Secure Community Refrigerator

Global Product Development 2007

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SMB: Smart Manufacturing & Business

Team 2

Seoul National University
Min-chul Shin
Hong-Shik Shin

Berlin Technical University
Kaan Özgen
Lena Mechik

University of Michigan
Jens Nielsen
Amy Siwek

Secure Community Refrigerator

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EXECUTIVE SUMMARY

The Secure Community Refrigerator (SCR) is a group residence appliance that is not only convenient for the user but good for the environment. The internet connection enables a closed-loop system in multiple ways:

(1) **Automatic Database Updating:** The locking mechanism securing each storage drawer will be connected to a database which can be automatically updated. This eliminates the need to manually re-assign storage drawers when tenants move. This will save time and resources.

(2) **Online Maintenance Monitoring:** The Secure Community Refrigerator will use the internet connection to improve maintenance. Sensors (such as thermocouples) will be placed in the refrigerator to monitor the internal temperature. A signal will be sent to the maintenance crew when temperatures go below or above the ideal temperature. There will also be a "Push for Maintenance" button located on the machine for users to report if anything is wrong with the machine, ranging from locking mechanism troubles to food spills. This button will automatically send a message to maintenance, signaling them that there is a problem. Automatically notifying maintenance saves time as well as reducing the amount of spoiled food during.

(3) **Online Grocery Ordering:** The Secure Community Refrigerator will have the option for online grocery ordering. The user can order groceries directly at the machine. This will enable a close-loop system since it will allow for the bulk delivery of groceries. This will eliminate the need for separate grocery trips by having one delivery to the entire refrigerator.

The SCR also has associated energy and material savings. Approximately 430 kWh/year are saved when using one community refrigerator in the place of five small refrigerators (equivalent to ~$39/year, based on a 2005 U.S. Government national average cost of 9.06 cents/kWh for electricity). About 4 m^2 of sheet metal, used for the outer cabinet, is saved per unit as well.

The Secure Community Refrigerator is a global product which will sell in multiple countries. The primary market for the SCR is dormitories in the United States with secondary markets including Korea and Germany. The core components of the product include the outer cabinet, locking mechanism, card scanning system, and cooling system. The unique components of the design are the number of individual storage drawers and the width of each storage drawer. The primary market will have five individual storage drawers while the secondary market will have thinner drawers, but seven per unit. The size of the drawers was determined from a market survey taken from college students from both markets. The estimated primary market size is 17,000 and will cost $1500 per unit. The estimated secondary market size is 15,000 and will cost $2,100 per unit.

INTRODUCTION

Company Overview: Smart Manufacturing & Business (SMB) Global Engineering Inc. was founded in September of 2007, with offices located in Berlin, Germany; Seoul, South Korea; and Ann Arbor, Michigan, USA. Founding members include Min-chul Shin (Mechanical Engineer), Hong-Shik Shin (Mechanical Engineering), Kaan Özgen (Industrial Engineer) Lena Mechik (Industrial Engineer), Jens Nielsen (Mechanical Engineer), and Amy Siwek (Mechanical Engineer). The company focus is developing marketable products that reduce waste and energy consumption for the global market. The core competencies of SMB Inc. include global design and mechanical system development. The team consists of experienced members representing multiple countries, such as Korea, Germany, and the United States, which supports the core competency of global design. An extensive knowledge of mechanical systems through higher education and work experience supports the core competency of developing mechanical systems.

Project Overview: The internet is becoming more accessible and wide-spread with the development of wireless technology. As well, the internet is growing to products outside of computers, such as appliances, digital VCRs, and MP3 players. Internet-ready appliances have a high potential for growth since each household has multiple appliances. Other trends in consumer products show a shift toward closed-loop systems. Pressure from environmental groups as well as limitations on resources have pushed the society into developing more closed-loop products. Companies need to keep their competitive edge through sustainability. Increasing energy regulations, such as Energy Star Ratings, helps reduce energy consumption. This project needs to combine these two trends to create a global product that is closed loop due to its internet-ready capabilities.

PROJECT IDEATION

Extensive team brainstorming led to the development of five project ideas, described in detail in the Decision Matrix, shown in Figure 1 on page 6. The Secure Community Refrigerator (SCR) was chosen as our final project because it strongly satisfied each design requirement. Extensive mechanical design will be needed in developing the individual storage boxes, refrigeration/cooling system, and locking mechanism. The design can also be modular by changing the size of the individual storage boxes which allows the design to be changed to fit a global market. The community refrigerator has definite internet-ready and closed-loop benefits. The community refrigerator will save material since one large refrigerator will replace five smaller refrigerators. This saves material such as steel, compressors, and reducers. The refrigerator will also be connected to the internet which will provide additional closed-loop benefits.

PROBLEM STATEMENT

Dormitories and apartments are not designed to optimize energy consumption throughout the building. Each apartment may have its own refrigerator, washing machine, or dishwasher. A community appliance is one way to eliminate waste and reduce energy consumption since it reduces the total number of appliances in the building. Some buildings do offer community appliances, but issues arise with stealing of possessions and management of the system. *The goal of this project is to design a refrigerator that eliminates material waste and reduces energy consumption while maintaining the privacy and security the consumer demands.*

Figure 1: *Decision matrix for identifying the final project. Community refrigerator was chosen as the final project because it satisfies all the criteria strongly.*

		DESIGN IDEAS				
Rating *1 – Minimal* *5 – Moderate* *9 - Strong*		**Remote Resource Monitoring System** Reduce energy consumption by monitoring resource levels used during different applications	**Accelerated Decomposing System** Create the optimal environment for food waste decomposition by monitoring heat and bacteria levels inside the system	**Automatic Clothes Transfer to Washing Machine** Create a more efficient laundry system that would identify, load, remove, and sort clothes in hotel laundry facility	**Home Efficiency Window System** Reduce energy usage in the home by remotely controlling windows opening/closing, depending on weather conditions	**Community Refrigerator** Create a community refrigerator designed to eliminate material waste and reduce energy consumption while still maintaining the privacy of the consumer
REQUIERMENTS	Internet Ready	9 *Resource levels sent to computer - feedback to consumer*	5 *Monitoring heat and bacteria but not essential for consumer*	9 *Identification system for clothes*	9 *Remotely controlling windows*	9 *Identification system for privacy of consumer*
	Supports Closed-Loop	5 *Persuades consumer to use less energy*	9 *Reuses food waste by reducing time for decomposition*	1 *Reduces workforce needed only*	9 *Reduces home energy usage*	9 *Reduces material waste by using community refrigerator*
	Marketability	9 *Inexpensive system to help consumer save money*	5 *Reduces time of decomposition*	5 *Reduces workforce needed at hotels*	9 *Inexpensive system to help consumer save money and energy*	9 *Refrigerator marketed toward community living spaces*
	Mechanical Design/ Technical Feasibility	1 *Minimal mechanical design*	5 *Unsure if ideal will work*	1 *Difficult to implement*	9 *Acceptable mechanical design within our limits*	9 *Acceptable mechanical design within our limits*
	Global Market	9 *Applicable everywhere*	9 *Applicable everywhere*	9 *Applicable where hotels are located*	9 *Applicable everywhere*	9 *Applicable where community living spaces exist*
	Team Interest	9 *Promising idea*	9 *Promising idea*	5 *Promising idea but difficult to implement*	1 *Promising idea but simple design*	9 *Promising idea*
	TOTAL	***42***	***42***	***30***	***46***	***54***

MARKET ANALYSIS

The primary market for the Secure Community Refrigerator is dormitories in the United States of America, while the secondary market is dormitories in Korea and Germany. Dormitories from these countries were chosen as the target market because they have the potential to be highly profitable in all three places. Many dormitories exist around the world and house many people in a single building, which makes it the ideal location for a common refrigerator. The occupants of dormitories consist of many young and single students who have low incomes, making them good candidates for the Secure Community Refrigerator system. In addition, it would improve the quality of life of the students while simultaneously reducing material waste and energy consumption. The Secure Community Refrigerator system will reduce the material and energy consumption and by replacing the need for multiple individual refrigerators. *"Kitchen and laundry appliances accounted for about one-third of household electricity consumption in 2001. Refrigerators, the biggest consumers among household appliances, used 156 billion kWh of electricity. More electricity was used for refrigerators than for space heating, water heating, or lighting."* taken from U.S. Household Electricity Report [1].

Market Research: In order to analyze the dormitory market, the focus of the market analysis was on a pilot case studies applied to the dormitories in cities located in the US, Korea, and Germany. Ann Arbor, Michigan, USA represents 0.045% of the total US population with 12,562 occupants [2]. Seoul, Korea represents 20% of the total Korea population with approximately 18,000 occupants [3]. Berlin, Berlin State, Germany represents 4% of the total Germany population with approximately 10,500 occupants [4]. Market research was conducted using 15 students from TUB, 16 students from UM, and 11 students from SNU. Results of the market

survey are shown in Appendix A.1. The survey showed a clear difference in amount, size, and type of refrigerated products between students of different countries. The project will address a global market by changing the size of the storage units based on the different requirements for each country, while maintaining the same core functions.

The exact dimensions of the individual storage units were determined using the market research as well as ergonomic anthropometric measurements [5] (measurements are shown in Appendix A.2). The calculations were made assuming a conservative height sample: a short woman's height. Assuming two community refrigerators can stack on each other, the conservative maximum height of the Secure Community Refrigerator is 1770 mm (calculations are shown in Appendix A.2). This means that each storage unit will have a maximum height of 885 mm. According to the market survey, the width should be near 400 mm for the US markets (250 mm for Korean/German markets). The depth was chosen to be 600 mm to make a total volume of 212 liters (133 liters for Korean/German markets) for each individual space.

Compared to the average volume of large household refrigerators (700 ± 100 liters), and the average volume of mini refrigerators (140 ± 50 liters) [6], the volume of the individual boxes is sufficient to suit an individual's needs. As well, the individual box could suit the needs of two customers (e.g. roommates) willing to share a refrigerated space. To determine the number of individual units in each appliance, the overall size was desired to not be much larger than an individual household refrigerator. With 5 individual units for the US model, and 7 for the Korean/German model, the overall volume would not be substantially larger than large refrigerators (1060 liters for the US model, and 931 liters for the Korean/German model). In order to emphasize modularity in the refrigerator design, the final dimensions and total volume were based on these target dimensions and volumes. The final product dimensions can be seen in the Detailed Product Design on page 9.

Market Size: The number of students living in the dormitories in Germany, Korea, and the United States was determined by researching the approximate total number of beds used at dormitories for each: Germany (262,500 beds), Korea (90,000 beds), and USA (279,156 beds) [2,3,4]. Therefore, the estimated total student population living in dormitories for both our primary and secondary markets is approximately 630,000 students (beds). Each Secure Community Refrigerator is designed to hold five individual storage units in the US, and seven units in Korea and Germany. Assuming initial sales near 30%, the approximate market volume is 17,000 complete units in the United States and 15,000 complete units in Korea and Germany.

Estimated Cost: The average cost of a mini-refrigerator (140 L internal volume) is approximately $250. The average cost of a standard size refrigerator (700 L internal volume) is $780 [6]. The Secure Community Refrigerator volumetrically equals 5 mini-refrigerators or 1.5 standard refrigerators. It also has the following additional benefits: common properties (buy 1 refrigerator, gain 5 separate units), improved service with internet-ready capabilities, lower level energy consumption, and space saving abilities. With these added benefits and compared to current refrigerator market prices, the Secure Community Refrigerator will cost approximately $1,500 in the primary market and $2,100 in the secondary market.

Customer and User Requirements: The community refrigerator must satisfy both the customer and user requirements. The customer for this product is the shareholder of the dormitory unit, such as the university or private company. The user of the product is the person living in the community living space who is interacting with the product. A storyboard was created to assist in determine the appropriate user requirements, shown in Appendix A.3. Some customer requirements include: safety, machine size, durability, price, and energy consumption savings. The user requirements include: safety, easy to open storage containers, food stays cold, cost to use, food security, minimal food smell transfer, flexible for different containers, storage volume, no errors when ordering food, access lights at night, and ergonomic factors.

