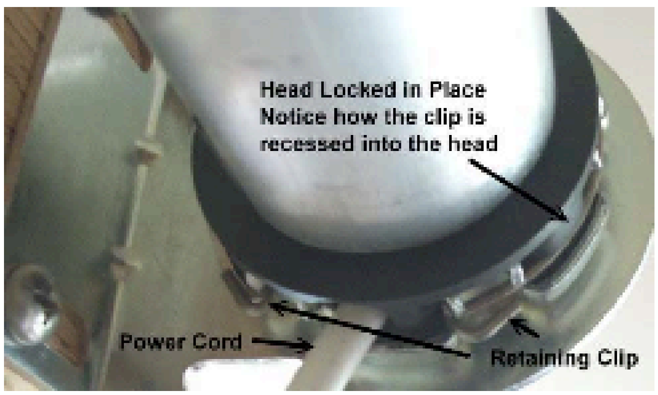
b) Insert the idler end of the shade into the idler bracket.

c) Swing the shade head up towards the motor head bracket.

d) Compress the idler by pushing shade assembly towards the idler bracket. This will provide the necessary clearance for the motor head to swing into place.

e) Insert head into motor bracket and make sure the power cord is positioned correctly. Manually snap the retaining ring in place if it does not do so automatically.





7) Level the Shade Assembly. Use a bubble level to check your shade installation. A small amount of out of level is typically OK but we prefer perfection. CAUTION: If the shade tube is out of level the material can walk off the tube during rotation and get damaged. As necessary shim or reposition brackets so the shade tube is level.

Double check the mounting bracket screws to ensure all are in place and properly tightened.

8) Test Operation. CAREFULLY operate the shade to ensure satisfaction in mounting and no material walk-off. If your shade is motorized it will need to be programmed using the appropriate instructions. During the first operation we recommend unrolling the shade all the way down even if this is past the lower limit to ensure the material is properly seated. Caution: The shade material is affixed to the tube using double sided tape. Do not unroll the shade to the point where it is stressing the tape.

