Super-Efficient Refrigerator

Final Report – MECHENG 589

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Executive Summary

The topic of conversation is energy consumption and energy saving at home. In this space we are looking at opportunities to conserve energy by improving a product or a process, therefore, reducing its energy consumption. This project aims to improve the eco sustainability of the domestic refrigerator by focusing on reducing the energy usage of the appliance. The energy used to power refrigerators is mainly supplied through burning of fossil fuels with an ever increasing economical and environmental cost. Therefore, any reduction in energy consumption will result in reduced CO2 emissions as well as reduced power bills for the end user of the refrigerator.

Each year 513 TWh of electricity is used in the US households. 19% of this energy is used to run the domestic refrigerator. A refrigerator's main power consuming component is the compressor which runs 80%-90% of the time keeping the inside temperature approximately 4 deg C. Furthermore, there are approximately 1500 million refrigerators in the world, many up to 20 years old. The interesting contradiction is that in colder climates where outside temperature is 4 deg C or less, households generally have a refrigerator inside the heated house working hard to cool the chamber down to a similar temperature to that outside the house

The project solves this inefficiency by using the outside cold air to improve the efficiency of the refrigerator in the most simple design execution. It also aims to change as little as possible in a conventional fridge. The need is based on the high volume of refrigerators in use globally and amount of time a refrigerator is running during each day. This is further explored in the whole system and life cycle thinking and it is shown that highest energy consumption stage in a refrigerator's life cycle is during the usage phase and it is in the form electricity running the compressor 80-90% of the time. So by sheer volume any improvement in reducing power consumption is usage phase of the refrigerator will add to up a significant gain in eco sustainability of a refrigerator globally and through its life cycle. This will also turn directly into financial gain for the end customer in terms of lower power bills and reduced CO2 emissions. The limitation of the idea is that it can only be successfully used in cold climates to gain maximum benefit and it required kitchen modifications for fit and operate the Super-Efficient Refrigerator.

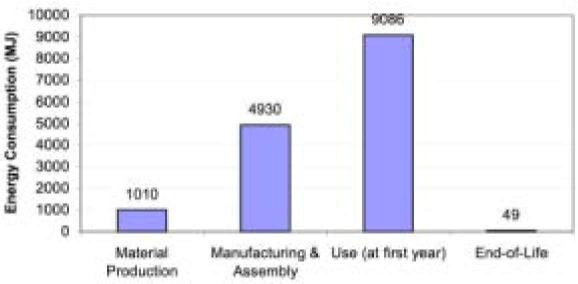
Although, the business case is not an automatic over the line case, it still shows a profit long term, therefore, still economically viable and the project reduces environmental impacts as well as providing economical benefits in the way of cost savings for the end user. Therefore, it is consistent with eco-efficient and sustainable design.

Introduction

According to US EPA 2004 data, the refrigerator / freezer accounts for 9 to 25% of the U.S household energy consumption. The refrigerator is amongst the most widely used appliances in the world and it is safe to assume every household in the developed countries has at least one average size refrigerator if not 2 or more, as well as most houses in the developing countries with at least one refrigerator. This is over and above commercial refrigerators used around the globe, in supermarkets, food outlets, restaurants, cafes, hospitals, hotels, laboratories, trucks, ships, planes, even morgues and many other places. Therefore, any improvement in eco sustainability of a refrigerator, however marginal will result in a significant impact on the environment through sheer volume and presence around the globe.

This project aims to improve the eco sustainability of the domestic refrigerator by focusing on reducing the energy usage of the appliance. The energy used to power refrigerators is mainly supplied through burning of fossil fuels with an ever increasing production cost. Therefore, any reduction in energy consumption will result in reduced CO2 emissions as well as reduced power bills for the end user of the refrigerator.

In order to justify the decision to focus on reducing the energy usage of the refrigerator the projects needs to consider the whole life cycle of a refrigerator, including resources, raw materials, manufacturing, use and end-of-life. A comprehensive LCA will take a considerable amount of time and resources which is beyond the scope of this project. Therefore, we refer to Life Cycle Optimization of Household Refrigerator-Freezer Replacement by Yuhta Alan Horie, from Centre of Sustainable Systems at University of Michigan. This report states that according to previous LCA studies conducted in Europe, Japan and the U.S; 88% to 97% of total refrigerator life cycle energy is consumed in the use phase regardless of the product size or lifetime (Foley; JEMAI 1995). This is backed up by another LCA on refrigerator the LER200 which also shows that the highest energy consumption of a refrigerator is during its usage phase. The report quantifies this in terms of resource consumption in grams of coal and emissions in grams of CO2. The LER200 LCA showed its resource consumption to be of the order of 265000 (g of coal in use) during usage to next highest value of 150000 in other life cycle stages. Its emissions to air was of the order of 779000 (g of CO2 in use) to next highest value of 170000 in other life cycle stages. Therefore, this project will focus in reducing energy consumption in the usage phase of the domestic refrigerator.



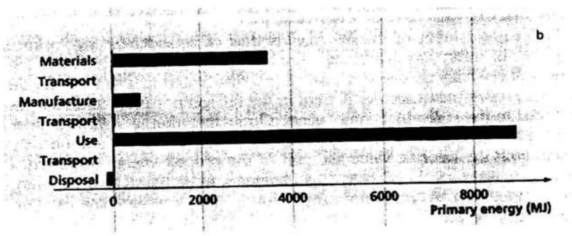


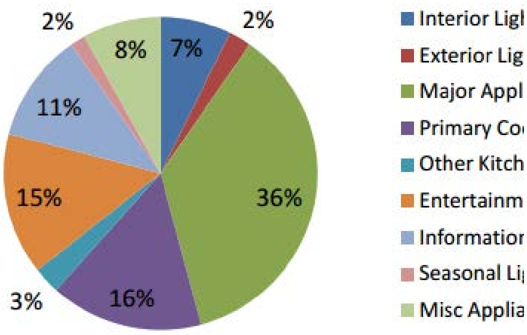
Figure 26.8b. Energy profile. Primary energy consumption

To further explore the energy consumption of a refrigerator in its usage phase we need to determine the overall magnitude of the energy consumption, its corresponding emissions, all the way to identifying the main energy consuming components of a domestic refrigerator.

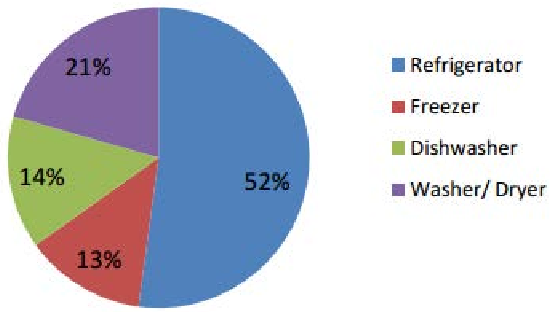
According to the EIA data 36% of US residential energy consumption is from major household appliances. 52% of this household appliance energy usage is contributed to the domestic refrigerators. This puts the refrigerator amongst the top 4 highest energy needs in the household and the major energy usage amongst appliances.

Source: EIA

Contribution of different products to the household electricity usage in the U.S

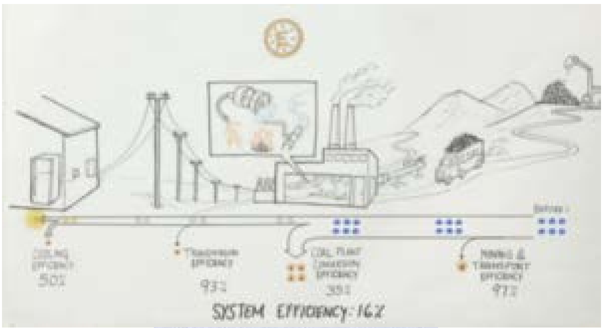


Detailing of main appliances electricity usage



Same source claims that 69% of US electricity is generated from coal, natural gas and petroleum with emissions of 2 lbs of CO2/kWh. This works out to be 461 million tons of CO2 emissions per year in the US from domestic refrigerators alone. This is only in the US; the trend is similar around the globe with variation on the power generation method and the resulting emissions. This data shows that globally there is significant energy consumption and emissions directly from domestic refrigerator usage in households. Any improvement in efficiency and energy consumption of a refrigerator will have a positive environmental impact.

Looking further into the usage phase, the energy used by the refrigerator has its own life cycle. Autodesk's Introduction to Energy Use in Design (http://www.youtube.com/watch?v=P-MJiXa69V4) outlines this cycle as shown below. This project will focus on the last step of the life cycle, the refrigerator itself which runs at an efficiency of 50%. Please note the lowest efficiency is power generation at 35%! (Not in the scope of this project)



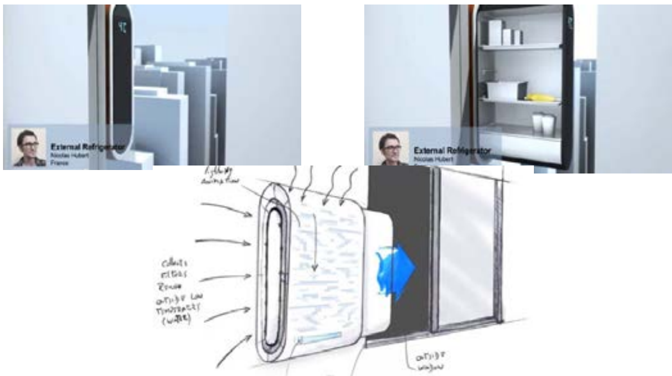
Life Cycle Optimization of Household Refrigerator-Freezer Replacement

The diagram above shows that for every energy unit saved during the usage of a refrigerator six energy units are saved in the overall energy delivery life cycle. This further strengthens the need for reducing energy consumption of a refrigerator.

In order to understand the overall improvements in refrigerator technology in recent times Yuhta Alan Horie in Life Cycle Optimization of Household Refrigerator-Freezer Replacement brings to attention the point that in the period between 1980 and 2002, although, the average size of a refrigerator and its power consumption has increased; US refrigerator efficiency has improved by 60%. The main conclusion from this information is that most conventional technology and major efficiency improvements have been explored over the past two decades. However, the fact remains that a refrigerator, in particular in cold climates, is a sealed box placed in a heated space, using electricity to cool its inside temperature to around 4 deg C, while the outside temperature maybe already 4 deg C or less. There seems to be a fundamental inefficiency in this concept and perhaps an opportunity to reduce power consumption of a refrigerator in such environment.

So the project will focus on the definition of eco-efficient design. Eco-efficient design is achieved when economically viable designs are created that significantly reduce important environmental and societal concerns relative to other available options. The designs need not transform or fundamentally alter consumption or emissions pattern, but they are much better than doing nothing! In this case a simple idea and concept maybe able to reduce the energy consumption of a significant volume of refrigerators by a small amount.

The idea of an energy efficient refrigerator is far from unique. However, using outside cold temperatures to minimise refrigerator power consumption is less common. Although, there are ideas documented from do-it-yourself cooler boxes to well thought out concepts such as one presented by Electrolux Design Lab 2010, there lacks any true product on the market with the ability to alternate between the traditional compressor and outside air to efficiently manage the temperature of the refrigerator.



To summarize a refrigerator is a high volume global appliance and a significant contributor to household energy consumption. In today's society energy is both environmentally and financially at a premium. Therefore, any reduction in energy consumption of a domestic refrigerator can add up to a significant environmental benefits as well as economical benefits to the end user. The refrigerator's main function is to use electricity to cool food to approximately 4 deg C. The main component of a refrigerator is its compressor using up to 80% of power consumed by the appliance. The compressor is on 80%-90% of the time to keep the refrigerator content at 4 deg C. Interestingly in some regions the outside temperature is already 4 deg C or less. Is it possible to harness the cool natural air temperature to minimise the compressor running time and hence, the refrigerator's overall energy consumption?

Description of the Baseline Domestic Refrigerator Being Improved

Any basic information search will explain that a domestic refrigerator is one of the most commonly used appliances in any home and it serves to preserve food, one of the most basic human needs. It is estimated that there are some 1500 million refrigerators around the globe and the modern refrigerator in its current form has been around since the 1940's. As suggested in the introduction the efficiency of the refrigerator has improved by 60% over the past two decades, mainly through improved compressor technology and electronic controls. In the same period many additional features have been added to the basic refrigerator increasing its functionality and energy consumption. Some include freezer section, ice makers, water chillers, display screens, lights, alarms and larger sizes in different formats (ie: side-by-side, freezer top, freezer bottom, extra draws, etc).

The working principle of a refrigerator is based on a vapour compression cycle used in most domestic refrigerators. Refrigerant fluid with low boiling temperatures and good heat exchange characteristics changes state to remove heat from the inside of the chamber. It then looses the gained heat through the condenser pipes to its surrounding environment in the room. For details refer to the figure below. There are other less common cycles such as absorption cycle which are used in smaller refrigerators such as car fridges or where compressor noise and vibration are not practical.

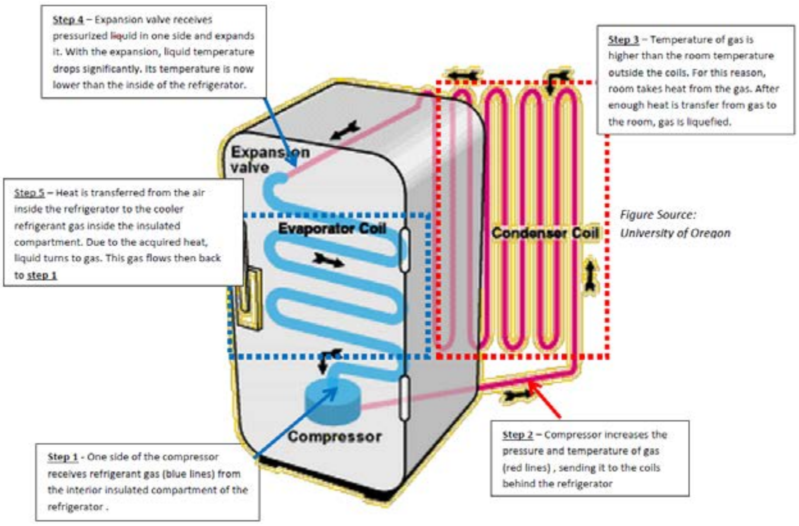
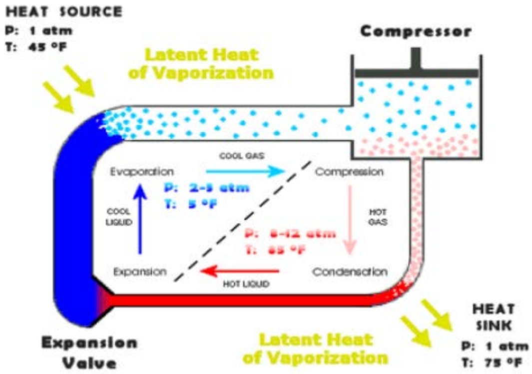


Figure Source:
University of Oregon website



According to energy star data on refrigerators the bench mark in energy efficient refrigerators is a Fischer and Paykel refrigerator only unit consuming 145 kWh/year. The more popular domestic refrigerator types are the side-by-side units with higher energy consumption range. According to published Samsung data their side-by-side units range between 398-621 kWh/year. Other non side-by-side units with top or bottom freezer units use approximately 13%-16% less energy than an average side-by-side unit.

Comparison of Models, Volume, and Consumption, 2003 and 2008

Type of Refrigerator	Models Offered (%)		Median Unit Volume (cubic feet)		Median Annual Electricity Consumption (kWh/year)		2008 Maximum Annual Energy Consumption (kWh/year)	
	2003	2008	2003	2008	2003	2008	Federal Standard	ENERGY STAR
Top Freezer	55	38	18	18	478	454	477	382
Top Freezer-Ice	3	0	18	–	482	–	–	–
Bottom Freezer	5	16	20	21	522	482	573	458
Bottom Freezer-Ice	0	2	–	25	–	554	689	551
Side by Side	5	4	24	25	640	580	661	529
Side by Side-Ice	32	40	25	25	668	607	722	578

Note: Median annual electricity consumption includes ENERGY STAR qualified models. 2008 Maximum Annual Energy Consumption values based on models that include automatic defrost, using median unit size for each configuration. Annual electricity use is calculated based on Adjusted Volume – (Fresh Volume) + 1.63 x (Freezer Volume). Energy consumption of an ENERGY STAR qualified model is calculated as consuming 20 percent less energy than a non-qualified model of the same size and configuration.

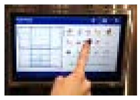
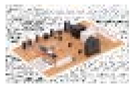
Sources: Models and Median Unit Volume from Federal Trade Commission, U.S. Department of Commerce, 2009. Federal standards from *National Appliance Energy Conservation Act, Code of Federal Regulations 10CFR430.32.* ENERGY STAR criteria from www.energystar.gov.

Based on the more popular choice of refrigerator in the US market this project will use an average side-by-side refrigerator unit with an ice maker using 578 kWh/year. The specifications for our benchmark refrigerator are as listed below.

- Reference refrigerator type: Side-by-side with ice maker
- Annual electricity consumption: 578 kWh/year
- Compressor output temperature: + 32° Celsius

- Compressor output pressure: 8.1 bar
- Condenser output temperature: - 15 Celsius
- Expansion valve output pressure: 1.5 bar
- Refrigerant mass per refrigerator: 0.120 kg

Having established a baseline products, in this section we are going to analyse the power consumption breakdown of the baseline refrigerator by major components. This information will be useful when examining areas of opportunity to improve a refrigerator efficiency and power consumption. As shown in the table below the compressor uses approximately 80% of a refrigerator’s power consumption and it is on 80%-90% of the time.

				
Compressor 80-150 Watts	Lights Bulb: 15 Watts LED: 1 Watt	Display / Touch screen 5-0 Watts	Ventilator 5-7 Watts	Circuit board 3-8 Watts

Design Ethnography

Frame the guiding questions – Design Ethnography

The topic of conversation is energy consumption and energy saving at home. In this space we are looking at opportunities to conserve energy by improving a product or a process, therefore, reducing its energy consumption. From the information presented in the previous sections, EIA data shows that each year 513 TWh of electricity is used in the US households. 19% of this energy is used to run the domestic refrigerator. A refrigerator’s main power consuming component is the compressor which runs 80%-90% of the time keeping the inside temperature approximately 4 deg C. Furthermore, there are approximately 1500 million refrigerators in the world, many up to 20 years old. So due to the relatively high and frequent power usage of a refrigerator, its high presence around the globe and the definite need for the appliance, it is evident that if we improve a refrigerator’s power efficiency and consumption even by a small amount, this will have a significant environmental, social and economical impact.

Much has been done already to make a refrigerator as efficient as possible. As per the introduction, through improvements in compressor technology and electronic controls, over the past two decades a refrigerator’s efficiency has improved by 60%. However, this does not mean a net reduction in power consumption. Cultural, social and economical factors have contributed to the end user, using larger refrigerator units with more features increasing power consumption in the same period of time.

One opportunity in this space does not seem to have been explored as much. The interesting contradiction is that in colder climates where outside temperature is 4 deg C or less, households generally have a refrigerator inside the heated house working hard to cool the chamber down to a similar temperature to that outside the house. At this stage of the project the guiding questions to define the project boundaries are, is it possible to seamlessly use the outside cold air in order to minimise the compressor’s workload? Are there certain geographical regions where this idea is more viable? What incentives and benefits are required to encourage users and stakeholders to use such product?

Define the “who” – Design Ethnography

The “who” for any project must identify stakeholders in the whole of the product life cycle, including their roles and expectations. The end user, manufacturer, distributor, logistic supplier, point of sale, subject matter experts, regulation and test centre bodies, review forums and a project client.

For the Super-Efficient Refrigerator, we are going to assume where the fit and function of the conventional baseline refrigerator has not changed all stakeholder's expectations are met. We will define the "who" for modified fit and function aspects of the Super-Efficient Refrigerator from its baseline product.

The end user of a domestic refrigerator can be anyone: male, female, of any age, race, culture or country. However, assuming the appearance and operation of a conventional refrigerator remains the same; the average everyday user will not notice any difference. Therefore, the specific end user, targeted by the Super-Efficient Refrigerator is the sub group of total end users who make the decision on which refrigerator to buy in the household. So the design, functionality, marketing content and business case must be geared towards the decision maker who will be convinced to choose the Super-Efficient Refrigerator over the conventional refrigerator. There are three types of decision makers. First is the person choosing a new fridge to replace the old one. This maybe male or female, head of the household or the minister for internal affairs! The second is the home owner planning the build of a new house and choosing new appliances. The third is the builder looking for a competitive advantage by choosing the Super-Efficient Refrigerator. Based on our research, due to the kitchen modification required to fit this product into the house it is unlikely that the first type of user finds this product suitable. That leaves us with the second and third category as the main target users.

