EWB Challenge Report

Cool Storage Solution
Devikulam, Tamil Nadu India
This report contains a design proposal, and corresponding evaluation, for a permanent cold storage system in developing communities. As part of the EWB challenge this solution has been developed for Devikulam, Tamil Nadu, India. The need for refrigeration and cold storage is often overlooked in developing communities despite the urgent need for adequate food and medicine storage. Extensive research has been undertaken into the many refrigeration systems currently available and evaluated in relation to Devikulam. We have endeavoured to maximise our use of local resources and to generate long term employment whilst designing a reliable and efficient cooling system. It is also hoped that the proposed design will increase the independence of the village, especially during monsoon season, and encourage further growth in the agricultural industry.
Executive Summary

The 2011 EWB (Engineering Without Borders) challenge focuses on a developing community, Devikulam, in Tamil Nadu India. In the EWB brief a multitude of problems and potential areas of work were highlighted; including, sanitation, housing and industrial growth. Our team quickly came to the conclusion that designing a solution for any one of these criteria would not provide a holistic improvement to the quality of life for the residents in Devikulam. After conducting preliminary research into the community, we were intrigued by the way of life of the residents, by what they deemed acceptable and what they hope for in the future. We were astounded by the fact that food that could not be consumed or sold, especially from the prawn industry, was discarded and basic medicine was only available in the nearest city of Pondicherry. The ability to store produce and medicine in a climate controlled, pest free environment is imperative in meeting the Millennium Development goals for developing communities. In our opinion refrigeration is an often overlooked tool for improving the quality of life in developing or rural communities.

Through this report we have outlined the design and implementation requirements of a storage and cooling system that will improve the retention of foodstuffs and allow for the storage of medicine. This is to generate new opportunities for further development within the community, primarily in the agricultural sector. Currently Devikulam is highly dependent on both neighbouring villages and the city of Pondicherry to source many perishable goods, as cold storage within the village is limited. Available storage is also often affected by pests, namely rats and ants. It is the goal of this project to make Devikulam more self-sufficient.

There is a common misconception that refrigeration is an overly complex task, requiring specialised equipment and materials. Therefore our primary design criteria were to make this system simple to build and use. We divided our solution into three components; the primary cooling system, the secondary cooling system and the chamber. After researching multiple cooling methods we settled on the Night Radiation Cooling system as our primary cooling system and the Peltier-Effect Heat Pump as our secondary cooling system.

The solution has a projected operational life of 15 to 20 years. The Night radiation system is most effective on clear nights with low humidity. It is capable of lowering the temperature to 7°C. The Peltier-Effect Heat Exchanger can further lower a compartment of the chamber to 1°C. This report contains two alternate chamber construction strategies, based upon the two separate design approaches. One design requires the construction of a stand-alone chamber, which requires a new foundation and more resources. The second design is an adaptation of an existing concrete structure to serve as the storage chamber. Due to the lower usage of resources, and reduced construction time, the adaptive alternative is the preferred approach. It allows for greater funding to be allocated towards the education initiative, and the implementation of the cooling mechanisms.

The project will be built in a multi-stage process with a coordinated education plan. The first stage is consulting with the community with regards to the project. The second stage will be the construction of the chamber, the third stage is the installation of the cooling systems by a consortium of local volunteers, local paid labourers, skilled professionals and the design team and the final stage will be the education of the local community. Many of the organic construction materials, such as bamboo for the wall reinforcements and wood for the storage lockers, are being
source directly from Devikulam’s local suppliers. Materials such as the insulation and structural bricks are to be sourced from suppliers in the cities of Pondicherry and Chennai.

Education of the local community will focus on appropriate and effective use of the chambers. Necessary training of workers to perform simple maintenance duties on the system will occur concurrently with the final stages of construction. The education strategy is based upon a series of talks with the community, to be delivered in the native language Tamil, along with periodic assessments of the chamber and its interaction with the community.