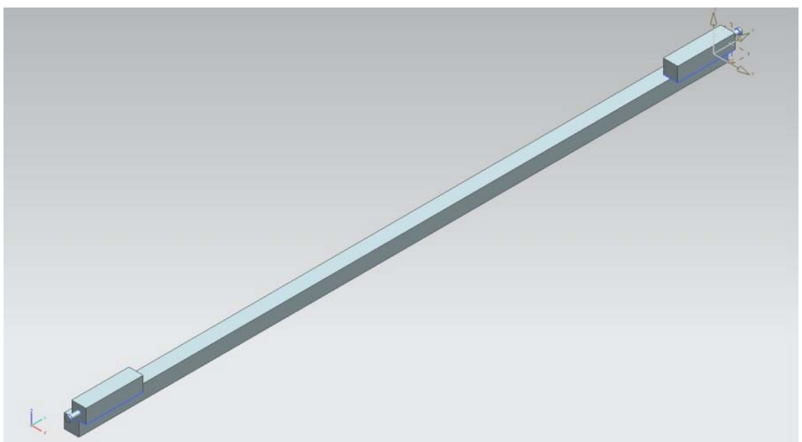
Appendix K
Bill of Materials

Part No.	Part Name	Qty.	Material	Color/Finish/Size (in)	Price ($)	Manufacturing Process	Notes
ST50-RTS	Somfy Sonesse ST50 RTS RF Roller Shade Motor w/ Remote	1	Plastic, Metal	Grey-Black, 31” L x 2.25” Dia	$321.44	None	AV-Outlet.com
9420800	Somfy Universal Idler w/ 10 mm Collapsible Shaft	1	Cast Steel and Nylon	Black, 5.4” L x 2” Dia	$15.99	None	AV-Outlet.com
9410651	Somfy Star Head Motor Bracket	1	Cast Steel	3.15” W x 3.75” H x 0.1” Thk	$12.99	None	AV-Outlet.com
9410635	Somfy Idler Bracket 10 mm	1	Cast Steel	3.15” W x 3.75” H x 0.1” Thk	$9.99	None	AV-Outlet.com
RTA6U50	Rollease 2.5” Crown and Drive Kit	2	Cast Steel and Nylon	2.5” Outer Dia	$9.99	None	AV-Outlet.com
RTEA6T16-4	Rollease 2.5” Roller Shade Tube	1	Aluminum	2.5” Outer Dia, 2.25” Inner Dia, 48” L	$24.75	Cutting to reduce length to 32”	AV-Outlet.com
-	Doorframe Base	2	MDF Board	48” L x 28” H x 0.25” Thk	$9.90	Cutting	Home Depot
-	Wood Trim	2	Wood	80” L x 0.75” H x 0.75” Thk	$14.34	Cutting to length	Carpenter Bros. Hardware
1850A19	48” T-Track	2	Aluminum	0.5”W x 48” L x 47/64” Thk	$22.04	None	McMaster-Carr.com
1850A17	36” T-Track	2	Aluminum	0.5”W x 36” L x 47/64” Thk	$17.36	None	McMaster-Carr.com
-	#9 Wood Screws (50 pk)	1	Steel	3” L x 0.358” Dia	$7.98	None	Home Depot
-	Wood (2 x 4)	-	Wood	3.5” W x 600” L x 1.5” Thk.	$18.54	Cutting to size	Home Depot
7216K515	Standard Male Plug	1	Plastic, Brass	1” W x 1” L	$4.79	Connecting to existing wiring	McMaster-Carr.com
Unknown	Quiet Barrier MD Sound Dampening Material	1	Vinyl Composite	36” W x 96”L x 1/8” Thk	$71.32	Cutting to size	acoustictrade
-	Doorway Wood Trim	3	Pine Wood	3” W x 80” L x 1” Thk	$7.25	Cutting to length	Home Depot
-	Wood Tacks (50 pk)	1	Steel	1” L	$1.49	N/A	Carpenter Bros. Hardware
-	Wood Nails (50 pk)	1	Steel	0.5” L	$1.49	N/A	Carpenter Bros. Hardware

Appendix L
Description of Design Changes Since Design Review 3

Our prototype design changed very little in the time between Design Review 3 and now. The main change was the removal of the steel template plate that was included in our original design. Due to a lack of time, we decided to forgo the steel plate and instead carefully mount the components directly to the doorframe. The steel template was going to be a guide for easier installation, but the time it would have taken to fabricate the steel plate would have equated to the time it took us to carefully install the components directly to the doorframe. This decision was also budget driven, since our project went significantly over the original $400.00 budget allotted to each team in ME 450.

Our bottom guide bar design changed slightly as well, due to unforeseen clearance issues between our doorframe and the door system itself. This change can be shown in the figure below, which shows the two smaller, slightly offset pieces of wood that are attached to the long piece of wood and hold the guide screws for the t-track system. In order to effectively mount the door material to the bottom guide bar and ensure smooth track movement, we had to offset those pieces.



We also developed a method for mounting the door material to the motor tube. This was absent in our Design Review 3 report, but is outlined thoroughly in our report. We decided to attach the door material to the motor tube using machine screws threaded into the motor tube itself. A pinch bar between the door material and the heads of the machine screws was also added for extra security.

Instead of using machined aluminum pieces for the bracket spacers, we decided to save money and use leftover two by four wood, which we determined was an adequate replacement for the machined aluminum pieces, and even more effective, since the entire bracket assemblies were attached with 2.5” long wood screws, which could then thread through the bracket and the door studs. This was a simple change of materials that was driven by our aforementioned budget concerns.