The stakeholders that are affected by the changes between the baseline refrigerator and the Super-Efficient Refrigerator are the manufacturer, distributor, logistic supplier and point of sale. The aim is to make the difference between the baseline and the improved product as transparent to the supply chain as possible. Therefore, during setup of the design specifications the needs of the above groups will need to be taken into account.

The expert's opinion and reviews of the Super-Efficient Refrigerator will play an important role in both getting the product to market as well as selling it. Therefore the "who's" such as regulation bodies, review forums and subject matter experts such as after sales service organisations, OEM refrigerator manufacturers must be consulted during the design process.

Based on the project business case there are two possible clients. One maybe a partner OEM refrigerator manufacturer, who will need to be convinced to take on the project and add the Super-Efficient Refrigerator to their product line-up. The other is a group of investors who will see a business case in investing in setting up a standalone company for the design and manufacture of the Supper-Efficient Refrigerator.

In conclusion from the results of this project the target end users will be able to save money on running cost for an initial investment outlay, the supply chain stakeholders will see little or no change to their methods and processes and the client will be able to increase profitability at the same time as meeting their social corporate obligations on eco sustainability.

Synthesize existing knowledge – Design Ethnography

Summary – For details see appendix III

There is extensive existing knowledge researched on domestic refrigerators. The details of each heading are documented in appendix III. Below is a summary of the findings that led to the decision making and design process through this project.

REFRIGERATORS ARE BIG ENERGY CONSUMERS

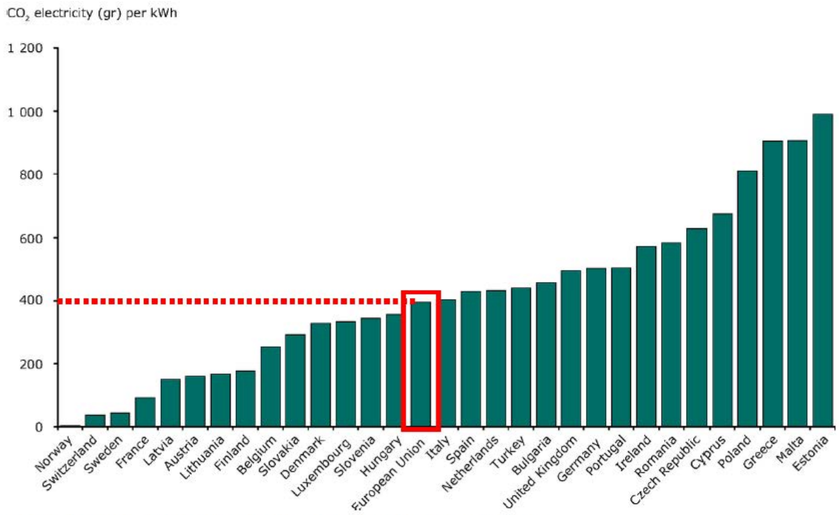
Household energy use represents some 513 TWh of electricity per year in the US alone. Approximately 19% of this consumption is from domestic refrigerators, making the fridge one of the top 4 power consuming appliances. The main contributors are the fact that refrigerators are running 80%-90% of the time and the very large number of refrigerators present around the world, approximately 1500 million. Therefore, the domestic refrigerator is a viable target for improving efficiency and reducing power consumption.

REFRIGERATOR LIFE CYCLE ENERGY CONSUMPTION

Based on information presented in two LCA reports referenced in this project, one year of in-use energy consumption is more than all other life cycle phases of the refrigerator combined. Therefore, in the process of improving efficiency the in-use cycle is the most appropriate of the life cycle phases to focus on

EMMISIONS FROM POWER GENERATION

Considering that approximately 69% of the whole electricity generated in the U.S. is based on coal, natural gas and petroleum, approximately 461 million tons of CO2 is being emitted each year just from the number of refrigerators in households. This amount is less in countries with cleaner power generation cycles but still a considerable figure.



CO2 emission per kWh of electricity generated in the European Union
Source: European Environment Agency

END-OF-LIFE CONCERNS

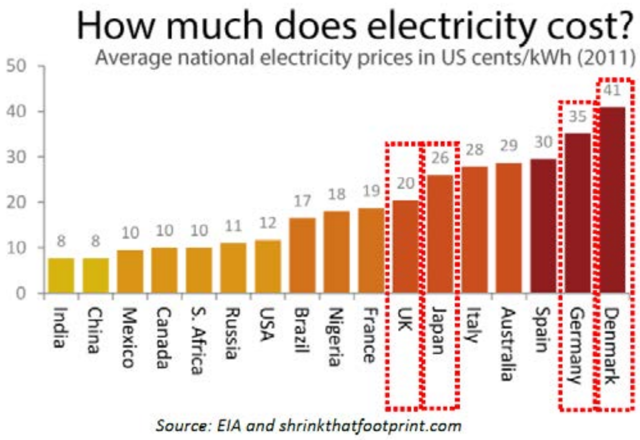
Although, the main concern in this project is reduction of energy consumption, there are other eco sustainability concerns with the disposal phase of domestic refrigerators. The main concern is with the recycling of the toxic refrigerant gas. Traditionally, fluorocarbons, especially CFC's (chlorofluorocarbons), were used as refrigerants. However, these gases have been phased out since they are ozone depleting and global warming inducing compounds. Modern day refrigerant is R-134A HFC (Hydroflourocarbon) which is safe for the ozone. Therefore, even though the quality and toxicity of refrigerant gases have been improved, up on disposal of old refrigerators it is vital that refrigerant is drained and disposed as per the guide lines rather than escaping into the atmosphere. Data shows in the US alone 25% of old refrigerators are not disposed thoughtfully, meaning there is the possibility that some or the entire refrigerant is released into the atmosphere. On average a refrigerator contains 120 grams of refrigerant; any reduction in this volume will reduce the end-of-life concerns regarding the release of the refrigerant into the atmosphere.

Other disposal concerns are presence of CFC's in the insulation foam pre 2005, contaminated oil (containing refrigerant) and finally the refurbishing of old refrigerators and re-use in developing countries, meaning inefficient old refrigerators with possible refrigerant leaks are still being used. The major concern with these is the re-gassing process which significantly adds to the environmental impact of the end-of-life cycle.

ELECTRICITY COST RESEARCH

The direct benefit and incentive of the Super-Efficient Refrigerator to the end user is the reduced household power bill each year. Research shows that the cost of electricity in both dollars and emissions is globally on the rise. This is much more evident and a deciding factor in Europe, in particular in countries such as Germany and

Denmark where electricity cost is very high. Therefore, a more favourable business case and the first market for the Super-Efficient Refrigerator are in countries where both electricity and emissions are at a premium.



CLIMATE RESEARCH

Similar to the cost of electricity, climate is a geographical factor that helps the business case and overall efficiency of the Super-Efficient Refrigerator. So far based on the ethnographic research there is much work done on improving and optimising the efficiency of a refrigerator. The main principal and need identify through our research is that in cold climates we are using energy to cool the inside of a refrigerator when the outside temperatures are at or below what is required inside the refrigerator. In such climates the use of the Super-Efficient Refrigerator makes complete sense even if it was to be cost neutral. Again due to the large number of refrigerators and emission concerns from power generation such improved efficiency will be welcomed globally

So looking at the overall globe's climate zones and population density in these zones we can map out a geographical boundary for this product. The Super-Efficient Refrigerator will be marketed in these zones. According to the Koppen classification the world can be divided into the following climate classes:

Group A – Tropical/megathermal climates: zones with constant high temperature with an average of 18 Celsius or higher during the 12 months of the year

Group B – Arid and semiarid climates:

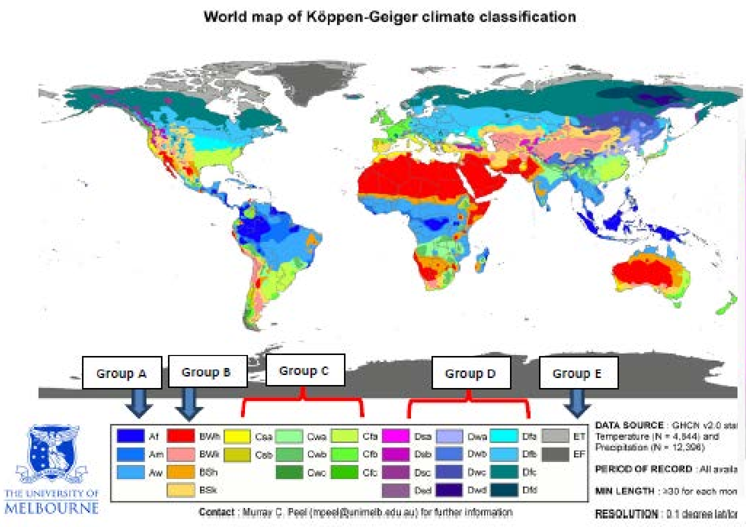
Group C – Mild Temperate/mesothermal climates: zones with average temperatures above 10 Celsius on the summer and averages from -3 to 18 Celsius on the winter

Group D – Continental/microthermal climates: zones with average temperatures above 10 Celsius on the summer and averages below -3 Celsius on the winter

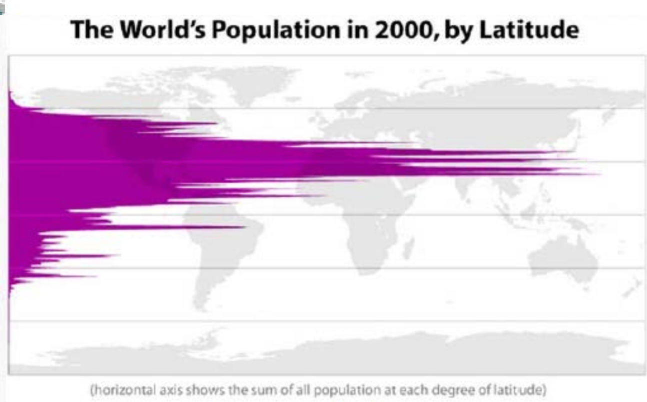
Group E – Polar climates: zones with average temperature below 10 Celsius during the 12 months of the year.

Group C	Group D	Group E
Western Europe, Southeast USA, South Japan, Southeast China, South Korea	**North of USA, South and Central Canada, Alaska, northern and eastern Europe, Russia, North Japan, North Korea**	**Northern Canada, Greenland, Northern Russia**

This information helps narrow down out target market to climate zones C, D and E.To further specify a geographical market boundary for the Super-Efficient Refrigerator the population density of each of the climate regions are examined. Up on investigation it is evident that most population in climate zones C,D and E are concentrated in the northern hemisphere between latitudes 27N and 40N.



Source: University of Melbourne



Source: radicalcartography

In conclusion, within climate zone C,D and E, mainly in the northern hemisphere there are densely populated regions with cold climates where our product improvement idea would have a favourable environment for success.

NEW HOMES AND REFRIGERATORS

According to energy star reports, in the US, from some 9 million new refrigerators sold each year prior to 2008, 20% were not replacing existing refrigerators. This figure has fallen to 5% since 2008, corresponding to the fall in new homes being build due GFC. This equates to just fewer than half a million new refrigerators entering the market into new houses, each year.

This number corresponds to a report presented by the US Census Bureau confirming that 483,000 new homes were constructed in 2012. Most of these new homes will be furnished with new refrigerators. From these new homes 67% were build by professional builders and 33% by owner builders.

FRIGORIFIC CYCLE

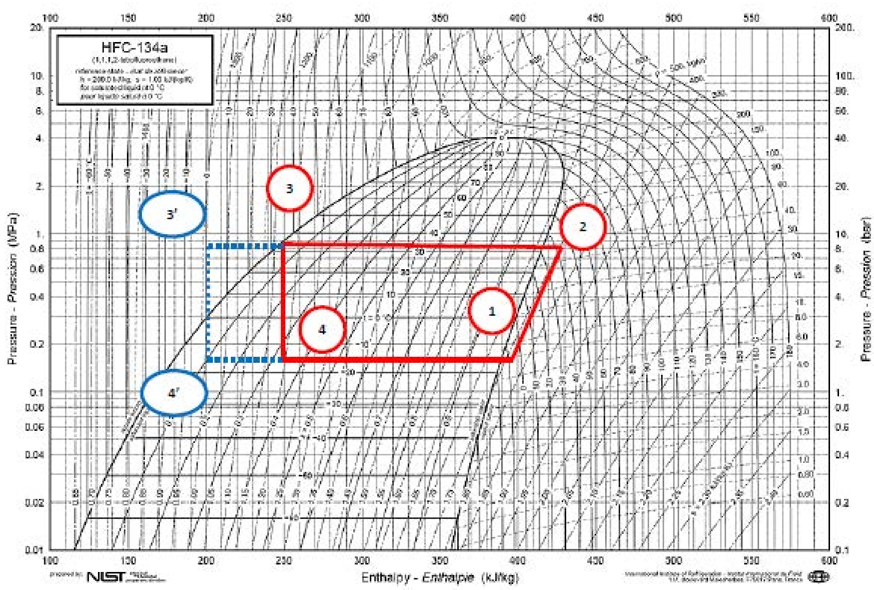
Frigorific cycle is the theoretical cycle representing refrigeration cooling cycle. The cycle consists of 4 steps summarized below.

Point 1 to 2: compression phase at constant entropy

Point 2 to 3: condensation phase, at a constant pressure and temperature

Point 3 to 4: expansion phase, at a constant enthalpy

Point 4 to 1: evaporation phase, at a constant pressure and temperature



Energy delta h2-h1 is provided by the compressor to the refrigerant as cooling energy. Energy delta h1-h4 is heat energy collected by the refrigerant from the refrigerator compartment. Therefore, cycle efficiency is the ratio of the two energy transfers,

(η) is $\eta = (h1-h4) / (h2 - h1)$.

The R134a pressure enthalpy graph shown in the previous diagram assumes common operating temperatures from W. Trevizan handbook. Temperatures T4 to T1 of -15 deg C and T2 to T3 of +32 deg C. Using sub-cooling, which in effect, is the theory behind the Super-Efficient Refrigerator the cycle efficiency can be improved by worthy increments. See the blue cycle line on the previous diagram.

from 30° to 0° C
$\eta = (h1-h4) / (h2 - h1) = (400 - 250) / (450-400) = 3$
Improved η: $(h1-h4') / (h2 - h1) = (400 - 200) / (450-400) = 4$ => 33% improvement

RESEARCH CONCLUSIONS
From the ethnographic research material presented above the following conclusions are made and targets set.

It was established that refrigerators are globally significant energy consumers mainly due to high quantity of refrigerators and the long running time of each domestic refrigerator. Looking at LCA data it was shown that the usage cycle of a refrigerator uses more energy in one year than the entire life cycle of the appliance. Hence, looking at improving efficiency of the domestic refrigerator in it usage phase is a viable eco sustainability improvement project.

Linking the power consumption and other refrigerator end-of-life concerns back to CO2 emissions provides a common scale for assessing the environmental impact of different options in the project as well as the environmental evaluation of the final product.

The target user of the Super-Efficient Refrigerator is defined geographically as cold climate countries with high energy cost. Also, based on kitchen modifications required to fit a Super-Efficient Refrigerator, it was shown that there is a reasonable size market of half a million new homes a year in the US alone that can be targeted. From these new homes two personas emerge. 67% are the professional builders who decide the type and price of the refrigerator they spec for the new house and 33% are the owner builders making the same decision.

The final section briefly explores the technical theory behind the Super-Efficient Refrigerator idea. It explains the refrigeration cycle efficiency improvement resulting from super cooling the refrigerant.

Determine data collection methods – Design Ethnography
After determining the end user demographic as builders or owner builders of new homes in cold climates with high electricity cost, the project needs data on the actual needs and wants of people with respect to refrigerators and energy saving. Also, we need people's perception of what the value of such concept is and their willingness to pay. To collect this data the project used an interview based data collection method. A number of questions were designed to collect the relevant data:

i. Do you consider power saving ideas in your daily life?
ii. Are you open to an alternative refrigerator setup in order to gain a saving on your power bill?
iii. How much money per year off your power bill do you consider a good enough saving to make it worth your while?
iv. How much extra are you willing to pay for an energy saving feature over and above whatever amount you decide to pay for a new fridge?
v. What is an acceptable payback time (how many years to make your money back?) for any money you decide to invest in an energy saving refrigerator in reduced power bill?
vi. If buying or building a new house do you consider energy saving features in your decision making process?
vii. If yes, if a new house is fitted with a power efficient refrigerator by the builder will it affect your decision?
viii. If yes, if a new house is fitted with a power efficient refrigerator by the builder how much premium are you willing to pay?

Develop the data collection structures – Design Ethnography

See appendix IV for the data collection table used to document the data. 30 people were interviewed by 4 interviewers. The list of questions and the table to record the results helped standardise the results. The questionnaire and interview structure setup was to be simple and to the point in order to minimise any misunderstandings during interpretation and analysis of the results.

Interpret the data – Design Ethnography

The objective of the interviews were to understand if people are really interested in energy saving products in their homes and to what length and cost will they go to get a more energy efficient appliance such as the Supper-Efficient Refrigerator. The final results are documented in the table below.

INTERVIEW QUESTIONS	FINAL RESUTLS
Do you consider power saving ideas in your daily life?	YES
Are you open to an alternative refrigerator setup in order to gain a saving on your power bill?	YES
How much money per year off your power bill do you consider a good enough saving to make it worth your while?	most people $50 but average $180
How much extra are you willing to pay for an energy saving feature over and above whatever amount you decide to pay for a new fridge?	most people $250 but average $330
What is an acceptable payback time (how many years to make your money back?) for any money you decide to invest in an energy saving refrigerator in reduced power bill?	most people 2 years but average 5
If buying or building a new house do you consider energy saving features in your decision making process?	YES
If yes, if a new house is fitted with a power efficient refrigerator by the builder will it affect your decision?	YES
If yes, if a new house is fitted with a power efficient refrigerator by the builder how much premium are you willing to pay?	NO - 12 people who said yes nominated less than 0.1%
INTERVIEW NOTES	Overall comment was that the saving must be real and take into account all costs

Almost all interviewees were interested in energy saving and they all said they would consider an efficient appliance over others when making a decision on buying one or designing and building a new house. Again almost all participants suggested that they would not expect to pay a premium for an energy efficient refrigerator if they are buying a new house, but it would help sway their decision in favour the house that is offering the Super-Efficient Refrigerator. On average they were willing to pay some $330 over and above a conventional refrigerator and expected a payoff of 5 years.

Description of Personas

In early stages of the project it was established that the following characteristics are required in the makeup of the persons adopting this technology.

Environmentally conscious users
Users looking to reduce running costs
The savvier and technologically aware user who can identify higher efficiency
Users higher on the Maslow's hierarchy of needs
Not users using a refrigerator on an absolute survival need bases

Furthermore, from the ethnographic data it is concluded that the personas that would be likely to adopt this product need to be from colder climates with higher energy cost. They are also more likely be building or considering the purchase of a new house. The two personas that would be likely to adopt this product are:

Joe a 40 year old engineer, living in an area with high electricity cost. He is planning to move to a new house since his family is growing and need more room. Joe has decided to purchase land and build a new house. He understands a bigger house along with high power costs will increase his overall energy consumption and cost significantly. Therefore, he is looking for as many energy saving measures as possible to reduce his new home's annual energy consumption. One such measure is energy efficient appliances such as refrigerators, ovens and heating/cooling appliances. Joe setup an investment versus payback equation with a 5 year payback period for each appliance.

John is a North American builder who owns a construction company in Detroit. After the 2008 crisis sale of new houses declined significantly and only recently it is starting to pick up again. Such economy made business difficult for John and competition tough. Therefore, John is looking for an edge over his competition to sway their purchase decision towards his houses. As people are starting to get more environmentally conscious, John believes that energy efficient appliances are a very good option to offer since they help the environment, offer a financial benefit to the end user and wouldn`t be a high investment compared to the overall construction cost.

