Accessible Countertop Oven

Engineering 90: Senior Design Project

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Abstract

For the completion of the Engineering 90 design project, we designed, constructed, assembled and tested a works-like prototype of an oven accessible to the handicapped. The innovative components of the oven include a conveyor to load and unload food to avoid the need to reach into the heated cavity, a door that rolls back into the oven to minimize protrusion from the oven body, and an automated system with food sensing for ease of use.

Background

The original concept of this project was to create a combined microwave and conventional oven, as envisioned by Professor Macken. The goal of this design project was to create a works-like prototype of this product. The product would be specially designed to be accessible for handicapped users. In order to design this product, user needs were identified, a variety of concepts were generated and narrowed down to the final design, materials were selected, and finally, components were built and tested leading to revisions in the design.

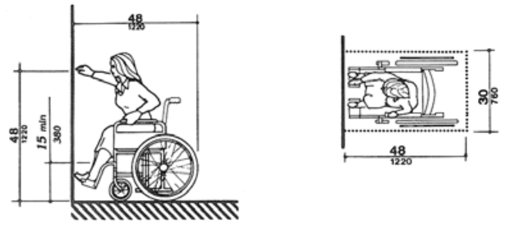
This report is organized as follows. Research on the user needs and the current products on the market will be discussed first, including the purchase of an oven for use in this project. From there, the report will be divided into the three main design components: the conveyor design, the door design, and the control system. Each of these sections will include the design goals and initial concepts considered, as well as details on the construction and materials used. Following this will be a description of the housing built for the oven, heat testing performed, user input and subsequent modifications, and the details of a looks-like model of the product. To conclude the report will be an acknowledgements section, a bibliography referencing the sources used, and the appendices.

User Needs Research

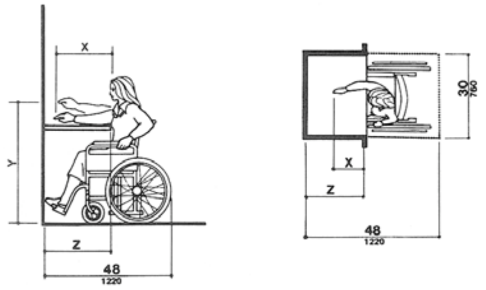
Extensive research has shown that ovens have not been designed for the handicapped. Specifically the American Federation for the Blind has also stated that no specialty products exist for the blind. Although there are ovens that have tactile controls that can be used by the blind, these products have not been optimized for their use. The National Federation for the Blind's *Suggestions for the Blind Cook* indicates the necessity of tactile controls for temperature as well as methods to avoid contacting the heated components of the oven.

Similarly, handicapped users in wheelchairs have reach constraints that are often ignored in the design of ovens. While there exist ovens that open to the side instead of up or down, these still prove to be inconvenient to use. There is clear need for a consumer product that addresses these concerns. An accessible countertop oven could make use of a rollback door to minimize outward protrusion from the oven body by the door. Additionally a loading mechanism was envisioned that would eliminate the need for the user to reach into the heated cavity. These ideas inspired this design.

Figure 1. Reach constraints of handicapped users



(a)
High Forward Reach Limit



NOTE: x shall be ≤ 25 in (635 mm); z shall be ≥ x. When x < 20 in (510 mm), then y shall be 48 in (1220 mm) maximum. When x is 20 to 25 in (510 to 635 mm), then y shall be 44 in (1120 mm) maximum.

(b)
Maximum Forward Reach over an Obstruction

Fig. 5
Forward Reach

Research on this project began with reading the Americans with Disabilities Act (ADA) and visiting various appliance stores to learn about the existing products on the market. While the ADA outlines building codes for handicapped people, it also showed us the reach constraints of handicapped users (Figure 1). Specifically of interest to us were the reach constraints of handicapped users for countertops. It is expected that handicapped users can place their wheelchairs below countertops, minimizing their reach constraints. This would be an added benefit of a countertop oven for an individual in a wheelchair.

Upon examination of the available countertop ovens, we realized that there were many combination microwave ovens already on the market. It was decided to focus on creating an accessible oven since it would not be novel to combine a microwave and an electric oven and additionally, to minimize the existing features that would need to be considered in the design.

Design Requirements

Because components of our design would occupy at least part of the oven cavity space, a larger capacity countertop oven was desired. Unfortunately, most of the larger ovens were combination microwave ovens. While a conventional oven was desired, there were none that would suit the size requirements of this project. A true oven was desired, rather than a toaster oven. Ideally the oven would be capable of cooking a full meal. Likewise, an electric countertop oven was desired. The reach constraints that would be considered in design would therefore be the countertop reach constraints mentioned earlier. Ample research on the internet and inquiries at local appliance stores narrowed down the options to three convection ovens: Hamilton Beach® Countertop Convection Oven, Waring Pro CO1500 1.5 Cu. Ft. Professional Convection Oven, and Haier RTC1700 Extra Large Capacity Convection Oven. Eventually, the Hamilton Beach® Countertop Convection Oven (Figure 2) was purchased at Boscov's in Media, PA because of its immediate availability.

Figure 2. Hamilton Beach® Countertop Convection Oven

Outline of Design and Construction

Concurrent with the aforementioned oven purchase was the designing of the components to add to the oven. Many concepts were generated, which are detailed in the Initial Concepts sections for both the conveyer and the door. Following the selection of the designs to pursue, materials were purchased and construction began. Construction started first on the conveyer system, and is detailed in the Conveyer Design section of the report. During the initial construction of the conveyer, the door went through several design iterations and material tests before construction could begin. The first door constructed proved to be unsatisfactory, and further construction was necessary. The details of the design and construction of the door are explained in the Door Design section of the report.

Following the construction of the mechanical components of the design, the electronic components of the oven were selected and code was written to have the oven automatically perform the required steps. The oven was put through several iterations in order to perfect the timing set in the code. The design of the electronic control system as well as the control box are described in the Control System section. All code is included in Appendix C. Additional testing was done with thermocouples to ensure minimal heat loss and to confirm that the sensor and mechanical components would function at high temperatures. The results of this testing are explained in the Testing section of the report. The results of testing proved that adjustments had to be made for high-heat performance. Additionally a looks-like prototype was designed in SolidWorks to show how a consumer version of the Accessible Oven would look. Images of the prototype as well as descriptions are included in the Looks Like Model section of the report.

Conveyer Design

Design Goals

The conveyor mechanism is one of the main components of the accessible oven. It function is to bring food into and out of the oven while minimizing user contact with the heated cavity. The conveyor functions by having a wire belt run across rods driven by sprockets on a shaft connected to a motor. The conveyor is composed of two bars of Unistrut, eight aluminum blocks, eight brass bushings, wire belt, a drive shaft, an idle shaft, two spacer rods, two guide rods and four adjustable feet. The estimated cost of purchasing these components is $250.00. However the cost of these components in a consumer oven would be significantly less. The conveyor is driven by a Groschopp 12 Volt DC motor. The dimensions for the conveyor mechanism are depicted in Figure 3.

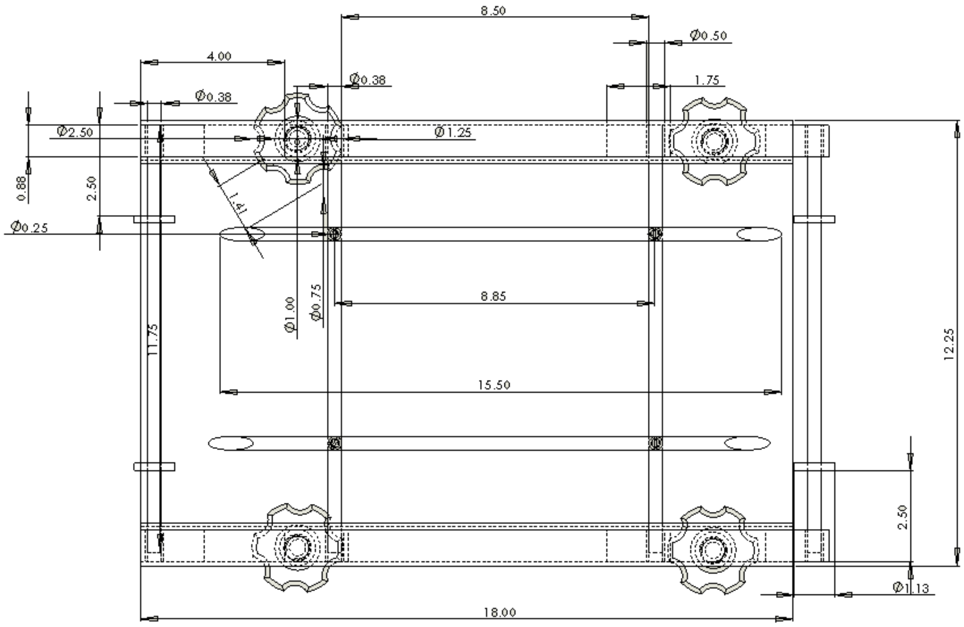


Figure 3. Conveyor dimensions

Initial Concepts

Several weeks were dedicated to the generation and selection of a design to address the needs of handicapped users. Concepts for the loading mechanism included using gravity to bring the food down an incline and having an arm that would extend out to catch the food (Figure 4). The problems with these ideas were that there needed to be something that would be able to be stored in the back of the oven and extend when necessary. This would allow the loading mechanism to be insulated from the heat of the oven during cooking, and would make it possible for users to touch the mechanism without burning themselves. It was difficult to consider a design that would fit a tray that would be the size of the cavity of the oven into the back or side of it without making the product extremely large. One idea was to make hinges in a loading arm so that it could roll into the back of the oven. Another idea was to use two trays instead of one. However, flaws in these ideas made them unreasonable to pursue, and another avenue was chosen instead. A conveyor mechanism was deemed the best option.

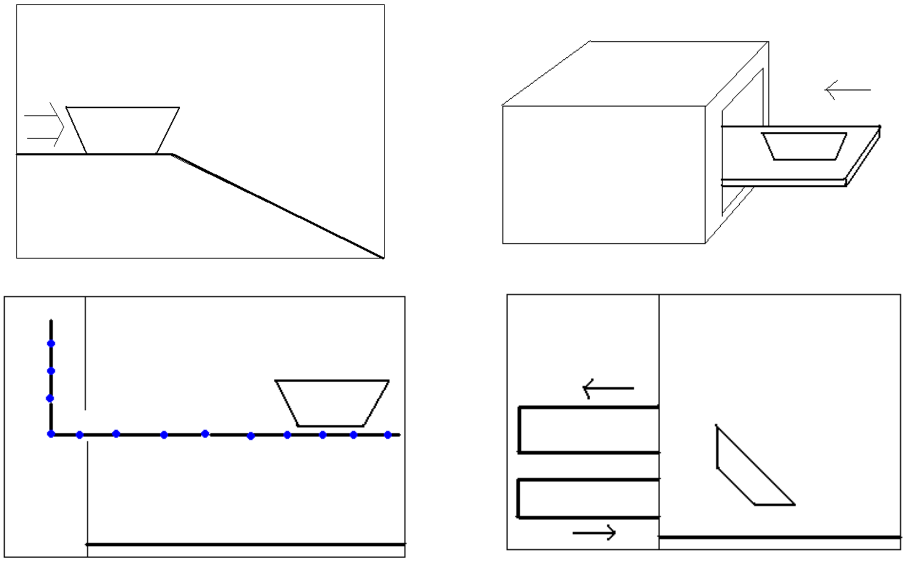


Figure 4. Initial concepts using an incline (upper left), extension arm (upper right), hinged arm (lower left), and two trays (lower right).

Construction of the Conveyor Mechanism

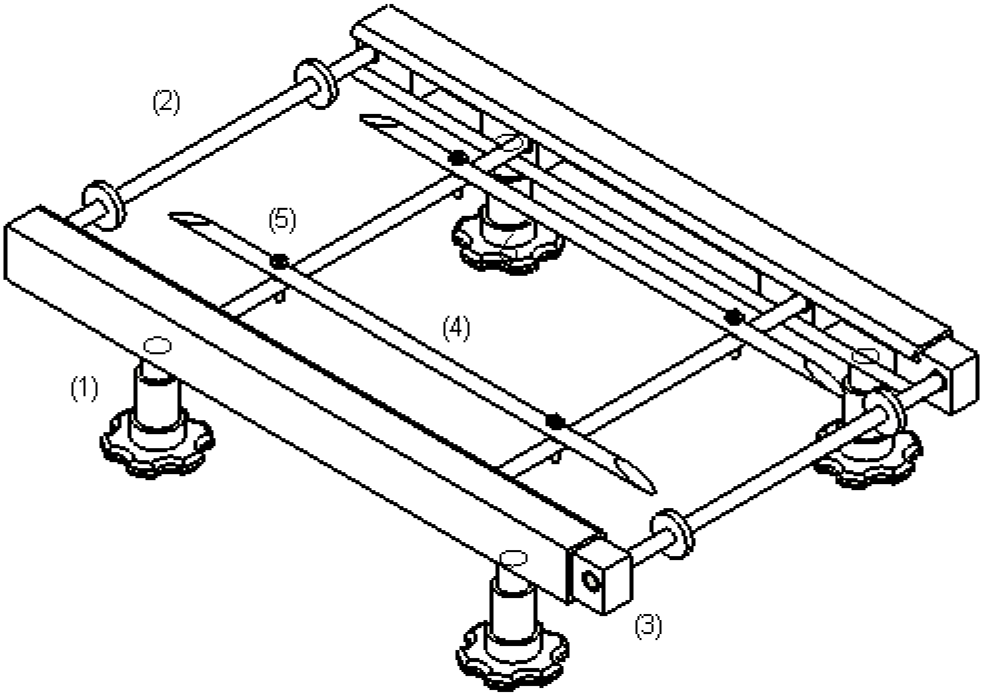


Figure 5. Diagram of the Conveyer Mechanism

There were several design constraints that were considered when creating the conveyor mechanism (Figure 5). The first major design constraint was that the conveyor apparatus needed to clear the heating coils that were on the floor of the oven. To address this concern, feet were added to the bottom of the conveyor structure that would allow for the adjustment of the height of the conveyor (1). Holes were drilled into the bottom of the conveyer structure, and these holes were tapped. This allowed threaded feet to be screwed into these holds, and for their height to be adjusted by screwing or unscrewing them from the base of the conveyer structure. Using these elements, the conveyor was adjusted to clear the heating coils, while also maximizing cavity space in the oven.