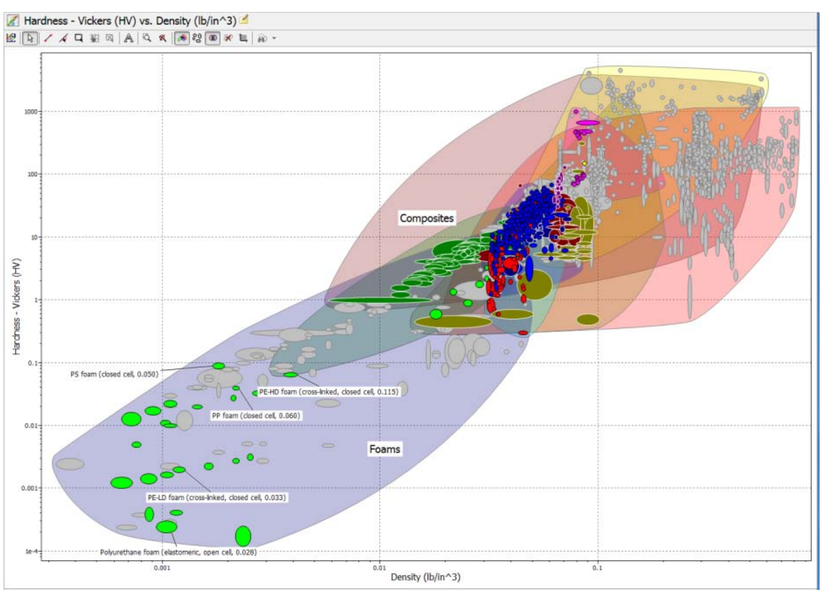
Appendix M

Material Selection

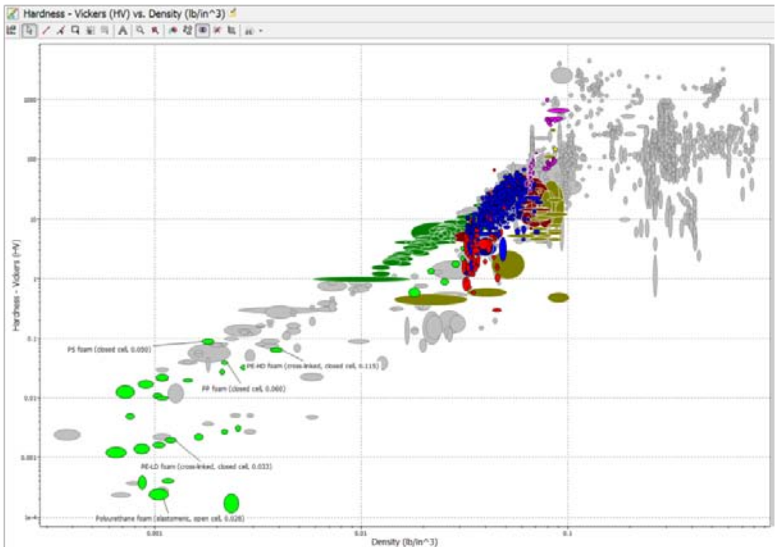
For our design, there were a few key material selections that we had to make. First, and perhaps most important, was the door material. This material was responsible for shifting our design away from simply a fabric barrier (such as the competing Motor Door) and towards a door substitute by providing the necessary privacy. That meant the door must block a similar amount of sound as a wooden door does. At the same time, the material had to be flexible (in order to roll up) and be as lightweight as possible in order to allow for the motor to move it up and down. Unfortunately, these are conflicting requirements. High density materials are better at blocking sound, but this meant the material would weigh more.

The first issue we encountered during this analysis was the lack of sound dampening property data. Sound dampening ability, or the ability of a material to absorb or block sound waves, is not dependent on a particular material property, so there is no certain way to predict sound dampening performance. For a particular material, the sound absorption coefficient must be tested for and calculated in a lab setting. Despite this problem, we did our best to estimate which materials would dampen more sound compared to others.

The process of dampening sound involves either absorbing sound waves and dissipating them as heat, or scattering sound waves so that they fall out of phase relative to each other. Materials with large specific surface areas, such as foams, are effective in accomplishing this. From first hand experience, we also knew that materials with large masses block sound effectively. Using the CES software, we plotted material hardness versus density. We predicted that materials with high density and low hardness would be most effective at dampening sound, and the CES plot confirmed this. Foams and other insulating materials fell within that range, as seen below.



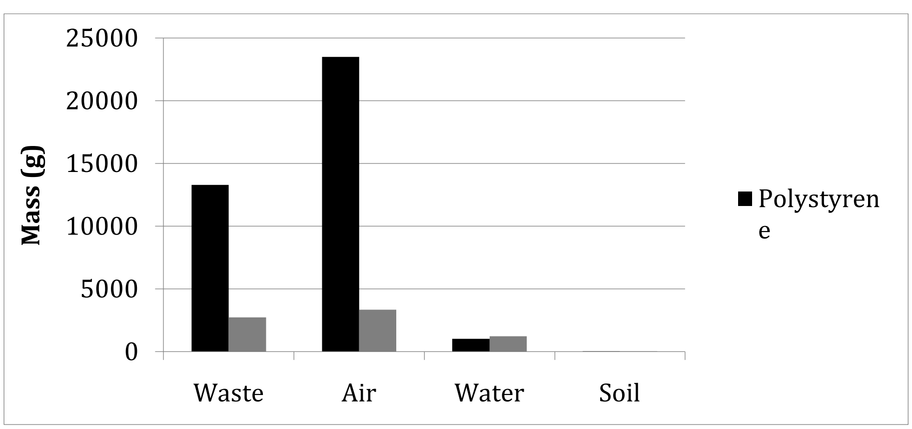
From here we set constraints in order to narrow down our options. We knew our door material dimensions were roughly 34 by 90 inches, and that we'd need the material to about 1/8 of an inch thick. Also knowing the lift capacity of our motor to be 28 pounds, we were able to find the density limit. Since price was also important to this project, we set a limit of three dollars per pound. Based on the maximum possible load of 28 pounds, our max material price would then be 84 dollars, which fit within our budget. CES showed these constraints on the plot by graying out the choices, which did not fit within these ranges. From here we chose five materials to consider, which are marked on the plot below.