Project Requirements and Engineering Specifications

BASELINE

Based on the more popular choice of refrigerator in the US market this project will use an average side-by-side refrigerator unit with an ice maker using 578 kWh/year. The specifications for our benchmark refrigerator are as listed below.

Reference refrigerator type: Side-by-side with ice maker
Annual electricity consumption: 578 kWh/year
Compressor output temperature: + 32° Celsius
Compressor output pressure: 8.1 bar
Condenser output temperature: - 15 Celsius
Expansion valve output pressure: 1.5 bar
Refrigerant mass per refrigerator: 0.120 kg

REQUIREMENTS

This project sets out to improve a domestic refrigerators energy efficiency using super cooling during the refrigeration cycle. This leads to the refrigerator offering the same volume, features and usability as a baseline conventional refrigerator with a reduced energy consumption. The benefits from this product are in two fold, globally due to the large number of refrigerators in use there will be a reduction in power consumption and at the user level there will a cost saving in the annual power bill. The following requirements need to be met:

- Refrigerator functionality must remain unchanged
- Minimise new components and changes to existing components
- Minimise modifications to the surrounding areas where the fridge will be placed
- Minimise any changes visible by the supply chain and the end user (other than cost)
- Avoid changes to the refrigerator that will require the baseline product to re-validate
- The refrigerant volume must be equal to or less than the baseline

SPECIFICATIONS

The main project requirement, energy saving or efficiency improvement can be converted to a target, but it will be relative to each climate zone:

For example Copenhagen and Detroit target ***<u>efficiency improvement = 23%</u>***

Average temperature in Copenhagen and Detroit is 10 C
Sub cooling from 30° to 10° C
η= (h1-h4) / (h2 – h1) = (400 – 250) / (450-400) = 3
Improved η: (h1-h4'') / (h2 – h1) = (400 – 215) / (450-400) = 3,7 => 23% improvement
Power target 578 kWh * 0.23 = 133 kWh

Cost Targets (from survey results):
<u>Saving in running annual costs = $180 per year</u>
<u>Overall cost increase of the refrigerator unit = $330</u>
<u>Maximum payback time = 5 years</u>

As it can be seen these targets can vary from climate zone to climate zone, user to user and baseline refrigerator to baseline refrigerator. Therefore, these targets are setup as min/max values. In any case where the targets are exceeded it may mean higher profit margins. It might also meet some cost targets but not all. In this case as long as there is an overall cost saving the target is considered met. For example if the overall annual cost saving of $180 is not realised but the initial investment is recovered over 5 years based on running cost savings, the project targets are met.

Therefore, please note as per the ethnography research suggested the main objective, requirement and hence, engineering target is refrigerator efficiency improvement. This is linked to the climate region and the maximum possible improvement according to the super cooling efficiency equation. This target will always be a percentage of the baseline refrigerator and should be achievable using any baseline conventional refrigerator. This means there is no absolute value to be compared to any competitors or benchmark.

Quantified Sustainability Evaluation of Baseline

Due to the limited scope of this project and good data available from previous refrigerator LCA projects, Life Cycle Optimization of Household Refrigerator-Freezer Replacement by Yuhta Alan Horie, from Centre of Sustainable Systems at University of Michigan and LCA of a refrigerator – LER200, the following conclusion was used as the starting point in this project's sustainability evaluation. "Previous LCA studies conducted in Europe, Japan and the U.S. indicate that 88% to 97% of total life cycle energy is consumed in the use phase regardless of the product size or lifetime (Foley; JEMAI 1995)".

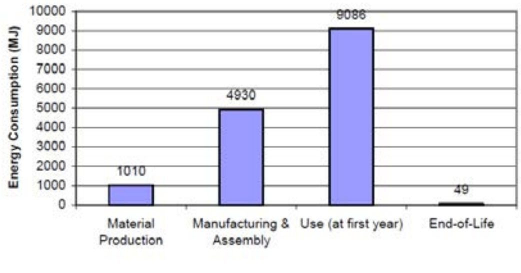
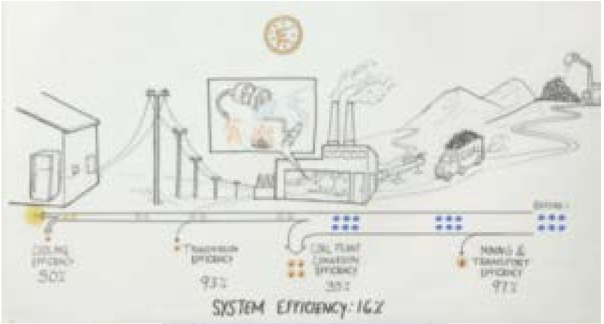


Figure 3.2: Primary energy consumption of 1997 model refrigerator-freezers in each life cycle phase at first year (MJ)

Furthermore, it was demonstrated that over 80% of the power consumption of most refrigerator types is by the compressor during the cooling cycle. Therefore, it is logical to consider the main contributor to the environmental emissions of a domestic refrigerator the power consumption of the compressor. The main source of emissions then becomes the power generation process.



Life Cycle Optimization of Household Refrigerator-Freezer Replacement

An example of the power generation cycle and the relevant efficiencies are shown in the above diagram. Based on this diagram for every unit of energy saved at the compressor there will be an overall six units of energy conserved through the whole energy production cycle. Another set of data on the US power generation emissions allows us to further quantify the domestic refrigerator's emissions to approximately 461 million tons of CO_2 being emitted each year just from the number of refrigerators in the US.

The design concept directly addresses the emissions during the use phase of the refrigerator by improving its efficiency, reducing power consumption and hence, reducing emissions from power generation. As the concept is very simple, using super cooling to improve refrigeration cycle efficiency, with very little changes to the baseline refrigerator we assume there will be no new life cycle problems.

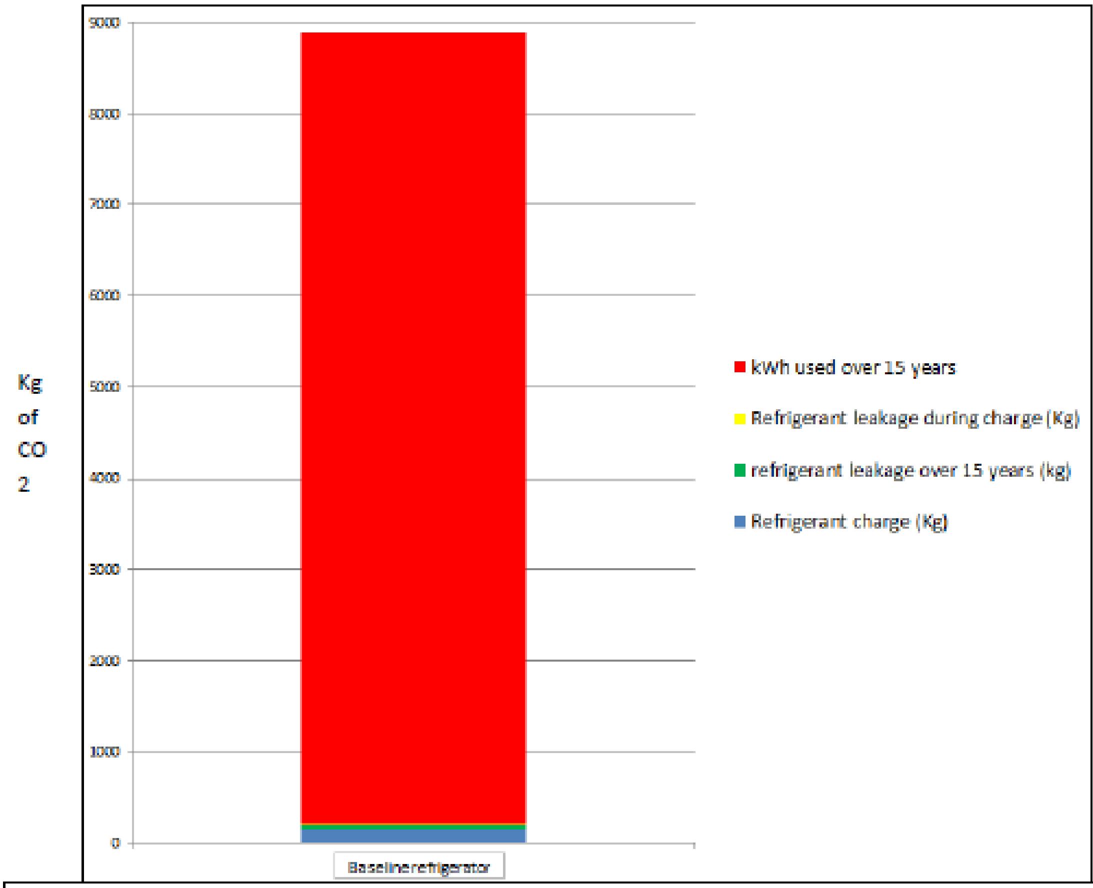
Although, the project direction is to focus on energy consumption and emissions from power generation as the main objective of the product improvements, we have examined environmental impact of the refrigerant over the life cycle of the baseline refrigerator. One option from energy consumption improvements is to reduce the volume of refrigerant while maintaining the electricity consumption. The research and calculations below show that the primary concern is still energy consumption.

From research data on the refrigerant's environmental impact it was assumed that there will be a leakage of 15% during the manufacturing process. This is the maximum leakage permitted by the US Environmental Protection Agency. During the usage phase 1 to 2 grams of refrigerant leakage per year is often seen in domestic refrigerators. It is also assumed that one recharge is required over the life time of a domestic refrigerator back up to the original 120 grams of refrigerant. Based on the following assumption the refrigerant leakage to the atmosphere is converted to CO_2 emissions and shown on the graph below.

Amount of refrigerant in a domestic refrigerator: 120 grams
Amount of refrigerant leakage per year: 2 grams
Maximum refrigerant leakage during manufacturing: 18 grams
CO_2 emissions per kWh of electricity: 1 kg CO_2/kWh
GWP relation between refrigerant and CO_2: 1 gram R134a = 1300 grams CO_2
Usage period of the refrigerator 15 years

It is clear from the graph below that the major emissions contributor by a large factor is still the power usage of the compressor. The next major emissions contributor is the refurbishing and recharge of refrigerant in old refrigerators for further use.

In this section the first four steps of TU Denmark Process have been deemed not relevant, but a brief description is included in appendix V. Step 5, quantifying the environmental impact is demonstrated in the previous graph in terms of CO_2 emissions. Please note throughout the project all emissions and environmental impacts have been converted and demonstrated in CO_2 equivalent terms.



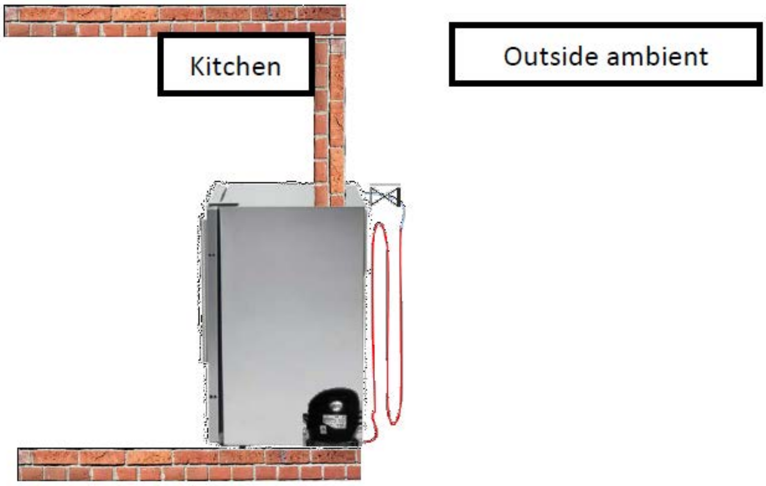
Baseline refrigerator		
Emission source	**Original scale**	**Converted to Kg CO2**
refrigerant charge at manufacturing (kg of R134a)	0,12	156
refrigerant leakage at manufacturing (kg of R134a)	0,018	23,4
refrigerant leakage over 15 years (kg of R134a)	0,03	39
kWh used over 15 years (kWh)	8670	8670

Concept Generation

At the start of the project the objective was simply defined as improve efficiency of a domestic refrigerator. Further into the project during ethnographic research it was determined that the most appropriate method for efficiency improvement would be super cooling of the refrigerant in the refrigeration cycle. Our research indicated that each 1 degree F variation in ambient temperature from the normal ambient temperature of the kitchen leads to a 2.25% to 2.5% variation in energy consumption. Thus, a refrigerator in an environment with a 70 degree ambient temperature will use 22-25% less energy than a refrigerator in a 80 degree environment. A refrigerator in a 90 degree environment will use 45-50% more energy than one in a 70 degree environment.

In early brainstorming concepts such as secondary external heat /cool exchange system and air circulation system to circulate outside air inside the refrigerator were considered. Due to the very specific direction, the use of super cooling concept, along with the project requirement of minimum change to the baseline refrigerator, all roads ended at the final three concepts presented here.

Concept 1



This concept is based on minimum changes to the refrigerator and super cooling the refrigerant by simply exposing the condenser pipes to the outside cold air. An opening in the wall should be provided to fit the whole width and height of the refrigerator. The refrigerator would be assembled with the whole condenser, compressor, rear wall and a considerable portion of the side wall positioned to the outside of the room.

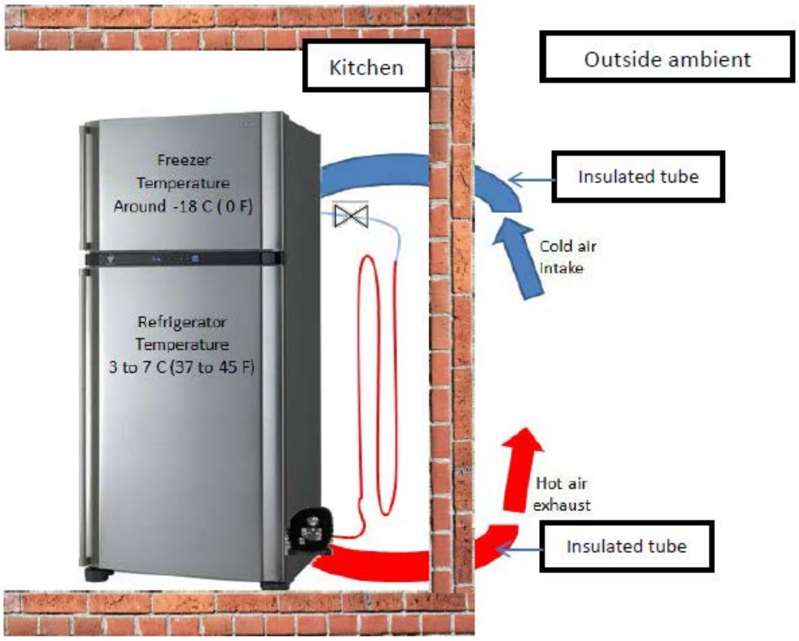
Pros:

- During cold days a direct benefit from cold outside air will be received
- Compressor may be 100% off depending on the intensity of cold days
- Minimum changes to refrigerator

Cons:

- Major kitchen modifications
- No control over the air temperature condenser pipes are exposed to – too cold/hot
- Not usable over the hot months or days
- Durability, corrosion and other issues from exposure to the elements
- Damage and anti theft measures required

Concept 2



In this concept the cold outside air flows into the refrigerator compartment through insulated tubing. This way better control of the temperature inside the refrigerator is possible by opening and closing the air flow as required. If the temperature outside is colder than the refrigerator temperature cold air flows from outside and hot air exhaust form inside. While the outside cold air is flowing through the compressor will be off. Considering that the compressor is responsible for 80 % to 90% of the power consumption in the fridge, a considerable energy saving can be achieved. If temperature outside is higher than the refrigerator temperature, valves are closed and regular cycle starts with compressor power.

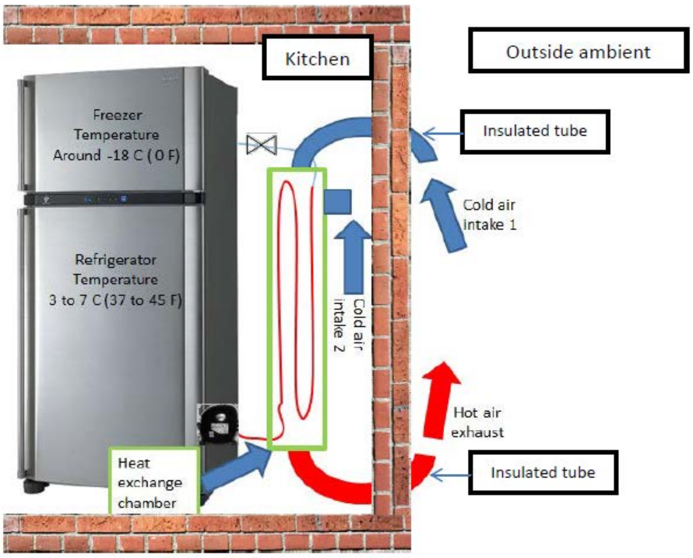
Pros:

- Minor kitchen modifications
- Better temperature control inside the refrigerator
- Maximum benefit of cold air inside the refrigerated section
- Existence of two systems one for cols days and another for warmer days

Cons:

- Kitchen modifications
- Risk of air contamination – air filters required
- Lack of humidity control inside – air dryers on air intake required
- May not operate freezer section
- Significant modifications to the inside of the refrigerator required to circulate air

Concept 3



Based on the idea that air temperature around the condenser plays a big role in the overall system efficiency, this concept circulates outside cold air around the condenser pipes super cooling the refrigerant. To avoid issues with the household heating efficiency, an insulated chamber can be designed around the condenser. Here if the temperature outside the room is colder than the room temperature, outside air goes inside the coil`s heat exchange chamber through intake 1. In this case, for each Fahrenheit of delta between outside and inside temperature, it is possible to reach a 2% energy consumption reduction*. If temperature outside is higher than room temperature, air from the room goes inside the coil`s heat exchange chamber through intake 2.

* Source: Energy Star

Pros:

- Minor kitchen modifications
- Regular refrigerator controls remain operational
- Minor modification to the refrigerator
- All refrigerator modifications are to the exterior of the unit
- Easily retro fitted to any conventional refrigerator

Cons:

- Still kitchen modifications required
- Possible interference with room temperature control
- Extra insulating components required to be added to the back of the refrigerator

Concept Selection

Similar to the concept generation section, the concept selection is very simple in this project. The requirements and evolving of the concept has meant that there are not a list of many different viable concepts, but, a well developed final concept based on the requirements, targets and iteration of each concept presented here. However, we still need to setup a selection matrix based on the requirements and targets set early in the project. The assessment criteria as per the requirements and target sections are listed in the pugh matrix below. The matrix shows that concept 3 meets energy efficiency criteria over the baseline with some modifications required to meet the change.

Criteria	Baseline	Concept 1	Concept 2	Concept 3
Energy efficiency improvement	- -	+	+ +	+ +
Impact on kitchen lay-out	+ +	- -	-	-
System complexity	+ +	-	- -	- -
Durability	+ +	- -	-	+ +
Food preservation	+ +	-	-	same
Temperature control	+ +	-	same	same

Alpha Design

Concept 3 increases the efficiency of the baseline refrigerator while keeping the complexity and costs to a minimum. The design changes compared to the baseline refrigerator are:

Insulated Chamber w/ Temperature Controlled Valves: The heat exchange process that occurs outside of the refrigerator compartment (condenser) needs to be well-insulated since outside air will be blown through this chamber. A poorly insulated chamber will allow cold air into the kitchen during winter. Most refrigerators today do not have condenser coils that are fully exposed like the small refrigerator shown below. These coolant coils release heat without the help of a condenser fan.

Small refrigerator with exposed coils

The coils and cooling fins on a typical side-by-side refrigerator are contained within the outer casing of the refrigerator and are located on the bottom near the compressor. The coils are compressed into a smaller area and a condenser fan helps increase convection and removes the radiating heat.

Our alpha design will need to provide additional seals to ensure that the coils and fins are not exposed to the air located within the kitchen. The new condenser chamber will be made from the same insulating materials as the sides of the refrigerator. This choice will give us some manufacturing cost advantages using existing materials already used and validated in the manufacturing process.

The new refrigerator will feature two air intake holes and two air exhaust holes. All four holes will include temperature controlled butterfly valves which move simultaneously. There will be two stages in which the system operates.