The environmental impact, the usage of wood and bamboo from local sources will result in a depletion of raw materials in the immediate area. For a project of this size however, the losses to natural reserves is expected to be minimal, when compared to large projects such as the construction of new temples, shops or classrooms. The insulation, polyurethane is chemically inert. During operation, the Night Radiation Heat Exchanging process will cause a minor reduction in the volume of the Devikulam Pond. This is expected to be offset by annual monsoon rains, leading to no long-term net loss of water to the ecosystem. The system is set to benefit from the low night-time humidity which will result in a more efficient night radiation system. The reduction in the spoilage of produce from farms and prawns will positively affect the local economy, environment and moral of residents. Currently native animals are harmed by pest control measures employed by the farmers, which will be unnecessary in this chamber. Therefore the native animals will not be harmed as much by the industry.

The costs associated with the construction of the design vary according to which alternatives are implemented. The chamber is fully capable of acting as a standalone structure, albeit without the ability to refrigerate. It is still able to provide a safe, pest free environment that will increase the shelf-life of many perishable goods. The costs associated with the education of the community and periodic assessment of the project comes to approximately $1600. It will cost approximately $800 to build a standalone storage chamber from scratch; whereas the cheaper adapted design will come to approximately $300. The installation of the Night-Radiation based system and associated maintenance costs is covered in initial building costs. The Peltier-Effect based system is slightly more complex than the Night-Radiation system, and will cost $150 to implement. It is more cost effective to implement the phases concurrently, as this ensures that the design team is always on site to direct the progress.

We hope that the Cool Storage facility will empower the local residents and allow them to realise their full potential in farming and agriculture. We wish to put the Pitchandikulam Forest Organisation in charge of running and maintaining the Refrigeration system as we believe they will be instrumental in bringing the community together and convincing them of our project’s viability and necessity. Our cooling system can be adapted for almost any size and the reason we have aimed for a large building, which is far more ambitious than creating a series of household ones, is to bring the community together and bridge social barriers. The project has the potential to not only positively impact the agricultural industry, but also the health and wellbeing of the residents. Hence we hope this gives Devikulam pride and a positive future.
## Contents

Executive Summary ................................................................. 2

Introduction ............................................................................. 10

Problem definition .................................................................... 10

Problem Scope ........................................................................ 10

Technical Review ...................................................................... 11

Industrial Context ..................................................................... 11

Geographical Context ............................................................. 11

Demographical Context ........................................................... 12

Farm Products and Storage ....................................................... 12

The Need for Refrigeration in Devikulam .............................. 13

Current Storage Techniques .................................................... 14

Alternative Refrigeration Technologies .................................... 15

Case Precedence ...................................................................... 15

Case Study 1: Adam Grosser .................................................. 16

Case Study 2: Sustainable Housing Project, Porto Rafti Greece ............................................................................ 16

Case Study 3: Roof Pond Cooling in Thailand ........................ 17

Design Requirements ............................................................. 18

Option 1: Absorption .............................................................. 19

Overview ................................................................................ 19

Physics .................................................................................... 19

Possible materials ................................................................... 19

Option 2: Peltier Cooler .......................................................... 20

Overview ................................................................................ 20

Physics .................................................................................... 20

Possible materials ................................................................... 20

Option 3: Night Radiation Cooling ......................................... 21

Overview ................................................................................ 21

Physics .................................................................................... 21

Possible materials ................................................................... 21

Option 4: Compression .......................................................... 22

Overview ................................................................................ 22

Physics .................................................................................... 22