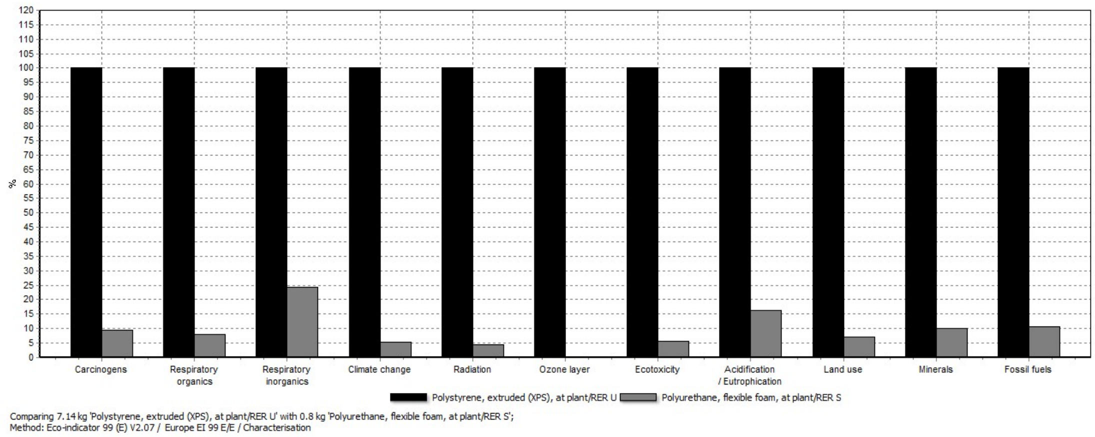
Although it appears there are many choices in the lower left area of the plot, this is misleading. Many of those choices are the same type of foam with slightly different material properties. For our analysis, we chose the foams that performed best within each family. The top 5 were polystyrene foam, polyethylene foam (high and low density), polyurethane foam and polypropylene foam.

Next, we analyzed two of the materials using SimaPro, to investigate the environmental impact of each one. The two that best fit our requirements were polystyrene and polyurethane foams. Using this software, we made plots of the emissions, weighted impact of the emissions, normalized damage caused by the average person, and a weighted normalized score which takes into account the importance of human health and resource consumption. Those plots are shown below.