Stage1 (winter)	Intake #1 Open (cold outside air)
	Intake #2 Closed (ambient kitchen air)
	Exhaust #1 Open (goes to outside)
	Exhaust #2 Closed (exhaust to kitchen)
Stage2 (summer)	Intake #1 Closed (cold outside air)
	Intake #2 Open (ambient kitchen air)
	Exhaust #1 Closed (goes to outside)
	Exhaust #2 Open (exhaust to kitchen)

Air intake/exhaust butterfly valves

The above is an example of an all plastic design for a butterfly valve. These valves are electrically actuated and will be wired in series to a thermostat. When the temperature of the air within intake #1 is less than a pre-defined room temperature, then the system will follow the sequence of Stage 1. When the temperature is warmer than this pre-defined value, then intake #1 will close and the system will follow the sequence in Stage 2.

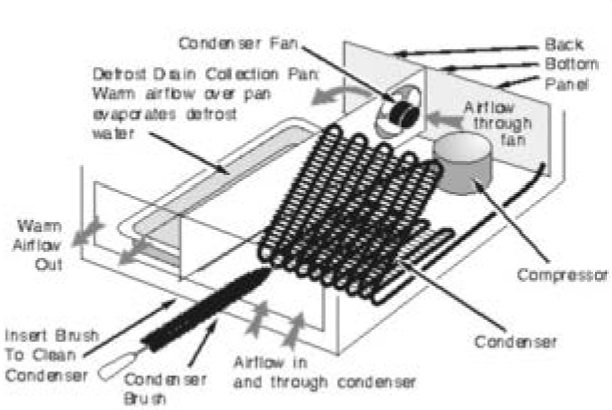
Ventilation Fan: A small ventilation fan may be contained within the condenser chamber to help facilitate air flow around the refrigerant coils. Without this aid, air temperature within the chamber will increase as the refrigerator compressor is operating.   Also, cold outside air may not adequately make it inside the chamber without this fan pulling the air in. The fan will consume between 5-7 watts when running. Further design studies will need to be conducted to determine if this fan can be completely eliminated, or possibly left on only when the system is in Stage 1.

Insulated Tubes: Current HVAC tubing on today's market is well suited for the tubing that will be used in concept 3. Fiberglas material surrounds the flexible steel tube and protects for temperatures between -20° and 240° F. We will use a 6 inch diameter flexible tube for our alpha design.

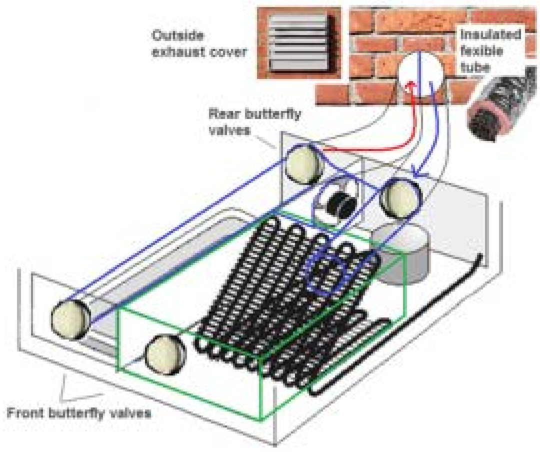
Hole(s) in Outside Wall: In order to extract cold outside air there will be a 6 inch hole drilled through the outer wall in the kitchen. The approach is similar to that of a clothes dryer vent, keeping sure that outside elements are restricted from entering the home. Further investigation will be required to determine whether or not flexible tubing would be required between the condenser chamber exhaust and the outside kitchen wall. A sealed system eliminates outside odours from entering the house, but may not be necessary if an exhaust filter is provided in our design.

Feedback On The Alpha Design

Additional feedback was sought by discussing the design with the same people from the initial interviews. A concept was drawn showing all the elements of our design while comparing the concept to that of a typical side-by-side refrigerator. On the left is the arrangement for the bottom section of a typical refrigerator. On the right is the picture of the alpha design with the modifications.



Typical refrigerator arrangement



Concept refrigerator arrangement

During this feedback there were some legitimate concerns on a few key design features.

<u>Evaporation of water in the drip tray</u> – In a normal refrigerator warm air helps evaporate the water in the drip pan. Our concept doesn't allow for that.

<u>Cleaning the coils</u> – Dust and pet hair can accumulate around the coils when the system is in summertime mode. Our only access point to the coils is through the front butterfly valve which may not provide enough room to get in and around the coils. The final design needs to consider a larger opening in the front, or possibly removable insulation around the chamber.

<u>Condenser fan</u> – The existing condenser fan may not be able to create enough airflow to successfully pull in the outside air and circulate it adequately around the coils. A more powerful fan may be required.
Foreign matter in ventilation system – The unit will be pulling air inside the house as well as exhausting air out. Insects, dust and dirt can potentially enter the cooling system or clog the entrance. To mitigate this risk, a fine wire mesh filter will need to be added at the outside air inlet.

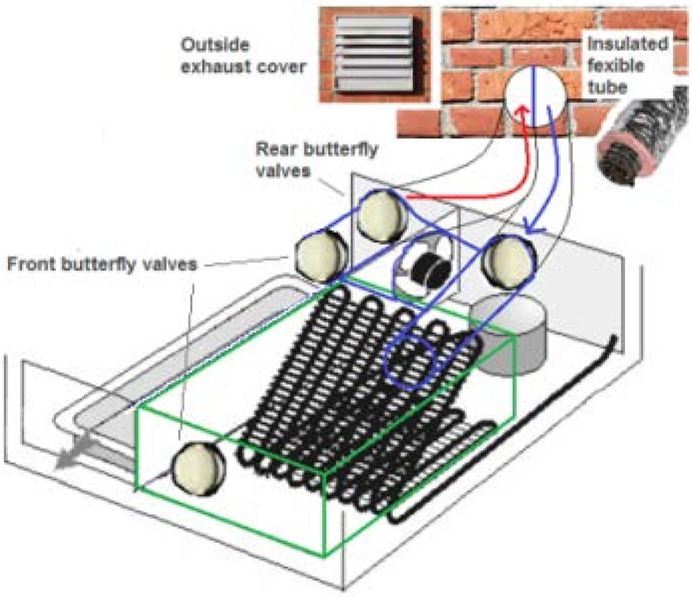
In addition to subjective feedback, a survey to quantify the likability of our product was conducted. The following 3 questions were asked:

- Will you be interested in replacing your existing fridge with this one?
- Will you be interested if you had to buy a new fridge for any reason?
- Will you be interested if you were getting a new house built?

Of all the survey responses, no one was interested in replacing their existing refrigerator with our concept in their pre-existing home, even if they were considering buying a new refrigerator. However, when asked about their next new home, 75% of the responses came back with a positive response as long as the new home is designed to fit a Super-Efficient Refrigerator.

Final Concept Description

In response to the feedback some design changes have been proposed for the final design. Moving the front exhaust valve and locating it before the drip pan. This will help better evaporation of water within the drip pan by allowing warm air to exhaust over the pan. The shorter exhaust has less material and could potentially reduce air restrictions when the system is in winter mode and the exhaust is being directed outside. Due to complexity concerns, it is decided to leave the front intake as a common valve rather than changing it to accommodate a larger opening. Once a prototype unit is built the effectiveness of cleaning the coils through the valve opening can be studied.



Final Design Concept

BUSINESS PLAN SECTION

Company Description

The space defining this company‘s nature of the business is energy savings at home. More specifically the company is involved with energy efficient domestic refrigerators. Domestic refrigerator is a high volume global appliance and a significant contributor to household energy consumption. In today’s society energy is both environmentally and financially at a premium. Therefore, any reduction in energy consumption of a domestic refrigerator can add up to a significant economical and environmental benefit. Economical benefits are in dollars saved in power bills by the end user and environmental benefits are reduced global energy consumption, hence, reduced emissions.

From statistics presented in this report and the results of the customer survey conducted during the project, the market need is identified primarily as annual savings in household electricity cost and the main customer group are builders or owner builders designing and building a new house that requires a new refrigerator. The Super-Efficient Refrigerator will meet the energy saving needs of this customer base by offering a solution that provides 20% to 30% efficiency improvement for their domestic refrigerator.

The company itself can be setup under three different scenarios. The first is starting up as a team within a refrigerator OEM. Next is, starting up a standalone company purchasing domestic refrigerators, adding an energy efficiency improvement modification kit to the product and reselling. The third is combining the first and second solutions, partnering with a refrigerator OEM’s, providing a design solution and helping them implement the solution on their product line. Exploring each of the three options briefly:

Option 1:

Minimum overheads

Modification to an existing product using existing infrastructure

Existing intellectual property protection infrastructure

Limited to the OEM’s product line and market penetration

Restrictions around business case and payback period

Option 2:

High initial investment and overheads

Extended period with no income and high expenses (setting up manufacturing facility)

Starting from zero market penetration and exposure

Lack of supply chain network from materials to point of sale

Warranty responsibility for the baseline product

High cost of intellectual property protection measures

Option 3:

Medium overheads – no manufacturing or supply chain overheads

Access to more than one OEM therefore larger product line up and market penetration

Access to the OEM’s manufacturing, prototyping and supply chain network

Some control over design direction, research and customer need focus

Change of main customer from end user to OEM client

Restrictions around business case and payback period

High cost of intellectual property protection measures

At a glance the investment required for starting a company from ground up, the challenges present in setting up all aspects of the business: design, manufacturing, sales, legal, supply chain and point of sale network makes option 2 not feasible. Therefore, from this point in the business plan we will look at options 1 and 3 referred to as “Business Model A” and “Business Model B” respectively.

Market Analysis

I order to improve efficiency of a domestic refrigerator and define the target market, the customer description and persona is linked to climate requirements and local energy cost. The target market is based on geographical locations with cold climates where average annual temperature is low and energy costs are high. Such markets include countries in the northern hemisphere, climate regions C, D and E (as described earlier in this report) and around Europe where electricity costs are at a premium. For example our first target market can be builders and owner builders in Northern US, Germany and Denmark.

European market has shown more success in implementing higher efficiency appliances. EU directives for efficiency labelling and eco-design have been in place since July 2011 and created 3 levels of labels (A+++, A++ and A+). According to a 2012 status report presented by the European Commission, since 2011, due to tax benefits more than half of all refrigerators and freezers have moved from the previous A rating to the new A+ and A++ rating. This EU requirement is being further improved by 5% in 2014.

According to a survey conducted by sears, 71% of US market home buyers expressed their interest in energy efficient appliances. Also, according to an energy star market profile from 2009, 40% of all refrigerators sold are energy star certified, which demonstrates an interest of the market on efficient products. These refrigerators are at least 10% more efficient than the federal targets for energy consumption.

Therefore, both the US market with its high volumes and the European market with its favourable climate and energy efficiency appreciation provide good starting markets. According to Energy Star reports and US Census data on new houses the US new refrigerator market accounts for 500,000 units a year. Similarly according to Eurostat the number of new refrigerators purchased for new house is estimated to be 750,000 units per year. This is a total of 1,250,000 refrigerators across the two markets. Assuming a market penetration target of 1% for the Super-Efficient Refrigerator, the total volume equates 12,500 units per year.

The growth in market size for this product depends on two factors. One is breaking into new markets and new customers demographics as the product matures and finds a name and reputation in the market. The other is the growth of the predicted market. As far new markets are concern it is beyond the scope of this report to accurately predict the growth, however, with further design improvements and minimising kitchen modifications it is desirable to add all and any customers looking for a new refrigerator to the possible customer persona.

According to energy star, the market share of energy star certified refrigerators didn`t grow from 2004 to 2008 in the USA. Also according to a Wall Street Journal article from Jan 2013, sales of appliances from all big North American manufacturers decreased in 2012. Considering a worst case scenario, there is no growth expected for the North American market. However, Europe data from GFK shows that between 2010 and 2011 the share of A++ labelled products increased from 7.5% to 10.5% and A+ from 47% to 55%. Furthermore, there is predicted economy growth in cold climate Eastern European markets such as Russia, Poland and Bulgaria which will provide market growth opportunities for the Super-Efficient Refrigerator.

The key concept for the Super-Efficient Refrigerator is that using the super cooling idea it can improve the efficiency of any baseline refrigerator, running on vapour compression refrigeration cycle, by 20%-30%. Therefore, choosing the right baseline product to improve will eliminate most direct competition. However, we need to assume any low energy domestic refrigerator without the modifications that are required for the Super-Efficient Refrigerator will be competing for the same segment of the market. Therefore, any refrigerator with total annual energy consumption of less than 150 kWh should be considered a competitor. There are very few refrigerators in the market matching this specification.

The strength of the Super-Efficient Refrigerator is that it provides a significant efficiency improvement and it can do this over and above any baseline refrigerator that might be its competitor. However, its main weakness is the modifications required to the space it sits in and its link to the outside which restricts its use.

The price point for a new product on the market such as the Super-Efficient Refrigerator plays an important role in sales and profits. There are two possible scenarios in this project. The first and most simple one is that our consumer survey of a relatively small number of people suggested that people are willing to pay on average up to $330 (or $250 based on normalised results)over and above the price of a conventional refrigerator. The other is to look at European data provided by GFK to the European Commission (for details see appendix III) suggesting that the average price difference between an A rated appliance and A+ rated appliance (efficiency improvement of 20%) is 87.5 Euros. Assuming worst case scenario we are going to use a delta cost over the baseline refrigerator of 87.5 Euros as an acceptable entry price into the market.

The major barrier to this product entering the market is its physical point of difference. Requiring extra components and modifying the kitchen space to fit and operate the appliance will require a culture change and a solid commitment to energy conservation, significant cost savings or short payback period.

Further to cost and culture, although, the product will have to comply with market regulations and be certified for energy consumption rating for each market, current regulatory measures do not rate appliances towards energy rating of houses. A shift in government regulations linking star rating of appliances to some minimum energy consumption rating of a new house will open the market right up for the Super-Efficient Refrigerator.

Product Description

The details of the product description have been documented in Alpha Design and Final Concept Description sections. The benefits of the Super-Efficient Refrigerator from the customers' perspective are reduced energy consumption with a net cost saving, investment versus running cost over the life of the appliance. Estimations predict a $16 cost reduction per year in the North American household and just under $50 per year in a German household. Assuming a 15 years usage for the appliance this equates to $240 to $700 saving for a $120 investment.

The other direct customer benefit is that the product’s fit and function, ability to meet the original designed customer needs and all popular features will remain the same as the baseline product. The simplicity of this idea with little or no change to the functions of the original product makes it a very attractive concept. It is currently a concept which up on further development, testing and validation will mature and provide more savings and alternative solutions for its challenges. Although, the efficiency improvement is entirely focused on the usage phase within the product life cycle, further development may assist other improvements such reduced use of refrigerant helping with disposal and end-of-life issues.

Going forward this concept will require a development and validation phase including a complete concept to prototype validation plan. It needs to meet all regulatory test programs as well as durability and reliability targets. Early design feedback showed that the concept is popular but refinements are required. There were several functional aspects that were modified based on feedback but a better visual, touch and feel clinic setup will be required for a more detailed feedback.

Marketing and Sales Strategy

MARKET PENETRATION STRATEGY

According to Energy Star`s market profile analysis, side by side refrigerator-freezer units represent more than 50% of market share in the North American refrigerator sales. However, GFK market analysis suggest 2 door bottom freezer model represents the majority of the European refrigerator sales. Ethnographic research and sales data suggests that Europeans are much more aware of energy efficiency and they are already paying premium rates for electricity. Therefore, it is appropriate to target the European market first. If successful in Europe and with further learnings product market can expand into North America with a different product line up, a side-by-side model of the Super-Efficient Refrigerator.

Detailed cost breakdown with materials and overhead costs is documented in appendix VI. After the following assumptions, for “Business Model A” (as described in Company Description Section) a profit of $55.11 per unit can be expected. This will amount to $275,000 per year in North American market and over $400,000 per year in the European market, not taking into account the initial investment.

* Operator salary: 2,500 USD per month (source: www.salary.com)
* Engineers/ Buyers salary: 5,000 USD per month (source: www.salary.com)
* Salary spend during development phase covered in initial investment
* No additional labour outside manufacturing, purchasing and engineering
* Volume calculated as 1% market penetration on new refrigerators sold for new houses
* Cost delta price to baseline product $64.89/unit. Target price of $120 per unit

For “Business Model B” the calculation is more complicated and the final profit will depend on the terms of partnership. In a simple scenario the overall profit quoted in “Business Model A” will have to be split between this company and the partner OEM. In other scenarios the OEM will pay a one-off fee for services and design and try to make that back on sales, or the OEM will offer this company a royalty for each unit sold.

COMMUNICATION & CHANNELS OF DISTRIBUTION STRATEGY

The communication strategy will be closely linked to the Business Model chosen. The main advantage of being part of an OEM (“Business Model A”) or partnering with an OEM (“Business Model B”) is the use of their supply chain network. This includes point of sale infrastructure, marketing resources, advertising and so on.

However, some of the obvious choices and good sources of feedback and reviews are trade expos, home shows, major department stores, TV and Radio advertising, live demonstrations at point of sale. Following certification process in each market taking part in media test and trials often provides good exposure for the cost of a few refrigerator units provided for testing. Point to remember is that the persona identified for this product are mainly builders and owner builders, so the focus needs to be on channels that reach such people, for example trade expos.

GROWTH STRATEGY

Growth strategy for proposed “Business Model A” is limited to the OEM’s product line up and market penetration. However, it can include offering the energy efficient super cooling kit on all models in all suitable markets. Since the volumes are low the business case for acquisitions, franchise opportunities and other such expansions on the account of this product alone is not a reality.

For “Business Model B” growth opportunities are a requirement for business success. As an independent engineering firm the company must be looking at partnering with as many OEM’s as possible to increase market penetration to the maximum 1% of all new refrigerators sold for new houses, as assumed in the business case. A growth strategy will start with the original market penetration plan, using Europe’s most popular refrigerator model as a baseline and getting a foot hold in the European market. After establishing in this market the company will focus on a second model in the US market. Up to this point it is the same company and work force. However, after success in the initial two markets growth strategy must be revised to enable the company to respond to market demand from that point on. This may include satellite arms for local OEM's (vertical strategy), new versions of the product developed for retro fit in existing houses (horizontal strategy) and even stand alone units manufactured under a new brand belonging to the company itself or under large store brands as their home brand.

As such possibilities open other considerations will have to be taken into account such as bill-of-materials reuse, modular design opportunities to increase component volumes and minimise tooling cost, etc.

Starting Funds And Breakeven Time

"BUSINESS MODEL A" – REFRIGERATOR OEM – Total Investment $3.7 million

- Engineering expenses: $1,000,000 – 5 heads, prototypes, patents, validation & certification
- Tooling $2,000,000 – include 2 injection moulding tools (Europ & US markets)
- Assembly fixtures $200,000 – added to existing production line
- Marketing $500,000 – as per marketing strategy
- annual volume of 12500 units
- profit margin $55.11 per unit – annual $275,000 US & $400,000 European markets
- payback period under 5.5 years or 67000 units

"BUSINESS MODEL B" – STANDALOAN WITH PARTNER OEM – Total Investment $2.2 million

As the full income of this business model is unclear, being part there of $675,000 in the first year or $55.11 per unit sold, divided between the OEM and this company, it can only be compare to "Business Model A". In terms on investment all tooling and manufacturing cost are taken out of the company's business case, however, the overheads for design and development must now include building and infrastructure cost.

- Engineering expenses: $1,200,000 – additional 20% overheads
- Facilities and equipment $1,000,000 – include test rigs, modelling software, etc
- At 50% the total profit payback is 6.5 years

The business case and payback period for both company set up scenarios is unfavourable and over acceptable terms. Generally most business cases are based on 1-2 year payback periods. Here we have 5-7 year payback period. This is not to say that the project is not viable under any circumstances. The business case is showing an eventual profit and it is based on worst case scenario. But the additional effort to get this business off the ground is working with governments and using the energy efficiency and environmental benefits of the project to compensate for its long term payback. This means providing tax breaks for end users or builders for using energy efficient appliances, providing energy efficiency credits for new houses that choose to use such energy saving appliances and so on. Such measures will see the business case and volumes for the Super-Efficient Refrigerator improve significantly.

Why is the project likely to be consistent with an eco-efficient or sustainable design?