Selecting an appropriate belt material was another major design consideration. The design called for a belt that would be driven by two gear sprockets on either end of the conveyor (2). Exactly how this would be achieved required the consideration of several alternatives. One idea was to connect metal rods to two chains that would be driven by the gears. The eventual construction used, however, was wire belt that fit into more wire belt so that the length could be easily adjusted by adding or taking away chains. These belts are commonly used in large toaster ovens found in public eating areas like dining halls. Due to the special spacing between the wires (0.375"), a drive and idle shaft with appropriate gear spacing were ordered from the manufacturer of the belt, APW Wyott.

The conveyer structure was designed to fit within the body of the oven while also supporting the selected drive and idle shaft. It was also essential that the shafts be able to rotate freely. Two bars of Unistrut were cut of equal length to serve as the frame of the conveyer (3). One inch aluminum blocks were cut such that they would fit within the Unistrut frame. The aluminum blocks could slide freely through the Unistruct making their position easily adjustable. The design was made as adjustable as possible from the beginning to make the eventual alignment of the frame simpler. Set screws were placed inside the aluminum blocks so that their position could be fixed after the conveyer was successfully aligned. To connect together the Unistrut frame, two aluminum spacer rods of equal length were cut (5). These rods were mounted into the aluminum blocks within the Unistrut. In addition the drive and idle shafts were mounted into the aluminum blocks. To allow the idle and drive shaft to rotate freely in the aluminum blocks, brass bushings were ordered. The bushings were press fit into aligned holes in the aluminum blocks, and reamed to the shaft diameter. This is shown in Figure 6.

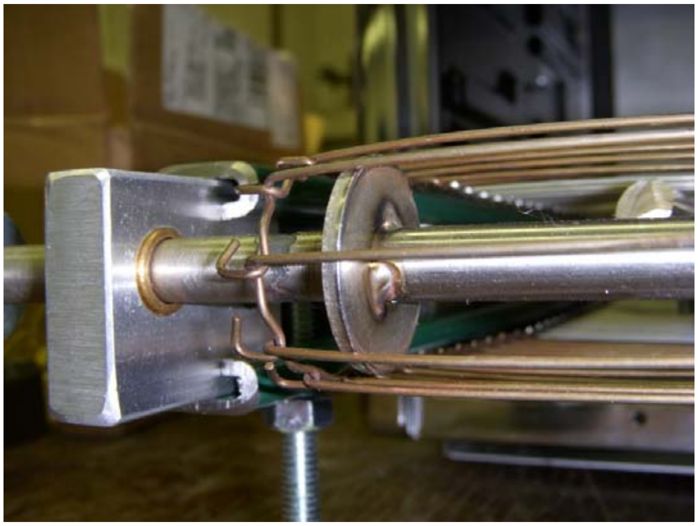


Figure 6. Driving shaft in a brass bushing inside one of the front aluminum blocks.

After finishing construction of the basic frame, the components needed to be aligned. This was eventually achieved by using parallels and trial-and-error. Alignment was performed by repeatedly adjusting the aluminum blocks, and tightening the set screws. Then ease of rotation was tested. This process was repeated until the shafts turned with little friction. The set screws were then tightened further to ensure that they would not shift position during rotation of the conveyer.

A coupling was developed to connect the selected Groschopp motor to the drive shaft. The coupling used set screws to maintain the connection between the motor and the shaft. Also, since the ordered drive shaft was not long enough to extend beyond the aluminum blocks, an extension was cut from available aluminum rods and welded to the shaft.

Modifications of Initial Design

After the basic construction was completed, the conveyer mechanism was tested. It was clear that due to the length of the conveyor, the wire belt could not support the weight of a plate or tray without sagging. Guide rods were placed parallel to the Unistrut in order to avoid this problem (4). These rods were mounted directly to the top of the spacer rods, and were designed to be of adjustable height. After testing the conveyer's functionality, the rods were filed. This ensured that after repeated cycling of the conveyer the belt would still run smoothly.

Another problem was revealed only after the conveyor had been in prolonged use. As the wire belt rotated, it would occasionally get caught in the screws holding the guide rods to the spacer cross rods (5). Once this happened, the motor would continue to rotate, causing the belt to deform. These screws were shortened to prevent the wire from contacting the screws. This allowed free rotation of the conveyor track. A photograph of the conveyor is shown in Figure 7.

Figure 7. Completed conveyor

Motor Selection

The design of the conveyor system necessitated a drive motor to maintain constant low rpm rotation of the conveyor track. This motor was selected during the construction of conveyer system. The first step in motor selection was to estimate the torque requirements for the system. We assumed that the drive and idler shafts of the conveyor mechanism would rotate with low friction (as a rough estimate we used 0.1 as a coefficient of friction). The maximum expected loading of the conveyor track would be approximately 10 pounds, therefore about 1 pound of force would be the maximum drive needed to turn the conveyor. The radius of the conveyor's drive teeth was 0.565 inches, therefore the torque requirements of the motor would be 0.565 lb-inches. However to be cautious we did a worst case estimate assuming a coefficient of friction of 1, which gave a maximal torque requirement of 5.65 lb-inches.

After consulting with Ed Jaoudi, we found several DC motors used for previous E90 projects that would meet our worst case torque requirements. However most of these motors operated at very high speed. The design required a low speed motor so that food loading would not be violent or overly rapid. The immediate option was to order an ideal motor to fit our design needs, or to make use of the one low speed, high torque motor available. This Groschopp 12V motor, Model PM6015-PS1960, produced over 88.9 lb-ft of torque and through a reducer operated at 13.3 rpm (Figure 8). Although it

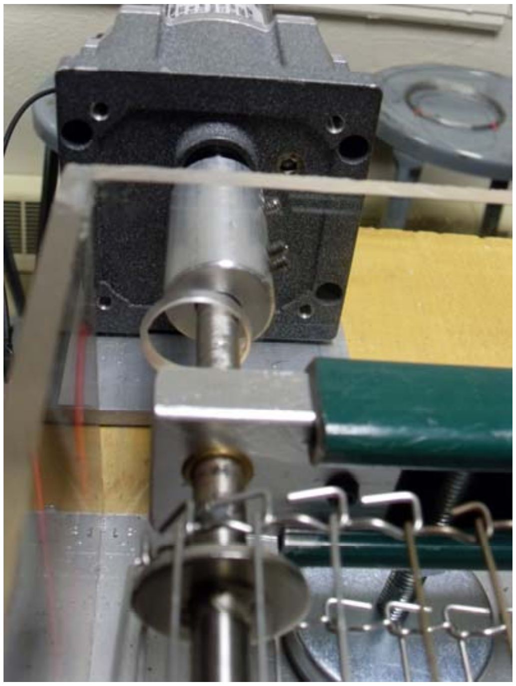


Figure 8. Groschopp motor used in the conveyor

was much larger than ideal, we ultimately selected the motor to avoid unnecessary expenses for the project. This motor would be directly coupled to the drive shaft of the conveyor system to move the track. Its direction was easily reversible by switching the polarity of the applied voltage to the motor.

Door Design

Design Goals

In order to prevent protrusions, the newly designed door would be made of a flexible sheet material that could roll on top of the oven. With this design, opening and closing the door would not require wheelchair-handicapped users to move away from the oven. As the door is on the front of the oven, it was desirable to design it in accordance with ASTM C1055-03: Heated System Surface Conditions that Produce Contact Burn Injuries (Appendix A).

Initial Concepts

There were two main ideas on how to approach the creation of a door that would not extend outwards. The first idea was to make the door using panels and have it open similar to the way a garage door functions. The panels would be made out of some clear material, perhaps glass, and would be connected to a gear system that would pull the bottom panel up. However, methods for connecting the panels seemed overly complex. Another issue was the complexity of the gear mechanism that would have to function at high heats inside the cavity of the oven. The second idea, which eventually was pursued, was to use a flexible material that could roll similar to a window shade. This idea was deemed the most realizable.

Material Selection and Initial Testing

The main criteria of the door material were that it withstand high heat, was food-safe, and could easily be worked. Potential materials obtained for the door were silicone baking sheets, alumina insulating sheets, and silicone rubber-coated glass fiber fabric. Testing on the different materials included heat tests on a hot plate as well as over the heated cavity.

According to ASTM C1055-03, for consumer products, no more than first-degree burns in 60 seconds is desirable. Table 1 shows the temperatures and times that cause first-degree burns [1].

Table 1. Temperatures and Times that Cause First-Degree Burns [1]

Temperature (°F)	Minimum Time for First-Degree Burn (s)
122	60
131	5
140	2
149	1

The silicone rubber-coated glass fiber fabric was Pyroblanket™, a product used as a flame-protective blanket in outdoor and offshore applications [2]. The advantages of this material were its high-temperature resistance (melting point > 1000°C) and imperviousness to contaminants. The fiber blanket can easily be sewn. The issue with using this material in door construction, however, is that it is not intended to be used in food appliances. The fiber fabric was tested using 1-layer, 2-layers, 4-layers, and 8-layers on a hot plate. Only at 8-layers did it pass the standards outlined by ASTM C1055-03. However, use of this material was limited because of its questionable food-safety as well as the 8-layer required thickness.

Silicone mats are rubbery products used as baking sheets. They are heat resistant up to 500°F, as well as food-safe. Unfortunately, the rubber consistency of the product makes it difficult to manipulate for construction. On their packaging it was specified not to heat these products on a hot plate. Therefore, testing was achieved using alligator clips to cover the opening of the oven while the oven was heated for 20 minutes. With 1-layer or 2-layers the door was too hot. 4-layers was adequate, but also quite thick.

After consulting with Professor Orthlieb about the available insulators in the materials lab, alumina insulating sheets and boards were obtained. Alumina insulating sheets are functional at temperatures as high as 3002°F. They are used as thermal insulation in furnaces, which make it desirable in its high temperature capacity, but low in its safety to use in an oven [3]. It was explained that the alumina sheets should not be a respiratory hazard unless they were in direct contact with the food. This material was therefore considered in the design of the door.

Translucent solid silicone was also tested, a material which was discovered in the later stages of the project. This material is functional up to 450°F, and is used in applications such as cushioning electronic assemblies, LCD displays, and food services [4]. Its FDA approval makes it an especially appropriate material for this project. Its transparency is also a desirable characteristic not found in most of the other material choices. The thickness of the sample tested was 0.125”. Testing was done on 1 and 2-layers of this material. 2-layers of the translucent solid silicone passed the ASTM standard.

Data from material testing can be found in Appendix B.

Door Construction

The results of the heating test proved that multiple layers of the different material would be necessary to satisfy the requirements of ASTM C1055-03. The issue then became how to connect the separate layers. Sewing/threading, riveting, gluing and stapling were different ideas of how to approach this aspect of the design.

The first design used three silicone mats sewn together with the leftover wire belt in between the layers of silicone. The wire belt would be attached to wires to pull the door over the top of the oven and would also provide some separation between the layers of silicone for further insulation. We visited several dry cleaning and shoe repair shops in hopes of sewing the material together. However, there were several issues that we ran across with this process. Most of the clerks that were consulted said that they could not sew through the rubbery material of the silicone without ripping it. One store said that it would be possible to sew through the material, but they did not have any heat-resistant thread. As the heat rises in the oven, the door and thread would also become hot, and it was crucial that these materials not be flammable at 400°F.

Several high temperature- resistant glues were purchased as another option of connecting the layers of material. PC Fahrenheit and Loctite Clear Silicone were the adhesive sealants eventually tested. PC Fahrenheit is stable up to 500°F and used for repairs on items such as mufflers, engine blocks, grills, and steam pipes [4]. Loctite Clear Silicone is commonly used for windows, kitchens, and bathrooms [5]. Small samples of the silicone mats and alumina insulating sheets were tested. Testing proved that these glues would be unusable in the design. The glue would not bond two silicone mat samples together or the silicone to the alumina insulating sheet. Other heat-resistant glues were considered; however, many of them were designed for use in automotive products and would not be suitable for use near food.

Door Prototype #1

The first version of the door that was built used two silicone mats and two alumina insulating sheets connected by rivets (Figure 9,10).

Figure 9. Door prototype #1 as seen from the side.

Figure 10. Riveted door on the oven.

The same alligator clipping method described above was used to test one layer of alumina sheet between two silicone mats. The insulation was not enough, however. There were concerns that using two layers of silicone would stiffen the door, but it was decided that a hot door was worse than a loss of flexibility, and the two-layer alumina design was selected.

Riveting proved to be difficult because of the flexibility of the silicone. The rivets would compress the material and fall out on the other side. Testing was done on scraps of the extra material to figure out a method that worked to combat this problem. Eventually washers were inserted on each side of the silicone and in the middle to prevent tearing. Once the main body of the door was riveted, it was desirable to cover the bottom of the door with another layer of silicone material. This would prevent the alumina from flaking off out of the bottom of the door.

The door material became distorted because of the rivets. Testing of the prototype showed that the door did not run smoothly through track. Teflon tape was used to help the door run smoother, but the movement was still not fluid. Likewise, the tape kept tearing in channel. Finally, gaps were cut in the alumina to make it more flexible, but the prototype did not function as well as we would have liked and another design was pursued.

Door Prototype #2

The main goal of the second design was to ensure that the door would run more smoothly through the track. All prior design constraints would also have to be met, including use of food safe materials on the inner side of the door (facing the heating cavity), and use of materials with heat resistant properties.

Since the silicone mats were food-safe they were still preferred as the material for the inner and outer walls of the door (since they could potentially contact food during the loading process). The second door design however did not make use of rivets. The distortion of the door by the rivets in the first design was considered unacceptable, and it was decided that hand threading the door together with wire would improve its appearance and functionality. The use of alumina insulating sheets inside the door was retained, however.

The second door was constructed as follows. A 15 inch long segment of extra conveyer track was used as the base of the doors structure. The conveyer track would fold along a tight arc in one direction, indicating that it could easily travel up and down a curved surface along the top of the oven. Since the track was rigid horizontally, it would also provide a more solid door for the user than did the first design. Starting at the bottom end of the section of conveyor track, ½ inch high strips of alumina were mounted onto the track alternating on each side of the track. For example, a strip would be mounted on the back surface along the bottom of the track. Then a strip would be mounted on the front surface ½ inch above the bottom of the track. The third strip would once again be on the back surface, and would be 1 inch from the bottom of the track. This pattern repeated until about 8 inches of track had been covered in this alternating pattern. The alumina was mounted to the conveyor track, by threading thin wire through the alumina by hand, and tying it around segments of the conveyor track. The insulation was mounted on alternating sides of the door to create air pockets within the door (on the side opposite the alumina at any given height.) These air pockets would help improve the insulating properties of the door due to air's low thermal conductivity.