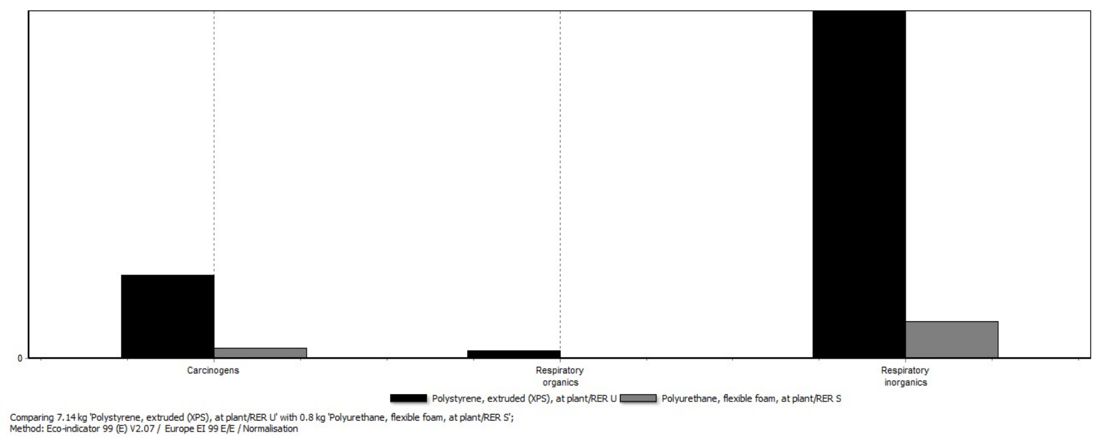
Total Emissions



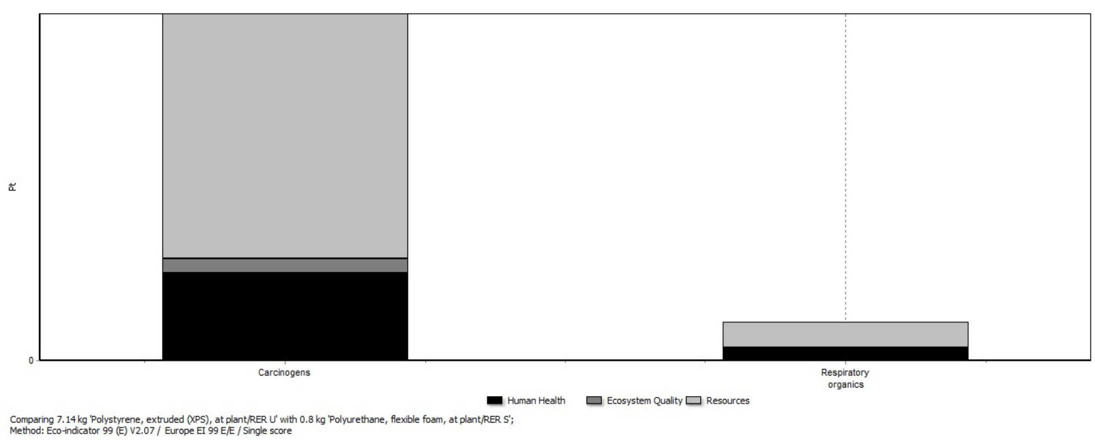
Characterized Plot



Normalized Plot



Single Score



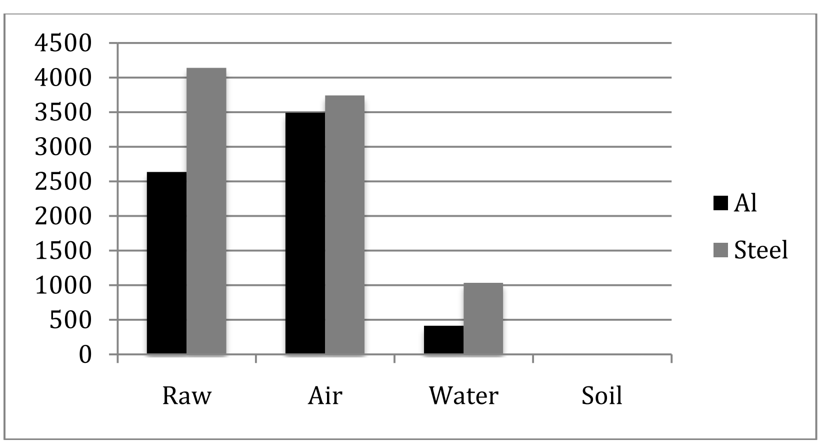
As we can see in these plots, polystyrene is far worse for the environment due to higher overall emissions and emission damages. It has higher emissions in every single category, as well as in the normalized and adjusted damage categories. In this case, the polyurethane foam would be the better choice. Looking at the point values for polystyrene, it appears as though "resources" would have the most important EcoIndicator 99 values, and also have the bigger impact when looking at the lifecycle of the material.

Although this analysis focused on these two foam types, this is not what we used in our prototype due to other outside factors. Due to the short time frame and our focus on constructing a proof of concept prototype, our material selection focused mainly on price and availability. After completing this analysis, we could consider using polyurethane foam, as it a moderate-density and low hardness material. However, before making a final judgment, we'd need to perform testing on the actual sound dampening ability compared to our current material, the QuietBarrier MD vinyl.
The second component we looked at was the side track that the material slots into. The track is runs along the sides of the doors, and is responsible for sealing out light and sound. Although a pin runs through the track to keep the door material aligned and in place, the track bears no significant load. Except in situations where a person pushes onto the door, for example, there will be almost no force on it at all. This meant we had to analyze the materials from a slightly different perspective. The parameters we focused on were price, water durability, and hardness. We wanted to keep price down, and since this door could be used in bathrooms, keep a moderate to excellent water durability rating. Since a pin will be sliding along the track, we needed a material rigid enough to support that. Although hardness is not the exact parameter we were looking for, it gave us a rough approximation of the range we should be looking in.