Eco-efficient design is achieved when economically viable designs are created that significantly reduce important environmental and societal concerns relative to other available options. The designs need not transform or fundamentally alter consumption or emissions pattern, but they are much better than doing nothing (ME589 Lecture Slides).

With the above definition, this project provides an opportunity to implement an eco-efficient design for a relatively significant energy consuming, everyday appliance. Power consumed by domestic refrigerator, in the US alone, generates 461 million tons of CO2 per year. Furthermore, it was shown that due to the inefficiency of the power generation and delivery cycle, for one unit energy required for use by the refrigerator six units of energy are used. Therefore, any saving on energy consumption have significant savings down the line. So as the volumes increase for this product so will the environmental benefits. Although, the business case is not an automatic over the line case, it still shows a profit long term, therefore, still economically viable and the project reduces environmental impacts as well as providing economical benefits in the way of cost savings for the end user. Therefore, it is consistent with eco-efficient and sustainable design defined above. A sustainable design covers a triple bottom line, the environment, the society and economy. In this project the eco-sustainability and the economy have been the main focus. The social aspect of the triple bottom line has not been considered in detail. Some aspects of the social bottom line is covered under possible unintended used of the concept discussed below, but, more details can be covered as recommendation for further work on this topic.

The foreseeable unintended use of this project will be consistent with what has happened over the past two decades. As refrigerator technology has improved over the past two decades, energy efficiency has increased by 60%. However, at the same time refrigerator size and features have increased making an overall increase in power consumption.

Design Critique

The strength of this design is in its simplicity. It identified one inefficient aspect of refrigeration and sets out to remove the inefficiency using super cooling during the refrigeration cycle. The aim is to implement the new design with minimum change to status que. The weaknesses of the design are the modifications required to the kitchen or the room the refrigerator will be housed in and its dependant on the cold climate to gain maximum efficiency.

There is much room for improvement in the design and development of the concept. The focus of the project was on design process and sustainability. More focus is required on further developing the concept and driving the project toward a physical prototype. As the design matures there will be many more concepts and a better concept selection process. Through a more focused design, development and validation process there maybe new opportunities and solutions to address the concept's limitations as well as some future modifications such as standalone retro fit kits or development of bolt-on units that will fit any refrigerator as a DYI kit.

Super-Efficient Refrigerator

Final Report – MECHENG 589

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APPENDIX I - Team introduction

Aaron Carmona

Automotive engineer with over 11 years of experience in vehicles and components development. Deep knowledge in program management, APQP, global communication and suppliers development.
Main skills:
Focus on technical matters
Black belt on design for six sigma
Skills in 3D modeling and kinematics studies on Unigraphics NX3 to NX5
Expertise in latches, handles, lock cylinders and window regulators and integration to door systems
Languages: English, German and Portuguese
Experience from advanced engineering to launch stages in more than 10 vehicles developments

Justin Francisco

I am a Senior Engineer (10 years) at General Motors. My background in the company was 9 years in Manufacturing Engineering, and 1 year currently in Product Engineering. While in Manufacturing my most notable position was a Battery Manufacturing Engineer. I was responsible for developing repair procedures and tools to aid in disassembly of the Volt battery pack. Today I work on active safety vehicle features, and my job is to work with our suppliers to develop and validate these features on our early build vehicles. I am very interested in how sustainable our new active safety features will be going forward in the market. Many of these new features are brand new vehicle technologies, and there is sometimes a fine line between customer needs and customer wants. We are trying to deliver new products that gain popularity and essentially become “must-haves” within the market. As a home-owner I have a do-it-yourself attitude towards home projects/improvements. I always do adequate research before making an important purchase.

Arash Harandian

Masters of Engineering in Global Automotive and Manufacturing Engineering from University of Michigan (2013!). Bachelor of Engineering (Mechanical, 1997) from Monash University, Melbourne.

Over 15 years of experience in automotive design, development, testing, manufacturing and project management at GM Holden. Further project management experience in event management at the Melbourne F1 Grand Prix, Adelaide V8 Touring Cars and Phillip Island Moto GP. More specific projects included Holden Utility body structure design, CO cabin intrusion, localization of the Australian Utility for the US market, mono fuel LPG body structure design and release, new Commodore underbody design engineer, Design for Six Sigma projects such Aluminum Roof to Steel Body design project. My main interest in sustainable design is the challenge of design process requirements that need to be taught throughout the engineering community to provide good design in all aspects of engineering. I think this is the most effective way in achieving any type of sustainability.

Jordan Morgan

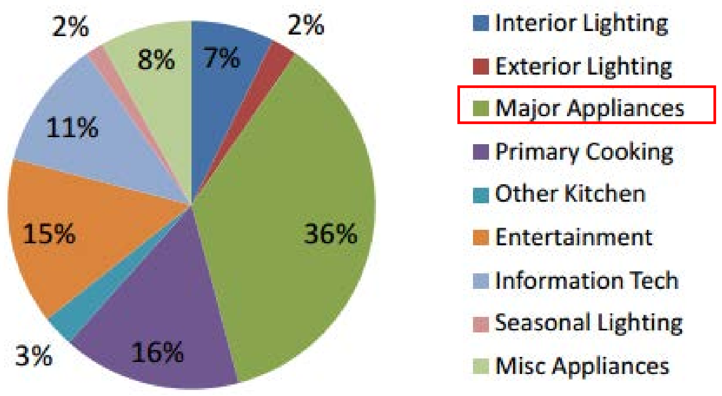
I am a full-time student in the Master of Engineering in Manufacturing Program. My Bachelor's Degree is in Industrial and Operations Engineering from the University of Michigan, therefore my primary focus is in operations. I have a certification in both Lean Manufacturing and Entrepreneurship from the University of Michigan, with additional experience in Six Sigma. As a full-time student who rents a large townhome with three other people, energy costs can become significant. I am very interested in in-home sustainability, more specifically ways to make cost-cutting technological improvements available for a wide range of users.

APPENDIX II – Team Members Information

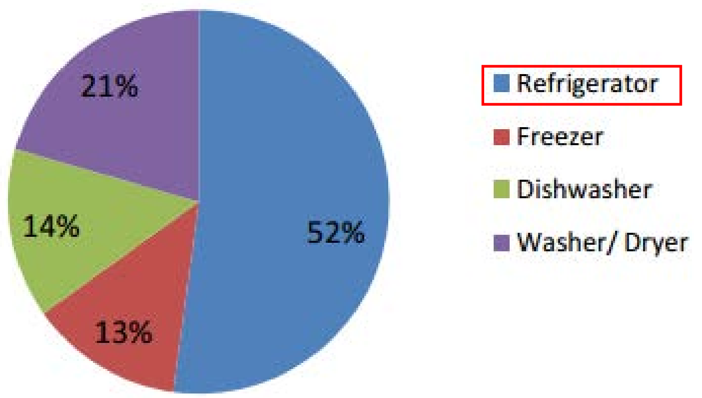
	Aaron	Justin	Jordan	Arash
Contact information (e-mail, cell, Facebook, etc.).	aaron.carmona@gm.com cell: +55 11 999354297 Linkedin profile:	justin.francisco@gm.com cell: 1 248 343 9993		ahar2@bigpond.com +61407407212
Preferred contact method and limitations *(ex., no calls after…)*.	no restriction	no restriction		email
Availability for meetings *(days, times)*.	see appendix 3	see appendix 3	see appendix 3	see appendix 3
Preferred meeting times and places.	see appendix 3	see appendix 3	see appendix 3	see appendix 3
Preferred work styles relating to teamwork.	Webex + conferencing	Webex + conferencing	Webex + conferencing	Webex + conferencing
Strengths related to teamwork.	I work with more than 100 engineers on my team.Have really no problems with teamwork	Has worked in multiple engineering groups with different skillsets and personalities		Many years and projects worth of eperience in team work. Good organising skills
Strengths related to the team's task.	I really enjoy deveoping new technologies. Have 1 patent. Almost black belt certified in DFSS. Lot of tools can be helpful	Job positions in past are related optimizing products or processes. Currently in DFSS training at GM.		Enjoy working in high performing teams and I like contribution and participation in such environment
Weaknesses related to teamwork.	English is not my native language.	Prioritizing work/school/personal activities.		Patients!
Weaknesses related to the team's task.	Work is very time demanding. Sometimes I`ll need to be flexible with time	I work hours are long lately, and I commute over 2 hrs per day.		Patients!
Personal Background *(whatever you want to share, such as major, interests, personality characteristics)*.	Mechanical engineer working for over 11 years in the automotive industry. Participation in more than 10 vehicle projects I`ve been working mainly on technical areas and just in the last year I`ve been assigned to a management position.	I have a BA in Mechanical engineering. I'm 1 year away from getting ESE graduate degree. Started working for GM as a student in 2000. Was hired full time in 2005.		Have had over 15 years of experience at GM Holden. Also have worked in other places such the Melbourne Grand Prix in project management and design engineer in smaller companies with innovative products. My main passion is design and solution finding
List anything else that you want your teammates to know.		Got married 10 months ago. No kids. Looking to move out of MI in a couple years.		Very active and always on the go, therefore time poor!

APPENDIX III – Research information

Refrigerators contribution to the North American households' energy consumption



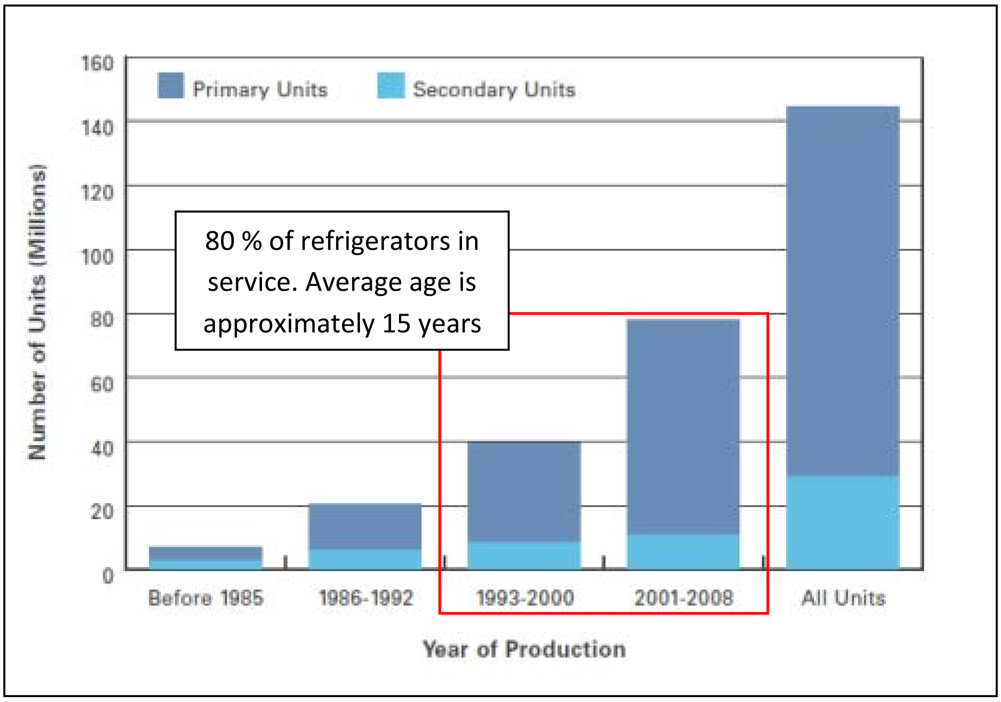
Contribution of different products to the household electricity usage in the U.S
Source: EIA website (http://www.eia.gov/)



Detailing of main appliances electricity usage
Source: EIA website (http://www.eia.gov/)

Refrigerator`s contribution to household`s energy consumption = 36% X 52% => 18,72 %

Refrigerators energy consumption over life cycle



Distribution of Refrigerators by Year of Production in the Installed Base in the USA
Source: Energy star (http://www.energystar.gov/)

Comparison of Models, Volume, and Consumption, 2003 and 2008

Type of Refrigerator	Models Offered (%)		Median Unit Volume (cubic feet)		Median Annual Electricity Consumption (kWh/year)		2008 Maximum Annual Energy Consumption (kWh/year)	
	2003	2008	2003	2008	2003	2008	Federal Standard	ENERGY STAR
Top Freezer	55	38	18	18	478	454	477	382
Top Freezer-Ice	3	0	18	–	482	–	–	–
Bottom Freezer	5	16	20	21	522	482	573	458
Bottom Freezer-Ice	0	2	–	25	–	554	689	551
Side by Side	5	4	24	25	640	580	661	529
Side by Side-Ice	32	40	25	25	668	607	722	578

Note: Median annual electricity consumption includes ENERGY STAR qualified models. 2008 Maximum Annual Energy Consumption values based on models that include automatic defrost, using median unit size for each configuration. Annual electricity use is calculated based on Adjusted Volume = (Fresh Volume) + 1.63 x (Freezer Volume). Energy consumption of an ENERGY STAR qualified model is calculated as consuming 20 percent less energy than a non-qualified model of the same size and configuration.

Sources: Models and Median Unit Volume from Federal Trade Commission, U.S. Department of Commerce, 2009. Federal standards from *National Appliance Energy Conservation Act, Code of Federal Regulations 10CFR430.32.* ENERGY STAR criteria from www.energystar.gov.

Most sold model

Side-by-side, consuming 578 kWh / year

Refrigerators sales by model and their energy consumption per year. North American market
Source: Energy star (http://www.energystar.gov/)

Life cycle energy consumption = 15 years X 578 kWh / year => 8670 kWh

Key source of electricity and associated emissions in North America

Fuel	Lbs of CO_2 per Million Btu	Heat Rate (Btu per kWh)	Lbs CO_2 per kWh
Coal			
Bituminous	205.300	10,128	2.08
Sub-bituminous	212.700	10,128	2.15
Lignite	215.400	10,128	2.18
Natural gas	117.080	10,414	1.22
Distillate Oil (No. 2)	161.386	10,414	1.68
Residual Oil (No. 6)	173.906	10,414	1.81

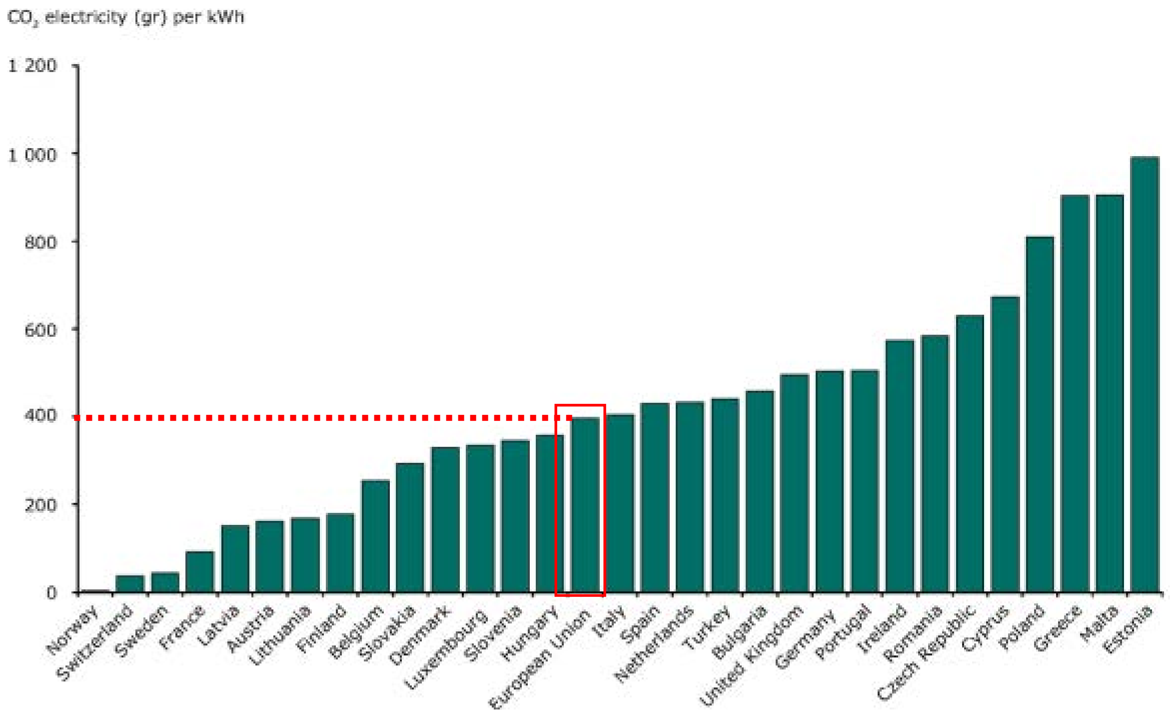
CO2 emission per kWh of electricity generated in the USA
Source: EIA website (http://www.eia.gov/)

67% of all electricity generated in the U.S. is associated with high CO2

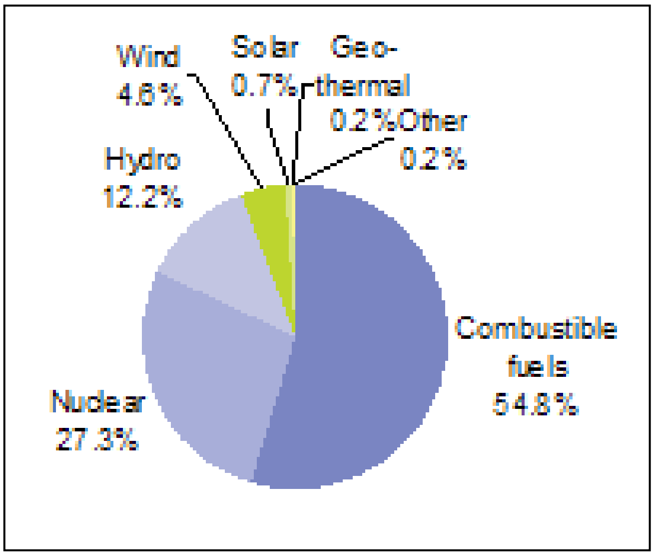
- Coal 37%
- Natural Gas 30%
- Nuclear 19%
- Hydropower 7%
- Other Renewable 5%
  - Biomass 1.42%
  - Geothermal 0.41%
  - Solar 0.11%
  - Wind 3.46%
- Petroleum 1%
- Other Gases < 1%

U.S. electricity generation by source
Source: EIA website (http://www.eia.gov/)

Key source of electricity and associated emissions in Europe



Average CO2 emission per kWh of electricity generated in the European Union
Source: European Environment Agency (http://www.eea.europa.eu/)



European Union electricity generation by source
Source: Eurostat (http://epp.eurostat.ec.europa.eu/portal/page/portal/eurostat/home/)

Refrigerators end-of-life concerns

There are a number of concerns related to the disposal of domestic refrigerators including refrigerants, insulation foams, and other hazardous components.

Refrigerants: The refrigerants in domestic refrigerators produced before 1995 most often contain chlorofluorocarbon (CFC). These CFCs contribute to the depletion of the earth's ozone layer and, being a greenhouse gas, play a role in the climate change in the earth's atmosphere. It is important that these refrigerants be removed properly before the disposal of a refrigerator so that the CFCs are not released into the atmosphere. Some bulk appliance pick up services may provide this removal after appliance pick up while others may require the owner to have the refrigerant removed before the appliance can be picked up. For the sake of injury prevention, it is essential that a certified professional remove the refrigerant. Even when using a pickup service, it is important to ensure the pickup service properly disposes of the appliances.

Refrigerators after 1995 are required to only contain hydrofluorocarbons (HFCs), which do not deplete the ozone layer but still contribute significantly to climate change as a greenhouse gas. Latest refrigerant can achieve at best a value of 1000 in equivalence to grams of CO_2. Current domestic refrigerators use approximately 120 grams of refrigerant. If all this refrigerant is not properly removed at the disposal, an impact equivalent to 120 Kg of CO_2 per refrigerator is possible. For this reason, this refrigerant must still be removed carefully.

Sources: Eurostat (http://epp.eurostat.ec.europa.eu/portal/page/portal/eurostat/home/)

U.S. Environmental Protection Agency Eurostat http://www.epa.gov/ozone/title6/608/disposal/household.html

Foams: The foam insulation used in refrigerators produced before 2005 most often contain either CFCs or hyrdochlorofluorocarbon (HCFCs) at which both deplete the ozone layer. There is currently no regulation on the removal of the foam insulation. Therefore, upon disposal of the refrigerators, these gases are often released. Refrigerators manufactured after 2005 do not contain foam that contains gases that are hazardous to either the ozone or the atmosphere.