Global Platform: This product will appeal to a global market because of its modular design. The outer casing of the community refrigerator as well as the identification system and locking mechanism will be similar for all versions of the product. The size of the storage unit will change depending on location. Market analysis shows that different countries refrigerate different types of items and different amounts of food so the individual storage device will be modular.

Existing Related Products

Market research showed that no current products exist in the market utilizing a common refrigerator for the dormitory market [7]. Existing refrigerators include home refrigeration units, industrial refrigerators, or walk-in coolers and freezers. Closed-loop refrigerator projects have been done in previous GPD classes. One project involves a refrigerator that reduces the amount of cold air leaking through the system. The focus of this past product was different, as the focus of the Secure Community Refrigerator is reducing waste by creating a community appliance, not reducing energy leakage in a home appliance.

Patent Research: The patent research showed multiple common refrigerator ideas that partially fulfill our need [8]. A description of the searched patents can be found in Appendix A.4. The patent, "Cabinet Refrigerator" (Patent No: KP019325), is a refrigerator designed for public access in a place such as a hospital or hotel. This design allows you to rent a drawer of the refrigerator while locking your food to keep it safe. The Secure Community Refrigerator is different than this patent in multiple ways. (1) The Secure Community Refrigerator has internet capabilities not included in the patent design. It also involves an identification card system which automatically opens the correct box. (2) The physical design of this patent is a standard drawer system. The Secure Community Refrigerator will be a modular design that will be applicable to a global market. The individual storage boxes will change in size, depending on the market.

PRODUCT ENGINEERING

Customer Requirements: Figure 2 on page 9 shows a list of customer requirements developed for the community refrigerator project.

Functional Analysis: Figure 3 on page 9 shows the function structure of the community refrigerator. The sub-functions include: (1) user identification, (2) storage box lock/unlock, (3) storage box open/close, (4) addition/removal of food, and (5) food cooling system. The function structure explains in detail the input of energy and signals need for the system to work properly.

Working principles were developed for each sub-function. Drawings for each working principle are located in Appendix A.5.

Figure 2: *Customer and user requirements for the community refrigerator system.*

Team 2	**Requirements List**		10/22/2007
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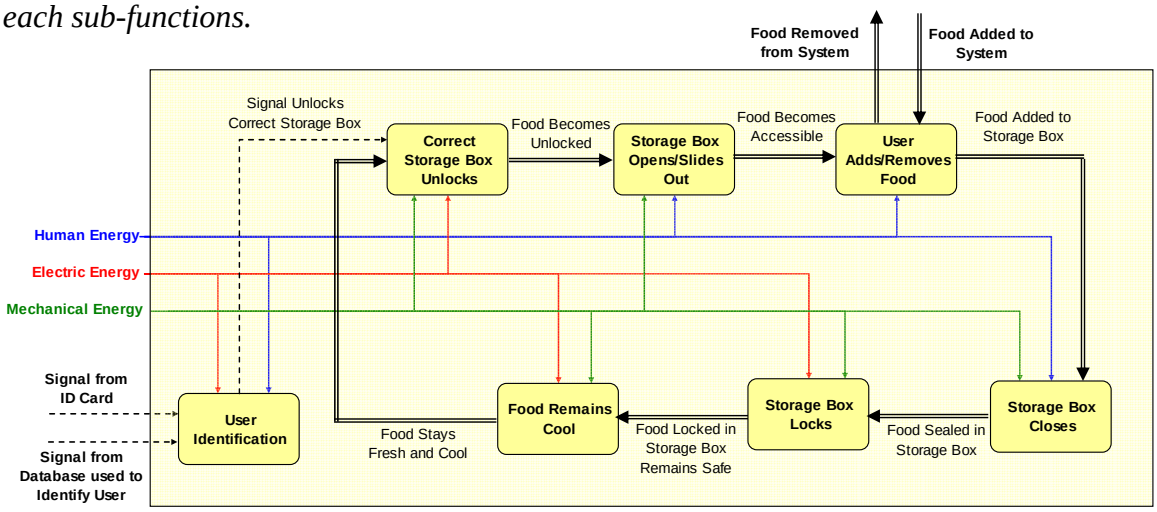
D/W	Required functions and constraints		
D	**Force:** force requred open and close unit must be < 25 N	W	**Heat Transfer:** minimize cold leaks through seals
D	**Motion:** smooth motion when opening storage box	W	**Food Secruity:** lock pry force > 200 N
D	**Temperature:** uniform temperature distribution 10-15 C	W	**Food Secruity:** cannot breach boundaries
D	**Safety:** no sharp edges	W	**Odor:** scent absorbers eliminate scent
D	**Safety:** minimize pinch points	W	**Complexity:** reduces maintance
D	**Safety:** no rapid motion	W	**Customize:** make storage units customizable
D	**Odor:** design air circulation system to eliminate odor	W	**Light:** Illuminate inside of storage box
D	**Durability:** lasts > 10 years	W	**Equality:** All storage units equal in performance
D	**Material:** non-corrosive	W	
D	**Cost:** marketed to universities ~$1,500	W	
D	**Volume:** volume specific for each global market	W	
D	**Identification:** accessible by college ID	W	
D	**Geometry:** comparable to regular fridge	W	
D	**Ergonomic:** top storage not over 1.5 m		
D	**Energy Consumption:** more efficient energy consumption		

Figure 3: *The function structure below shows the energy, material, and signal input/output for each sub-functions.*



Final Concept Selection: Four final concepts were developed from combinations of the working principles, shown in Appendix A.5, and then evaluated against the design criteria. The design criteria were generated using the customer demands and engineering specifications. Figure 4 on page 10 explains the details of each final concept. Figure 5 on page 10 shows the final concept evaluation table. From this analysis, Concept A emerges as the superior design. Its simplicity, modular functionality, and safety make it our priority for the final design concept.

Platform Structure: The core element of the platform structure is the outside cabinet of the community refrigerator and well as the identification system and locking mechanism. The element that varies according to the market need is the individual storage compartment. The US market will have larger individual storage compartments then the Korean/German market due to trends in food items and consumption. The Korean/German product will house more storage compartments, but with smaller individual volume when compared to the US product.

Figure 4: *Final concept generation table. Sub-functions categories: (1) User ID, (2) Storage Box Lock/Unlock, (3) Storage Box Open/Close, (4) Addition/Removal of Food, and (5) Cooling System. Details of each sub-function category are shown in Appendix A.5.*

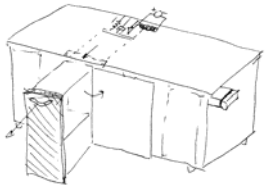
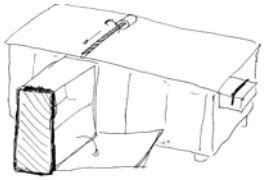
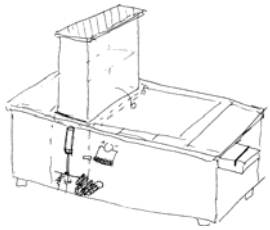
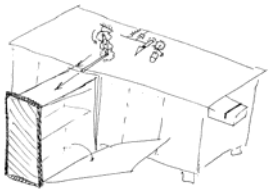
Concept A	**Concept B**	**Concept C**	**Concept D**
1. ID Card	1. ID Card	1. ID Card	1. ID Card
2. Electromagnetic Lock	2. Linear Screw	2. Electromagnetic Lock	2. Motor Controlled Lock
3. Manual	3. Linear Screw	3. Pneumatic Cylinder	3. Gear Linkage System
4. Manual	4. Manual	4. Manual	4. Manual
5. One cooling system	5. One cooling system	5. Individual cooling system	5. One cooling system
			

Figure 5: *Final concept evaluation table shows Concept A is the superior design*

Criterion				Concept A	Concept B	Concept C	Concept D
	Item	Details	Weight				
1	Function	Minimizes cold leaks	3.0	8	4	8	4
2	Robust	Less functional variations	2.0	8	6	4	3
3	Simple	Minimize number of parts	3.0	5	6	6	4
4	Manuf.	Simple machining	2.0	7	6	6	4
5	Assembly	Easy to assemble	2.0	6	6	6	5
6	Clean	Easy to clean	1.0	8	8	8	7
7	Safety	Safe design	3.0	9	9	9	9
Sum		Total of (weight x grade)		116	101	109	82
		Priority		**1**	**3**	**2**	**4**
Conclusion		**We chose concept A as our final design**					

Satisfaction of Project Requirements: The Secure Community Refrigerator is a global product with the United States as the primary market and Korea and Germany s the secondary market. The SCR will contain five individual storage units for the primary market while the secondary market will have seven smaller individual storage units. The size of the storage units was determined from the market research conducted on college students in the primary and secondary markets. The refrigerator will also be connected to the internet which will provide additional closed-loop benefits (see diagrams in Appendix A.6). The online components include:

(1) The locking mechanism securing each storage drawer will be connected to a database which can be automatically updated. This eliminates the need to manually re-assign storage drawers when tenants move. This will save time and resources.

(2) The Secure Community Refrigerator will use the internet connection to improve maintenance. Sensors (such as thermocouples) will be placed in the refrigerator to monitor the internal temperature. A signal will be sent to the maintenance crew when temperatures go below or above the ideal temperature. There will also be a "Push for Maintenance" button located on the machine for users to push if anything is wrong with the machine, ranging from locking mechanism troubles to food spills. This button will automatically send a message to maintenance. Automatically notifying maintenance saves time which reduces the amount of spoiled food.

(3) The Secure Community Refrigerator will have the option for online grocery ordering. The user can order groceries directly at the machine. This will enable a closed-loop

system since it will allow for the bulk delivery of groceries. This will eliminate the need for separate grocery trips by having one delivery to the entire refrigerator. A screen shot of the website used for ordering groceries can be found in Appendix A.7.

DETAILED PRODUCT DESCRIPTION

Structure: Figure 6 shows the detailed engineering drawings of the core components of the Secure Community Refrigerator. The core components will be used in both the primary and secondary markets and includes the outer cabinet, locking mechanism, card scanning system, and cooling system.

Figure 6: *Core components used in both the primary and secondary markets.*

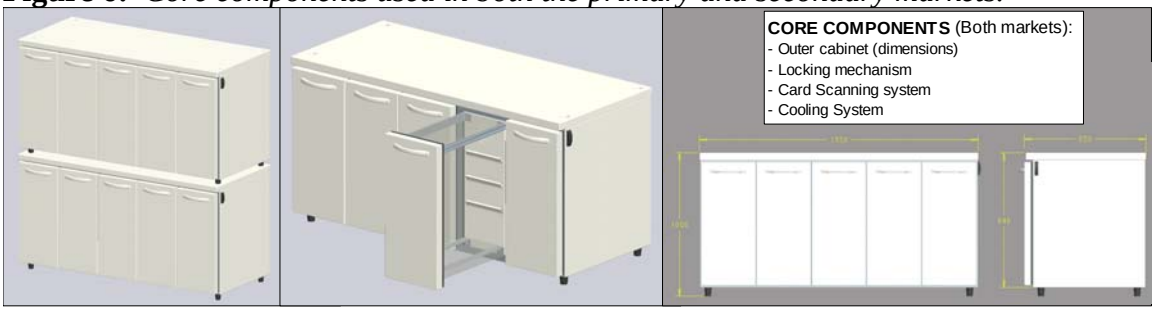
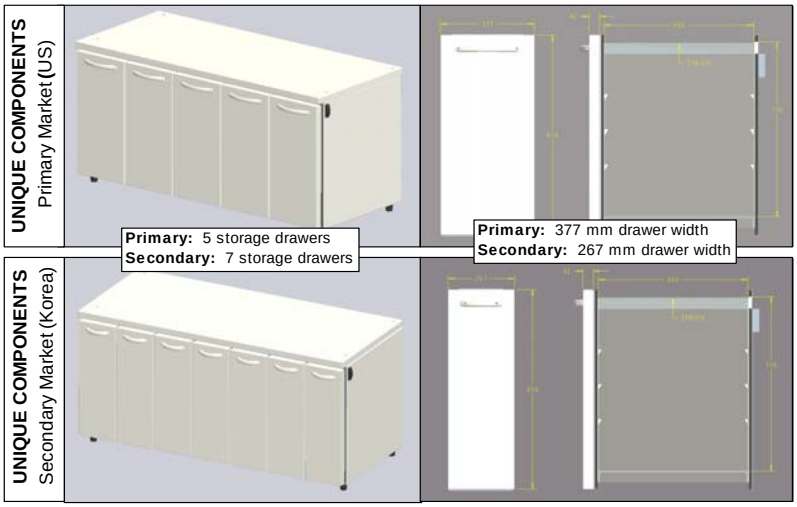


Figure 7 shows the detailed engineering drawings of the unique components of the Secure Community refrigerator. The primary market design contains five individual storage compartments while the secondary market design contains seven compartments. The drawer width of the secondary market design is smaller than the primary market design, which allows for more compartments to fit into the unit without changing the overall size of the unit.