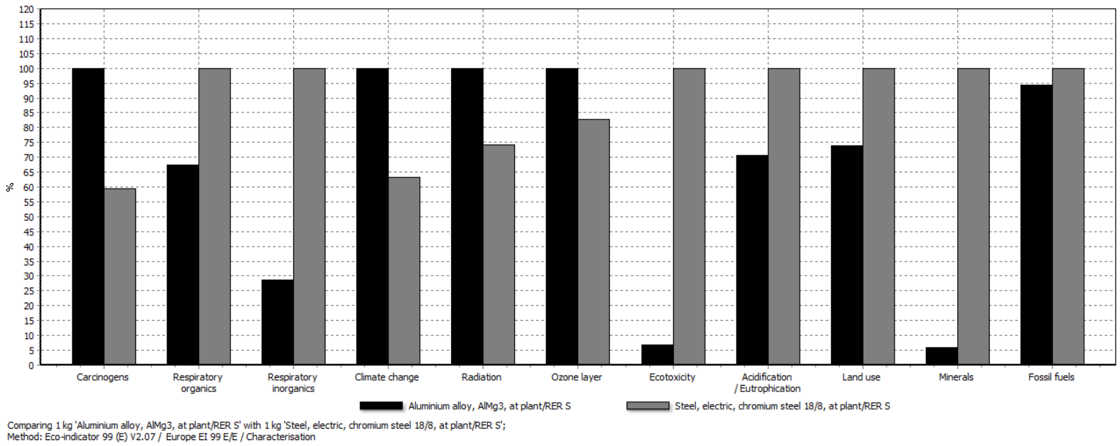
After considering these parameters, we selected five possible materials: aluminum, brass, stainless steel, pine (wood) and concrete. Some of these materials have disadvantages that are not shown in the parameter analysis. For example, although concrete is relatively cheap and has a high water durability, it is not a realistic choice to use in forming a track system. Considering these other factors, we selected aluminum and stainless steel for further analysis using SimaPro.

As before, we looked at four plots showing different environmental damage and emissions, shown below.