Source :U.S. Environmental Protection Agency Eurostat

http://www.epa.gov/ozone/title6/608/disposal/household.html

Other Components: There are a few concerns among the other materials used in refrigerators when disposing of the appliances. The first of these is the oil used in the machines. This oil can often mix with the machine's refrigerant. It is essential that this contaminated oil be removed properly before the disposal of the machine. The electrical components of the machine can also contain harmful substances. Some switches and relays on machines produced before 2000 can contain mercury. All possibly hazardous electrical components should be removed before the disposal of the machine. Most often the metals used in the machines are recycled, while the glass, foams, and plastic are just sent to landfill.

Source : U.S. Environmental Protection Agency Eurostat

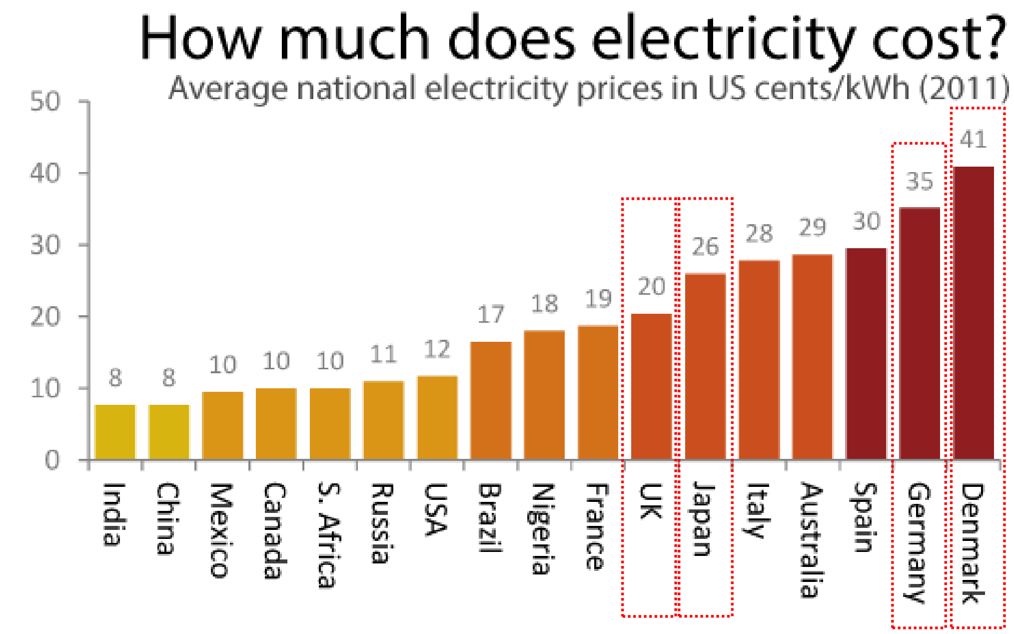
http://www.epa.gov/ozone/title6/608/disposal/household.html

Resale Concerns: One of the possible outcomes of refrigerator disposal is the refurbishing and resale of the unit. These refurbished units are often sold to developing countries. Because these units most often lack in energy efficiency due to obsolete technology and long lifespans, resale is not the best option when considering the environmental consequences.

Source:U.S. Environmental Protection Agency Eurostat

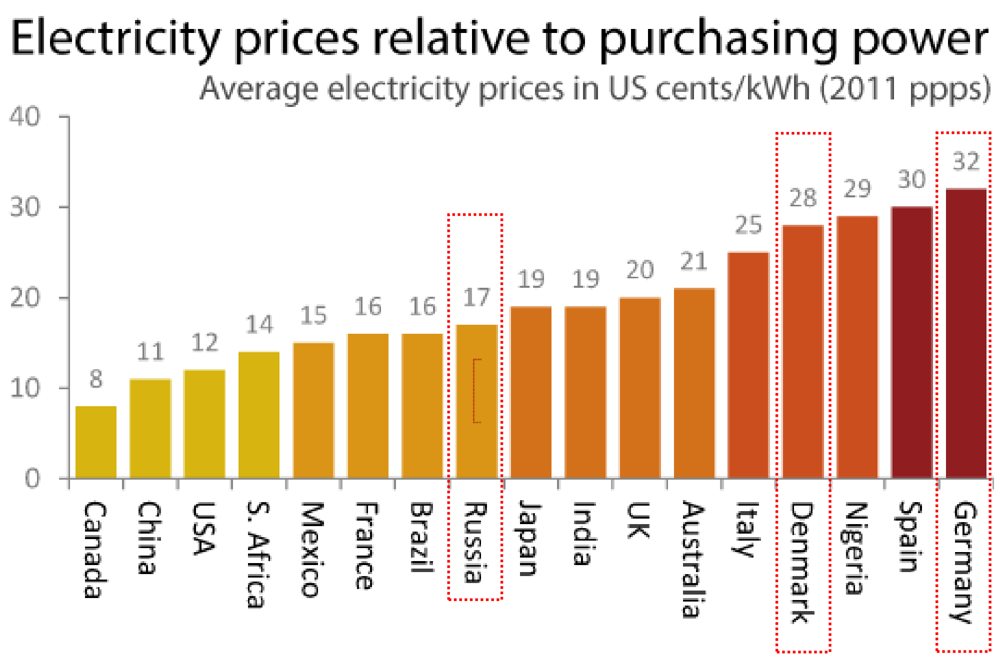
http://www.epa.gov/ozone/title6/608/disposal/household.html

Electricity cost around the world



Source: EIA and shrinkthatfootprint.com

Source: EIA and shrinkthatfootprint.com



Source: EIA and shrinkthatfootprint.com

Climate research

Considering the team`s main idea of improving the refrigerator efficiency by using the outside air in colder condition compared to either the room where the fridge is located or the interior compartment of the refrigerator, it is very important to understand which regions around the world could have a climate from which our design solution could take the most benefit. It is also very interesting to know which kinds and how many people live in these areas, so that this information can help us to refine our target persona.

To enable a more clear understanding about the climate zones and its temperatures, it is very appropriate to define the main world climate classes according to Koppen classification:

Group A - Tropical/megathermal climates : zones with constant high temperature with an average of 18 Celsius or higher during the 12 months of the year

Group B - Arid and semiarid climates

Group C - Mild Temperate/mesothermal climates: zones with average temperatures above 10 Celsius on the summer and averages from -3 to 18 Celsius on the winter

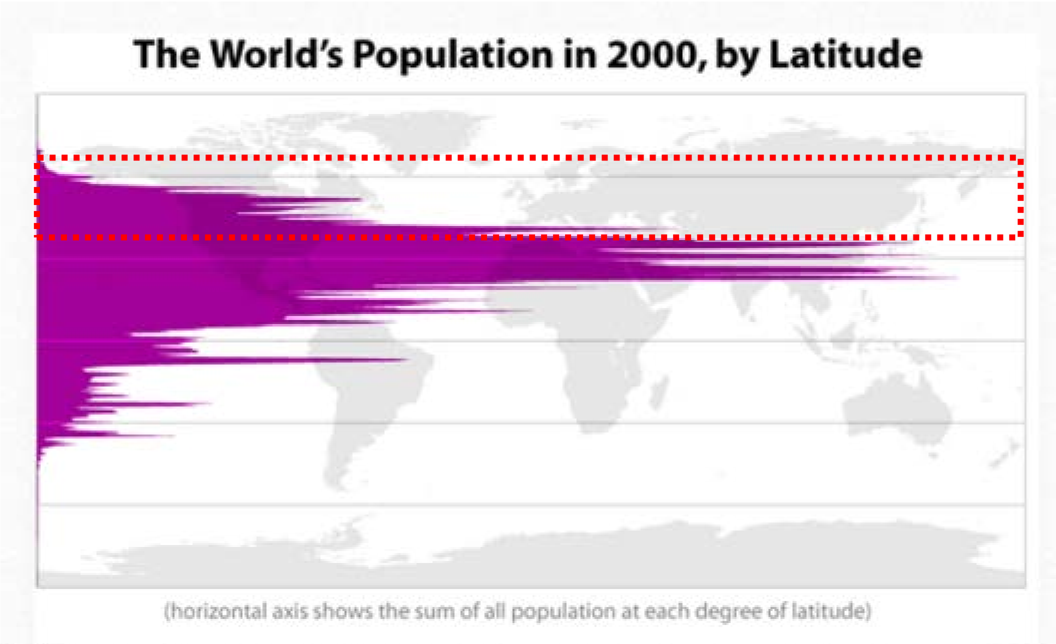
Group D - Continental/microthermal climates: zones with average temperatures above 10 Celsius on the summer and averages below -3 Celsius on the winter

Group E - Polar climates: zones with average temperature below 10 Celsius during the 12 months of the year.

Each group has some sub-groups which specify other climate characteristics such as humidity for example. However, these other characteristics may be covered in the future of this project if necessary. For now, focus will remain in the A,B,C,D and E groups and their temperatures.

Looking at these designations, it is worthier to start focusing on regions with climates of C, D and E classes, which apparently could offer a predominantly cold weather that could be more favorable to our idea. However, if the team finds other concepts or possibilities during the project development, this data can be always reevaluated and other areas can be considered.

By splitting the world into northern and southern hemispheres, the team found out that there are very few C,D and E class areas in the southern hemisphere where a considerable amount of people live. For this reason, we can start to narrow down our persona by the ones living in the northern hemisphere. Furthermore, data shows that 88% of population lives above the equator line.

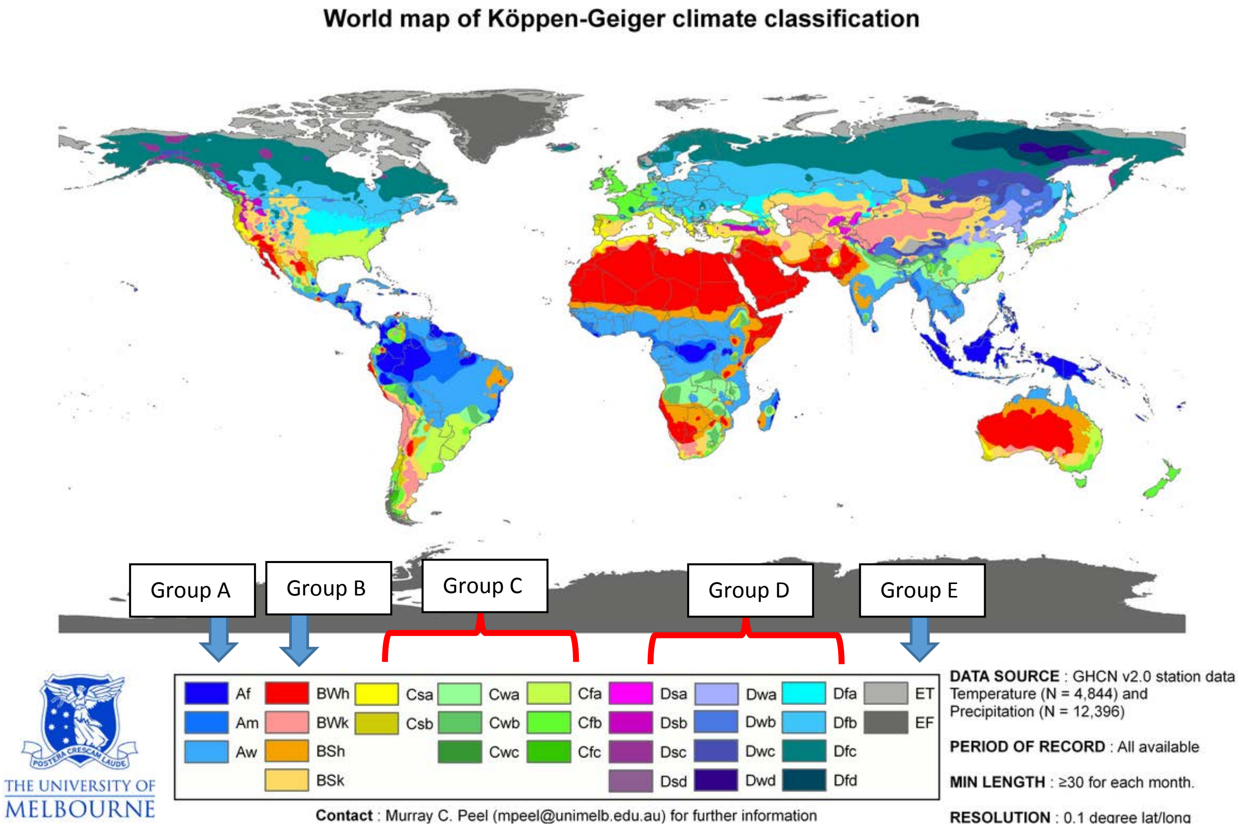


Source: www.radicalcartography.com

In addition to that, data shows that predominant cold areas of C, D and E classes are located above the latitude 27 N. Climate zone D is more often found above the latitude 40 N.

Below is a chart summarizing some key regions of the world and their classification in C, D and E groups:

Group C	Group D	Group E
Western Europe, Southeast USA, South Japan, Southeast China, South Korea	North of USA, South and Central Canada, Alaska, northern and eastern Europe, Russia, North Japan, North Korea	Northern Canada, Greenland, Northern Russia



Source: University of Melbourne

The conclusion is that mainly in the northern hemisphere there are densely populated regions with cold climates where our product improvement idea would have a favorable environment for success.

New households X new refrigerators

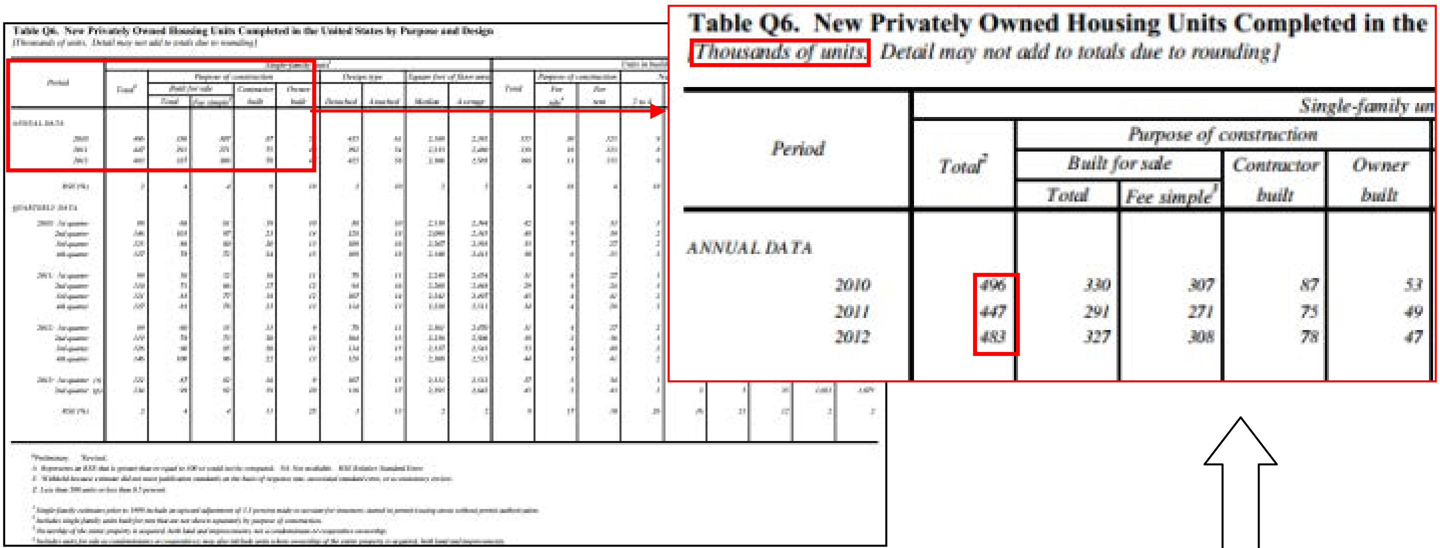
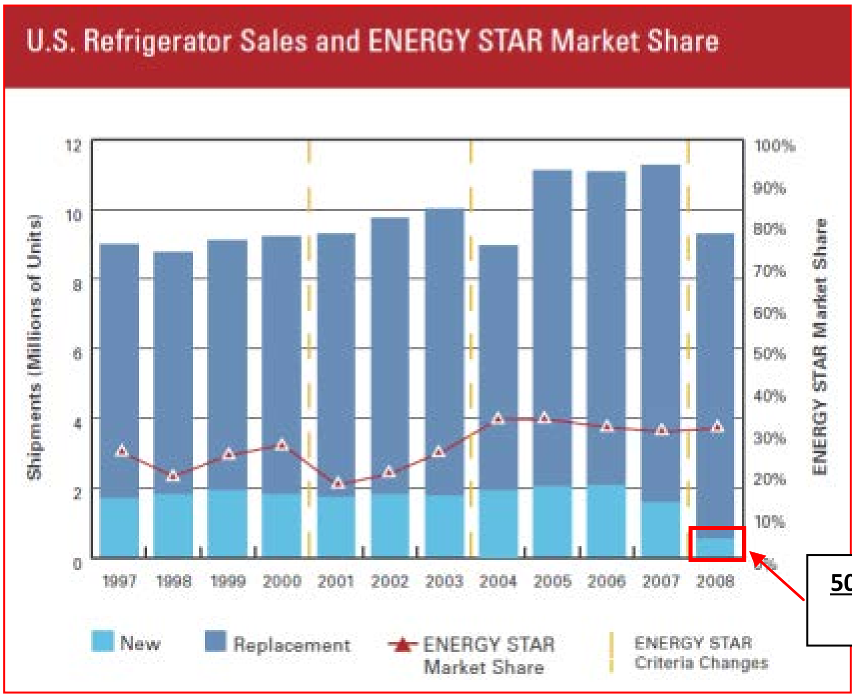


Table Q6. New Privately Owned Housing Units Completed in the
[Thousands of units. Detail may not add to totals due to rounding]

Period	Total[2]	Single-family units: Purpose of construction: Built for sale: Total	Fee simple[3]	Contractor built	Owner built
ANNUAL DATA					
2010	496	330	307	87	53
2011	447	291	271	75	49
2012	483	327	308	78	47

Year 2012 new residences construction concluded in thousands of units
Source: U.S. Census Bureau (http://www.census.gov/construction/nrc/)

New residences and refrigerators sales not to replace old units practically match



500.000 Units sold not for replacement

Source: Energy star (http://www.energystar.gov/)

Theory of frigorific cycle

Before looking into the details of the condensing portion of a refrigerator`s cycle, we need to understand the theory behind the frigorific cycle efficiency. The comprehension of a few terms is necessary:

Enthalpy: Is the energy contained at a certain amount of mass or volume. Commonly enthalpy is designated as " h " and the commonly used unit is kJ / kg. For the purposes of this study, the enthalpy will always be referred to as the energy for a given amount of refrigerant.