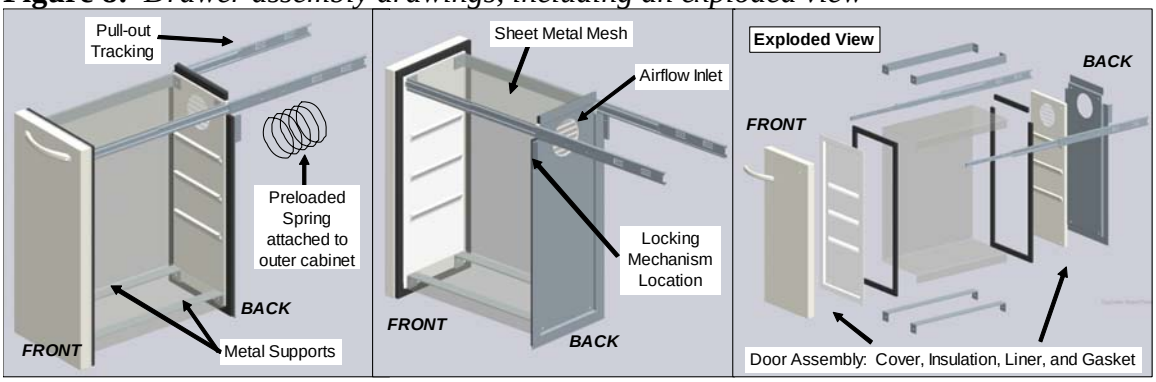
Figure 7: *Unique components of the Secure Community Refrigerator include the number of storage drawers and the width of each storage drawer*



Drawer Assembly: Figure 8 on the following page shows the individual drawer assembly for the primary market. The front and back of each drawer will be made of a metal cover, insulation, liner, and gasket as shown in the exploded view. The box housing is made of bent steal sheet mesh which will allow for increased air circulation. Metal supports will mount at the bottom the storage unit to increase the stiffness of the shelf. The airflow will enter the storage box through a vent at the top back of the box. Adjustable shelves will be added to maximize the space usage of the storage box. A preloaded spring will be connected at the back of the unit to assist in the opening of the drawer. Tracking will allow the drawer to slide in out of the unit with

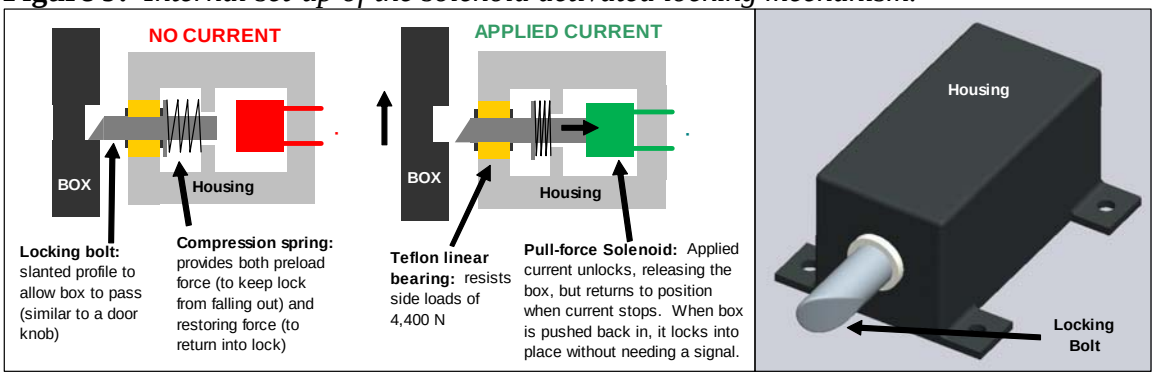
minimal force. The drawer was also designed to minimize cold air loss. When the drawer is completely pulled out, a magnet force attracts the back panel to the drawer opening, sealing the gap.

Figure 8: *Drawer assembly drawings, including an exploded view*



Locking Mechanism: The locking mechanism will consist of a pull-force solenoid, compression spring, locking bolt, and bearing all enclosed in a plastic housing as shown in Figure 9 on the following page. When current is applied to the solenoid, the locking bolt will release into the housing allowing the storage box to be opened. The locking mechanism will be connected to the identification card reading system which controls the status of each lock in the entire system. The locking mechanism will be placed in the upper back side of each storage box, as shown in Figure 8 above.

Figure 9: *Internal set-up of the solenoid activated locking mechanism.*



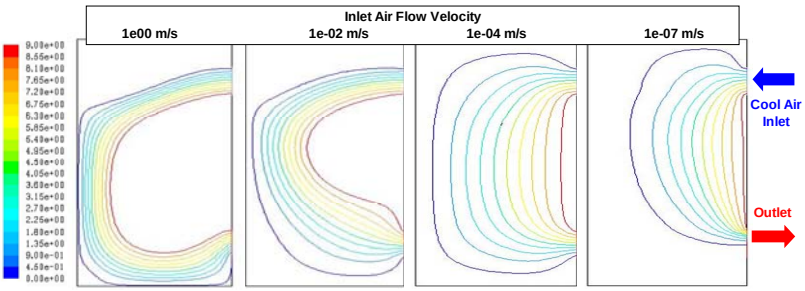
ENGINEERING ANALYSIS

Power Requirements: The Secure Community Refrigerator will decrease total power consumption for the entire building. A large refrigerator consumes roughly 520 kWh/year while a miniature refrigerator consumes roughly 190 kWh/year [6]. One Secure Community Refrigerator will replace five miniature refrigerators. This will save approximately 430 kWh/year, assuming the Secure Community Refrigerator consumes the same amount of power as a large refrigerator. This power savings comes out to $39/year, based on a 2005 U.S. Government national average cost of 9.06 cents/kWh for electricity.

Material Savings: The Secure Community Refrigerator saves material since it merges multiple mini-refrigerators. The primary market Secure Community Refrigerator with five storage drawers saves approximately 4 m^2 of sheet metal per unit when compared to five separate mini-refrigerators (calculations are shown in Appendix A.9). Since the Secure Community Refrigerator shares refrigeration components, less compressors, evaporators, condensers, and electrical plugs will be used. Assuming a primary market size of 27,000 units, 108,000 refrigeration components as well as approximately 108,000 m^2 of sheet metal will be saved assuming the Secure Community Refrigerator replaces five miniature refrigerators.

Airflow Requirements:
Temperature distribution is depended on the inlet velocity of the cold air. An analysis was completed using Fluent software and the storage box dimensions derived in the market analysis. The cool air inlet is through the upper back panel of the storage box while the outlet vent is on the lower back panel. The cross-sectional view of the airflow pathlines for a variety of air inlet speeds are shown in Figure 10. This analysis shows an inlet cool air velocity on the order of 10^{-4} m/s will create the most uniform cool air distribution.

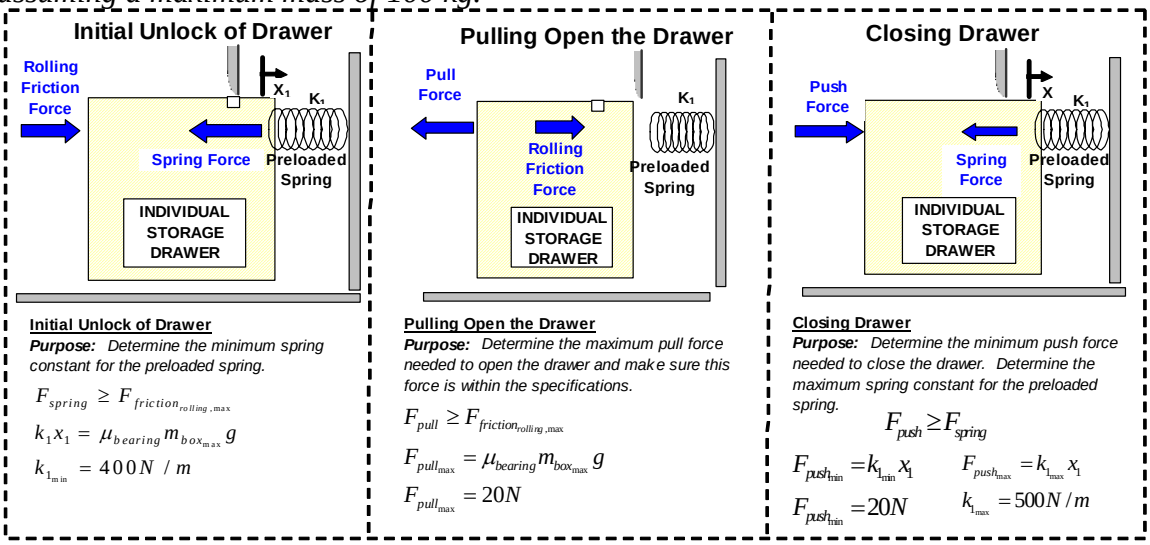
Figure 10: *Fluent model airflow pathlines of the cross-section of the individual storage boxes. Inlet air velocities on the order of 10^{-4} m/s create the most uniform airflow and temperature distribution.*



Force Requirements: The force required to open and close the individual storage drawer must be less then 25 N (6 lbs) in accordance with the specifications outlined in our customer requirements. Analysis was completed to ensure the design will meet these criteria. A preloaded spring will be used to help open the drawer once it becomes unlocked. The specifications of the preloaded spring were calculated to maintain push and pull forces within our specifications. Figure 11 on the following page shows a summary of the force requirement calculations (detailed calculations shown in Appendix A.10). The preloaded spring constant must be between 400 N/m and 500 N/m to maintain push and pull forces within specification, assuming a maximum drawer mass of 100 kg.

Critical Elements: The two critical components of the Secure Community Refrigerator are the internet-ready unlocking system and the individual drawer assembly. The unlocking system is critical because the system will not function properly if the lock malfunctions. The lock must be strong enough to secure the storage unit is closed as well as can withstand many cycles of opening and closing. If the locking mechanism fails, the drawers will not close properly or will remain permanently locked. The individual drawer assembly is critical to the system since it is where the user will store their food. The drawer must have the correct dimensions and tolerances in order to ensure the drawer will open and close properly with minimal force. The drawer must be robust to different weight capacities as well as many cycles of opening and closing.