Figure 11. Backside of door prototype #2

After the insulation had been attached to the conveyor track, the back side of the oven was attached to the conveyor track insulated structure. A silicone mat was hand threaded to the structure using a thin metal wire. The front side of the door was also attached in a similar manner using an additional silicone mat. Threading was performed along several lines of internal conveyor track to both silicone mats to ensure a strong connection. The backside silicone was attached more tautly than the front side, since the front side of the silicone would be stretched as the door traveled around a curve (Figure 11).

During testing of the first door it had become clear that silicone material did not run cleanly through the guides we had created. Experimenting with metal rods showed, that a horizontal cross cavity rod would run smoothly up and down the channels in front of the oven. To improve smoothness of oven motion, a metal rod was mounted across the bottom of the door. The rod was placed between the front and back silicone mats and was threaded to the internal conveyor track to keeps its position fixed. The door was tested, and ran acceptably through the channels in front of the oven with the metal rod keeping position in the channels at all times.

To improve the professional appearance of the door, a layer of Pyroblanket^{TM} was mounted across the front side of the door. The Pyroblanket^{TM} was stapled along the corners to the previously described door structure. Although the outer surface of the door was no longer food safe, the use of an extra outer layer of material had an additional benefit of lowering the outside temperature of the door during cooking (Figure 12).

Figure 12. Final door used in oven with Pyroblanket ™ on the outer layer

Tests of the doors functionality while connected to the selected motor confirmed its successful function, although additional changes were made to the door supports as described in a later section. Heat tests were also performed and the door maintained function under heating at 400 degrees, albeit at a slower rate of opening and closing.

Door Prototype #3 and #4

Although Door Prototype #2 successfully met all of the project's design constraints, materials testing revealed that translucent silicone might be a superior construction material for a commercial oven door. Since heat testing of translucent silicone was not possible until later in the semester, it was not initially clear that the material had some advantages over the other materials being considered. However after obtaining a sample of the material it became clear that the translucent silicone was heat resistant and FDA approved like the silicone baking sheets, while also being significantly easier to work with in construction. Two design prototypes were created from the sample to demonstrate the potential application of the material for an oven door. Due to time constraints heat testing of these prototypes could not be performed. Information on these designs is included in this report as supporting information for the potential construction of a consumer product. It is important to note that Door Prototype #2 functioned successfully after repeated testing, and the focus of these designs was not to replace Door Prototype #2 in the works like model. Instead its purpose was to determine how feasible this material would be to work with in construction, and to determine if a viable door could be made from it.

Prototype #3 was constructed with two layers of translucent silicone. These solid sheets were connected together using a row of screws along the left and right sides of the door. Additionally, a single screw was attached at the bottom of the door to ensure that the structure remain rigid during loading (Figure 13). Prototype #4, also constructed from translucent silicone, was made out of three layers for increased insulation. The three layers were fixed together with screws. Instead of a solid sheet, the material was cut into five panels (Figure 14). These panels were connected with hinges screwed to an extra strip of material. The hinges allowed the door to be flexible in one direction but not the other. The hinged design proved to be extremely flexible, however there would be some

Figure 13. Prototype #3 consisting of two layers of translucent silicone

concerns about heat loss between the door panels (Figure 15). Additionally construction of the door prototypes demonstrated that although the material was more workable than silicone baking sheets, silicone material in general can be difficult to cut and connect.

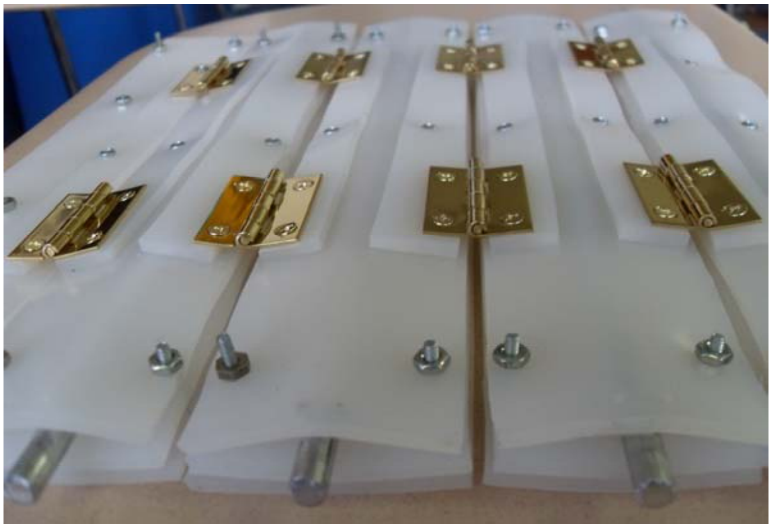


Figure 14. Prototype #4 showing flexible five panel hinged design

Figure 15. Prototype #4 showing gaps between hinged panels

Door Motor Selection

Selection of a motor capable of opening the door proved difficult due to the desire for a second lower RPM motor. If the motor raising the oven door was too rapid the process would seem violent and could damage the door. Testing several motors currently available in the engineering department, indicated that under loading some of the high RPM motors would rotate at a much lower speed. Ultimately a Torque Systems DC Servomotor was found to be the most ideal motor currently available. It could produce enough torque to lift the door, and also to extend the springs. Additionally although it rotated more quickly than would be ideal, it was acceptably slow that the door was not damaged during testing.

Door Motorization

Figure 16. Back rod connected to motor

In order to motorize the movement of the door, a motor, motor mount, rod, and cable were used. The cable, which has a maximum tensile strength of 11pounds, was tied to the wire belt inside the door (Figure 11). The cable was also connected to a rod at the back of the oven (Figure 16). This rod was coupled with the motor (Figure 17), causing the door to rise when the motor is powered. A motor mount was required to connect the motor to the back of the oven. The motor mount is simply an aluminum angle that is fastened to the roof of the oven by three machine screws. The angle is also fastened on its other face to the door drive motor.

Figure 17. Motor mount and coupled rod.

Figure 18. Guide channel with back edge cut off.

Additionally, two guide channels were added to constrain the movement of the door. Notches were cut on the back edge of the channels to allow the door to curve earlier for smoother movement (Figure 18). To further aid in a fluid door motion, a rod was added to the top of the oven behind the door that would roll with the door. The rod was mounted into the existing body

Figure 19. Adjustable Guide

Figure 20. Teflon Covered Rod

of the oven. Small holes were drilled into the oven body, and the rod was rested in these holes. Holes were drilled into the ends of the rod and tapped such that a larger washer could be fixed to each end of the rod. These larger washers would serve to fix the rods position within the oven, while still allowing free rotation of the rod. To ensure free movement of the rod, it was also covered in Teflon tape after several tests of door function (Figure 20). The use of the Teflon tape slightly improved smoothness of door opening and closing. In addition to this rotating rod, ½ angled aluminum was formed into a support track to support the door if it opened beyond the vertical channels (Figure 19, 20).These channels were made adjustable, and were filed at connection points to ensure smooth running of the door along the track. Testing of he door confirmed that it ran smoothly on the created track, and that the rotating rod allowed it to be lowered and raised more rapidly.

Spring Selection

The spring component was crucial to the door design. The springs had to fit in the 0.375" channels that held the door in place. They had to have a high enough spring constant to bring the door down, but not too high that the motor would not be able to smoothly bring the door up. We were fortunate enough to find springs in the machine shop that fit our requirements and did not have to order springs online that would match with calculations made. The length to use for the springs was determined experimentally.

Several iterations were required to figure out an appropriate way to fix the springs to the door and to the oven. The eventual design used is as follows. The springs were attached to two small aluminum plates fixed to the bottom of the oven. The bottoms of the springs were tied to washers that kept the spring in place. The top of the springs were connected to the bottom rod of the door. They were tied to prevent them from slipping through the drilled holes (Figure 21).

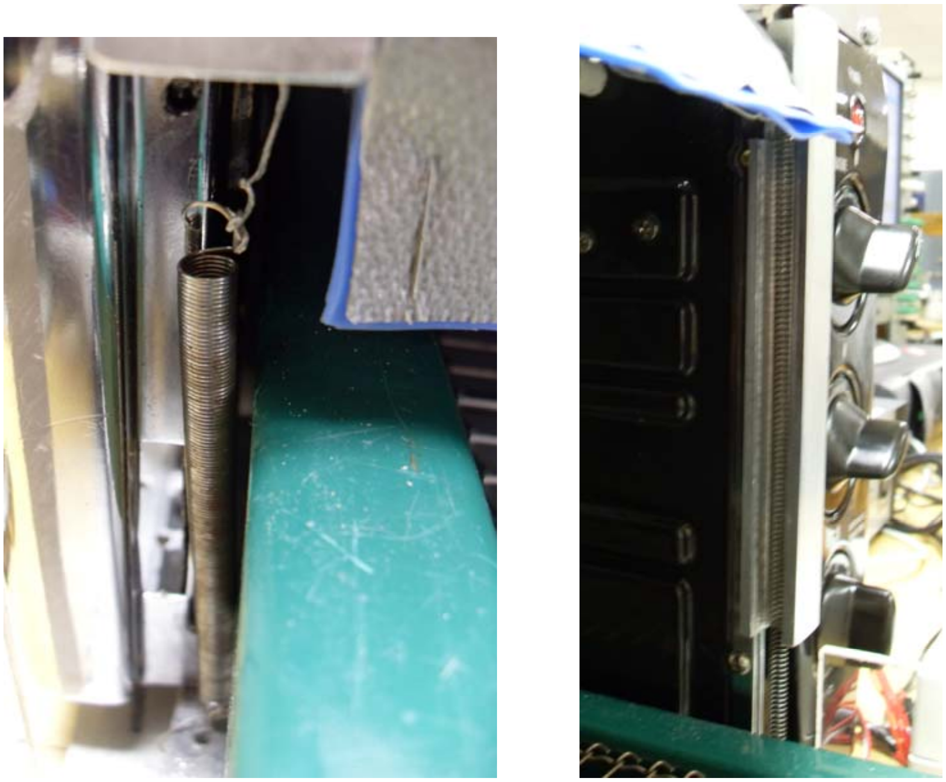


Figure 21. Spring when the door is closed and open.

Control System

Design Goals

The design of the control system involved a series of basic goals. The first of these goals was to make use of varied tactile controls to ease control of the system for the visually impaired. This implementation is explained in the Initial Concepts and the Controls sections. An additional goal was to automate the loading and unloading procedure for the oven. This would make the system simpler to control, and prevent unintentional misuse of the system.

To automate the loading and unloading process, electronic methods of motor control were selected for the door and conveyer system. The control systems for the door and conveyer are outlined in the Conveyer Control and Door Control sections respectively. To automate the process, a Programmable Integrated Circuit (PIC) was used to control the conveyer and door motors following a basic loading procedure. This loading/unloading process is detailed in the Automated Loading and Unloading section. A food sensing system was also developed and employed to further simplify the loading process. This food sensor allowed the oven to automatically load food fully into and out of the heated cavity, preventing the user from ever having to reach into the oven during the heating process. For a blind user, the use of a food sensor would be even more ideal, since they would not have to control the loading of the food directly. This could have been dangerous, if the user was unsure if the food was fully loaded into the oven body. This food sensor was then integrated with the door and conveyer controllers using the PIC. The implementation of the food sensor, and details of its functionality are included in the Food Sensing section.

Initial Concepts

The Hamilton Beach oven that was altered for this project has three control knobs. Since knobs are considered superior to touch buttons for visually impaired users this part of the control system did not need to be altered significantly. The top knob is the temperature control knob, the middle knob is the cooking type knob (ex. Convection, Bake, Broil), and the lowest knob is a timer. The timer knob has a stay on position that will leave the oven on as long as it is plugged in. The oven also has four heating coils (two on the top of the heating cavity and two at the bottom). The broil function turns on the two upper heating coils, bake turns on all four heating coils, and convection turns on all four heating coils as well as an internal fan. These basic controls were not altered. However, two embossed markings were added to the temperature control knob after showing the product to a visually impaired user. These markings will be discussed in further detail in the User Input section.

Additional controls were added for the conveyor system as well as the motorized door. A PIC (16F877A) was used to control the conveyor motor, the door motor, and also a food position sensor. Control push button switches were connected to the PIC, and mounted into a plastic enclosure. The PIC was programmed to follow a loading and unloading procedure for ease of use. The control system was tested repeatedly under heating, and the programming was altered to improve functionality. This program is available for reference in Appendix C.

Door Control

The door to the oven is raised using a Torque Systems, PM Field DC Servo Motor. This motor requires a DC input of 12 Volts, and was initially controlled by turning off and on a DC power supply. To control the door electronically, a high power N type transistor (MJE3055T) was implemented as a switch. The drain of the transistor was attached to a 12 Volt power supply, and the source was grounded. The gate of the transistor was connected to an output pin of the PIC 16F877A. By setting the output voltage of this pin to high (5V), the transistor was effectively turned on, applying the 12 volt voltage to the DC motor. This would cause the door to rise until fully open. As long as the input pin was left high, the door would remain fully open. However switching the input pin to a low voltage (0V) would cause the transistor to switch off, turning off the motor. The door would then be pulled closed by two springs. This open and close mechanism would be controlled by the PIC as part of the oven's overall function.

Conveyor Control

The conveyor loading and unloading mechanism was driven by the Groschopp P0615-PS1960 motor attached to the drive shaft. It was necessary for the motor to rotate clockwise to unload the oven and counterclockwise to load it. Therefore the applied 12 DC volts to the oven would need to be able to reverse polarity. Initially a simple reversible switch was considered to run the motor in both directions. However, a goal of the project was to control both motors electronically such that oven function could be automated as much as possible. By requiring a manual switch to reverse polarity, the direction of rotation of the motor could not be controlled by the PIC. Therefore electronic methods of reversing polarity were considered.

After consulting with Professor Cheever, an H Bridge mechanism was considered. A diagram of an H bridge is shown in Figure 22.