Entropy: is a measure of the number of specific ways in which a thermodynamic system may be arranged in a given temperature and pressure

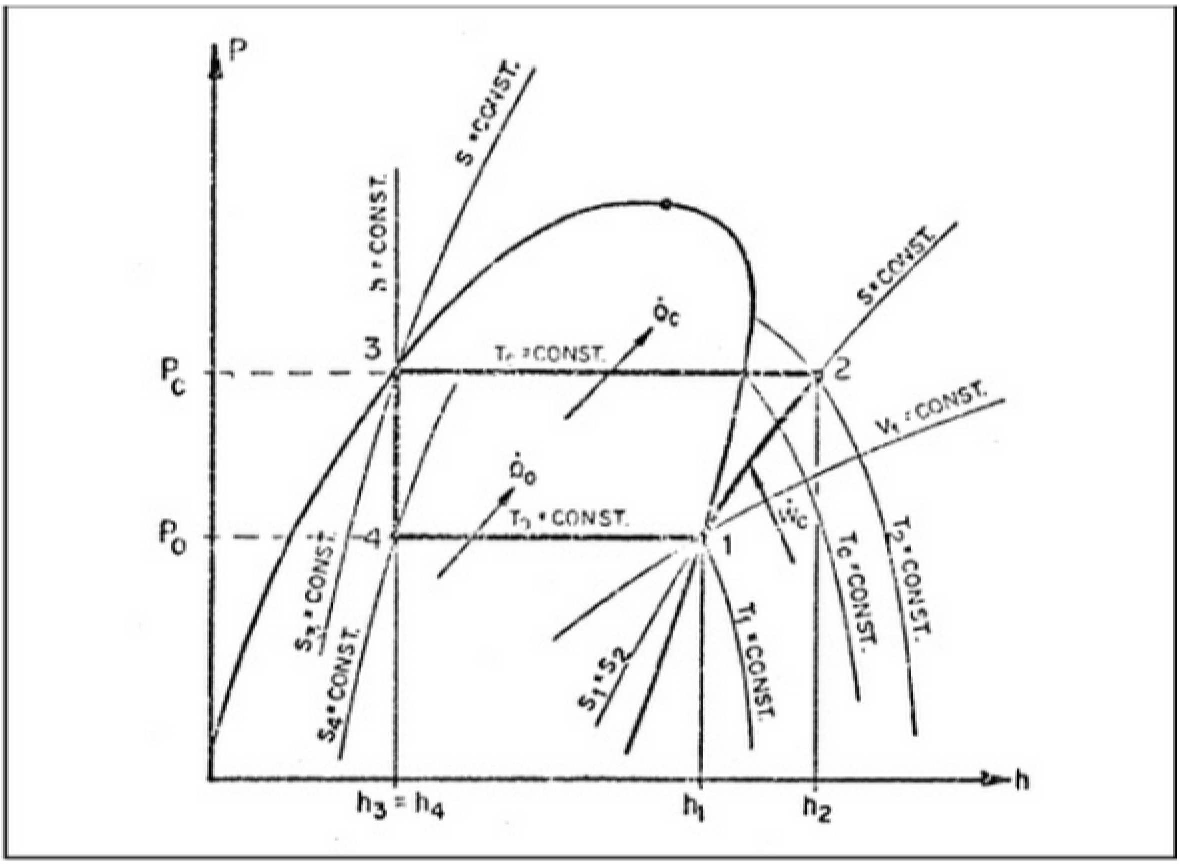
Frigorific cycle: It is the theoretical cycle which represents the perfect function of a refrigeration machine. The scheme shown below represents this cycle, where:

Point 1 to 2: represents the compression phase, being theoretically performed at a constant entropy

Point 2 to 3: represents the condensation phase, being theoretically performed at a constant pressure and temperature

Point 3 to 4: represents the expansion phase, being theoretically performed at a constant enthalpy

Point 4 to 1: represents the evaporation phase, being theoretically performed at a constant pressure and temperature



Scheme of a theoretically perfect frigorific cycle
Source: Thermodynamics handbook, 5th Edition, by Professor W. Trevizan

The basic equation to calculate the cycle efficiency (η) is the following:

Ƞ = (h1-h4) / (h2 – h1)

The portion h2-h1 represents the amount of energy provided to the refrigerant by the compressor.
h1-h4 represents the amount of energy collected by the refrigerant from the refrigerator compartment.

It is comprehensive that the system efficiency is basically the proportion between the amount of energy spent in the compressor and the amount of energy used to cool the refrigerator.

Influence of sub-cooling on the cycle efficiency

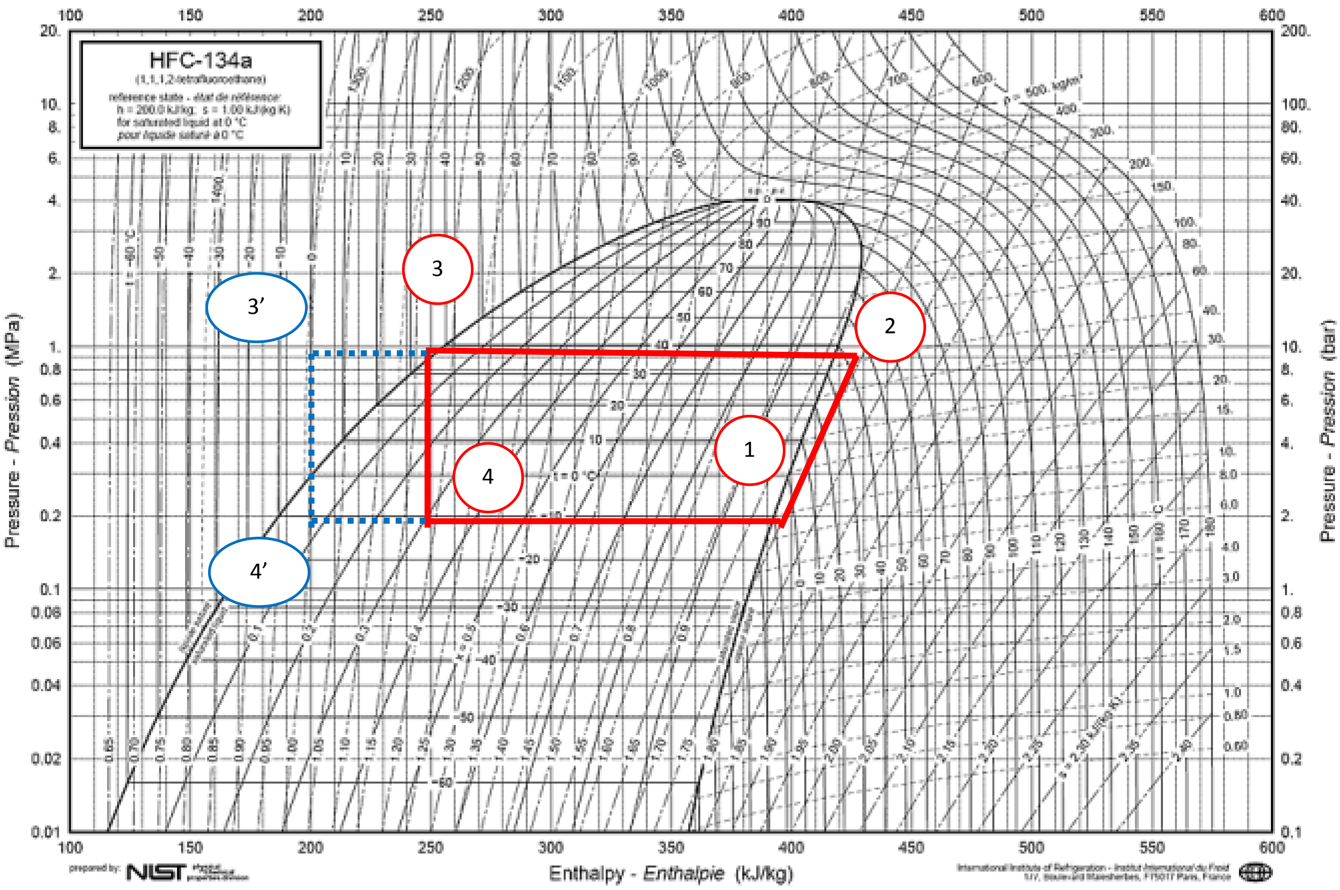
Sub-cooling is a process used in some refrigeration machines like air conditioners with the intention of improving the refrigeration efficiency.

Looking at the refrigeration cycle efficiency equation,

Ƞ = (h1-h4) / (h2 – h1)

By keeping h2 and h1 constants, it is possible to increase Ƞ by decreasing h4.

The scheme below shows an R134a pressure versus enthalpy graph and the ideal frigorific cycle on it. The temperatures T4 to T1 (-15 C) and T2 to T3 (+32 C) were taken from literature (W. Trevizan handbook) as being common operation temperatures for the refrigerant inside domestic refrigerators. An additional cycle is also drawn in blue to illustrate the effect of refrigerant sub-cooling to 0 Celsius on enthalpy h4, which is able to improve the cycle efficiency.



Exa

For

Ƞ= (h1-h4) / (h2 – h1) = (400 – 250) / (450-400) = 3
Improved Ƞ: (h1-h4’) / (h2 – h1) = (400 – 200) / (450-400) = 4 => 33% improvement

Key learning about the markets:

European market seems to be the one with more success on implementing higher efficiency appliances. New EU directives for efficiency labeling and Eco-design are in place since July 2011 and created 3 new levels of labels (A+++, A++ and A+). According to a status report presented by the European Commission about energy efficient appliances in 2012, since only 2011, around 50% of all refrigerators and freezers have moved from the previous A rate to the new A+ and A++ rate due to taxes benefits. However, labeling program is setting more aggressive targets each year. For a product to be labeled at A+ class (which represent the majority of refrigerators being sold in Europe today), additional 5% of efficiency will be needed in 2014.

A report entitled "Research on EU product label options" presented by the European Commission shows a detailed analysis about the consumers' willingness to pay in regards to energy efficiency products. Unfortunately, among many appliances, refrigerators and freezers were not evaluated. However, products at a similar price and energy consumption, such as wash machines, were under analysis. For a wash machine for example, 39,8 % of the respondents would pay premium money to have a more efficient product. The minimum average premium money they would pay is 64,19 Euros. Same situation occurs with the other products under analysis.

Talking about the US market, there is also a tendency on improving energy efficiency on refrigerators. According a survey conducted by sears, 71% of home buyers expressed their interest in energy efficient appliances. Also, according to an energy star market profile from 2009, 40% of all refrigerators sold are energy star certified, which demonstrates an interest of the market on efficient products. These refrigerators are at least 10% more efficient than the federal targets for energy consumption.

Market size:

Thinking in the key densely populated markets with favorable climate, like North America and Europe, below are some numbers of overall refrigerator sales:

- In US, approximately 9 million refrigerators are sold each year. More specifically, 500.000 refrigerators are sold for new residences (not to substitute a previous refrigerator). Both data according to Energy Star.

- In European market, according to Eurostat, 5 million refrigerators were sold in 2009. Data from Eurostat also shows that approximately 750.000 new residences were permitted in 2012.

As previously explained in our ethnography section, due to the lay-out limitation offered by our design, the team believes that our key users would be those moving to new residences. Summing the new residences from North America and Europe, our market would represent 1.250.000 units per year.

It is very difficult to estimate the sales volume of our product inside the overall amount of refrigerators being sold to these new residences. Being very conservative, the team is assuming that a small market share of 1% is possible to be reached. That would mean **12.500 units per year**. Further on section 17, calculation will be shown to demonstrate the minimum amount of refrigerators that need to be sold per year for a breakeven condition. The volume of 12.500 annual units will be assumed for overhead costs estimates and to enable a sense of how much that would impact the final cost.

Could that market grow over time?

According to energy star, the market share of energy star certified refrigerators didn`t grow from 2004 to 2008 in the USA. Also according to a Wall Street Journal article from Jan 2013, sales of appliances from all big North American manufacturers presented a decrease in sales in 2012. Considering a worst case, we can assume that there is not a growth expected for the North American market

In Europe however, growth in the energy efficient refrigerator`s market share is significant. Data from GFK shows that the share of A++ labeled products increased from 7,5 to 10,5 % only between 2010 and 2011. In the same period of time, also A+ certified products increased their share from 47 to 55 %.

Very important information is that in addition to the energy efficient market share increase in Europe, there is a huge overall economy growth in some important big cold climate Eastern Europe economies like Russia, Poland and Bulgaria, which could also help to increase overall sales of appliances in those regions.

Who is your competition?

Essentially all big appliances manufacturers have efficient refrigerator lines in the market, however some key brands are already known by the public and also by some organizations like energy star (see attachment YYYY) for having the most efficient products which can overcome the federal consumption targets in about 25% to 40%, in a large amount of the offered models. They are: (If I have time I`ll put all the fridges from the report in excel and do the average)

* Samsung
* Frigidaire
* GE
* Subzero

In Europe, these are some of the most efficient brands according to topten.eu (website which analyzes the best products in Europe)

Reference: http://www.topten.eu/english/household/refrigerator_inbuilt/2-door.html

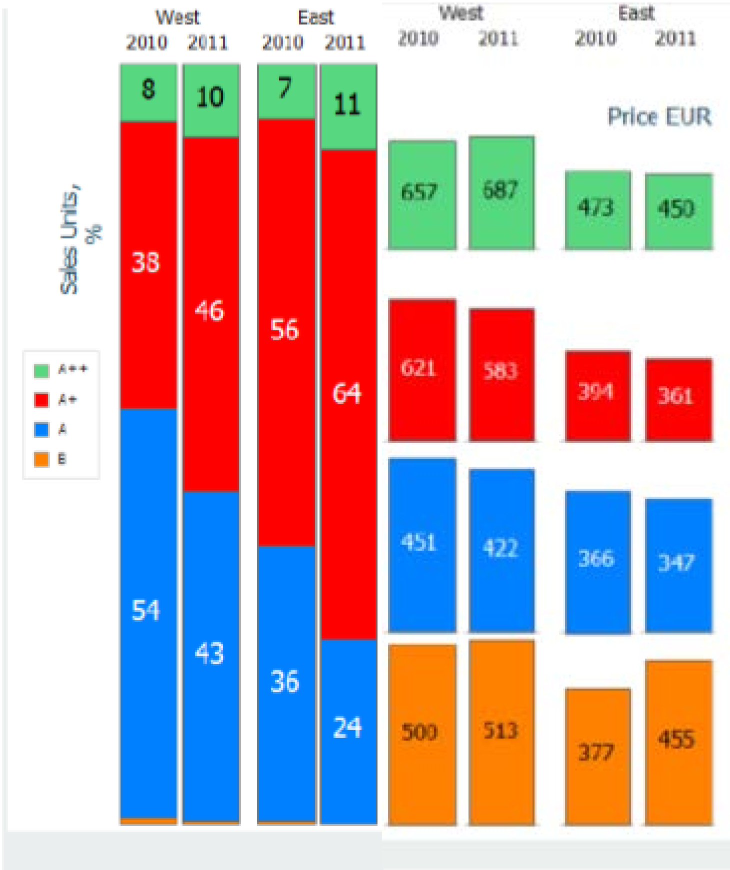
* Liebherr (key competitor , very efficient and sold in most EU contries)
* Electrolux
* Siemens

What conceptual advantages do you have over your competition?
The amount of energy savings which can be achieved with our product is much higher compared to refrigerators with the same characteristics (size, optional and compressor), since they exchange heat at the condenser with a much warmer source. As it is a brand new concept, it could be used as an advantage to enable a higher efficiency than the competitors can achieve.

What weaknesses do you have relative to your competition?
Clearly, our weak point is the lack of assembly flexibility compared to the current refrigerators in the market. Once our product is installed, there will be not much more flexibility than a few centimeters to each side, limited by the length of the insulated tubes which collect the air from the outside. For major disposition changes in the kitchen, additional money will need to be spent to adapt walls to the new refrigerator`s position.

How will you price your project? What evidence do you have that customers are willing to pay that price?

The chart below was extracted from a report prepared by GFK to the European Commission showing statistics of overall appliances sales. This is the specific portion about the 2 Doors Refrigerator sales. Looking at the chart we can see that the sales of higher efficiency class products (A+ and A++) have significantly increase in only 1 year, approximately from 7,5 % to 10,5 % market share on A++ products and from 47 % to 55% on A+ products.
Also the sales prices averages increase for these higher efficiency products. In average, an A+ product costs 87,5 Euros more than an A class product. On the top of that, an A++ class product costs in average 96,5 Euros more than an A+ product.

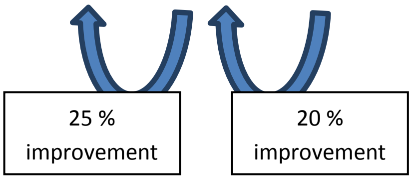


Source: GFK - Latest Trends in Major Domestic Appliances Efficiency in Europe, Russia, and Ukraine

Looking at the efficiency improvement needed to move from an A class to an A+ class (20%) and also to move from an A+ to an A++ (25 %) and also taking into account that the proposed design detailed in section 3 is capable of providing approximately 23% of improvement, the team believes that the efficiency improvement can be priced in at least **87,5 Euros** in Europe.

Tab. 8: New EU energy efficiency classes for household refrigerating appliances from December 2011 to 30 June 2014 (source EC)

A+++	A++	A+	A	B	C	D	E	F	G	Efficiency Class
EEI<22	22≤ EEI <33	33 ≤ EEI < **44**	**44** ≤ EEI < 55	55 ≤ EEI < 75	75 ≤ EEI < 95	95 ≤ EEI < 110	110 ≤ EEI < 125	125 ≤ EEI < 150	EEI ≥ 150	kWh consumption



Source: European Commission

In addition to the market facts, important information was found on a survey presented to the European Commission entitled "Research on EU product label options". It shows a detailed analysis about the consumers' willingness to pay in regards to energy efficiency products. Unfortunately, among many appliances, refrigerators and freezers were not evaluated. However, products at a similar price and energy consumption, such as wash machines were under analysis. For a wash machine for example, 39,8 % of the respondents would pay premium money to have a more efficient product. The minimum average premium money they would pay is 64,19 Euros. Same situation occurs with the other products under analysis. Looking at this data, the value of 87,5 Euros (U$ 120) seems to be a good delta price increase for our selected concept in Europe.

Similar information to that found in European databases wasn`t found in North American databases. However, the interviews performed by the group (see Ethnography on section 2) show that most respondents would pay U$ 250 for an energy efficient refrigerator.

Considering that the information gathered in Europe was obtained through market data and also through the interview of many more people, the team understands that the price increase of **U$ 120** is more reliable. For this reason, on the next steps of this business plan this will be the considered price.

What barriers exist to your entry to the market (include regulatory barriers).

There is a big paradigm which needs to be broken. Currently there is no domestic refrigerator in the market which captures the air from the outside. Due to the need of pipes, a big culture change would be necessary since the refrigerator position in the house would need to be planned since the sketch, in the same way a bathroom or an externally vented hood is.

Another important step to get our product in the market is the certification process. We would need to approve our refrigerators by energy star. This would not be an issue since approximately 10% of improvement would be necessary, while our product could offer 23% of improvement.

A more challenging scenario occurs in the European labelling procedure. We would need to certify our product jump in energy efficiency class, which would require an improvement of approximately 20%, which is very close to the 23% estimated by the group to our concept.