Possible materials ................................................................... 22
Option 5: Stirling Cycle .................................................................................................................. 23
Overview ........................................................................................................................................ 23
Physics ........................................................................................................................................... 23
Possible materials .............................................................................................................................. 23
Analysis Table of Different Cooling Methods ................................................................................. 24
Alternative Design – Below Ground .................................................................................................. 26
Option 1: Chamber and Night-Radiation Heat Exchanger ................................................................. 26
Option 2: Chamber and Peltier-Effect Heat Exchanger ..................................................................... 26
Option 3: Chamber with both Night-Radiation and Peltier-Effect Heat Exchangers ..................... 26
Night Radiation Cooling (Primary cooling) ....................................................................................... 29
Calculation ....................................................................................................................................... 30
Peltier cooler (Secondary Cooling System) ......................................................................................... 32
Metals .............................................................................................................................................. 33
Materials ......................................................................................................................................... 33
The Chamber .................................................................................................................................... 36
Perlite .............................................................................................................................................. 36
Research of Common Construction Materials/ Materials Required .............................................. 37
Size specifications: .............................................................................................................................. 37
Chamber Construction ...................................................................................................................... 39
Overview: ......................................................................................................................................... 39
Phase 1 – Research and Consultation: 2 Weeks .................................................................................. 39
Physical Site Analysis: ....................................................................................................................... 39
Phase 2 – Primary Construction of Chamber/Cooling Systems: 4 Weeks ........................................ 40
Foundation Preparation: .................................................................................................................... 40
Pouring of Concrete Foundation: ...................................................................................................... 40
Erection of Perlite/Concrete Walls: ................................................................................................... 40
Brick Generation: .............................................................................................................................. 41
Application of Polyurethane: ............................................................................................................. 41
Erection of Internal Walls: ................................................................................................................ 41
Roof Assembly: ................................................................................................................................. 41
Shade Construction / Application: ..................................................................................................... 41
Implementation of Night-Radiation Scheme: .................................................................................... 42
Implementation of Peltier Scheme: .................................................................................................... 42
Disposal of Waste: ............................................................................................................................. 42
Relocation Cost .................................................................................................................................................. 57
Fiscal Charts ...................................................................................................................................................... 58
Start Up Costs Option 1- With Government Housing ..................................................................................... 58
Start Up Costs Option 2-Without Government Housing (Low Perlite Price) .................................................. 58
Start Up Costs Option 3 (Rare)-Without Government Housing (High Perlite Price) ................................. 59
Risk Evaluation .................................................................................................................................................. 59
Pre-construction risk: .................................................................................................................................. 59
Workers......................................................................................................................................................... 59
Civilians .......................................................................................................................................................... 60
Post construction risk: .................................................................................................................................. 60
Workers......................................................................................................................................................... 60
Civilians .......................................................................................................................................................... 60
Wild Life ......................................................................................................................................................... 61
Ethical Evaluation ......................................................................................................................................... 63
Ethical Issues in Construction ......................................................................................................................... 63
Ethical Issues in Site Determination .............................................................................................................. 63
Ethical Issues in Access Protocols ................................................................................................................. 64
Ethical Issues in Communal Chamber Use ..................................................................................................... 64
Future Design Adaptations .............................................................................................................................. 65
Team Reflection ................................................................................................................................................ 65
Anirban Ghose ................................................................................................................................................ 66
Michael Holmes ........................................................................................................................................... 67
Andy Chen ..................................................................................................................................................... 67
Kelvin Hsu .................................................................................................................................................... 68
James Lee ....................................................................................................................................................... 69
Works Cited ..................................................................................................................................................... 70
Prototype: Polyurethane .................................................................................................................................... 73
Aim: ............................................................................................................................................................... 73
Method: ......................................................................................................................................................... 73
Results: ........................................................................................................................................................... 74
Conclusion: ..................................................................................................................................................... 74
System Dimensions: ..................................................................................................................................... 75
Cooling Chamber: ......................................................................................................................................... 75
Cooling chamber sectional view ..................................................................................................................... 76

Team ForeSense University of Sydney
Cooling Chamber Wall layers ................................................................................................. 76
Cooling chamber top view ...................................................................................................... 77
Mud steps ............................................................................................................................... 77
Cooling chamber roof section ............................................................................................... 78
Peltier Cooler ........................................................................................................................ 78
Peltier Cooler top view .......................................................................................................... 79
Peltier Cooler Section View .................................................................................................. 79
FORE–SENSE Constitution ................................................................................................. 80
**Introduction**
The lack of refrigeration is an issue that hinders possible improvement to the quality of life in many areas of the developing world. In most western societies it is seen as a high tech solution and is largely taken for granted. These are the primary reasons why it is often overlooked as a necessity in communities such as Devikulam. We are trying to develop a sustainable and low cost refrigeration system that will allow for the storage of perishable goods and medicine.