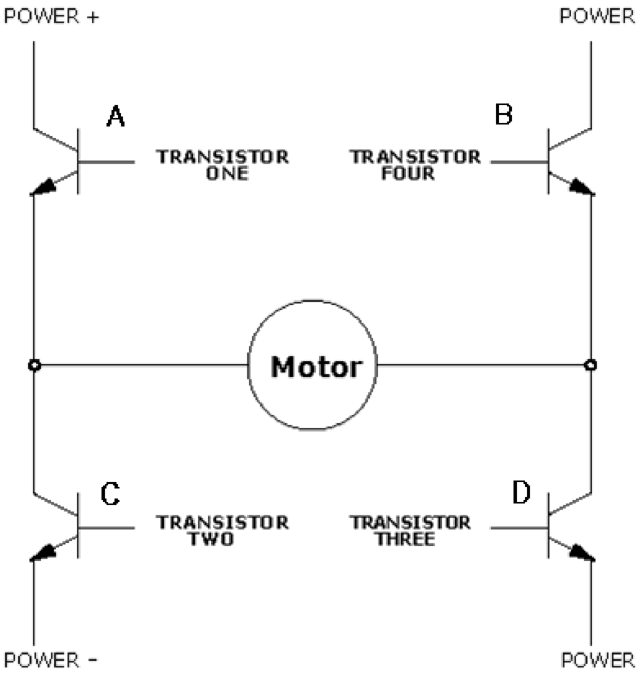


Figure 22. Diagram of an H-Bridge[6]

If the gate of transistor one is called input A, the gate of transistor two is called input B, the gate of transistor three is called input C, and the gate of transistor four is called input D, then turning A and C high would turn the motor forward (while leaving B and D low). When A and C are high current is through the motor in one direction. This direction is reversed by turning B and D both high (while leaving A and C low). Then the current will be in the opposite direction, causing the motor to rotate in the opposite direction. In this way an H-bridge allows an electron input signal to determine the direction of rotation of a DC motor.

Two H-Bridge IC's were ordered to control the conveyor motor. The L6203 ICs were selected at the advice of Professor Cheever. They could handle the maximum current drive (3.4 amperes) and were also immediately in stock. After their arrival, leads were soldered to the base of the H-bridge IC since its legs would not fit into a conventional breadboard. The test circuit from the datasheet was built and tested [7]. The logic switches available on the breadboard were used as inputs for the H-Bridge in testing. However before the circuit was completed and connected to the drive motor, Professor Cheever informed us that a variable speed motor controller had been used to control the Groschopp PM6015-PS1960 in a previous E90. After finding the KBBC 24 Volt Motor Controller it was immediately realized to be superior to the H-bridge IC that had initially been selected. The KBBC Motor Controller (Figure 23) was significantly more expensive than the L6203, however due to its availability from a previous project and its superior functionality it was selected to control the conveyor mechanism.

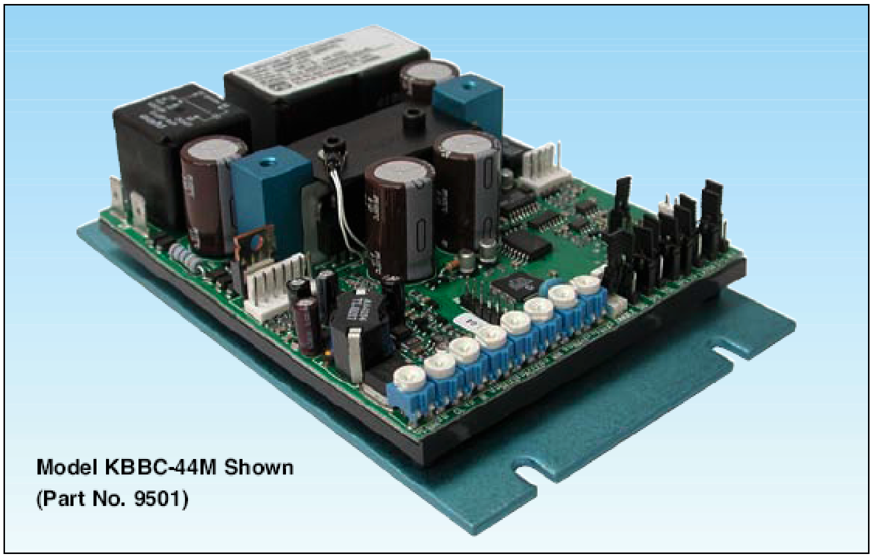
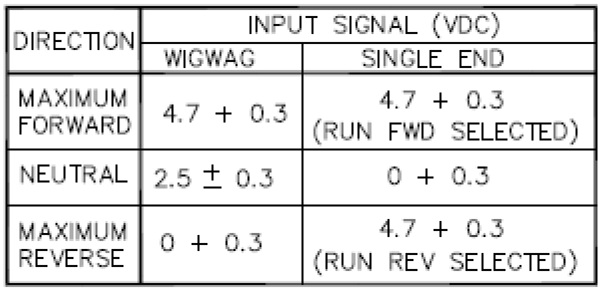


Figure 23. Photograph of motor controller [8]

The KBBC Motor Controller has several functional modes that allow for logic signals to reverse the direction of rotation of a DC motor. Although the KBBC motor would not be included in the design of a consumer product, the following information is included to clearly explain how the works like prototype produced in this project functions.

The KBBC motor controller has many adjustable features, such as speed controls and acceleration and deceleration controls. After consulting with the datasheet for Motor Controller well as its instruction manual it was determined that the Wig-Wag mode of operation would be most suitable for conveyor control [8][9]. The Wig-Wag mode allows reversal of motor direction without adjusting any knobs, only through input logic signals. This was ideal since the PIC 16F877A could be programmed to output logic signals to control motor operation. The following table (Figure 24) describes the input signals that control motor operation in Wig-Wag mode:



DIRECTION	INPUT SIGNAL (VDC)	
	WIGWAG	SINGLE END
MAXIMUM FORWARD	4.7 + 0.3	4.7 + 0.3 (RUN FWD SELECTED)
NEUTRAL	2.5 ± 0.3	0 + 0.3
MAXIMUM REVERSE	0 + 0.3	4.7 + 0.3 (RUN REV SELECTED)

Figure 24. Motor Controller Operation Table [9]

Since the conveyor would be in neutral mode for much of the oven's use, it was important that the PIC 16F877A be able to output 2.5 +0.3 Volts as well as a high and low output. Consulting the PIC control manual however quickly resolved this issue, as the PIC could output both a high output (5 Volts), a low output (0 Volts), and a floating output (2.5 V). The motor was connected to the PIC and several tests were run to confirm correct functioning. The variable speed knob on the controller was adjusted to slow the speed of the conveyor slightly until it seemed ideal for loading. Additionally the accelerate and decelerate knobs were tweaked until the loading operation seemed ideal.

Food Sensing

Figure 25. Sensor used in food sensing

To further automate the food loading and unloading process a method to detect the position of the food was designed. The food sensing system would minimize the need for a user to directly control the conveyer motor, allowing the food to completely and enter and exit the oven automatically.

Several options were considered to detect food position. It was decided that the simplest implementation would be tested first, and more complex methods would be considered afterwards if the first method failed. This first design idea, involved using a simple photodiode in photovoltaic mode to read the light levels outside the oven. The photodiode would be mounted to the side of the Unistrut conveyor track, and an LED would be shined directly onto the photodiode from across the channel. In this orientation food placed onto the track would obstruct the signal from the LED to the photodiode. Low voltage readings on the photodiode would indicate the presence of food. This simple design was constructed and readings were taken of the diode's output voltage using a multimeter. The setup did not work effectively. The voltage readings on the photodiode were very low with or without the presence of food on the conveyor track. To improve the design reflective tape was obtained, and wrapped around the photodiode casing (Figure 25). This increased the light incident on the sensor, and increased the voltage readings. As testing continued, it was determined that the cross channel LED did not significantly improve performance of the system. Since light levels in the room were already fairly high (assuming standard room lighting) the photodiode would register a voltage swing of about 0.3 Volts without the presence of the LED. This level of voltage change would be enough to register consistently using the Analog to Digital Convertor built into the PIC 165877A. Connecting the sensor to an analog to digital input pin on the PIC confirmed that it would register the presence of food in a room as long as some lighting was present. The position of the sensor was also reconsidered due to the removal of the cross channel LED and the reliance on in-room lighting. Since lighting in the room can reasonably be expected to come from above the photodiode, it was mounted at the base of the oven facing upwards (Figure 22). This would maximize light incident on the sensor in ordinary home environments. Additionally since the food would now be loaded directly above the sensor, it increased the ease of food detection. The food would directly block the light above from reaching the sensor. Rough testing of the setup indicate that it will function effectively as a food sensor in a variety of lighting environments. To expand the project the food sensor could be made more robust, perhaps sensing a pulsed light signal to differentiate the signal from ambient light.

Integration of Control System

Following the creating and testing of the food sensor, the selection of the KBBC Motor controller, and the successful control of the door motor, the entire process was automated via the PIC 165877A. The source of the door motor transistor was soldered to ground of the PIC. The drive transistor’s drain was soldered to the negative terminal of the door motor. The door motor’s positive terminal was connected to positive power supply. Also, the gate of the drive transistor was connected to input/output pin E2 on the PIC. By programming the PIC to raise this value to high the door would successfully open and remain open. Programming the PIC to set the value of E2 low would close the door and it would remain closed.

The next step in the integration process involved combining the KBBC Motor Controller and the PIC. Pin C0 on the PIC was connected to the motor control input for Wig Wag mode. Ground of the PIC, was soldered to ground of the KBBC Motor Controller, and also connected to ground of the power supply. Positive power supply was connected to the supply input of the KBBC Motor Controller. Testing confirmed that applying a low voltage to pin C0 would rotate the conveyor drive motor counterclockwise, a neutral or floating input would turn the motor off, and a high input to pin C0 would turn the motor clockwise.

The food sensor was then connected to the PIC. The positive lead was soldered to ADC pin 3 on the PIC, and the negative lead was grounded. Testing confirmed that an numerical value representing the scaled voltage from the sensor was being successfully obtained. The value varied depending on the amount of light incident on the sensor. In a typical lighted room the value recorded by the pin would be around 25 or 30. When covered by food the sensor reading was typically between 5 and 10 by the pin. However since light levels in a room would be variable the sensor's ambient light level was calibrated before each use. For example, after turning on the oven would read the light level by the sensor several times, and use the average value as an approximation of the light level present in the room. This value would then be used as a point of comparison to determine if food was present in the room. Values below 50% of the ambient room value could typically be expected to indicate the presence of food. However the sensitivity level of the sensor is adjustable, and testing will be performed to find the ideal value for operation.

To protect the electronic components, as well as increase the ease of use of the oven, the KBBC Motor Controller and the PIC were placed inside a plastic enclosure. The KBBC Motor Controller was mounted several inches above the PIC such that their components would not come in contact if the enclosure was moved. An LED and two push button inputs were mounted to the outside of the casing. These components were also connected to the PIC. The LED functions as a READY light indicating that the oven is ready for user input. The first push button mounted in the middle of the panel, is a circular button, and is used to open and close the door. The second push button is an unload button that is used to bring food back out of the oven. Labels were placed below the buttons and the light to indicate their function.

An AIM Precision Regulated DC Power Supply (with output 13.8 V DC with maximum current 10 Amps) is used to drive the KBBC Motor Controller and the drive transistor for the door motor. This high current power supply is required since the conveyor motor draws 3.4 Amperes during operation, and the smaller available power supplies could only output 2 amperes.

Applicability to Consumer Product

The previously mentioned control system functioned successfully as a prototype model of the Accessible Oven. However it is important to note that several of its design features would be altered significantly in a commercial product. Several of the components chosen were selected due to their immediate availability in the Engineering Department. For example, the Groschopp motor that controlled conveyer operation far exceeded the torque requirements necessary for this oven. Ideally a smaller, and cheaper motor could be employed. The same is true for the motor that controls door operation. Using smaller motors would also allow less expensive drive electronics to be employed, while lowering overall power consumption. Other features however, such as control by a PIC would likely remain unchanged in a consumer product.

Automating Loading and Unloading

After all the control buttons, inputs, and outputs had been connected to the PIC, it was programmed to load food in for a user and perform several functions automatically. The general procedure the PIC runs is shown below, followed by the rationale for this automated procedure.

- The oven waits for the Door Open/Close Button to be pressed. Once the button is pressed the door opens.
- After the door is opened, the oven automatically calibrates the food sensor to the ambient light level of the room. It waits to load the food until the food sensor is triggered.
- After the food has passed beyond the sensor (it once again detects full room light) it continues to rotate the oven for a small amount of time to ensure that it is fully within the oven cavity. The oven records that food has been loaded inside it.
- The oven waits either for more food to be input (loading would proceed as before) or for the door Open/Close Button to be pressed.
- If the button is pressed the door will close. At this time the food would be expected to be cooking.

- If the Open/Close Button is pressed the door will open. The user can check the food determine if the food is finished cooking. If the Open/Close Button is pressed again, the door will close so that cooking will resume.
- If the Unload button is pressed the conveyor will bring food back out to the user. The food will stop either once it is fully passed the oven door, or if it is a larger item it will stop immediately before it hits the front panel of the oven casing.
- If the Open/Close Button is pressed, the oven door closes. The oven is now once again ready for loading.

This procedure was designed to be easy to follow and intuitive. Loading of the food is entirely automatic after the user places an item onto the conveyor. The door does not close after loading so that the user has the opportunity to check if the food before cooking. After food has been placed in the oven, the unload button can be used to bring the food back to the user. The user does not need to flip any switches to make the conveyor motor load and unload food. Also the user is not expected to turn the motor off once the food is in position. This would be particularly difficult for blind users who would have to locate the position of the food by touch. The automation of loading greatly simplifies the cooking process and could be beneficial for any user. Additionally the unload procedure successfully allows a user to avoid reaching into the heated cavity. Similarly to the loading process, the automation of the unloading simplifies overall operation for the user and minimizes need to use controls. The timer built into the oven could also be of use during cooking. All code run by the PIC 165877A in implementing this automated loading and unloading process is included in Appendix C.

Controls

Figure 26. Control box with tactilely different buttons

The controls for the door and conveyor mechanisms were chosen to be tactilely different in order for blind users to easily distinguish between them (Figure 26). The door mechanism is controlled by a circular button, while the conveyor uses a square-shaped button. A ready light was also added for other users to indicate the ready-status of the oven.