Figure 11: *Summary of force requirement calculations for unlocking the drawer, opening the drawer, and closing the drawer. The preloaded spring constant must be between 400 N/m and 500 N/m. The pull and push forces will be within specification using this spring constant, assuming a maximum mass of 100 kg.*



Initial Unlock of Drawer

Purpose: *Determine the minimum spring constant for the preloaded spring.*

$$F_{spring} \geq F_{friction_{rolling,\max}}$$

$$k_1 x_1 = \mu_{bearing} m_{box_{\max}} g$$

$$k_{1_{\min}} = 400N/m$$

Pulling Open the Drawer

Purpose: *Determine the maximum pull force needed to open the drawer and make sure this force is within the specifications.*

$$F_{pull} \geq F_{friction_{rolling,\max}}$$

$$F_{pull_{\max}} = \mu_{bearing} m_{box_{\max}} g$$

$$F_{pull_{\max}} = 20N$$

Closing Drawer

Purpose: *Determine the minimum push force needed to close the drawer. Determine the maximum spring constant for the preloaded spring.*

$$F_{push} \geq F_{spring}$$

$$F_{push_{\min}} = k_{1_{\min}} x_1 \qquad F_{push_{\max}} = k_{1_{\max}} x_1$$

$$F_{push_{\min}} = 20N \qquad k_{1_{\max}} = 500N/m$$

PRODUCT MANUFACTURING

Product Bill of Materials: Figure 12 shows a summary of the Product Bill of Materials for the Secure Community Refrigerator. Appendix A.8 contains the full detailed Product BOM, including sizes and material, for each component.

Figure 12: *Summary of the Product Bill of Materials for the Secure Community Refrigerator. The extended Product BOM is shown in Appendix A.8.*

PRODUCT BOM- Top Level

Part Description	Qty	Part Description	Qty
COMMON PARTS			
Supplied Parts		*Custom parts*	
Compressor motor	1	Top cover - 2mm thick	1
Condenser fan	1	Side panel - 2mm thick	2
Evaoprator fan	1	Back panel - 2mm thick	
Air duct	1	Bottom panel - 2mm thick	
Heat exchanger fins	1	Suppoort posts	6
Throttle valve	1	Inside covering - 2mm thick	1
Refrigerant tubing	15 m	End Unit mounting bracket	2
Refrigerant	2 L	Unit mounting bracket	4
AC motor controller	1		
Electrical connection harness	2 m		
AC power cord	1 m		
Magnetic card reader	1		
Legs	6		
Hardware, sheetmetal screws	100		
Adhering Insulation	10 L		
UNIQUE PARTS			
US Model		**Korean Model**	
Supplied Parts		*Supplied Parts*	
AC power converter	1	AC power converter	1
Custom parts		*Custom parts*	
Steel seal face plate	1	Steel seal face plate	1
ASSY- Inidividual unit (US)	5	Adtnl unit mounting bracket	2
ASSY- Locking Mechanism	5	ASSY- Inidividual unit (Korean)	7
		ASSY- Locking Mechanism	7

Individual Unit- SUB-BOM

Part Description	Qty	Part Description	Qty
COMMON PARTS			
Supplied Parts		*Custom parts*	
Adhering Insulation	1 L	Structural bar - 600mm long	4
Full-extension cabinet pull	2		
Unit mounting hardware	10		
Hardware, sheetmetal fasteners	10		
UNIQUE PARTS			
US Model		**Korean Model**	
Supplied Parts		*Supplied Parts*	
Door handle	1	Door handle	1
Door seal (adhesive back)	1	Door seal (adhesive back)	1
Back seal (adhesive back)	1	Back seal (adhesive back)	1
Custom parts		*Custom parts*	
Shelf housing - 2mm thick	1	Shelf housing - 2mm thick	1
Door structure - 2mm thick	1	Door structure - 2mm thick	1
Door inside panel - 3mm thick	1	Door inside panel - 3mm thick	1
Back structure - 2mm thick	1	Back structure - 2mm thick	1
Back inside panel - 3mm thick	1	Back inside panel - 3mm thick	1
Shelf	1	Shelf	1

Locking Mechanism- SUB-BOM

Part Description	Qty	Part Description	Qty
COMMON PARTS			
Supplied Parts		*Custom parts*	
Linear motion shaft bearing	1	Housing, back	1
Bearing retaining rings	2	Housing, front	1
Spring retaing ring	1	Rounded locking pin	1
Conical spring	1		
Solenoid - 10mm diameter	1		
Mounting hardware	4		

SMB will outsource all of the components and sub-assemblies needed to make the Secure Community Refrigerator and then assemble them in-house. The refrigerator cabinet, cooling system, and drawer sub-assemblies will be outsourced from Whirlpool Corporation since this company already has an extensive knowledge on how to manufacture refrigeration components. The locking mechanism and identification card scanner will be outsourced from a low-cost country, such as China. The outsourced subassemblies will be assembled into a complete unit at one of SMB's manufacturing facilities. The SCR will be package and stored at the facilities until ready for sale. The most critical process for mass production is assembly because assembly speed has the greatest influences over the total number of products built per day.

PROTOTYPE

The final deliverable is a physical prototype of the Secure Community Refrigerator (see Figure 13). The prototype includes multiple individual storage units housed in one larger unit that unlock with the use of the internet-ready kit and an identification card. The prototype is different from the main design due to constraints on time and money. The prototype does not include the refrigeration system essential for the main design. Refrigeration is not one of SMB's core competencies, so the refrigeration components will be outsourced. The prototype is also made of different material then the main design. The main design will be constructed using mostly steel while the prototype is made with a wood outer cabinet and steel interior storage drawers.

Figure 13: Pictures *of the Secure Community Refrigerator prototype, taken in Berlin, Germany*

Prototype Bill of Materials: A prototype bill of materials was created to assist in the prototyping phase of the project. Figure 14 on the following page shows the part needed along with whether it needed to be bought or made in-house. Most of the structure was made internally, with the majority of the outsourcing coming from McMaster Carr. We outsourced the components that were to difficult to make ourselves, such as the tracking and solenoid. We were in charge of machining all the metal and wood components. A prototype CAD drawing was created to communicate the exact dimensions across Germany, Korea, and the United States, in order to minimize mistakes and errors. Examples of these CAD drawings can be found in Appendix A.11.

Figure 14: *Prototype Bill of Materials*

Overall				
Part	**Description**	**Make/Outsource**	**Supplier/Material**	**Quantity**
Top Panel	Outer structure	Make	Wood	1
Side Panel	Outer structure	Make	Wood	2
Back Panel	Outer structure	Make	Wood	1
Bottom	Outer structure	Make	Wood	1
Wheels		Outsource	McMaster	4
Paint		Outsource	Baushouse	2
Button, on/off switch	Used for maintence button	Outsource	Baushouse	3
Sheet metal	Used in drawer openings for magnetic seal	Make	Sheet metal	1
Magnetic Tape	On back panel of individual box for magnetic seal	Outsource	McMaster	1
Foam Strip	Foam seal of front door panel to drawer opening	Outsource	McMaster	1
Support structure	Wood support structure for outer frame	Make	Wood	4
Individual Box				
Part	**Description**	**Make/Outsource**	**Supplier/Material**	**Quantity**
Expanded Steel (mesh)	Structure of box	Make	Steel	3
Front Panel		Make	Wood	3
Back Panel		Make	Wood	3
Full-extension tracking	Sliding mechanism for pulling out drawers	Outsource	McMaster	6
Tracking Mounting Bracket to Individual Box	Connects tracking to individual box	Make	Aluminum	6
Tracking Mounting Bracket to Ceiling	Connects tracking to ceiling	Make	Aluminum	6
Front Panel to Back Panel Bracket	Connects front panel, back panel, and expanded metal	Make	Aluminum	6
Door handles		Outsource	McMaster	3
Springs	Used to assist in door opening	Outsource	McMaster	12
Spring Housing		Make	Wood	3
Locking Mechanism				
Part	**Description**	**Make/Outsource**	**Supplier/Material**	**Quantity**
Solenoid	Locking mechanism translational motion	Outsource	McMaster Carr	3
Locking Piston	Connects to solenoid to extend length	Make	Aluminum	3
Bearing	Supports locking piston	Outsource	McMaster Carr	3
Bearing Housing	Holds bearing	Make	Plastic	3
Mounting Bracket	Used for mounting solenoid to refrigerator	Make	Wood	3
Identification Card Scanner	Used for unlocking drawer	Outsource	Online	1
Locking Bracket	Bracket connecting individual drawer to locking piston	Make	Aluminum	3

Assembly Plan: Before traveling to Berlin, Germany for the design exposition, all the necessary components were purchased, then machine and/or cut. The work was divided between the three countries working on the project. The Korean team members purchased an identification card reader and made the necessary programs to run the prototype. The German team members purchased the wood necessary for the design and cut the pieces to size. The American team members purchased the metal components and completed the essential machining. Once the entire team arrived in Berlin, assembly began followed by debugging the system. The assembly began with building the sub-assemblies early in the week, ending with the construction of the final prototype.

BUSINESS PLAN

Target Sales Volume: Global modular design of SCR enables us to reach different markets in all the corners of the world which increases the profitability. The number of students living in the dormitories in our primary market, the United States, and secondary market, Germany and Korea, were determined by researching the approximate total number of beds used at dormitories for each.

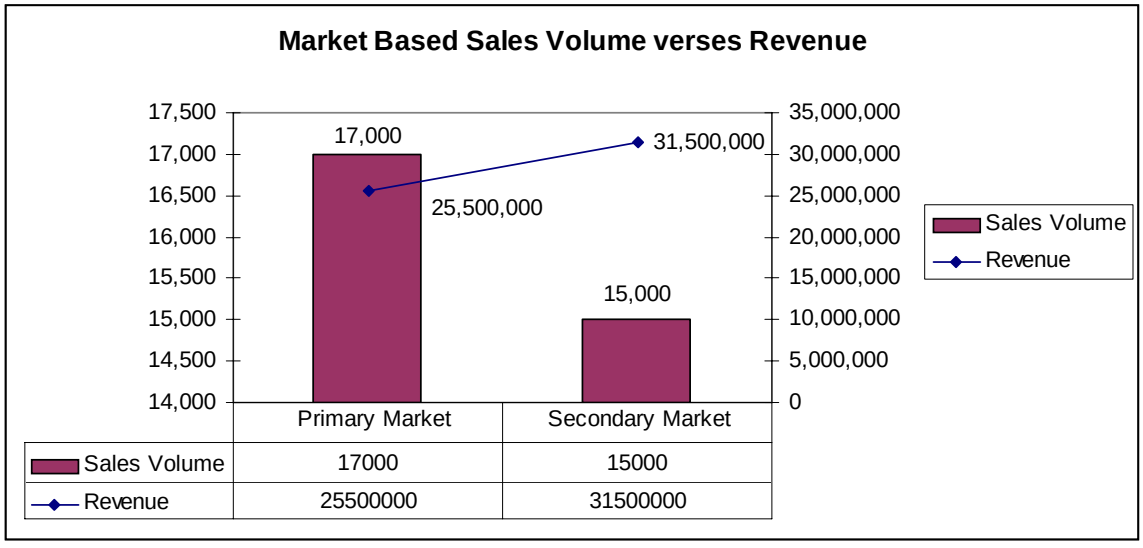
- Primary Market: USA = 279,156 beds
- Secondary Market: Germany = 262,500 beds and Korea = 90,000 beds

The estimated total student population living in dormitories is 279,156 students (beds) for our primary market and 352,500 students (beds) in our secondary market. Each Secure Community Refrigerator is designed to hold five individual storage units in the United States and seven units in Korea and Germany. This translates to approximately 55,831 complete units in the primary market and 50,357 in the secondary market. Assuming initial sales of the Secure Community Refrigerator near 30%, our estimated sales are 17,000 units for the primary market and 15,000 units for the secondary market. The price for the primary and secondary markets differs based on number of drawers used according to the material usage.

Product Changes for Secondary Market: Common elements like the identification system and the outer casing will be the same for all versions of the product. Market analysis shows that different countries refrigerate different types of items and different amounts of food so the individual storage drawer will be different depending on the market. Due to the modular design of SCR, these functional changes are easy to achieve by simply changing the width of drawers and increasing the total number of drawers per unit.

Estimated Price per Market: The average price of a mini-refrigerator (140 L internal volume) is approximately $250. The average price of a standard size refrigerator (700 L internal volume) is $780 [6]. The Secure Community Refrigerator volumetrically equals 5 mini-refrigerators or 1.5 standard refrigerators. It also has the following additional benefits: common properties (buy 1 refrigerator, gain 5 separate units), improved service with internet-ready capabilities, lower level energy consumption, and space saving abilities. With these added benefits and compared to current refrigerator market prices, the Secure Community Refrigerator will cost to the end user approximately $1,500 in our primary market USA and $2100 in our secondary market Korea. These prices were determined assuming the value to the consumer for each individual storage drawer is approximately ~$300. Figure 15 shows the market based sales volume versus revenue. The primary market has a lower revenue but higher market volume.