**Problem definition**
The project aim for Fore-Sense is to develop a system that provides a sustainable and practical solution to refrigerate agricultural produce and medicinal goods that are required in the village. This will be achieved by designing a solution with three parts. The first part is a chamber that is built from local materials to be insulated and able to maintain a relatively lower temperature than its immediate surroundings. The second part shall require a heat pump to be devised to lower the temperature of a small section of the chamber. Finally the third part requires a system that will be designed to dispose of the heat in a safe manner without adversely affecting the environment.

By implementing this project we are looking to provide immediate independence for the village as they can store their own medical goods. During the implementation it will be important to have the people in the village involved with the construction so they can understand, appreciate and value the refrigeration system. The long term impact of the cooling system is to increase the people’s productivity as they will not have to process foodstuffs daily to ensure freshness. We are focusing primarily on the passive refrigeration process called Night-Radiation-Cooling, with a secondary Peltier heat pump to bring a small region of the entire system to sub-zero temperatures to store essential medical goods.

**Problem Scope**
In Devikulam there is a lack of capital and infrastructure, however, modern refrigeration is a resource-exhaustive process in terms of both power and cost. Therefore, we are looking into recent innovations in the field of thermodynamics, which have allowed for lower-cost refrigeration systems to be built. These systems cannot match the output of modern, more expensive systems, but are still able to provide a stable cooling environment that can drastically improve the shelf life of perishable food items, which is a key issue facing many rural societies.
## Technical Review

### Industrial Context
In Devikulam, almost 82% of households work in an agriculture-related business (Turner, EWB, 2011). Due to this, the foods that communities harvest play a vital role in providing their income. Despite this, the Devikulam community have no means of storing their harvest in a pest free, temperature regulated area; resulting in the harvest being spoilt before being sent to the market (Grosser, 2007). This decreases the value of the villager’s produce and thus reduces their profits. By introducing new methods for the storage of perishable goods, such as a simple refrigeration device, the produce of the local harvest can be stored fresh to be sold at the market at its optimal price, increasing the profits gained (UNEP OzonAction). This will result in increased employment for the community and a betterment of their current standard of living. Refrigeration in developing countries is therefore needed so that perishable goods can be stored longer. Also, because Devikulam is an agriculturally-heavy community, this is a huge factor in reducing dependency as it improves the employment rate, by being able to sell fresher supplies in larger quantities.

### Geographical Context
The refrigeration system is required to function in the following geographical context to be able to positively impact the industry of Devikulam. The village of Devikulam is located in the south-east region of India, within the Vilupurram district of the state of Tamil Nadu. The village constitutes an area approximately 400 metres long and 250m wide. Habitation is divided into two primary areas, the village, which is inhabited by the Most Backward Class, and the colony, which is home to the Scheduled Class of the area.

The colony comprises just over 22 households, whilst the village contains about 75. Most farming plots of land in the region are between 2 and 5 acres in size, although those owned by residents of the colony have significantly smaller plots of about ¼ of an acre (Turner, EWB, 2011). The pollution from the prawn industry is a major factor in the viability of the area for agricultural development. The land is also recovering from the after-effects of the 2004 Tsunami, which increased salinity levels in the water-table and soil. Hence it is necessary to encourage sustainable farming practices. It is necessary to encourage sustainable farming practices to encourage natural land rejuvenation. Refrigeration will enhance this by allowing farmers to utilise more efficient farming methods, as less produce will go to waste.

The village features two ponds, one to the north-east of the village, and the larger pond directly to the west. The village is named after this pond, which is currently used for washing cattle, bathing and swimming (Turner, EWB, 2011). Due to bacterial contamination it is not viable to drink. However
we are able to use it for our refrigeration system. There is currently no large centralised facility for crop or medicinal storage. We wish to account for this with a sustainable refrigeration unit.