Housing

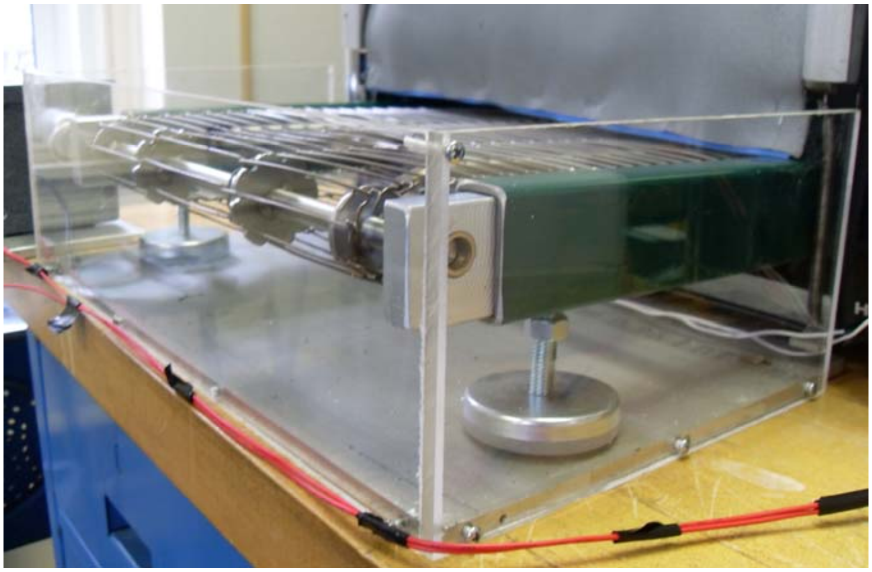


Figure 27. Housing on the front of the oven.

To prevent contact with the front of the conveyor, a housing was built to enclose the oven (Figure 27). As the conveyor extends from the inside cavity to outside of the oven and is made of metal, it conducts the heat generated by the heating coils. It was therefore desirable to create a barrier between this heated object and the user.

The material needed to be transparent to allow users to still see the conveyor, insulating so it would not become hot, and strong. Plexiglass was used to create the front and side walls of the housing. The bottom piece that connects the plexiglass to the oven did not need to be transparent, and therefore, was made out of a ½” sheet of aluminum.

Larger screws connected the aluminum base to the bottom of the oven while small ¼” screws connected the plexiglass to the aluminum. A hole was constructed in the left wall for the connector between the conveyor and the motor.

Testing

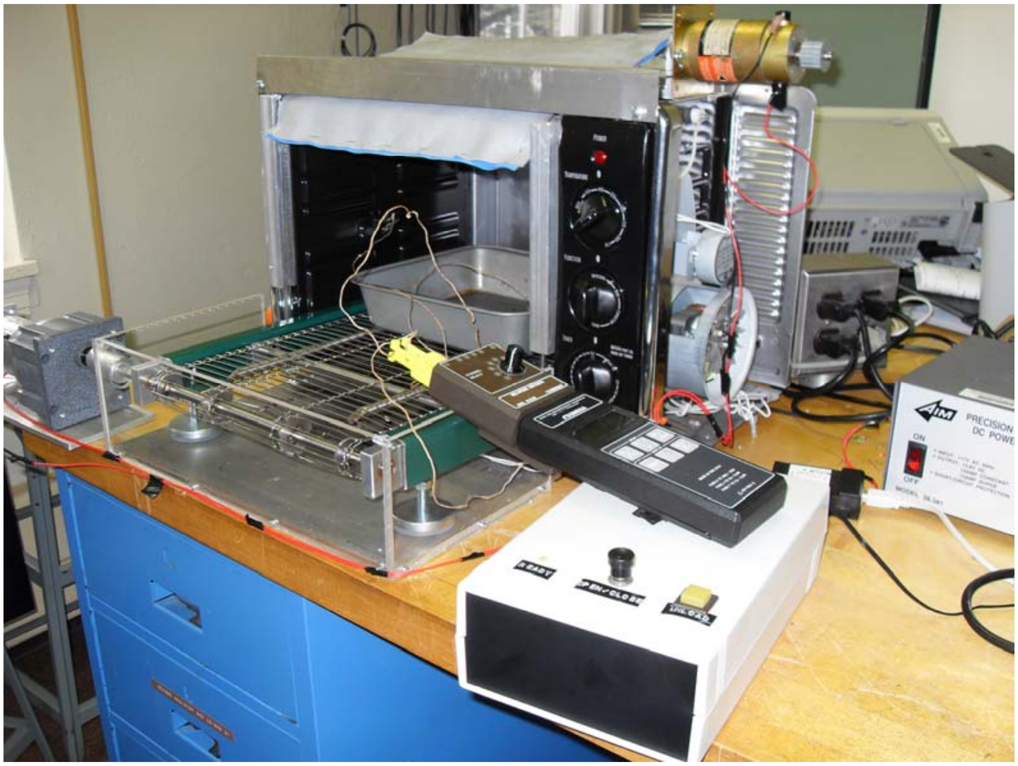


Figure 28. Heat testing using thermocouples

After construction of the door and conveyor mechanisms were complete and functioned as defined in the programming, testing began to ensure that the oven would continue to function at high heats. The oven was set at 350ºF and left to heat for 15 minutes. At this point, the door was opened and a plate was loaded into the heated cavity. After heating for another 15 minutes, the door was opened and the plate was taken out. The conveyor and the sensor functioned at the high temperature, however, the door began to jam once the oven was heated. The cause of this failure of movement seemed to be the formation of an air pocket between the layers of the door. As the door was heated, the different materials that comprise the door thermally expand at different rates, causing air to fill between the layers of materials. The addition of the air to the depth of the door prevented it from going over the curve at the top of the oven.

In order to address this issue, the springs were shortened to increase the downward force to bring the door down. Likewise, small slits were cut into the back of the door to allow the air in the cavity to disperse. The oven was run through several iterations of the aforementioned procedure until the oven functioned adequately.

An additional facet of the heat testing was to check the heat properties of the oven. The construction of the door and conveyor left space in the oven where heat could dissipate. A thermocouple was placed on the tray in the cavity of the oven and another was placed on the wall of the oven (Figure 28). The oven was set to a temperature of 400ºF. After 20 minutes, the tray was at 363ºF and the wall was 240ºF. Ideally insulation would be inserted in the gaps in the conveyor to reduce this heat loss.

User Input

In order to understand if the product was intuitive to use and satisfied the user needs as identified at the beginning of the project, a user was brought in to test the oven. The blind user was first acquainted with the product and its various features, followed by a test of its functionality. She recommended making changes to the temperature dial as it had no tactile indication of the different temperatures. In order to address this concern, a sticker was placed on the dial that would indicate to the user where the dial was pointing (Figure 29). This way, users could remember the temperature reading based on the location of the sticker.

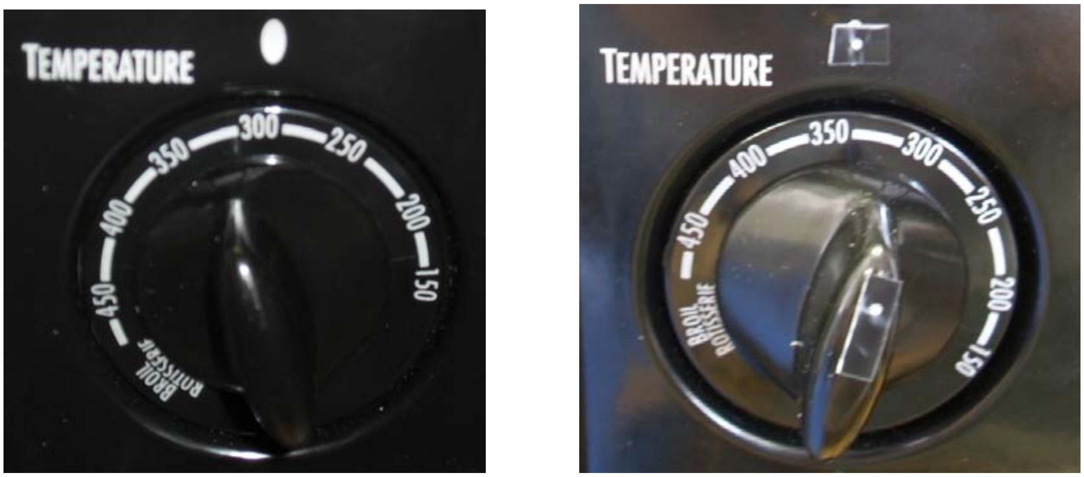


Figure 29. Comparison of the temperature dial before and after the user's recommended addition.

Looks-like Model

The scope of this project was to create a works-like prototype of the accessible oven. However, this opens up the question of what the product would actually look like if it were sold to consumers. In order to address this question, a looks-like prototype was modeled in SolidWorks and can be seen in Figure 30. This model contains the components that are in the works-like prototype, but builds them into the body of the oven for easier manufacturing. The motors used in the actual product would be much smaller than those used in the prototype. The cavity of the oven can be separated from the electronic controls section (Figure 31) to allow users to clean the oven.

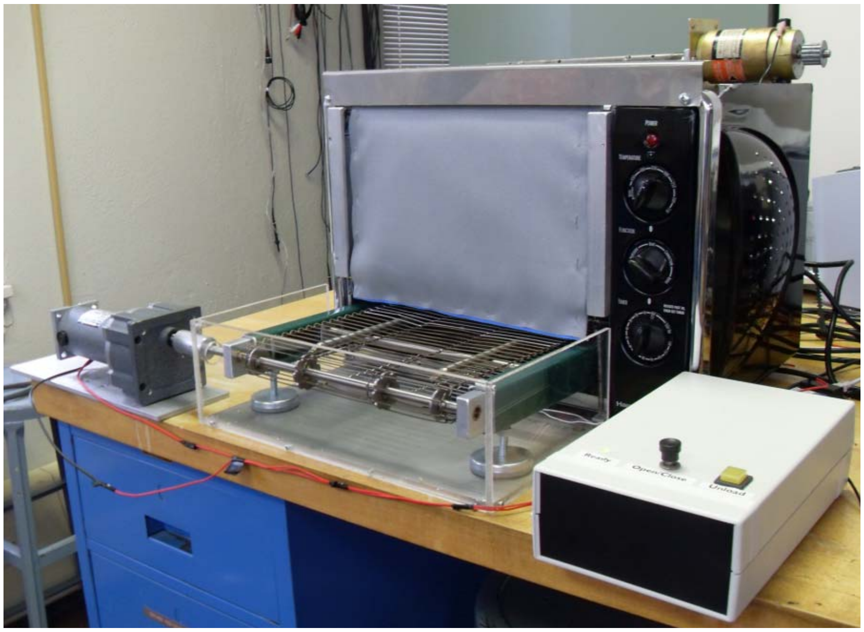
Another aspect of this oven that makes it different from our prototype is that there are different tactile controls. Each of the controls can be separated by function by the type of movement required to adjust the setting. Additionally, speakers could allow for auditory confirmation of oven settings.

Figure 30. Looks-like model made in SolidWorks

Figure 31. Detachable control section. Each of the controls requires a different type of movement.

Acknowledgments

This project would not have been possible without the help and guidance of several members of the Swarthmore Engineering Department. Laura Wolk took the time to help give us feedback on our product. Grant Smith's technical expertise, assistance in the machine shop, and advice on all of the mechanical components of this project were invaluable. Likewise, Edmond Jaoudi provided us with the electronic devices and supplies used, as well as suggestions on the design. Additionally, Professor Orthlieb's knowledge of different materials and properties were essential in the construction of the door, and Professor Cheever's advice on all of the electronic components was indispensable. Lastly, we must thank Professor Macken for being our advisor, giving us this idea, guiding us through the design process, and ensuring that we had a viable project.



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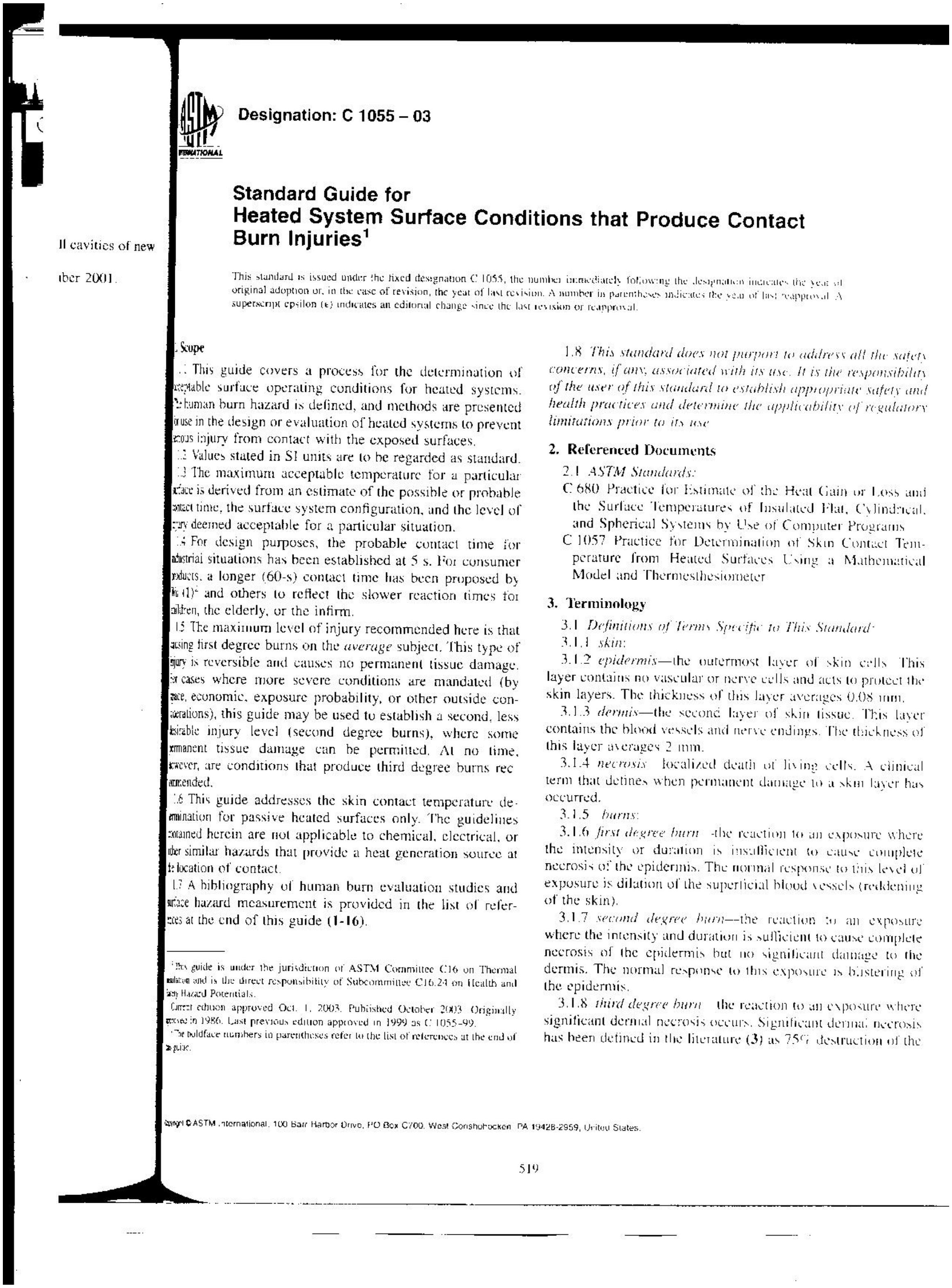
Appendix A: ASTM C1055 – 03



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Designation: C 1055 – 03

Standard Guide for
Heated System Surface Conditions that Produce Contact Burn Injuries[1]

This standard is issued under the fixed designation C 1055; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This guide covers a process for the determination of acceptable surface operating conditions for heated systems. The human burn hazard is defined, and methods are presented for use in the design or evaluation of heated systems to prevent serious injury from contact with the exposed surfaces.