Figure 15: *Market based sales volume versus revenue. 1 is the primary market (United States) while 2 is the secondary market (Korea and Germany). The revenue for the secondary market is slightly higher than primary market, but the sales volume is bigger for the primary market.*



Outsourcing: The components and sub-assemblies will be outsourced and then assembled in an in-house facility in preparation for sale. Below is the breakdown of cost:

- Cabinet (not including drawers) **$400**
  - *Includes cooling system, insulation, metal cover, wiring, etc.*
- Drawer sub-assembly **USA: $100; Korea and Germany: $90**
  - *Includes metal casing, brackets, drawer slides, insulated door, etc.*
- Locking mechanism **$10**
  - Includes 12 VDC solenoid, linear bearing, mounting bracket, etc.
- Identifications system **$50**
  - Example: RFID $50, Magnetic card reader $30, Barcode $50, Number pad $7.50

The total cost of outsourcing for each market is:

- Outsourcing Total USA = ($400 + $50) + 5 x ($10 + $100) = $1000
- Outsourcing Total Korea and Germany = ($400 + $50) + 7 x ($10 + $90) = $1150

Assembly: Assembly will be in Mexico for the primary market. Assuming $10 an hr for 5 hrs of building with 2 people working, the total assembly cost for the primary market is $100. For the secondary market, assembly will take place in Turkey. Assuming $12 per hr for 7 hrs of building with 2 people working, the total assembly cost for the secondary market is $112.

Logistics: The container volume of a transportation vehicle is approximately 70,000 liters. The SCR package is approximately 1,000 liters. This leads to a $15 logistics cost per unit, assuming there are 70 SCRs per container and each transportation container costs $1,000.

Product Manufacturing Cost: The above analysis was give to estimate the total production costs in both the primary and secondary markets.

- ***Grand Total Primary Market (USA) = $1,115***
- ***Grand Total Secondary Market (Korea and Germany) = $1,277***

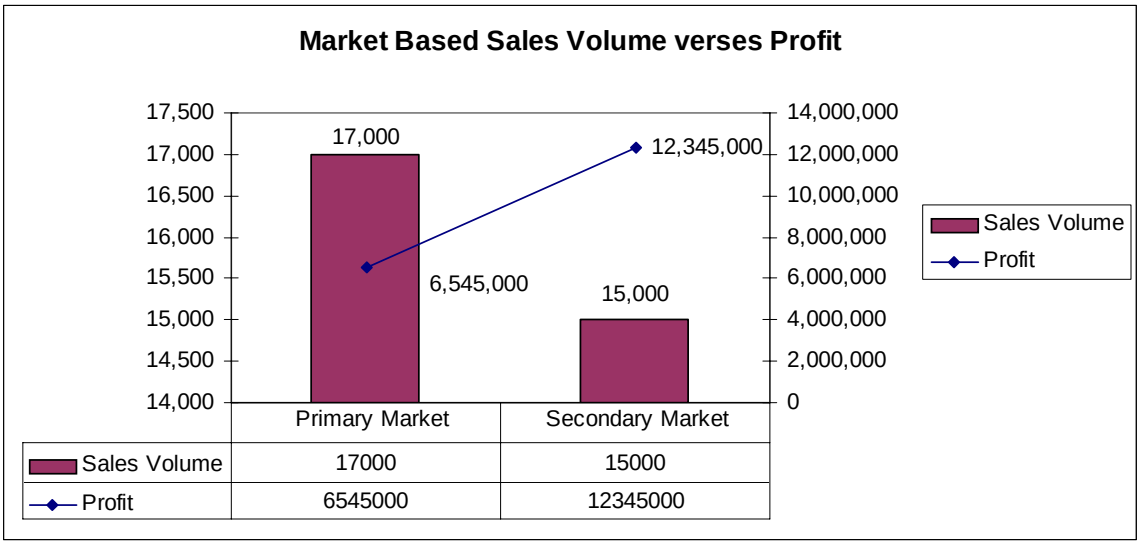
Figure 16 on the following page shows the market based sales volume verses the profit. The graph shows the primary market has higher profit, but a smaller sales volume. Even though the profit from the secondary market is higher, SMB first wants to spread their presence in the market. This will be achieved by first getting into the larger United States market, followed later on by the secondary market.

Marketing and Logistics: The launch of the primary market model is currently scheduled for the first quarter of 2009. This should provide enough time to complete necessary product testing and negotiations with suppliers. The secondary market launch is scheduled for first quarter 2010. The secondary market launch is scheduled for a year after the primary launch since feedback from the primary market launch will be used to refine the secondary market design.

We chose to assemble the primary market units in Mexico and the secondary market units in Turkey in order to utilize low-cost manufacturing countries while maintaining a close distance to the market location.

We chose to launch in the United States first since it has the largest market volume. SMB chose to get into the larger US market first in order to maximize the number of products on the market, regardless of the lower profit margin. Sustainability is more important than profit at SMB.

Figure 16: *Market based sales volume versus profit.*



PROJECT SUMMARY

The Secure Community Refrigerator is a group residence appliance that is not only safe and convenient for the user but good for the environment. Each individual storage unit will be secured with a locking mechanism that will only open with the correct identification card. The internet connection enables a closed-loop system in multiple ways (see Appendix A.6 for explanatory diagrams):

(1) **Automatic Database Updating:** The locking mechanism securing each storage drawer will be connected to a database which can be automatically updated. This eliminates the need to manually re-assign storage drawers when tenants move. This will save time and resources.

(2) **Online Maintenance Monitoring:** The Secure Community Refrigerator will use the internet connection to improve maintenance. Sensors (such as thermocouples) will be placed in the refrigerator to monitor the internal temperature. A signal will be sent to the maintenance crew when temperatures go below or above the ideal temperature. There will also be a "Push for Maintenance" button located on the machine for users to report if anything is wrong with the machine, ranging from locking mechanism troubles to food spills. This button will automatically send a message to maintenance, signaling them that there is a problem. Automatically notifying maintenance saves time which reduces the amount of spoiled food.

(3) **Online Grocery Ordering:** The Secure Community Refrigerator will have the option for online grocery ordering. The user can order groceries directly at the machine. This will enable a closed-loop system since it will allow for the bulk delivery of groceries. This will eliminate the need for separate grocery trips by having one delivery to the entire refrigerator.

The Secure Community Refrigerator is a global product which will sell in multiple countries. The primary market for the SCR is dormitories in the United States with secondary markets include Korea and Germany. The primary market volume is near 17,000 units, each costing $1,500. The secondary market volume is 15,000 units, each costing $2,100. The core

components of the product include the outer cabinet, locking mechanism, card scanning system, and cooling system. The unique components of the design are the number of individual storage drawers and the width of each storage drawer. The primary market will have five individual storage drawers while the secondary market will have thinner drawers, but seven per unit. The size of the drawers was determined from a market survey taken from college students from both markets (Appendix A.1).

A physical prototype was successfully built for the design exposition in Berlin, Germany. The prototype was slightly different in size and material, but it was a good representation of what the product will look like and how it will function. The prototype demonstrates the maintence and unlocking database system internet features and the website demonstrates the online ordering system.

LESSONS LEARNED

The majority of the project objectives for the Secure Community Refrigerator were successfully carried out (approximately 95%). The objectives included developing a promising design concept, completing a quality report with all relevant information, and building a representative prototype. The objectives not completed are in regards to the prototype. Limitations in SMB's electrical engineering knowledge restricted the use of the internet-ready kit for the prototype. The internet applications of the project would have been better represented with a better knowledge of how to utilize the internet ready kit.

The biggest lessons learned were in regards to building a prototype in three different countries. Extreme planning was crucial since each of the three countries were machine or cutting material before meeting in Berlin, Germany. To limit mistakes, a set of CAD drawing was completed of the prototype design to ensure the appropriate size and dimensions. Another lesson is in regards to traveling with prototype parts. Some small parts were left behind and not taken to Berlin which increased the amount of effort needed to make the prototype since parts needed to be reproduced. A simple inventory list would have prevented this mistake.

The biggest frustration in Global Product Development was regarding the internet-ready kit. We did not have an electrical or computer engineer on our team so there was limited knowledge on how to integrate it into the prototype. Little assistance was provided on its intended use. The internet-ready kit itself was also very fragile. It did not contain any over current protection which led to burning out the first kit. It would have been helpful if a more robust internet-ready kit was given, since this was the first time our team had worked with one. No one on our team was familiar with the required computer language as well which made the project more difficult.

The most effective means of communication was through email. Frequent emails were sent out assigning project tasks for individuals to keep the project moving forward. We also utilized Google Documents and Google Chat. Google Documents was a good way to share files, but Google Chat was extremely inefficient. Weekly video conferences were held as well which were good for conveyed complicated ideas not easily described with words.

ACKNOWLEDGMENTS
Thanks to all the students who participated in our market research, as well as to Semih Severengiz, Professor Saitou, Seung-bum and Professor Suk-won for their assistance in our brainstorming sessions. Additionally, we would like to thank Professor Patil for his valuable guidance.

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[5] DIN (Deutsches Institut fur Normung) Tables DIN 33402-2 and DIN 33411 (Tables shown in Appendix A.2)
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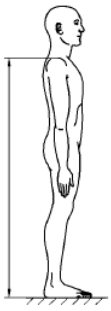
[8] Patent Search Links
www.kipris.or.kr

Appendix A.1 Market Study Questions

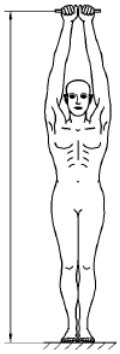
	University	**TUB**	**UM**	**SNU**
1	Total participants:	15	16	11
2	Lived in a dormitory at least once	4	13	8
3	Fridge users	15	16	9
4	Common groceries put in a fridge	Juice, Cheese, Bread, Fruit, Vegetables, Frozens, Beer, Butter, Meat, Yogurt, Eggs	Juice, Cheese, Bread, Fruit, Vegetables, Frozens, Beer, Meat, Left-overs, Eggs	Juice, Milk, Water, Fruit, Vegetables, Eggs
5	The biggest bottle in the fridge. (Liters)	2	8,8	2
6	Average bottle size. (Liters)	1,466667	2,840625	1,666667
7	Biggest case. (LengthxWidthxHeight)	50x30x20	40x40x20	40x30x30
8	The volume of the widest case. (cm3)	30000	32000	36000
9	Average volume of widest cases. (cm3)	9633,333	13173,44	12843,75
10	Average fridge usage per day	10,53333	2	6,222222
11	Width of the biggest bottle	15	30	15
12	Number of students using egg holders in the fridge	10	2	4
13	Average number of shopping trips per month	9	3,3125	4,888889
14	Number of students willing to share the fridge with neighbors	5	5	1
15	Max number of students willing to share the fridge	10	10	6
16	Average number of students willing to share the fridge	3,4	3,75	3,4
17	Idea of using a locked community fridge with neighbors is GOOD	11	12	9
18	Idea of using a non-locked community fridge with neighbors is GOOD	4	4	1
19	Average amount would be paid extra in case an online delivery service for your groceries in €	1,466667	4,04375	2,063636

Appendix A.2 Storage Box Dimensional Analysis (Ergonomic Measurements and Calculations)