APPENDIX IV –Interview Results (part 1)

	FINAL RESUTLS		AH - WOJ	AH - SD	AH - EM	AH - VO
Do you consider power saving ideas in your daily life?	YES		YES	YES	YES	NO
Are you open to an alternative refrigerator setup in order to gain a saving on your power bill?	YES		YES	YES	YES	YES
How much money per year off your power bill do you consider a good enough saving to make it worth your while?	most people $50 but average $180		$100+	1-2 YEARS OVERALL SAVING	$50	30%
How much extra are you willing to pay for an energy saving feature over and above whatever amount you decide to pay for a new fridge?	most people $250 but average $330		$250	1-2 YEARS OVERALL SAVING	10-15%	3 YEARS OVERALL
What is an acceptable payback time (how many years to make your money back?) for any money you decide to invest in an energy saving refrigerator in reduced power bill?	most people 2 years but average 5		3 YEARS	1-2 YEARS	LIFE OF APPLIANCE	2 YEARS
If buying or building a new house do you consider energy saving features in your decision making process?	YES		YES	YES	YES	NO
If yes, if a new house is fitted with a power efficient refrigerator by the builder will it affect your decision?	YES		FAVOURABLE	FAVOURABLE	FAVOURABLE	N/A
If yes, if a new house is fitted with a power efficient refrigerator by the builder how much premium are you willing to pay?	NO - 12 people who said yes nominated less than 0.1%		0	YES	$300	N/A
INTERVIEW NOTES	Overall comment was that the saving must be real and take into account all costs		NEEDS TO BE WELL INTEGRATED INTO THE DESIGN	NEED TO SEE INVESTMENT / SAVING TO DECIDE	N/A	SEES ENERGY EFFICIENCY AS DROP IN QUALITY AND HENCE IS LOOKING FOR A "COMPENSATION"

	FINAL RESUTLS		AH - DB	AH - NM	AH - TJ	AH - JD
Do you consider power saving ideas in your daily life?	YES		YES	YES	YES	NO
Are you open to an alternative refrigerator setup in order to gain a saving on your power bill?	YES		YES	YES	YES	YES
How much money per year off your power bill do you consider a good enough saving to make it worth your while?	most people $50 but average $180		$100	OVERALL SAVING	>5%	N/A
How much extra are you willing to pay for an energy saving feature over and above whatever amount you decide to pay for a new fridge?	most people $250 but average $330		$1,000	OVERALL SAVING	<20%	20%
What is an acceptable payback time (how many years to make your money back?) for any money you decide to invest in an energy saving refrigerator in reduced power bill?	most people 2 years but average 5		15 YEARS	4-5 YEARS	2-3 YEARS	N/A
If buying or building a new house do you consider energy saving features in your decision making process?	YES		YES	YES	YES	NO
If yes, if a new house is fitted with a power efficient refrigerator by the builder will it affect your decision?	YES		FAVOURABLE	FAVOURABLE	FAVOURABLE	FAVOURABLE
If yes, if a new house is fitted with a power efficient refrigerator by the builder how much premium are you willing to pay?	NO - 12 people who said yes nominated less than 0.1%		$1,000	OVERALL SAVING	0	0
INTERVIEW NOTES	Overall comment was that the saving must be real and take into account all costs		[illegible]	CONCERN ABOUT APPEARANCE OUTSIDE THE HOUSE AND THE FACT THAT FRIDGE WILL HAVE TO BE ON AN EXTERNAL WALL	UNLIKELY FOR A FRIDGE TO PLAY ANY PART IN BUYING OR BUILDING A HOUSE	[illegible]

APPENDIX IV –Interview Results (part 2)

	FINAL RESUTLS		AH - O	AH - DJ	Rafael	Marcelo
Do you consider power saving ideas in your daily life?	YES		YES	YES	Yes	yes
Are you open to an alternative refrigerator setup in order to gain a saving on your power bill?	YES		YES	YES	Yes	yes
How much money per year off your power bill do you consider a good enough saving to make it worth your while?	most people $50 but average $180		N/A	$100-$200	$50	150
How much extra are you willing to pay for an energy saving feature over and above whatever amount you decide to pay for a new fridge?	most people $250 but average $330		0	$500	$50	250
What is an acceptable payback time (how many years to make your money back?) for any money you decide to invest in an energy saving refrigerator in reduced power bill?	most people 2 years but average 5		N/A	5 YEARS	1 year	1,5 years
If buying or building a new house do you consider energy saving features in your decision making process?	YES		YES	YES	yes	yes
If yes, if a new house is fitted with a power efficient refrigerator by the builder will it affect your decision?	YES		FAVOURABLE	MAYBE (IF BETTER THAN MY EXISTING ONE)	yes	yes
If yes, if a new house is fitted with a power efficient refrigerator by the builder how much premium are you willing to pay?	NO - 12 people who said yes nominated less than 0.1%		0	0	No additional money. Perhaps year payback. But it would also be a favorable selection criteria	Not much, considers it to be more a markting tool to sell the house than a tool to increase the cost of the house (comparing the cost of the fridge to the overall cost of the house)
INTERVIEW NOTES	Overall comment was that the saving must be real and take into account all costs		IT NEEDS TO OFFER SURPRISE AND DELIGHT AND BE COOL TO HAVE, THEN I'LL PAY WHATEVER	my real concern with the project would be whether the savings are real savings, or whether my heating system will work harder in winter to compensate for the efficiency of the refrigerator.	Acceptable impact on the kitchen depends on the amount of energy reduction. NO additional money to be paid on the appliance, but the reduction would be a selection factor	

	FINAL RESUTLS		Alexandre	Antonio	Cristiano	Antonio Caputo
Do you consider power saving ideas in your daily life?	YES		yes	yes	yes	yes
Are you open to an alternative refrigerator setup in order to gain a saving on your power bill?	YES		yes	yes	yes	Yes,only if the kitchen is new
How much money per year off your power bill do you consider a good enough saving to make it worth your while?	most people $50 but average $180		$150	$50	$0	$75
How much extra are you willing to pay for an energy saving feature over and above whatever amount you decide to pay for a new fridge?	most people $250 but average $330		20% more on the price o fthe fridge	$100	Wouldn´t check the cost. Prefer to check the efficiency	$100
What is an acceptable payback time (how many years to make your money back?) for any money you decide to invest in an energy saving refrigerator in reduced power bill?	most people 2 years but average 5		1 year	2 years	1 year	If price is affordable wouldn´t care so much about the time (energy is more important)
If buying or building a new house do you consider energy saving features in your decision making process?	YES		yes	yes	yes	yes
If yes, if a new house is fitted with a power efficient refrigerator by the builder will it affect your decision?	YES		yes	yes	not buying a new house	yes
If yes, if a new house is fitted with a power efficient refrigerator by the builder how much premium are you willing to pay?	NO - 12 people who said yes nominated less than 0.1%		the price of a fridge plus 20%	600	not buying a new house	no extra money. Would be more like a marketing feature
INTERVIEW NOTES	Overall comment was that the saving must be real and take into account all costs		If a new layout in the kitchen is necessary, all expenses associated to this new layout must be offset by the savings. About buying a house with a better frisge it is necessary to compare other relevant issues, such as maintenance costs, if it´s easy to find a repair shop, etc....	already uses energy savings ideas at home. Would buy an efficient fridge only if it does not affects the style of the kitchen	Already projected the kitchen in such a way that the door does not stays too much time open (fridge close to the oven). He says that on last rebuild lot of windows were placed to reduce costs with lighting	

APPENDIX IV –Interview Results (part 3)

	FINAL RESUTLS		Israel	Lisa N	Doug D	Kevin L
Do you consider power saving ideas in your daily life?	YES		yes	YES	YES	YES
Are you open to an alternative refrigerator setup in order to gain a saving on your power bill?	YES		yes	YES	YES	YES
How much money per year off your power bill do you consider a good enough saving to make it worth your while?	most people $50 but average $180		200	$50	I saved around 60% of the bill (gas and elec)on my furnace so I'd expect the same (don't know the running cost) if I change the fridge	$30
How much extra are you willing to pay for an energy saving feature over and above whatever amount you decide to pay for a new fridge?	most people $250 but average $330		600	$200	30% (assuming same or better quality as well)	less than $100
What is an acceptable payback time (how many years to make your money back?) for any money you decide to invest in an energy saving refrigerator in reduced power bill?	most people 2 years but average 5		1 year	2 YEARS	3 YEARS	3 YEARS
If buying or building a new house do you consider energy saving features in your decision making process?	YES		yes	YES	YES	YES
If yes, if a new house is fitted with a power efficient refrigerator by the builder will it affect your decision?	YES		yes	NO	Possibly in conjunction with other energy saving options	YES
If yes, if a new house is fitted with a power efficient refrigerator by the builder how much premium are you willing to pay?	NO - 12 people who said yes nominated less than 0.1%		600	$0	As above 30%	$100
INTERVIEW NOTES	Overall comment was that the saving must be real and take into account all costs					

	FINAL RESUTLS		Sahm L	Brian S	Derek H	Jon M
Do you consider power saving ideas in your daily life?	YES		YES	YES	YES	YES
Are you open to an alternative refrigerator setup in order to gain a saving on your power bill?	YES		YES	NO	YES	YES
How much money per year off your power bill do you consider a good enough saving to make it worth your while?	most people $50 but average $180		Depends on the investment required to achieve the savings. 50$ a year would make me interested in understanding the ROI.	$75	Significant cost savings required	half the cost
How much extra are you willing to pay for an energy saving feature over and above whatever amount you decide to pay for a new fridge?	most people $250 but average $330		20% premium, between 200 to 400$	$100	$200.00 would be my initial estimate. I would want to know more about the efficiency rating compared to a normal refrigerator but I would pay allot more if the efficiency increase by 50%.	$300-400
What is an acceptable payback time (how many years to make your money back?) for any money you decide to invest in an energy saving refrigerator in reduced power bill?	most people 2 years but average 5		5 YEARS	2 YEARS	5 YEARS	6 MONTHS
If buying or building a new house do you consider energy saving features in your decision making process?	YES		YES	YES	YES	YES
If yes, if a new house is fitted with a power efficient refrigerator by the builder will it affect your decision?	YES		All things equal, yes, but this would not be on a top 10 list of factors.	YES	NO	YES
If yes, if a new house is fitted with a power efficient refrigerator by the builder how much premium are you willing to pay?	NO - 12 people who said yes nominated less than 0.1%		300 to 500$	$50	$200	$300-400
INTERVIEW NOTES	Overall comment was that the saving must be real and take into account all costs				If the builder can match the price increase without charging 3x his cost then I would select the option but if the builder is going to significantly increase the price then I opt to purchase my appliances myself. Actually it can be cheaper to purchase the appliances yourself but some builders will offer the appliances just above his cost which is cheaper than the self-purchase.	

APPENDIX V – TU Denmark Process

TU Denmark Sustainability Evaluation

STEP 1

What should the product be used for?

The domestic refrigerator is used to provide a continuously cool compartment that enables users to store and preserve of food and other temperature sensitive items.

What does the product do?

This product uses compressors to pump refrigerant fluid inside pipes that run through both the inside and outside of the refrigerator. The refrigerant removes the heat from the inside compartment or compartments of the refrigerator, transferring the heat to the air outside subsequently maintaining a cool space inside the refrigerator. The inside compartment of the refrigerator must stay at or below a certain temperature to keep certain foods from spoiling. There are usually settings on the refrigerator to set the desired temperature for the compartment.

For whom?

This product can be found in most homes throughout the developed world. Domestic refrigerators are not restricted to any specific consumers, but are used by just about any type of consumer.

For how long?

A very reasonable expectation for the lifespan of a domestic refrigerator is at least 10 years. The average expected payback time from our interviews was 5 years. Therefore it is within reason to assume the expected lifespan of a unit to be 10 years or longer.

How often?

A domestic refrigerator is the only household appliance that is almost continuously running. The average household refrigerator compressor runs 80-90% of the day.

Where in the world?

Refrigerators are utilized in most developed countries. Most people in the world today use refrigerator technology to preserve their food. The only restriction to this technology would be electricity availability.

The domestic refrigerator has such a long expected lifetime, during which it runs continuously. For this reason, much of the environmental impact can be attested the product's time of use. Any of the other environmental impacts can be credited to the materials that are used for the function of the machine. The refrigerant used in the condensers of domestic refrigerants can have a significant impact on the environment if it is not contained and disposed of properly. Thanks to improvements in the energy consumption standards pertaining to domestic refrigerators, the usage stage of refrigerators has seen significant improvements over the past few decades. The establishment of refrigerant management specifications also helps to minimize the impact of the refrigerant on the environment.

STEP 2

Raw Materials	Manufacture	Transport	Use	Disposal
Steel Plastic granules Refrigerant Fluid	Piping Condenser Electrical Components Wire Adhesives Fasteners Insulation Foam Injection Molding Blow Molding Cutting Steel Shaping Steel Fastening parts (powered tools) Blowing foam insulation Soldering electrical parts Individual packaging	Packaging (cargo bins) Lifts Trucks Trains Cargo Ships	Electricity Refrigerant leakage	Recycle of metals Recycle of plastics Insulation foam removal Refrigerant removal Landfill deposits

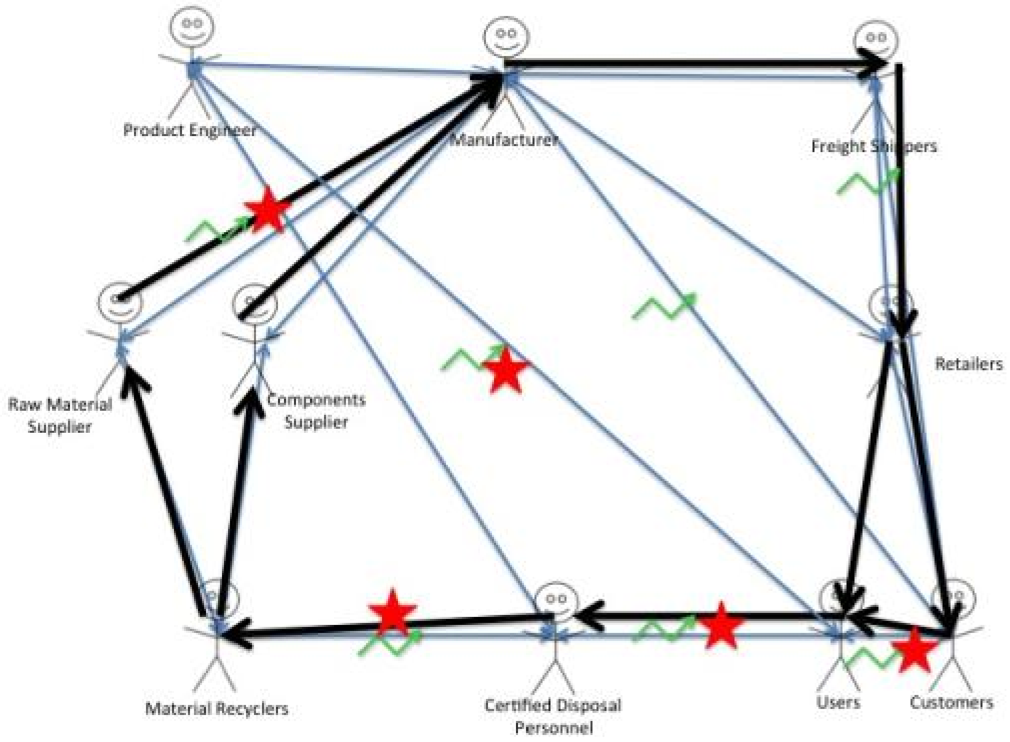
The environmental impacts of the individual domestic refrigerator can be credited mostly to the materials used and the energy consumed during the product life. Many of the materials used, including metals and plastics, present relatively few environmental impacts because of the ease of recycling such materials. The refrigerant used, however, can be difficult to recycle and if not managed or disposed of correctly, can present significant environmental issues relative to the small amount of refrigerant being used. The long duration of the product life makes the energy consumption of the domestic refrigerator a priority when considering the individual environmental impacts of the product. The environmental impact of the energy consumption of the domestic refrigerator during production is assumed to be significantly lower because of the mass production of the units. The customer is well aware the environmental impacts during the use stage of a domestic refrigerator. Evidence of this can be seen in the marketing of energy efficient appliances, like those listed as “energy star” compliant.

STEP 3

	Raw Materials	Manufacture	Transport	Use	Disposal
Materials	Steel Plastic granules	Piping Condenser Electrical components Wire Adhesives Fasteners Insulation foam	Packaging (cargo bins)		Recycle of metals Recycle of plastics Insulation foam removal Landfill deposits
Energy		Injection molding Blow molding Cutting steel Shaping steel Fastening parts (powered tools) Blowing foam insulation Soldering electrical parts Individual packaging	Packaging (cargo bins) Lifts Trucks Trains Cargo Ships	Electricity	Recycle of metals Recycle of plastics Insulation foam removal
Chemicals	Plastic granules Refrigerant fluid	Adhesives Insulation foam Injection molding Blow molding Blowing foam insulation Soldering Electrical parts		Refrigerant leakage	Recycle of plastics Insulation foam removal Landfill deposits
Other					

The biggest focus of improving the environmental impact of the domestic refrigerator can be found in both the energy and chemicals categories. The materials category presents few available improvements for the overall environmental impact. The importance of improving the energy consumption of the domestic refrigerator during its extended lifespan has already been discussed. It is also of high importance to attempt to reduce the amount of environmentally harmful chemicals present in the domestic refrigerator.

STEP 4



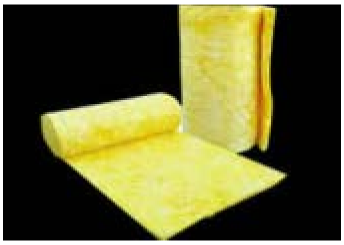
In the stakeholder network, the most important areas for improvement centered first around improving the usage by the customers and users and the communication between the product engineers and the users to accomplish this. The other areas for improvement all involved the handling and transfer of materials, especially the refrigerants.

APPENDIX VI –Cost Data

- Plastic chamber: 2 kilograms, >PP< injected cover

Total cost: U$ 9,00
Source: GM cost estimator

- Fiber glass insulation: 1 m2, 25 mm thickness



Total cost: U$ 2,00
Source: GM cost estimator

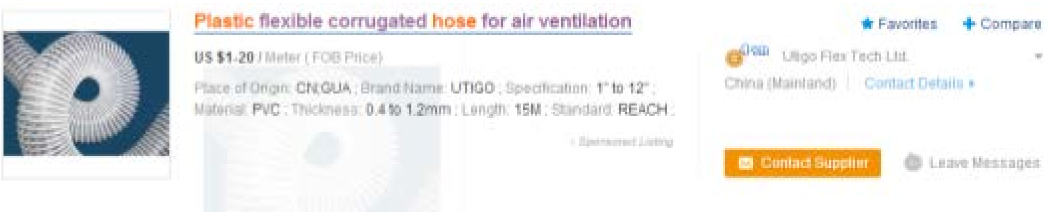
- Attachment bolts: 8 bolts, U$ 0,10 each

Total cost = U$ 0,80
Source: GM cost estimator

- Insulation for ventilation hoses: Reference from air conditioning.

Total cost = U$ 4,87
Source: EBAY

- Flexible ventilation hoses: Reference from air conditioning. 1,90 meters.



Total cost = U$ 20
Source: Alibaba

- Air circulation fan: To enable air flow inside the chamber. Similar power to a bathroom fan.

4" 5"6" Powerful Bathroom Fan/ Exhaust Fans/Ventilator

US $3.62-4.67 / Piece (FOB Price)
1500 Pieces (Min. Order)

Place of Origin: CN ; Brand Name: HX ; Material: Plastic, New ABS ;
Certification: CE ; Installation: Wall Mounted,100MM ; Power (W): 14 ; Type:

View 20+ similar products

Total cost = U$ 4,67
Source: EBAY

- Outside exhaust cover: 500 grams, >PP< injected cover

Total cost: U$ 4,0
Source: GM cost estimator

- Wiring:

Cabo Duflex 1.5mm Rolo com 100m Branco - Induscabos

R$ 54,90 à vista

2 meters, 1.5 mm2 diameter.
0,55 R$ / m = 0,25 U$

Total cost = U$ 0,50
SOURCE: C&C

- Thermocouple: 2 thermocouples, for outside and room temperature acquisition

1 PCS 100cm Length Wire Temperature K-type Thermocouple Sensor Probe Tester 1 M

From China

$1.15
Was: ~~$1.22~~
Buy It Now

Total cost = U$ 2,25

SOURCE: EBAY

TOTAL MATERIAL COST : U$ 48,09

Overhead costs:

- **Electricity to assemble additional components:** Assuming there will be one additional screw driver operating the whole day to attach the additional components to the refrigerator. According to data found on Stanley website, the energy to tighten 4800 bolts would be only U$ 1.50. Considering 8 additional bolts per refrigerator and a sales volume of 12,500 refrigerators per year, that would mean approximately an annual cost of U$ 25 per year to keep the screw driver working. The group understands that this cost is not relevant to the overall product cost. The investment to buy a screw driver system was already considered.

- **Assembly of pipes:** The group assumed that all the pipes will be attached to the refrigerator by the customer at the moment of the installation at their homes. So, no additional labor costs for it.

- Team is also assuming that other supporting areas such as logistics, maintenance and sales will not be affected by the design changes we are proposing with our concept.

- **Additional labor:** Assuming 2 additional people to install the system to the refrigerator and 1 additional person to bring parts from warehouse to the assembly lines. Also, 1 additional buyer and 1 engineer would be necessary to maintain the administration of additional parts over time.

Operator salary: 2500 USD per month X 12 months X 3 people = 90.000 USD/year

Engineer/Buyer salary: 5000 USD per month X 12 Months X 2 people = 120.000 USD/ year

210.000 USD / year split on 12.500 units / year => **TOTAL LABOR COST: 16,8 USD per unit**

TOTAL PRODUCT COST = U$ 48,09 + U$ 16,80 = U$ 64,89

APPENDIX VII – Temperature Averages

Copenhagen - Denmark		
Month	**Average minimum temperature (Celsius)**	**Average maximum temperature (Celsius)**
january	-1	4
february	-1	4
march	0	7
april	3	11
may	7	16
june	11	19
july	13	22
august	13	22
september	10	17
october	6	12
november	3	7
december	0	5
Total average temperature	**8,75**	

Copenhagen average minimum and maximum temperatures
Source: www.worldweatheronline.com

Detroit - USA		
Month	**Average minimum temperature (Fahrenheit)**	**Average maximum temperature (Fahrenheit)**
january	19	32
february	21	35
march	29	46
april	39	59
may	49	70
june	60	79
july	64	84
august	63	81
september	55	74
october	43	62
november	34	49
december	24	36
Total average temperature	**50,29166667**	

Detroit average minimum and maximum temperatures
Source: the weather channel