1.2 Values stated in SI units are to be regarded as standard.

1.3 The maximum acceptable temperature for a particular surface is derived from an estimate of the possible or probable contact time, the surface system configuration, and the level of injury deemed acceptable for a particular situation.

1.4 For design purposes, the probable contact time for industrial situations has been established at 5 s. For consumer products, a longer (60-s) contact time has been proposed by Wu (1)[2] and others to reflect the slower reaction times for children, the elderly, or the infirm.

1.5 The maximum level of injury recommended here is that causing first degree burns on the *average* subject. This type of injury is reversible and causes no permanent tissue damage. For cases where more severe conditions are mandated (by space, economic, exposure probability, or other outside considerations), this guide may be used to establish a second, less desirable injury level (second degree burns), where some permanent tissue damage can be permitted. At no time, however, are conditions that produce third degree burns recommended.

1.6 This guide addresses the skin contact temperature determination for passive heated surfaces only. The guidelines contained herein are not applicable to chemical, electrical, or other similar hazards that provide a heat generation source at the location of contact.

1.7 A bibliography of human burn evaluation studies and surface hazard measurement is provided in the list of references at the end of this guide (**1-16**).

1.8 *This standard does not purport to address all the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to its use.*

2. Referenced Documents

2.1 *ASTM Standards:*

C 680 Practice for Estimate of the Heat Gain or Loss and the Surface Temperatures of Insulated Flat, Cylindrical, and Spherical Systems by Use of Computer Programs

C 1057 Practice for Determination of Skin Contact Temperature from Heated Surfaces Using a Mathematical Model and Thermesthesiometer

3. Terminology

3.1 *Definitions of Terms Specific to This Standard:*

3.1.1 *skin:*

3.1.2 *epidermis*—the outermost layer of skin cells. This layer contains no vascular or nerve cells and acts to protect the skin layers. The thickness of this layer averages 0.08 mm.

3.1.3 *dermis*—the second layer of skin tissue. This layer contains the blood vessels and nerve endings. The thickness of this layer averages 2 mm.

3.1.4 *necrosis*—localized death of living cells. A clinical term that defines when permanent damage to a skin layer has occurred.

3.1.5 *burns:*

3.1.6 *first degree burn*—the reaction to an exposure where the intensity or duration is insufficient to cause complete necrosis of the epidermis. The normal response to this level of exposure is dilation of the superficial blood vessels (reddening of the skin).

3.1.7 *second degree burn*—the reaction to an exposure where the intensity and duration is sufficient to cause complete necrosis of the epidermis but no significant damage to the dermis. The normal response to this exposure is blistering of the epidermis.

3.1.8 *third degree burn*—the reaction to an exposure where significant dermal necrosis occurs. Significant dermal necrosis has been defined in the literature (**3**) as 75% destruction of the

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[1] This guide is under the jurisdiction of ASTM Committee C16 on Thermal Insulation and is the direct responsibility of Subcommittee C16.24 on Health and Safety Hazard Potentials.

Current edition approved Oct. 1, 2003. Published October 2003. Originally approved in 1986. Last previous edition approved in 1999 as C 1055–99.

[2] The boldface numbers in parentheses refer to the list of references at the end of the guide.

dermis. The normal response to this exposure is open sores that leave permanent scar tissue upon healing.

3.1.9 *contact exposure*—the process by which the surface of skin makes intimate contact with a heated surface such that no insulating layer, film, moisture, etc., interferes with the rapid transfer of available energy.

3.1.10 *insulation system*—the combination of an insulation material or jacket, or both that forms a barrier to the rapid loss of energy from a heated surface. The insulation system may involve a broad range of types and configurations of materials.

3.1.11 *jacket*—the protective barrier placed on the exposed side of an insulation to protect the insulation from deterioration or abuse. The jacket material can be made of paper, plastic, metal, canvas cloth, or combinations of the above or similar materials.

3.1.12 *thermesthesiometer*—a probe device developed by Marzetta **(13)** that simulates the thermal physical response of the human finger to contact with heated surfaces.

4. Summary of Guide

4.1 This guide establishes a means by which the engineer, designer, or operator can determine the acceptable surface temperature of an existing system where skin contact may be made with a heated surface.

4.2 The process used in the analysis follows the outline listed below:

4.2.1 The user must first establish the acceptable contact exposure time and the level of acceptable injury for the particular system in question.

4.2.2 Secondly, the user determines the maximum operating surface temperature. This determination is made either by direct measurement (if possible) or by use of a calculation at design conditions using a method conforming to Practice C 680.

4.2.3 Next, utilizing the contact time (4.2.1), the maximum surface temperature (4.2.2), and the graph, Fig. 1, the user determines the potential injury level. If the operating point falls below the injury level specified (4.2.1), then no further analysis is required. (See Note 1.)

NOTE 1—The following equations have been developed from the original data used to generate Fig. 1 for easier use of this figure

$$T_A = 15.005 + 0.51907 \times Ln\,(\text{time} \times 1000) + 352.97 / (Ln\,(\text{time} \times 1000))$$

$$T_B = 39.468 - 0.41352 \times Ln\,(\text{time} \times 1000) + 190.60 / (Ln\,(\text{time} \times 1000))$$

where:

T_A = critical contact temperature for complete transepidermal necrosis, °C.
T_B = critical contact temperature for reversible epidermal injury, °C.
time = elapsed contact time, s.
Ln = natural logarithm.

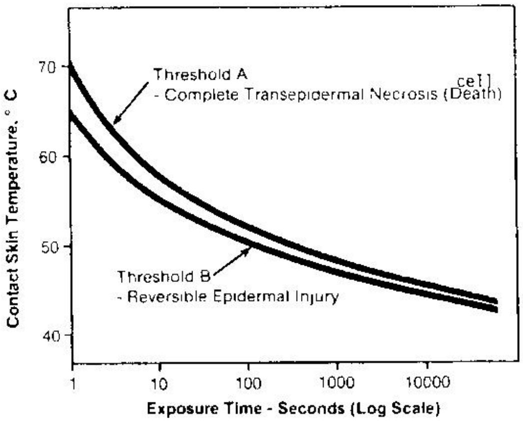
4.2.4 If the injury level exceeds that specified, further analysis of the system is required using either the thermesthesiometer (a direct method) or an additional calculation. Both methods are described in Practice C 1057.

4.2.5 If after this additional analysis the system still exceeds the injury level criterion, then the system is unacceptable for the criterion specified and the design should be revised.

5. Significance and Use

5.1 Most heated apparatus in industrial, commercial, and residential service are insulated, unless thermal insulation would interfere with their function; for example, it is inappropriate to insulate the bottom surface of a flatiron. However, surface temperatures of insulated equipment and appliances may still be high enough to cause burns from contact exposure under certain conditions.

5.2 This guide has been developed to standardize the determination of acceptable surface operating conditions for heated systems. Current practice for this determination is widely varied. The intent of this guide is to tie together the existing practices into a consensus standard based upon scientific understanding of the thermal physics involved. Flexibility



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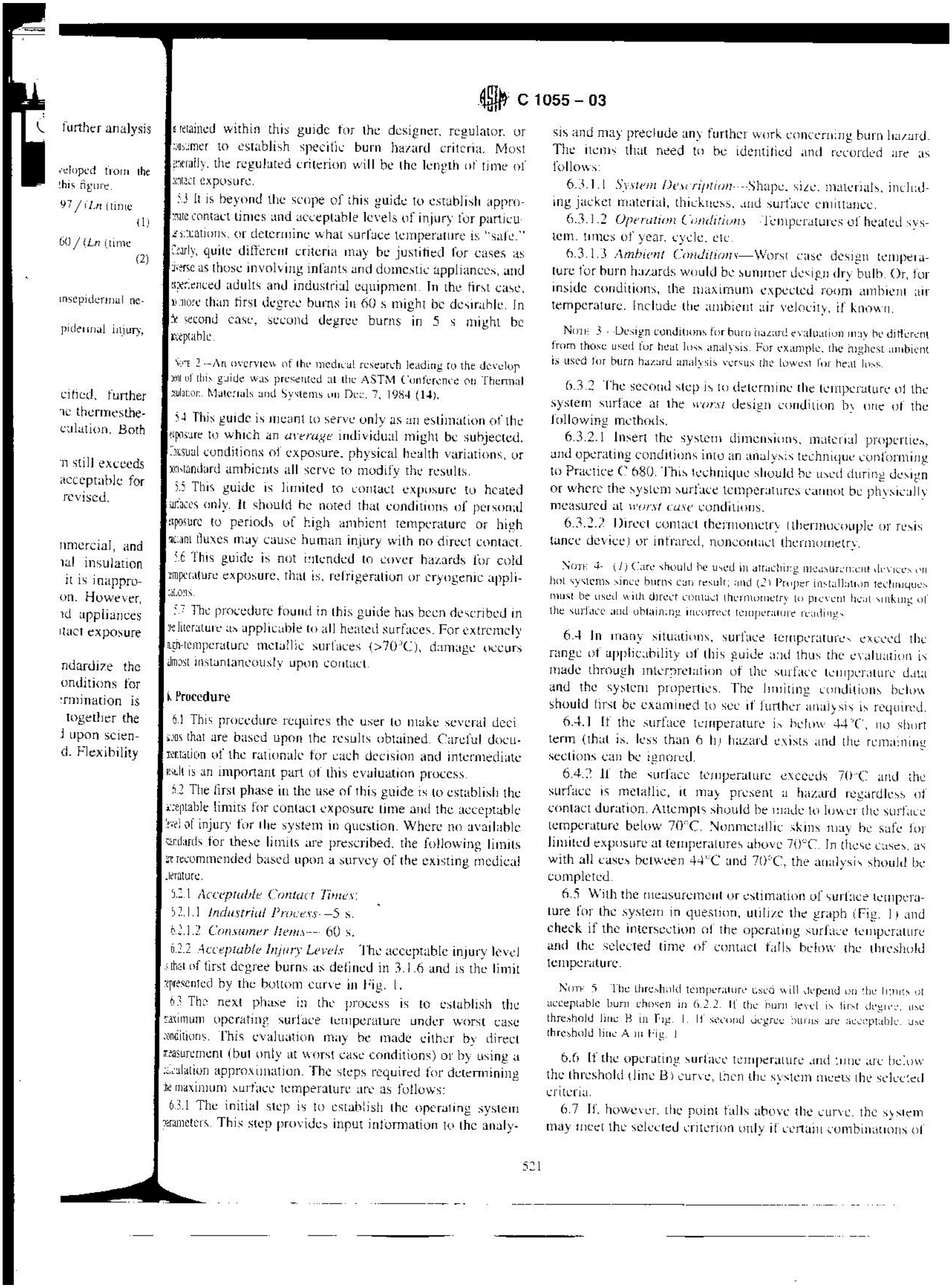

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is retained within this guide for the designer, regulator, or consumer to establish specific burn hazard criteria. Most generally, the regulated criterion will be the length of time of contact exposure.

5.3 It is beyond the scope of this guide to establish appropriate contact times and acceptable levels of injury for particular situations, or determine what surface temperature is "safe." Clearly, quite different criteria may be justified for cases as diverse as those involving infants and domestic appliances, and experienced adults and industrial equipment. In the first case, no more than first degree burns in 60 s might be desirable. In the second case, second degree burns in 5 s might be acceptable.

NOTE 2—An overview of the medical research leading to the development of this guide was presented at the ASTM Conference on Thermal Insulation, Materials and Systems on Dec. 7, 1984 (**14**).

5.4 This guide is meant to serve only as an estimation of the exposure to which an *average* individual might be subjected. Unusual conditions of exposure, physical health variations, or nonstandard ambients all serve to modify the results.

5.5 This guide is limited to contact exposure to heated surfaces only. It should be noted that conditions of personal exposure to periods of high ambient temperature or high radiant fluxes may cause human injury with no direct contact.

5.6 This guide is not intended to cover hazards for cold temperature exposure, that is, refrigeration or cryogenic applications.

5.7 The procedure found in this guide has been described in the literature as applicable to all heated surfaces. For extremely high-temperature metallic surfaces (>70°C), damage occurs almost instantaneously upon contact.

6. Procedure

6.1 This procedure requires the user to make several decisions that are based upon the results obtained. Careful documentation of the rationale for each decision and intermediate result is an important part of this evaluation process.

6.2 The first phase in the use of this guide is to establish the acceptable limits for contact exposure time and the acceptable level of injury for the system in question. Where no available standards for these limits are prescribed, the following limits are recommended based upon a survey of the existing medical literature.

6.2.1 *Acceptable Contact Times*:

6.2.1.1 *Industrial Process*—5 s.

6.2.1.2 *Consumer Items*—60 s.

6.2.2 *Acceptable Injury Levels*—The acceptable injury level is that of first degree burns as defined in 3.1.6 and is the limit represented by the bottom curve in Fig. 1.

6.3 The next phase in the process is to establish the maximum operating surface temperature under worst case conditions. This evaluation may be made either by direct measurement (but only at worst case conditions) or by using a calculation approximation. The steps required for determining the maximum surface temperature are as follows:

6.3.1 The initial step is to establish the operating system parameters. This step provides input information to the analysis and may preclude any further work concerning burn hazard. The items that need to be identified and recorded are as follows:

6.3.1.1 *System Description*—Shape, size, materials, including jacket material, thickness, and surface emittance.