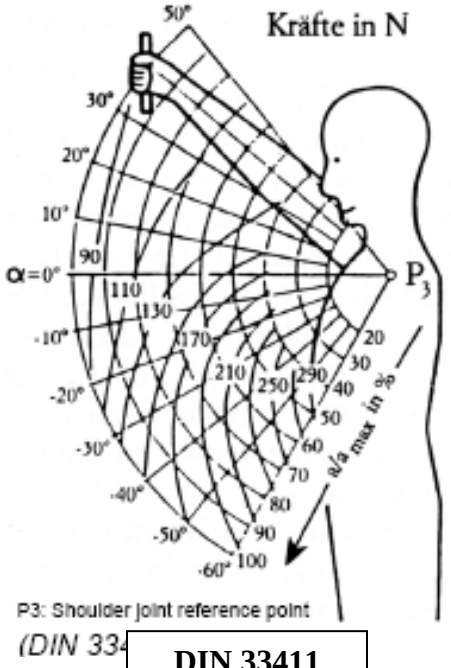
DIN 33402-2



Altersgruppen	Schulterhöhe mm					
	Männer			Frauen		
	Perzentil					
Jahre	5	50	95	5	50	95
18–65	**1 345**	**1 450**	**1 550**	**1 260**	**1 345**	**1 425**
18–25	1 375	1 480	1 600	1 285	1 370	1 460
26–40	1 360	1 465	1 565	1 270	1 355	1 435
41–60	1 330	1 435	1 535	1 255	1 340	1 415
61–65	1 300	1 410	1 500	1 230	1 315	1 385



Altersgruppen	Reichweite nach oben, beidarmig (Griffachse) mm					
	Männer			Frauen		
	Perzentil					
Jahre	5	50	95	5	50	95
18–65	**1 975**	**2 075**	**2 205**	**1 840**	**1 945**	**2 025**
18–25	2 000	2 130	2 245	1 855	1 995	2 085
26–40	1 980	2 095	2 220	1 845	1 955	2 035
41–60	1 960	2 050	2 195	1 835	1 930	2 005
61–65	1 930	2 015	2 150	1 820	1 910	1 955



DIN 33411

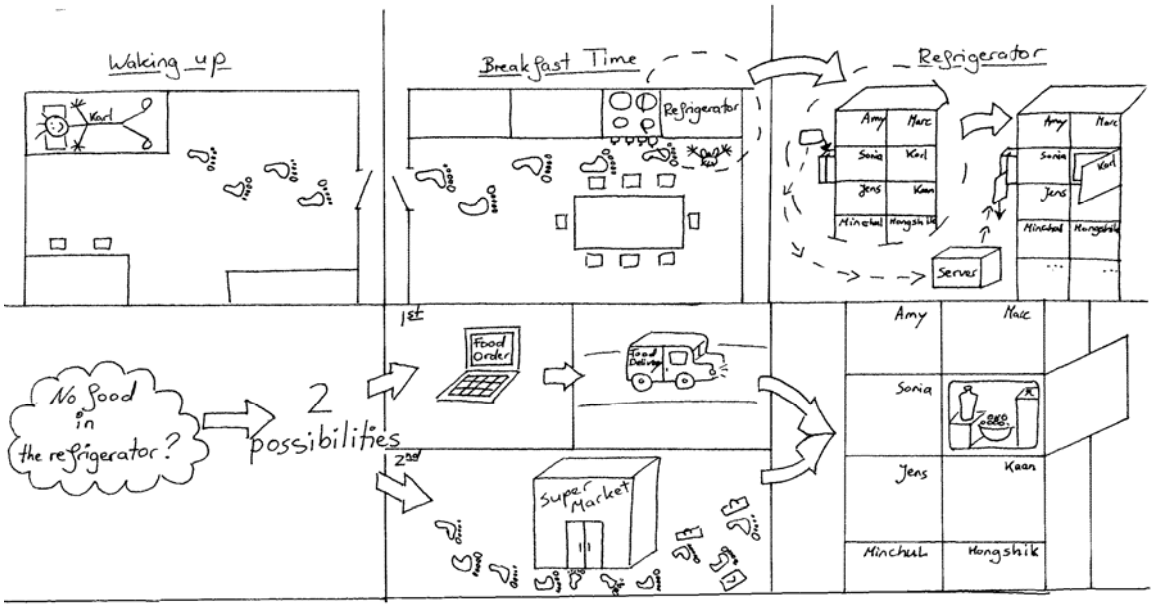
Average Women Measurements

Average height of women: 1345 mm
Average arm length: 1945 – 1345 = 600 mm
Vertical arm length at 45 degree angle: 600 x sin(45) = 425
Max ergonomic height of grabbing objects for average women: 1345 + 425 = 1770 mm

Refrigerator height (two units stacked) = 1770/2 = 885 mm height of each individual storage unit

Volume = Height x Width x Depth = 885 mm x 400mm x 600 mm
Volume = 212 liters
Height comes from ergonomics (885 mm)
Width comes from market survey (400 mm)
Depth comes from existing refrigerator measurements (600 mm)

Appendix A.3 Story Board – Demonstrates the need by the consumer of the product.

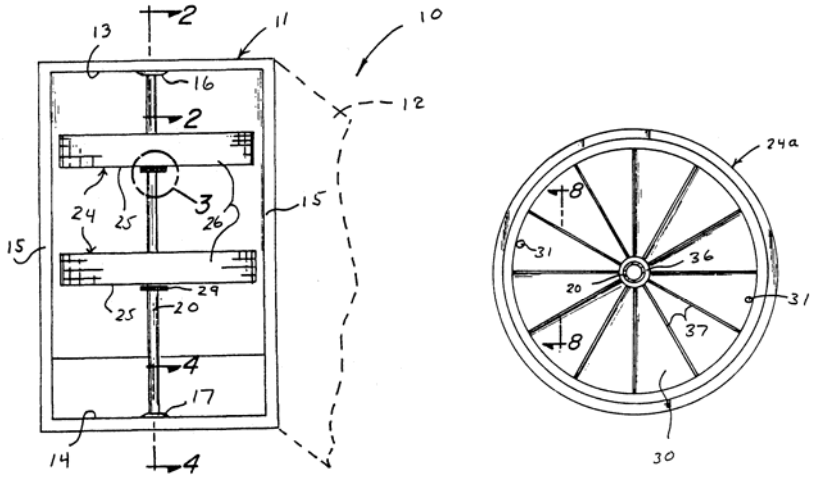


Appendix A.4 Patent Search

1. US/EP

1) Refrigerator with rotatable shelves(Patent No : US005277488A)

- A refrigerator or freezer of a storage refrigerator unit includes a central support shaft mounted within the refrigeration cabinet having support containers adjustably mounted along the support shaft. The shaft structure is rotatably mounted within the cabinet for access to various portion of each container.



2) Refrigerator of freezer display cabinet with a horizontal access opening(Patent No : EP0710460A1)

- The invention refer to a refrigerator or freezer display cabinet comprising a box with side walls and a bottom for furnishing goods through a horizontal access opening of the box, a frame running around the upper edges of the side walls.

3) Method of manufacturing : Refrigerated repositories and sales management system for refrigerated storage(Patent No : US007246504B2)

Appendix A.4 (CONT) Patent Search

- A method of manufacturing cooling storage units and a sales management system is to be provided for the same permitting the exclusion of a made-to-order production system which indispensably requires pre-shipment cooling tests.

4) Refrigerator cabinet with separate food storage rooms(Patent No : EP1167901A1)

- A refrigerator cabinet of a type intended for application in professional kitchens and catering operations, which is provided with at least two separate storage rooms adapted to accommodate food-stuffs of different kind

5) Refrigerator cabinet having a lockable compartment for valuables(Patent No : EP0246207A1)

- Cabinet having a lockable compartment for valuables. The object of the invention is to bring about such a Cabinet which in a suitable way houses a lockable compartment for valuables.

6) RF pont of sale and delivery method and system using communication with remote computer and having features to read a large number of RF tags(Patent No : US0069018A1)

- A method and system for providing point-of-sale and point-of-delivery and/or distribution of products in a restricted access unit near the customer.

7) Transparent reach-through curtain for open refrigerators(Patent No : UN004296792)

- A transparent, flexible curtain with spaced access points is provided for installation over the opening of a display type open refrigerator or the sort used in retail food markets.

2. KP
   1) Cabinet refrigerator(Patent No : KP019325)
      - This cabinet refrigerator is for group residence like a dormitory, hotel, hospital which is needed to be used public. It keeps safety each user’s stuff. Also it saves energy than individual refrigerator.

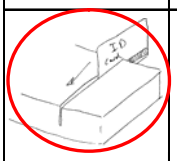
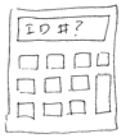
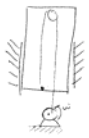
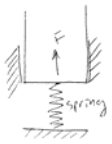
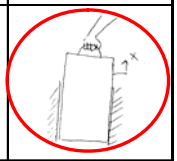
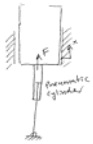
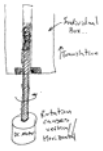
   2) Multiple refrigerator which keeps stuff different temperature(Patent No : KP0020420)

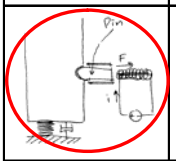
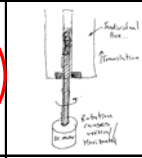
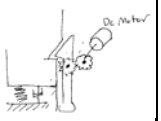
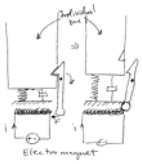
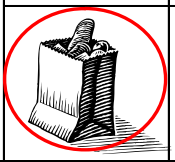
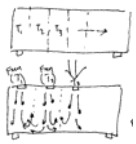
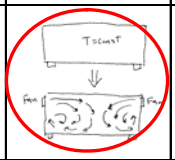
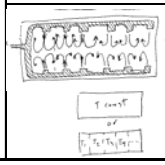
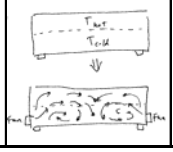
   3) Refrigerator consist of vertical/horizontal cabinet(Patent No : KP0014308)

   4) Rotating cabinet refrigerator (Patent No : KP015323)

   5) Method of controlling and monitoring system in refrigerator(Patent No : KP0033147)

Appendix A.5 Drawings for Working Principles

Sub-Function	Working Principal #1	Working Principal #2	Working Principal #3
User Identification	ID Card Identification	Key Pad Identification	
			
Storage Box Opens/Closes	Motorized Movement	Potential Energy	Manual
			
			
			
			

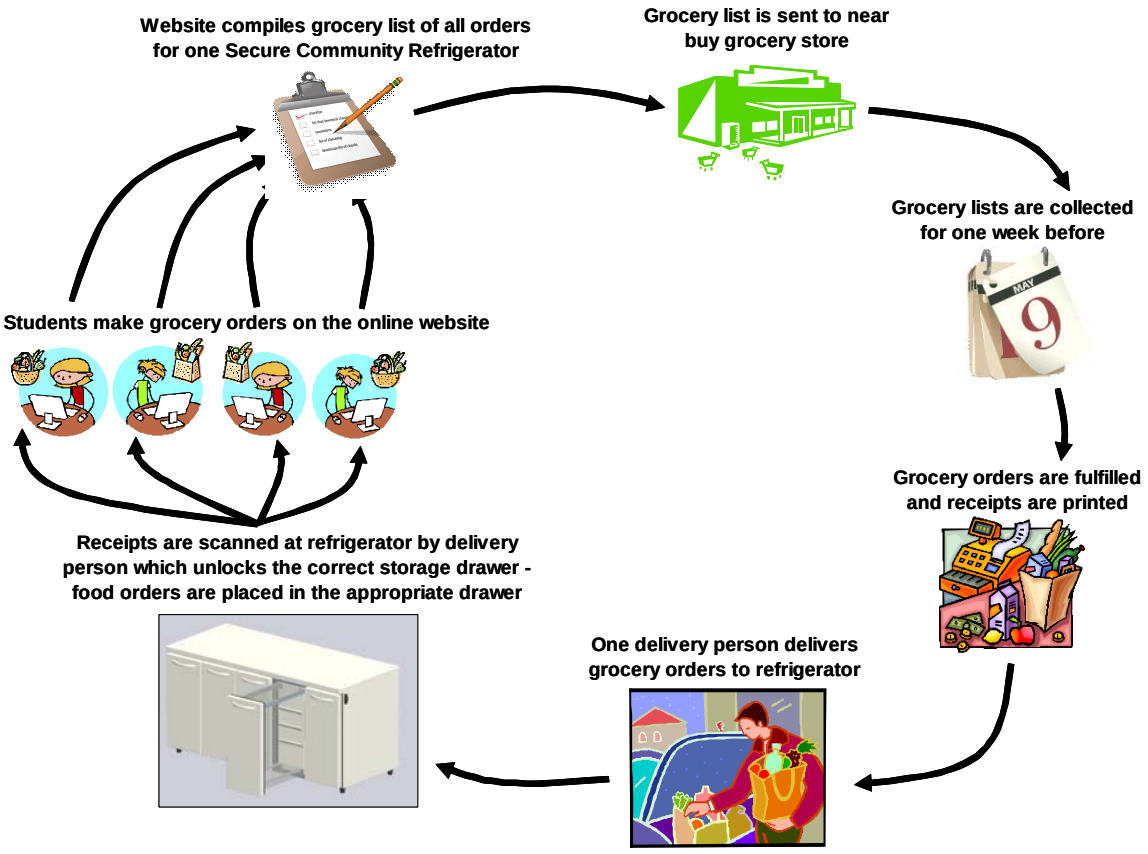
Sub-Function	Working Principal #1	Working Principal #2	Working Principal #3
Storage Box Unlocks/Locks	Electromagnetic Switch	Translational Screw (driven by motor)	Gear System Mechanism
			