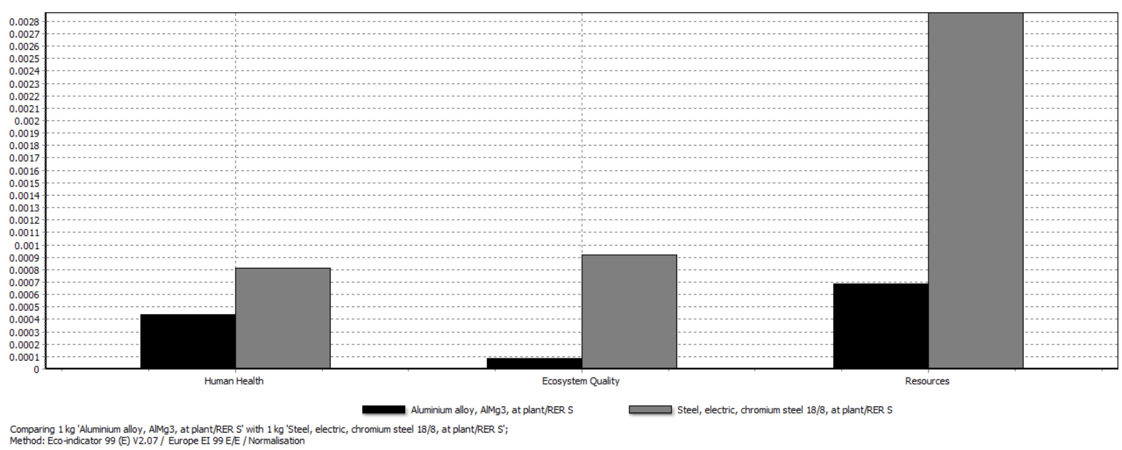
Total Emissions



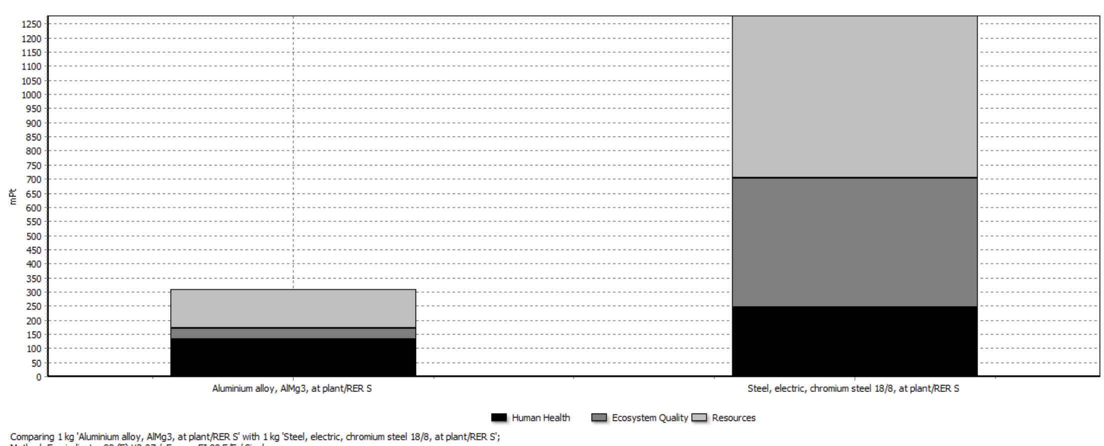
Characterized Plot



Normalized Plot



Single Score



In the case of these materials, the better choice is not immediately clear. Each one is better in certain categories, so some tradeoffs will have to be made. In the total emissions plot, stainless steel is worse in all four categories. However, in the characterization plot, which shows the effects on human health, eco-toxicity and resources as a percentage of the maximum. In this plot, we see that in some categories, such as carcinogens, climate change, and ozone layer, aluminum is worse. However, in these categories, steel is not far behind and is usually over 50% of the aluminum score. But in the categories where steel is worse, aluminum is often substantially lower. For example, in “Respiratory inorganics”, aluminum is just under 30%. Looking at the normalized plot, steel again produces more emissions and damage on the environment per person. And lastly, in the single score plot, steel is substantially larger, with very large values for ecosystem quality and resources compared to those for aluminum.

In the end, aluminum would be the better choice for the environment. This is what we used in our design, so no changes would need to be made. We identified the track system as one area of our design that we could improve upon, so we should consider aluminum components when making these decisions.

Manufacturing Process Selection

Our product will likely not be installed in a large percentage of homes throughout the United States. Although the US is facing a growing elderly population, our product is a fairly specialized item. Although we hit the price point we were aiming for, it is not a cheap system, so installing it throughout a home would be fairly expensive. In reality, a person looking to install our system may only install it in one or two key locations in their home. Because of this, a large production volume is not needed. Dr. Mark Ziadeh expressed interest in recommending a system like this for his patients, so an initial run of around 10 units may be realistic. If the product proves to be effective, this could be expanded into a product volume into the thousands in order to take advantage of the growing elderly population. In theory, this could stretch into the millions, however, not everyone will need to replace the traditional doors in their houses with our product.

The manufacturing processes for the two components analyzed above are fairly basic. The sound dampening material simply needs to be cut to size and have holes drilled to attach to the roller tube. The material does not need tight tolerances, as the T-track will hold any variations in the material width. Additionally, if the material is too long, it can simply be held on the spool without consequence. The material cannot be undersized, however. Undersized door material would mean the full doorway would not be covered, rendering our product ineffective. The CES software recommends cutting the sound dampening foam using a water jet. This would also ensure that the material could be cut to be square, which will help the alignment as the material is rolled up and down. This would be a quick process and could be adjusted to fit a variety of door widths and heights. After it is cut to length, it needs to be attached to the tube. Holes can be drilled into the material at regular intervals in order to ensure it aligns properly with the tube. Again, tolerances are not an issue here, because the pinch bar will hold most of the material weight and the force is not concentrated on these holes.
Considering the basic T-track used in our current design, the most effective way to make this would be through extrusion. We need long, thin pieces of aluminum, so machining is not a

realistic option. Extrusion would be a fast process and would allow us to cut it to lengths that we need. Dimension tolerances are not an issue here because the goal of the T-track is to capture any excess material that overlaps. However, the track does need to be smooth and free of sharp edges, in order to protect the material as it slides. This could be accomplished through sanding or filing, although extrusion generally features good surface finish.