6.3.1.2 *Operation Conditions*—Temperatures of heated system, times of year, cycle, etc.

6.3.1.3 *Ambient Conditions*—Worst case design temperature for burn hazards would be summer design dry bulb. Or, for inside conditions, the maximum expected room ambient air temperature. Include the ambient air velocity, if known.

NOTE 3—Design conditions for burn hazard evaluation may be different from those used for heat loss analysis. For example, the highest ambient is used for burn hazard analysis versus the lowest for heat loss.

6.3.2 The second step is to determine the temperature of the system surface at the *worst* design condition by one of the following methods.

6.3.2.1 Insert the system dimensions, material properties, and operating conditions into an analysis technique conforming to Practice C 680. This technique should be used during design or where the system surface temperatures cannot be physically measured at *worst case* conditions.

6.3.2.2 Direct contact thermometry (thermocouple or resistance device) or infrared, noncontact thermometry.

NOTE 4—(*1*) Care should be used in attaching measurement devices on hot systems since burns can result; and (*2*) Proper installation techniques must be used with direct contact thermometry to prevent heat sinking of the surface and obtaining incorrect temperature readings.

6.4 In many situations, surface temperatures exceed the range of applicability of this guide and thus the evaluation is made through interpretation of the surface temperature data and the system properties. The limiting conditions below should first be examined to see if further analysis is required.

6.4.1 If the surface temperature is below 44°C, no short term (that is, less than 6 h) hazard exists and the remaining sections can be ignored.

6.4.2 If the surface temperature exceeds 70°C and the surface is metallic, it may present a hazard regardless of contact duration. Attempts should be made to lower the surface temperature below 70°C. Nonmetallic skins may be safe for limited exposure at temperatures above 70°C. In these cases, as with all cases between 44°C and 70°C, the analysis should be completed.

6.5 With the measurement or estimation of surface temperature for the system in question, utilize the graph (Fig. 1) and check if the intersection of the operating surface temperature and the selected time of contact falls below the threshold temperature.

NOTE 5—The threshold temperature used will depend on the limits of acceptable burn chosen in 6.2.2. If the burn level is first degree, use threshold line B in Fig. 1. If second degree burns are acceptable, use threshold line A in Fig. 1.

6.6 If the operating surface temperature and time are below the threshold (line B) curve, then the system meets the selected criteria.

6.7 If, however, the point falls above the curve, the system may meet the selected criterion only if certain combinations of insulation or jacketing, or both, are used. Analysis procedures for the jacketing/insulation effects are outlined in Practice C 1057. Two methods provided in Practice C 1057 are briefly described below.

6.7.1 The calculation technique provided in Practice C 1057 uses system geometry, material properties, and temperature conditions to estimate the maximum contact temperature used in Fig. 1 when the heat capacity effects of the surface are to be considered. Once this maximum contact temperature is determined, the user returns to steps 6.5-6.7 for the refined analysis.

6.7.2 An alternative to calculation of the contact temperature is available for those systems that are already operating. The thermesthesiometer **(13)** provides an analogue measurement of the same phenomenon as the computer method models (6.7.1). Care should be used in applying the thermesthesiometer since it must be applied at *worst case* conditions if the hazard potential is to be evaluated. Practice C 1057 outlines the correct procedures for use of this device for surface hazard evaluation. The output from the thermesthesiometer is the maximum contact temperature of the skin that can be related to Fig. 1 with no corrections for surface type needed.

6.8 If, after analysis using Practice C 1057, the system temperature still fails to meet the selected criterion, then increasing insulation, changing jacketing, or other means must be used to lower the surface temperature. Practice C 680 will be helpful in determining the levels required.

6.9 Once a new level of jacket and insulation is determined, the analysis above should be repeated to confirm safe operating conditions.

7. Report

7.1 Any report citing the use of this guide should include the following information:

7.1.1 System description,

7.1.2 System operating conditions (either measured or design),

7.1.3 Ambient conditions (either measured or design),

7.1.4 Method of surface temperature evaluation used, calculation or measurement,

7.1.5 Method of analysis of hazard potential, calculation, thermesthesiometer, contact time, and hazard level selected, and

7.1.6 Statement of analysis of results and conclusions.

8. Precision and Bias

8.1 As stated in the Scope, this procedure is valid for the *average* person. Individuals may be tolerant or sensitive to burns depending upon physical condition, age, ambient conditions, emotional state, etc. The literature **(1, 4, 5)** has shown, however, agreement on pain response and tissue damage for a panel of subjects to within approximately 10 %.

9. Keywords

9.1 burns; epidermal injury; heat; injuries; skin contact temperatures; thermal insulation

APPENDIX

(Nonmandatory Information)

X1. RATIONALE

X1.1 Background—General

X1.1.1 Man has faced the potential of skin burns from touching hot surfaces since the discovery of fire in prehistoric times. He was concerned more with treatment of the injury than with the development of some means to prevent its occurrence. As civilization advanced, man developed crude insulation forms to control the extremes of heat to which he was exposed. The greatest improvement to these systems came since the industrial revolution where the use of high temperature power and process systems dictated the development of modern insulation systems, that not only conserve energy but also protect process products during manufacture. As technology expanded to include higher temperatures, more complex processes, and thus more worker exposure situations, worker organizations and later governmental agencies demanded the increased use of insulation for personal protection.

X1.1.2 At the same time that the workplace was becoming more hazardous, the increased development of consumer products that heated, steamed, or cooked increased the potential hazards found in consumer products and forced the use of more insulation and protection for the operator. Personal protection now is required everywhere for consumer products. Examples include curling irons, ranges, irons, dryers, dishwashers, light fixtures, and furnace and heating fixtures.

X1.1.3 The obvious solution is to simply insulate the heated part and thus isolate the hazard from the user. Unfortunately, the random application of insulation without detailed analysis can sometimes disrupt the process (that is, overheating where some loss is desired) or be an economic handicap to the overall cost of the project. Most applications of insulation to heated process systems are made on the basis of trade-offs between the cost of the installed insulation and the cost of the energy loss. Using this criteria or the more common rule-of-thumb approach, that is, "put on about an inch like we always do," can create exposed surface temperatures that exceed even the shortest term human exposure limits. Thus, to protect both operators and casual visitors in an area, an analysis of all exposed surfaces must be undertaken to identify those having temperatures capable of causing burns.

X1.1.4 When consumer product and industrial system designers recognized the need to design for personnel safety, they established what they felt were safe operating limits in

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exposed surfaces. Since limited research data was available before 1950, many industries chose to establish their own standards for maximum surface temperatures based upon combinations of available research results and personal experience. This remains as the current method for the evaluation of surface hazards.

X1.1.5 In 1983, Committee C16 undertook the study of a proposal to establish a *standard* criteria for evaluating burn hazard potential. This standard was to be well documented and easily used. As an adjunct to this effort, a second standard was proposed to establish a means for evaluating existing or proposed systems for hazard level by either physical measurement or mathematical modeling.

X1.2 Background—Physiological Mechanism of a Burn

X1.2.1 Previous to World War II, little research has been performed in developing an understanding of the physiology of burns to the human body. With the increased destruction potential of more powerful weapons, burn injuries became a common battle problem and the military began to support research to study the relationships between burn damage and the severity of exposure. At that time, little was known about the mechanism by which hyperthermia (high temperature exposure) leads to irreversible damage. The chemical reactions occurring within the skin cells upon exposure and the relationships between exposure temperature and duration on the transfer of heat into the skin were also subjects of research.

X1.2.2 The first significant research on the subject was conducted by Henriques and Moritz at the Harvard Medical School **(2, 3, 8, 9, 10, 11)**. The results were released for publication in 1946 through 1948. This research, performed primarily on swine (which happen to have similar skin properties to humans), with some human subjects added later, helped define the significant parameters controlling the flow of heat into the skin. Later, the relationship between temperature and duration of exposure to the extent of damage observed was established to serve as a guide for future work. Some of the significant results of this initial work **(2)** are:

X1.2.2.1 The burning of human skin occurs as a complex, nonsteady heat transfer between a contacted medium, that is, a hot surface, and the surface of the skin. The rate of heating depends upon the temperature and heating capacity of the source and the heat capacity and thermal conductivity of the skin layers (see Fig. X1.1). Neglected in these studies were the flow of blood to carry heat away and the physiological changes in skin properties as the damaged zone traverses the outer skin layers.

X1.2.2.2 Factors that cause increased complexity of the problem include: (*1*) site variations with respect to the thickness of the different skin layers; (*2*) variations of initial conditions within the skin with respect to time, position, and physical condition of the subject; (*3*) the unknown average rate of blood flow through the skin layers and variations within the layers with respect to location and ambient temperatures (warm ambient causes increased flow near surface and cold ambient results in less flow near surface); and (*4*) the appearance of watery fluids in variable quantities upon exposure that result in alterations of skin density, heat capacity, thickness, and thermal conductivity.

X1.2.2.3 Analysis of the experimental results showed that it was possible to assume average conditions and to develop an approximate first order Fourier's law equation to describe the transient heat flow in the contact problem. The modeling work by Henriques neglected the influence of contact resistance and blood flow and assumed that both the skin and touched surface could be treated as semi-infinite. Succeeding experiments showed that the assumption of semi-infinite solids and neglecting blood flow were valid for the time/temperature conditions of interest. The experiments performed at Harvard used a direct contact water bath which avoided the issue of contact resistance.

X1.2.3 After their initial work was complete, Moritz and Henriques extended their work to include the effects on human skin of hyperthermia of varying duration and varying degrees of intensity. These studies **(3)** led to a clearer definition of the degree of burning. Several additional conclusions were forthcoming from that research and are outlined as follows:

X1.2.3.1 The pain reaction to prolonged hyperthermia exposure first occurs as a stinging sensation at between 47.5° and 48.5°C. The level of discomfort does not always correlate with the level of damage sustained or with intensity between subjects or the same subject on different days.

X1.2.3.2 The lowest temperature where epidermis (outside skin layer) damage occurs is approximately 44°C when it is sustained for approximately 6 h. It is possible to extrapolate this result to conclude that longer exposures might cause damages at temperatures below 44°C.

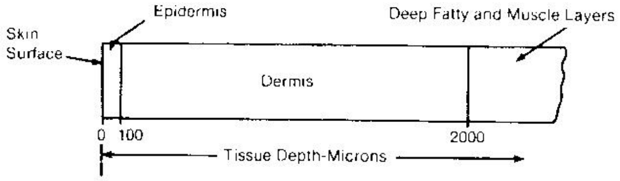

FIG. X1.1 Cross Section of Human Tissue

X1.2.3.3 As the temperatures of contact increase above 44°C, the time to damage is shortened by approximately 50% for each 1°C rise in temperature up to about 51°C.

X1.2.3.4 Testing showed that increasing the pressure of contact within an expected range was not sufficient to collapse the blood vessels and cause an increased vulnerability of the epidermis to thermal injury.

X1.2.3.5 At temperatures above 70°C, the rate of injury from a high capacity surface exceeds the body reaction time (less than 1 s to have completed epidermis cell death) such that the blood vessel location or flow has little effect on the level of burn.

X1.2.3.6 The level of skin damage to the duration and intensity of surface contact can be related by the following curve (Fig. 1). Exposures below the lower curve should not produce permanent injury in normal humans. Exposures between the curves are described as second-degree burns and have intermediate levels of cell damage. Exposures at levels above the top line are defined as third-degree burns that cause deep, permanent cell damage and scarring.

X1.2.3.7 After the initial research described above, several other researchers studied the same problems to extend the knowledge of burns to more realistic situations. Most significant here are problems with contact resistance and source surfaces having non-infinite thermal inertias. Wu **(1)** took the analysis developed by Moritz one step further by adding the heat transfer reaction for a source of high energy. His treatment, assuming contact between two semi-infinite bodies of finite thermal inertia (as measured by the square root of thermal diffusivity) at different temperatures, showed that sources of low inertia, for example, wood, insulation, and some plastics, cause a slower rise in skin temperature than a source of high thermal inertia, for example, steel and aluminum, at the same temperature. In short, this is explained by observing that high thermal inertia materials can make more energy available at the surface in a given time than those of lesser thermal inertia.

X1.2.3.8 Wu also pointed out that cell death (necrosis) is a result of irreversible thermal denaturation of the protein present within the cell. This denaturation is a rate process having a very high temperature coefficient that corresponds to a very high activation energy. In short, the higher the temperature of exposure, the faster damage occurs. This explanation confirms the results of Henriques and Moritz. Wu also developed the information presented in Fig. X1.2 that outlines the relationship between the pain sensation, exposed skin color, tissue temperature at 80 μm depth, and cell process.

X1.2.3.9 Stoll **(4)** on the other hand, looked at the relationship between pain, reaction times, and injury and found approximately ±10% day-to-day variation in pain thresholds for individual human subjects. This research established a minimum time to sense the pain and react to it at any temperature to be a minimum of 0.3 s. For those situations where pain was reached beyond 0.3 s Stoll found that complete epidermal necrosis occurred at a time approximately 2.5 times the time for initial pain sensation.

X1.2.3.10 Several years after his initial work, Wu (5) proposed a third model composed of three layers (see Fig. X1.3) so that the properties of the surface layer and the substrate could be different. This model describes the identical case to that of an insulation covered by a jacket material. The equations Wu developed are a basis for establishing a extrapolation of Moritz's work to real insulated systems.

X1.2.3.11 Wu also recommended that a 1-min exposure limit be used for design purposes for persons who have slow reactions (infants, elderly, or infirmed) or who *freeze* under severe hazard conditions. The influence of contact resistance was shown to also have significant effect. Hatton et al. (6) demonstrated that the results of Stoll on pain and blistering times were better correlated if a finite contact resistance was included in the model. He defined pain as the point in which the interface between the epidermis and dermis reaches a temperature of 44°C. His improved correlations were accomplished using a surface coefficient of 1000 (W/m^2·K); however depending upon skin conditions, this coefficient could range down to as low as 10 (W/m^2·K).