Demographical Context
For the proper implementation of this project, the unique demographics of the community must be taken into account. Devikulam hosts a population of roughly 360 people. There is a significant disparity between the colony and the village inhabitants, as the Most Backward Class (MBC) have a higher percentage of luxury items and assets per household (Turner, EWB, 2011). Despite the limited interaction between the classes there is no hostility between the villagers and those who live in the colony, and interaction between the classes does occur at certain village events. The primary religion is Hinduism, and worship occurs at various temples in the village. Of the 70 households recently surveyed, approximately 60 specify agriculture to be their primary occupation, and of these 60, 30 households claimed to be labourers who worked for other farmers (Turner, Engineers Without Borders Australia FAQ Forum, 2011). There seems to be no social stigma against refrigeration.

Table 1 Source: Devikulam Survey

<table>
<thead>
<tr>
<th>Summary table for the people in Devikulam:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of people</td>
</tr>
<tr>
<td>Number of livestock</td>
</tr>
<tr>
<td>Number of families in agriculture</td>
</tr>
<tr>
<td>Total village income (Rupees)</td>
</tr>
</tbody>
</table>

Farm Products and Storage
The primary produce cultivated in the state of Tamil Nadu (of which Devikulam is a part) consists of tapioca, sugarcane, rice, peanuts and watermelon (Turner, EWB, 2011). The women are in charge of storing and transporting foodstuffs for this community in particular.

Current practices for storing produce include the following:

1) Legumes and pulses are dried.
2) Hessian bags are stacked on top of each other, mainly through manual labour, with no machinery involved.
3) Metal traps are utilised for rodent control.

Some use polythene-lined bags and zinc phosphate for rodent control, but this sort of poison can affect domestic animals. It is also expensive and may need expertise to use it correctly and safely. Other storage methods which are adopted in larger farms include; pre-treatment of storage structures, use of metal storage bins, use of tin-cone for storage structures and the application of anticoagulants for rat control.
However, there are a higher percentage of farmers who apply more "primitive" storage techniques, due to lack of knowledge and technical assistance. Thus postharvest losses can be up to 9% of total production, 6% of which occurs in poor storage. These sentiments and statistics can be found in the article titled 'Postharvest technology of rice: role of farm women in storing grains.'

<table>
<thead>
<tr>
<th>Recommended practice</th>
<th>Small farmers</th>
<th>Big farmers</th>
</tr>
</thead>
<tbody>
<tr>
<td>No.</td>
<td>%</td>
<td>No.</td>
</tr>
<tr>
<td>Dry grains before store</td>
<td>5 100</td>
<td>50 100</td>
</tr>
<tr>
<td>Use impregnated bags</td>
<td>- -</td>
<td>6 12</td>
</tr>
<tr>
<td>Use polythene-lined bags</td>
<td>26 52</td>
<td>25 50</td>
</tr>
<tr>
<td>Keep bags on planks and leave passages</td>
<td>36 72</td>
<td>40 80</td>
</tr>
<tr>
<td>Pre-treatment of storage structures</td>
<td>5 10</td>
<td>15 30</td>
</tr>
<tr>
<td>stack bags horizontally</td>
<td>50 100</td>
<td>50 100</td>
</tr>
<tr>
<td>Use metal storage bins</td>
<td>15 30</td>
<td>3 6</td>
</tr>
<tr>
<td>Use tin-cone plates for storage structures</td>
<td>9 18</td>
<td>21 42</td>
</tr>
<tr>
<td>Fumigate with ethylene Dibromide Ampulse</td>
<td>1 2</td>
<td>4 8</td>
</tr>
<tr>
<td>Use metal traps for rodent control</td>
<td>43 86</td>
<td>45 90</td>
</tr>
<tr>
<td>Use anticoagulants for rat control</td>
<td>7 14</td>
<td>18 36</td>
</tr>
<tr>
<td>Use pre-baiting and poison baiting for rates (with zinc sulphate)</td>
<td>21 42</td>
<td>34 68</td>
</tr>
</tbody>
</table>