			
User Adds/Removes Food	Manual	Order Groceries Online	
			NOT FOR INITIAL SCOPE OF PRODUCT - BENEFIT FOR NEXT GENERATION PRODUCT
Food Remains Cool	Storage Boxes Individually Cooled/Controlled	One Cooling System for Entire Unit	
			
			

Appendix A.6: Diagrams explaining how the internet connection enables a closed loop-system

Online Grocery Ordering System

SAVES TIME: One person deliveries groceries instead of every student going to separately store

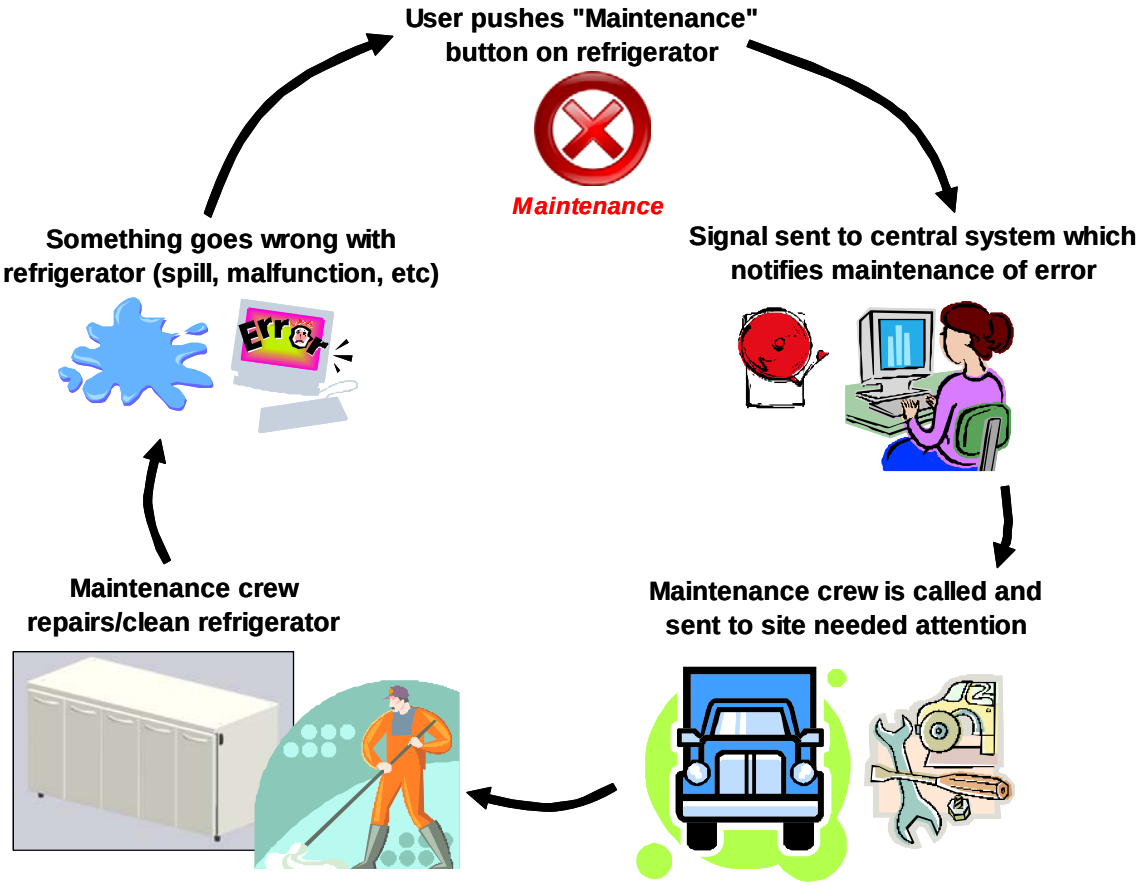
SAVES RESOURCES: Only one person delivers groceries instead of each student traveling separately - saves resources such as gasoline



Appendix A.6 (cont): Diagrams explaining how the internet connection enables a closed loop-system

Online Maintenance System

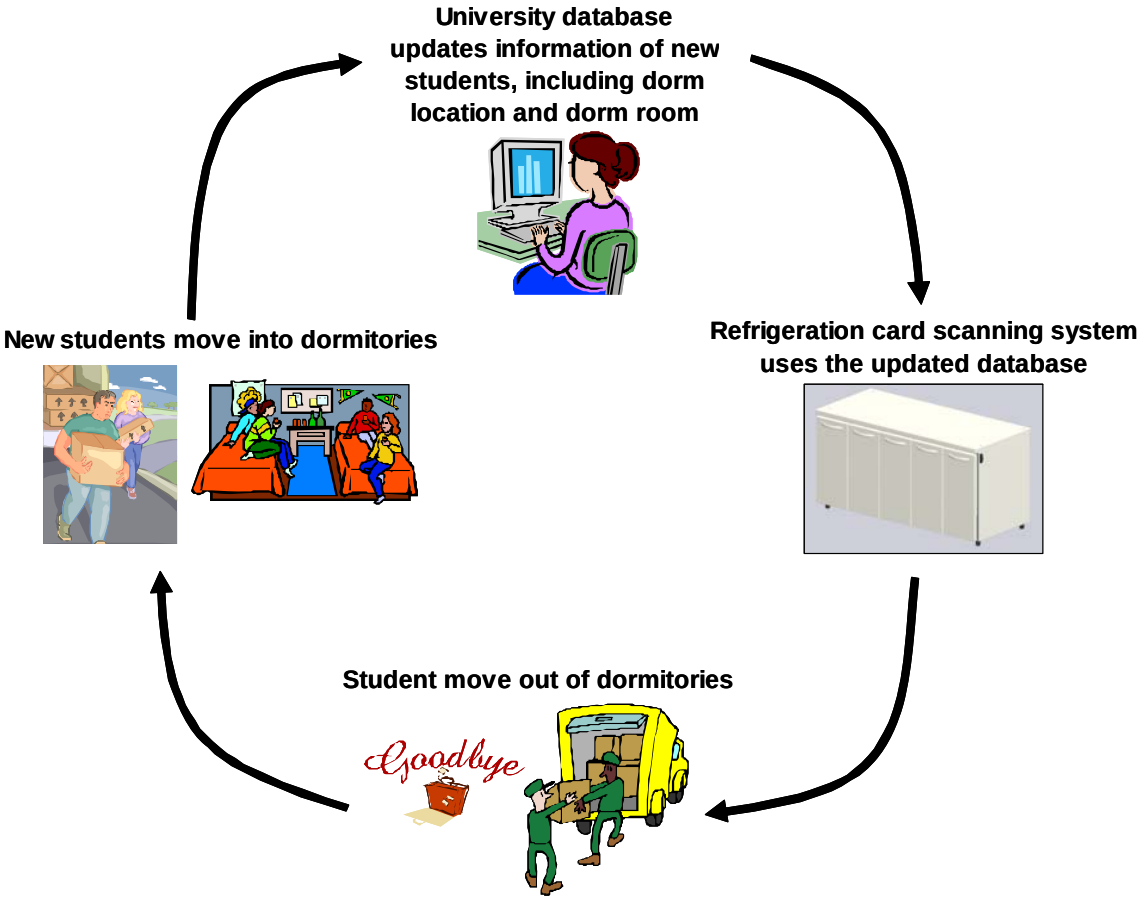
SAVES TIME: Less time between repairs
SAVES RESOURCES: Less time to maintenance means less food is spoiled



Appendix A.6 (cont): Diagrams explaining how the internet connection enables a closed loop-system

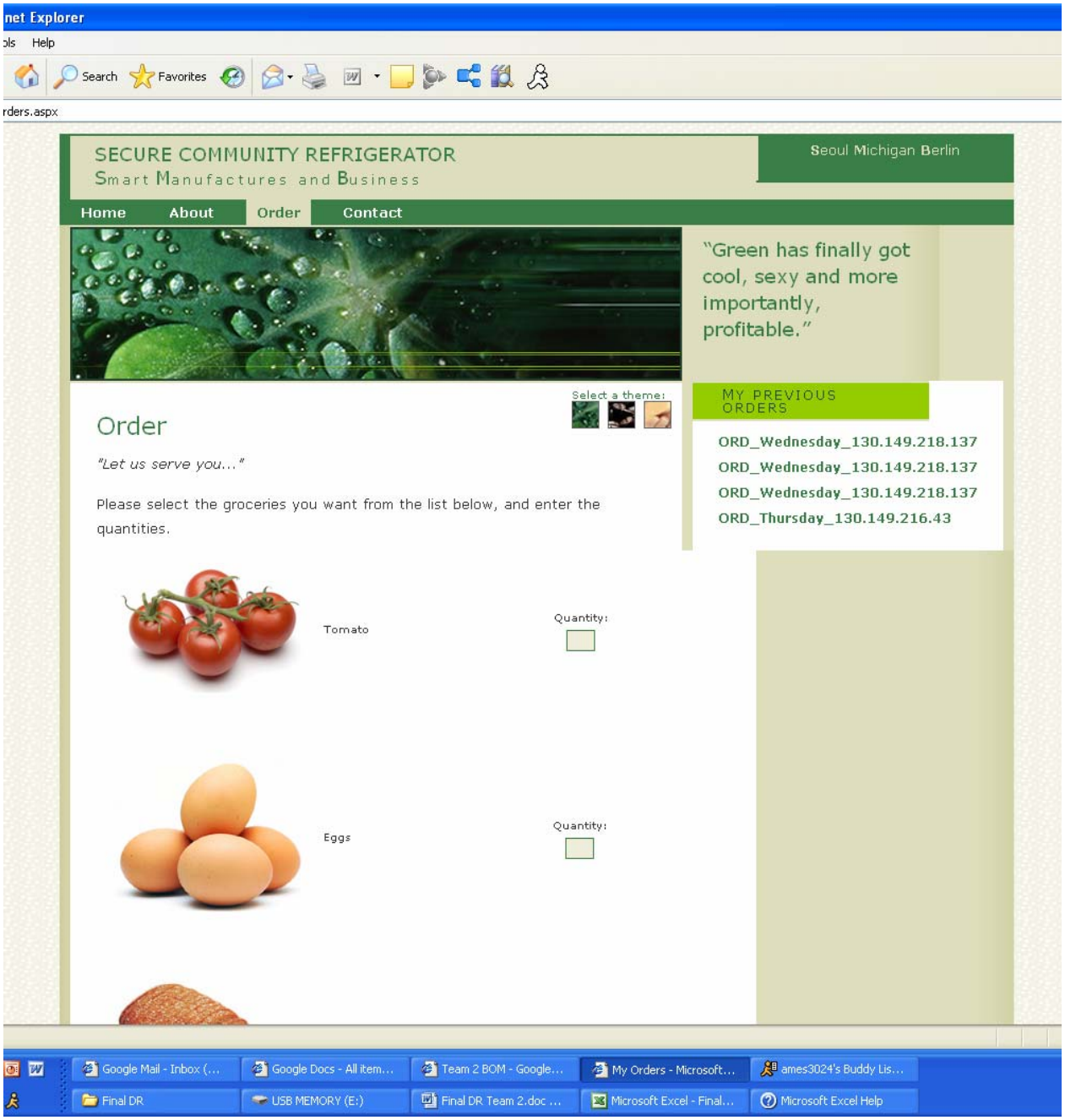
Automatically Updating Database

SAVES TIME: Database automatically updates instead of manually re-assigning storage drawers