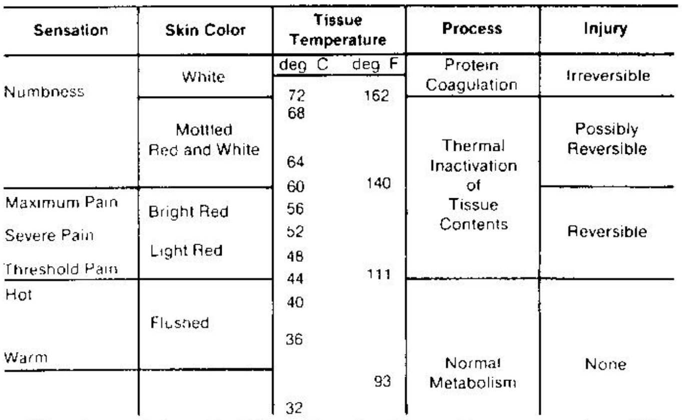

FIG. X1.2 Thermal Sensations and Associated Effects Throughout Range of Temperatures Compatible with Tissue Life

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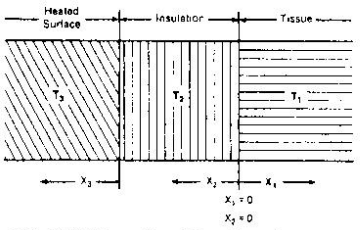

FIG. X1.3 Schematic of Heat Transfer Model

X1.2.3.12 Finally, McChesney **(7)** added a final point to the understanding of burn prevention when he suggested that some factor be included in the analysis to account for the heating wave which continues to penetrate the skin for some time after the contact is removed. He did not, however, venture a guess as to what that factor should be since it would depend upon the method of cooling the contact location on the skin.

X1.3 Background—C16 Activity

X1.3.1 In 1983, members of Committee C16 requested that a task group be established to study the problem of burn hazard evaluation. The initial task group was established within the C16.24 Health and Safety subcommittee with the charter to establish "a guide for the determination of safe surface operating conditions for heated systems." The scope of this work included: (*1*) to establish a uniform definition of the human burn hazard; and (*2*) to establish a usable practice for design or evaluation, or both, of heated systems to prevent serious injury upon contact with exposed surfaces. After initial review of the scope and objectives, a second area was identified which was necessary to support the work of the first group. At the fall 1983 Committee C16 meeting, a task group within Subcommittee C16.30 on Thermal Measurements, was established with the objective to develop the analytical tools necessary for evaluating the contact burn potential of heated surfaces either on existing equipment or during design. These tools, when used with the guide established by the first group, are intended to provide to the user, designer, or manufacturer the procedures needed to evaluate the relative safety of a piece of hardware or system.

X1.3.2 A survey was made of available literature to establish the state of the art on the subject and to determine what standards were already in place. The information in the background section of this Appendix summarizes some of the significant work done to date in this area. Significant technical papers which relate to burn hazard evaluation and associated medical research are listed in the References **(1-16)**.

X1.3.3 In April 1984, each task group presented the first draft of the proposed standards. The two draft standards received final society approval in February 1986. The Guide C 1055, developed by Subcommittee C16.24, establishes the definitions of burn hazards and a guide for evaluating the combinations of time of exposure, surface temperature, and surface composition that make up a system with potential hazards. Practice C 1057, developed by Subcommittee C16.30 has identified two tools for the evaluation of specific systems for hazardous conditions. The first tool, intended for existing systems, is a device called the thermesthesiometer. Developed by Marzetta **(13, 15, 16)** at National Institute of Standards and Technology, this device simulates the thermophysical reaction of the human skin to touch contact with a heated surface. Although this device is relatively accurate and easy to use, it has the drawback of requiring an existing system for test and cannot be used during the design phase. The second tool identified combines the previously established Practice C 680 method for surface temperature prediction with the modeling work of Dussan **(12)** to predict, for a given design, the expected contact temperature for the system. This temperature is a function of surface temperature and composition of both the jacketing material and insulation substrate. The designer then refers in Guide C 1055 to determine the safety of the surface.

X1.4 Summary

X1.4.1 Personal injury resulting from contact with heated surfaces can be prevented by proper design of insulation systems or other protective measures. The work of Subcommittee C16.24 on Health and Safety and Subcommittee C16.30 on Thermal Measurements has established a guide for what constitutes *safe* surface conditions and has standardized the tools by which proposed or existing systems can be examined for potential burn hazard. These standards, supported by significant research into both the physical and medical processes involved, provide the designer the tools he needs to balance the expected exposure times, operating conditions, and system geometry to obtain the safest yet most economical systems.

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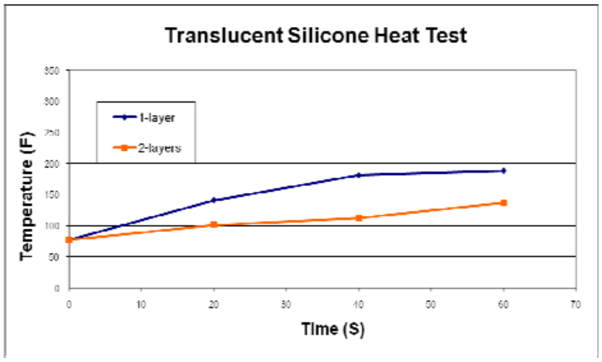
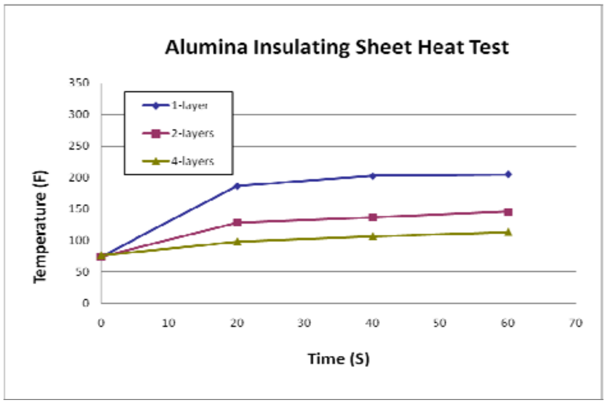
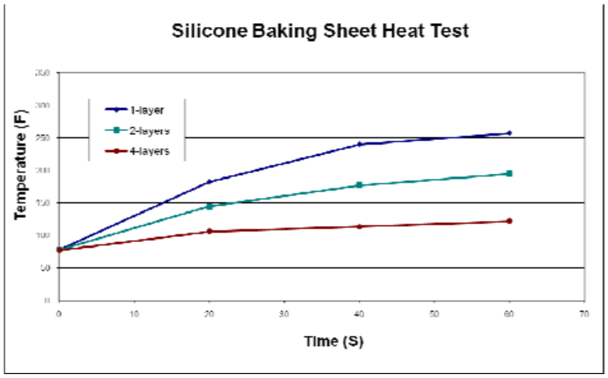
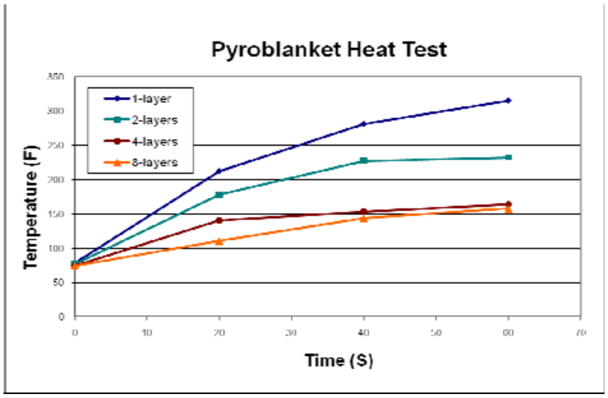
Appendix B: Material Heat Test Data









Appendix C: C Code

```
#include "C:\Documents and Settings\mcalafu1\Desktop\MotorControl\main.h"

void main()
{   int adcChan4; //sensor reading from Channel 3
    int level; //calibrated light level
    int i;  //generic counter
    int found;
    int open; //refers to status of door
    int count; //generic counter
    float time; //records time of conveyer operation as a safety mechanism
    int stat; //status indicator

   //RA4 is the door control button
   //RB0 is the motor control button

   setup_adc_ports(NO_ANALOGS);
   setup_adc(ADC_OFF);
   setup_timer_0(RTCC_INTERNAL|RTCC_DIV_1);
   setup_timer_1(T1_DISABLED);
   setup_comparator(NC_NC_NC_NC);
   setup_vref(FALSE);

   setup_adc(ADC_CLOCK_DIV_32);
   setup_adc_ports(ALL_ANALOG);
   set_adc_channel(3);


   output_low(pin_e2); //door is closed
   output_float(pin_c0); //c0 is conveyer pin
   //RA5 is analog channel 4
   delay_ms(1);
   output_high(pin_b1);
   //Oven ON
   stat = 1; //oven is empty
   //output_high(pin_e2);


   while(1){


   //WHEN DOOR OPEN BUTTON PRESSED
```

```
if(input(pin_a4)==FALSE){
  output_low(pin_b1);

  //OPEN DOOR

  output_high(pin_e2); //open door

  //Wait for door to open
  delay_ms(1000);

  //CALIBRATE OVEN

  level = 0;
  i = 0;
  adcChan4 = 0;

  while(i<5){
    delay_ms(1);
    adcChan4 = read_adc();
    delay_ms(5);
    level = level + adcChan4;
    delay_ms(1);
    i = i+1;
  }
    level = level/5; //find current light level
    level = .50 * level; //level is recalibrated... any light lower than this
                  //level is assumed to be due to presence of food

  output_high(pin_b1); //Indicate that oven is ready for loading

  i=1;
  found = 0;

  delay_ms(5);

  while(i==1){ //DOOR OPEN LOADING MODE

      adcChan4 = 0;
      count = 0;

      while(count < 3){
         adcChan4 = adcChan4 + read_adc();
         delay_ms(5);
```

```
        count = count + 1;
    }
    adcChan4 = adcChan4/3;


    while(adcChan4<level){ //Then food is in the path!
      output_low(pin_b1);
      found = 1;
      output_low(pin_c0); //Make the conveyer motor turn!
      stat = 0; //oven is loaded

      adcChan4 = 0;
      count = 0;

      while(count < 3){

        if(!input(pin_a4)){ //Close the door and stop the conveyer
        i=0;
        delay_ms(5);
        adcChan4 = 300;
        count = 9;
        }

        adcChan4 = adcChan4 + read_adc();
        delay_ms(5);
        count = count + 1;
      }
      adcChan4 = adcChan4/3;
      delay_ms(1);

      if(count == 10){ //if button is triggered
      }else{
      count = 5;}

      }

    if(count == 5){ //if food is passed the sensor --> allow it to get in
        delay_ms(3000); //allow motor to turn long enough to get food
    }             //fully in --> unless button was pressed

  output_float(pin_c0); //Stop the conveyer motor
  output_high(pin_b1);
```

```
   //if(stat == 0){
   //  if(!input(pin_c3)){


   if(!input(pin_a4)){ //close the door and stop the conveyer
      i=0;

   }
  }
  output_low(pin_b1);
  //LOADING COMPLETE - TIME TO CLOSE DOOR
  //output transistor door open pin low
  open = 0; //DOOR IS CLOSED

  i = 0;
  output_low(pin_e2);   //closes door
  delay_ms(5);
  output_high(pin_e2);
  delay_ms(3);

  while(i<4){
  output_low(pin_e2);
  delay_ms(50);
  output_high(pin_e2);
  delay_ms(6);
  i= i+1;
  }

  output_low(pin_e2);
  i=0;


  delay_ms(2000); //Time for the door to close
  output_high(pin_b1);

 i=1;

 if(stat == 0){ //oven needs to be unloaded, something is inside

 while(i != 0){
   level = 250;
   delay_ms(1);
```

```
if(!input(pin_a4)){ //DOOR OPENING - UNLOAD MODE
  output_low(pin_b1); //turn off ready light
  output_high(pin_e2);  //opens door
  open = 1; //DOOR IS OPEN
  delay_ms(2000);//Wait for door to open
  output_high(pin_b1); //turn it back on

  //Recalibrate the sensor
     level = 0;
     i = 0;
     adcChan4 = 0;

     while(i<5){
       delay_ms(1);
       adcChan4 = read_adc();
       delay_ms(5);
       level = level + adcChan4;
       delay_ms(1);
       i = i+1;
       delay_ms(1);
       adcChan4 = 0;
       }
     level = level/5; //find current light level
     level = .5 * level; //level is recalibrated... any light lower than this
                   //level is assumed to be due to presence of food

     delay_ms(1);
}

  while(open == 1){ //While the door is opened



   if(!input(pin_c3)){ //If Conveyer Unload is pressed

     output_low(pin_b1); //turn off ready light


     found = 0;

     output_high(pin_c0); //move out the food
     stat = 1;
```

```
while(found == 0){

  adcChan4 = 0;
  count = 0;

  while(count < 3){

    if(!pin_a4){
      i = 0;
      found = 1;
      count = 3;
      delay_ms(1);
    }

      adcChan4 = adcChan4 + read_adc();
      delay_ms(5);
      count = count + 1;
  }

  adcChan4 = adcChan4/3;

  if(adcChan4 < level){
      found = 1;
  }
 }
level = level * 1.7;
time = 0; //reset time counter

while(found == 1){
  if(time < 4.2){

    if(!pin_a4){
      i = 0;
      found = 0;
    }

    adcChan4 = 0;
    count = 0;

    while(count < 3){

      if(!pin_a4){
        i = 0;
```

```
          found = 0;
          count = 3;
          delay_ms(1);
        }

        adcChan4 = adcChan4 + read_adc();
        delay_ms(5);
        count = count + 1;
      }

      adcChan4 = adcChan4/3;
      delay_ms(5);

      if(adcChan4 > level){
        found = 0;
        delay_ms(10);
      }
      else{
        time = time + 0.023;
      }

   }else{
    output_float(pin_c0);
    found = 0; //the object is big, and is already fully out
    output_high(pin_b1); //turn it back on
   }
  }
   output_float(pin_c0); //stop conveyer
   delay_ms(10);
   output_high(pin_b1); //turn it back on
}

if(!input(pin_a4)){
  i = 0;}

if(i == 0){
  //CLOSE THE DOOR - We're done!

  i = 0;
  output_low(pin_e2);   //closes door
  delay_ms(5);
  output_high(pin_e2);
  delay_ms(3);
```

```
            while(i<4){
            output_low(pin_e2);
            delay_ms(50);
            output_high(pin_e2);
            delay_ms(6);
            i= i+1;
            }

            output_low(pin_e2);
            i=0;

            output_low(pin_b1); //turn off ready light
            delay_ms(2000);//Wait for door to close
            output_high(pin_b1); //turn it back on
            open = 0;
            i = 0;
           }
          }

          if(stat == 0){ //oven still needs to be unloaded
            i = 1;}

       }
      }
    }    output_high(pin_b1); //ready light is on
    }



  }
```