Appendix A.7: Webpage screen shots of online grocery ordering system

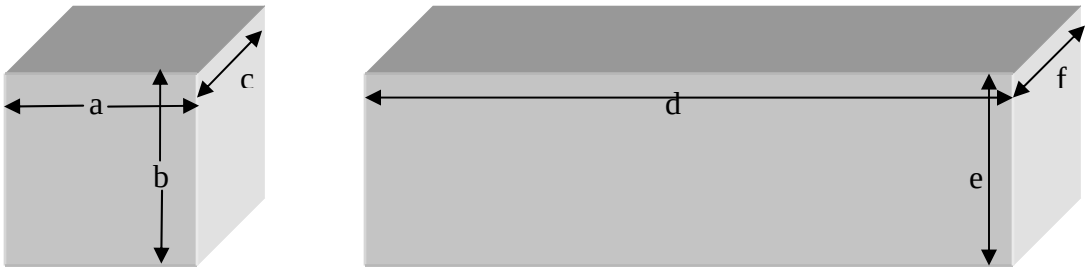
Appendix A.7 (cont): Webpage screen shots of online grocery ordering system



Appendix A.8 Bill of Materials – Product

PRODUCT BOM- Top Level					
Part Description	**Size (mm)**	**Material**	**Finish**	**Process**	**Qty**
Common Parts					
Supplied Parts					
Compressor motor		n/a	n/a	n/a	1
Condenser fan		n/a	n/a	n/a	1
Evaoprator fan		n/a	n/a	n/a	1
Air duct	30mm outside diameter	n/a	n/a	n/a	1
Heat exchanger fins		n/a	n/a	n/a	1
Throttle valve		n/a	n/a	n/a	1
Refrigerant tubing	3mm OD, 0.5mm thickness	Copper	n/a	n/a	15 m
Refrigerant		R-134a	n/a	n/a	2 L
AC motor controller		n/a	n/a	n/a	1
Electrical connection harness		n/a	n/a	n/a	2 m
AC power cord		n/a	n/a	n/a	1 m
Magnetic card reader		n/a	n/a	n/a	1
Legs		Steel	Painted	n/a	6
Hardware, sheetmetal screws		Stainless Steel	No finish	n/a	100
Adhering Insulation	Bulk	?		Spray/Injection	10 L
Custom parts					
Top cover	2mm thick	Steel Sheetmetal	Painted, textured	Stamping, bending, welding	1
Side panel	2mm thick	Steel Sheetmetal	Painted, textured	Stamping, bending, welding	2
Back panel	2mm thick	Steel Sheetmetal	No finish	Stamping, bending, welding	
Bottom panel	2mm thick	Steel Sheetmetal	No finish	Stamping, bending, welding	
Suppoort posts	25mmx25mm square tube	Steel	No finish	Cutting, welding	6
Inside covering	3mm thick	Fiber glass? PPE?	Gloss cosmetic finish	Thermoformed	1
End Unit mounting bracket	2mm thick	Steel Sheetmetal	No finish	Stamping, bending	2
Unit mounting bracket	2mm thick	Steel Sheetmetal	No finish	Stamping, bending	4
US Model					
Supplied Parts					
AC power converter	120VAC to 12 VDC	n/a	n/a	n/a	1
Custom parts					
Steel seal face plate	2 mm thick, 5 openings	Steel Sheetmetal	No finish	Stamped	1
ASSY- Inidividual unit (US)					5
ASSY- Locking Mechanism					5
Korean Model					
Supplied Parts					
AC power converter	220VAC to 12 VDC	n/a	n/a	n/a	1
Custom parts					
Steel seal face plate	2 mm thick, 7 openings	Steel Sheetmetal	No finish	Stamped	1
Adtnl unit mounting bracket	2mm thick	Steel Sheetmetal	No finish	Stamping, bending	2
ASSY- Inidividual unit (Korean)					7
ASSY- Locking Mechanism					7
Individual Unit- SUB-BOM					
Part Description	**Size (mm)**	**Material**	**Finish**	**Process**	**Qty**
Common Parts					
Supplied Parts					
Adhering Insulation	Bulk	?		Spray/Injection	1 L
Full-extension cabinet pull	610mm long	Steel	n/a	n/a	2
Unit mounting hardware		Stainless steel	n/a	n/a	10
Hardware, sheetmetal fasteners		Stainless steel	n/a	n/a	10
Custom parts					
Structural bar	600mm long	Steel	Brushed	Cast, machined	4
US Model					
Supplied Parts					
Door handle	Center to center width	Stainless steel	Coated, textured	n/a	1
Door seal (adhesive back)		Polyurethane foam	n/a	Cut	1
Back seal (adhesive back)		Magnetic vinyl strip	White	Cut	1
Custom parts					
Shelf housing	2mm thick	Steel sheet (mesh)	Painted	Trimmed, bent	1
Door structure	2mm thick	Steel Sheetmetal	Painted, textured	Stamping, bending, welding	1
Door inside panel	3mm thick	Fiber glass? PPE?	Gloss cosmetic finish	Thermoformed	1
Back structure	2mm thick	Steel Sheetmetal	No finish	Stamping, bending, welding	1
Back inside panel	3mm thick	Fiber glass? PPE?	Gloss cosmetic finish	Thermoformed	1
Shelf		Steel wire	Painted	Trimmed	1
Korean Model					
Supplied Parts					
Door handle	Center to center width	Stainless steel	Coated, textured	n/a	1
Door seal (adhesive back)		Polyurethane foam	n/a	Cut	1
Back seal (adhesive back)		Magnetic vinyl strip	White	Cut	1

Appendix A.9 Material Savings Calculations



Firstly, using SCR will simply save side insulation material since SCR merges multi mini-refrigerators.

If we treat the SCR United States version with 5 drawers material savings calculation will be the following:

Insulation Material Used in a Mini-Refrigerator= 2ab+2bc+2ac

Insulation Material Used in 5 Mini-Refrigerator= 5 * (2ab+2bc+2ac)=10ab+10bc+10ac

Insulation Material Used in SCR = 2de+2ef+2df

Since de=5ab, ef=bc, df=5ac
Insulation Material Used in SCR = 2*5ab+2bc+2*5ac=10ab + 2bc + 10ac

Therefore insulation material saving=10ab+10bc+10ac-(10ab + 2bc + 10ac) = **8bc**

In an average mini-refrigerator ‘b’ would be 84cm and ‘c’ would be 60cm.

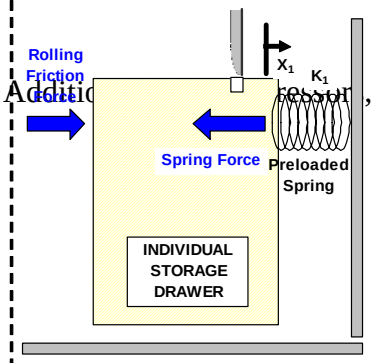
Consequently insulation material saving by using SCR will be roughly 4m^2 which is slightly enough to insulate 1,6 mini-refrigerator.

Additionally, 4 compressors, 4 compressor cables and 4 plugs will be saved as well.

Appendix A.10 Engineering Analysis of Force Requirements for Individual Storage Drawer

Additional resistor, 4 compression springs and coupling

Initial Unlock of Drawer



Initial Unlock of Drawer

Purpose: *Determine the minimum spring constant for the preloaded spring.*

Once individual storage box is unlock, it will pop slightly open. This will only happen if the spring force is greater then the rolling friction force since the drawer is on tracking with rollers. **This analysis determined that the spring constant for the preloaded spring must be greater than 400 N/m (2 lb/in).**

Variables:

$\mu_{bearing} = 0.02$

$m_{box_{max}} = 100kg$

$g = 9.81m/s^2$

$x_1 = 0.05m$

Equations:

$F_{spring} \geq F_{friction_{rolling,max}}$

$k_1 x_1 \geq \mu_{bearing} m_{box} g$

$k_{1_{min}} = \dfrac{\mu_{bearing} m_{box_{max}} g}{x_1}$

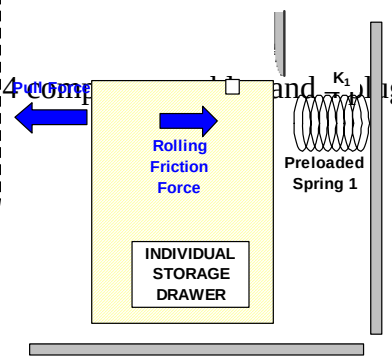
$k_{1_{min}} = \dfrac{(0.02)(100kg)(9.81m/s^2)}{(0.05m)}$

$k_{1_{min}} = 400N/m$

$(k_{1_{min}} = 2lbs/in)$

μbearing determined from website source for steal rolling on steal
http://www.roymech.co.uk/Useful_Tables/Tribology/co_of_frict.htm

Pulling Open the Drawer



Pulling Open the Drawer

Purpose: *Determine the maximum pull force needed to open the drawer and make sure this force is within the specifications.*

Once is unlocked, the user must pull the drawer open. The pull force must be greater then the rolling friction force. **This analysis proves the maximum pull force is within our specifications.**

Variables:

$\mu_{bearing} = 0.02$

$m_{box_{max}} = 100kg$

$g = 9.81m/s^2$

Equations:

$F_{pull} \geq F_{friction_{rolling,max}}$

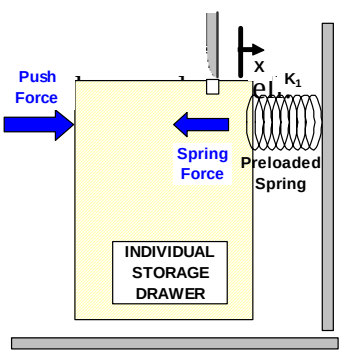
$F_{pull_{max}} = \mu_{bearing} m_{box_{max}} g$

$F_{pull_{max}} = (0.02)(100kg)(9.81m/s^2)$

$F_{pull_{max}} = 20N$

$(F_{pull_{max}} = 4.5lbs)$

Closing Drawer



Closing Drawer

Purpose: *Determine the minimum push force needed to close the drawer. Determine the maximum spring constant for the preloaded spring.*

In order to close the door, the push force must be greater than the spring force. The rolling friction is not taken into account since rolling friction only acts when the motion starts at rest. **This analysis determined the spring constant range must be between 400 N/m and 500 N/m to maintian forces within the specifications.**

Variables:

$k_{1_{min}} = 400N/m$

$x_1 = 0.05m$

$F_{push_{max}} = 25N$

Equations:

$F_{push} \geq F_{spring}$

$F_{push_{min}} = k_{1_{min}} x_1$

$F_{push_{min}} = (400N/m)(0.05m)$

$F_{push_{min}} = 20N$

$(F_{push_{min}} = 4.5lbs)$

$F_{push_{max}} = k_{1_{max}} x_1$

$k_{1_{max}} = \dfrac{F_{push_{max}}}{x_1}$

$k_{1_{max}} = \dfrac{25N}{0.05m}$

$k_{1_{max}} = 500N/m$

$(k_{1_{max}} = 3lbs/in)$

Appendix A.11 Examples of prototype CAD drawings