**Distribution of respondents, by storage method adopted**

Hence by providing adequate storage for agricultural produce, the inefficiencies in these farming techniques can be reduced and profits can be raised. This will also encourage more sustainable farming practices that do not force farmers to over farm their land. Current farming techniques are as follows:

<table>
<thead>
<tr>
<th>Type</th>
<th>Use</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Satellite soil map</strong></td>
<td>Helps to collect nutrient status information to aid in soil management and fertilizer applications.</td>
</tr>
<tr>
<td><strong>Chisel ploughing</strong></td>
<td>Softens the upper layer of the soil to allow proper drainage and aeration for the soil.</td>
</tr>
<tr>
<td><strong>Drip irrigation</strong></td>
<td>Reduces water and fertilizer requirement, keeps the top soil dry which lessens weed infestation, properly maintains moisture which reduces flower and fruit drop, improves aeration by 40% which nourishes root growth, and maintains relative humidity to less than 60% to lessens infestation of disease and pest.</td>
</tr>
<tr>
<td><strong>Community nurseries</strong></td>
<td>Is developed by the precision farmers with the guidance of the university scientist to produce healthy vegetable seedlings.</td>
</tr>
</tbody>
</table>

**The Need for Refrigeration in Devikulam**

When taking into account the eight different design areas of Industry Development, Building Construction, Transportation, Sanitation, Energy, ICT and Housing, the abstract viability of a large
refrigeration system seems improbable. However the refrigeration solution will have a great impact on the agricultural industry through its reduction in food spoilage, which will lead to a bolstering of income for many farmers.

Many current, alternative methods of refrigeration for developing countries are of a much smaller scale. Most are based upon a passive cooling approach (A A M Sayigh, 2000) that requires no electrical energy to operate. There is extensive work currently being conducted into the creation of cooling systems in Northern Thailand (A A M Sayigh, 2000). Other common methods require exploitation of chemical reactions, or input of physical work or electrical energy. The passive solutions are generally cheaper to implement, but are less efficient in terms of heat extraction from the target. These smaller-scale approaches to personalised storage are ineffective in terms of industrial impact, and are focused towards the improvement of storage in the home. Whilst this is certainly advantageous when compared to no refrigeration at all, it does not lead to as great an improvement in the quality of life of the local population that a larger facility can provide. This is because the larger facility allows for storage of market export. The increase in profit from export sales provides a gateway for funding for other projects, as well as facilitating a possible expansion of the agricultural industry.

Another basic right of any human being is the right to good health, according to the United Nations Millennium Development goals. Without refrigeration it is difficult to store vaccines and other remedies that require low temperatures to be effective. As a result of this many medications have to be brought in from other areas when needed, greatly increasing Devikulam’s dependency on other villages and cities. A refrigeration system will provide ample space for the effective storage of medications.

**Current Storage Techniques**

Currently, a common method utilised by farmers is to store agricultural goods in a pit in a field. This causes a loss of 30%-40% of agricultural produce due to rotting and sprouting (India Development Gateway 2011). Other farmers employ a more developed, low cost storage structure by using clay, bamboo, cow droppings, and other locally attainable raw materials. The size of these structures is normally around 2m × 2m × 1.4m with a thickness of 20cm, as shown at the right (India Development Gateway 2011). This method avoids sprouting, infestation, and the rotting of agricultural goods for five months.
**Alternative Refrigeration Technologies**

We have considered and investigated a number of existing and conventional technologies, which have been implemented in developing countries around the world. Such systems include Absorption Refrigeration, Compression and the Stirling Cycle. All of these systems act as heat pumps, to reduce the temperature within a confined space by removing heat and pumping it into another location. The Absorption, Compression and Stirling systems utilise the fundamentals of energy absorption during the evaporation of liquids, whilst the Peltier system achieves this energy absorption through the transfer of electrons.

Absorption refrigeration was commonly utilised in large freezing works in the 1920s (The Crosley Icy ball), however it is now commonly applied as a small refrigeration unit, fitted into many varieties of recreational vehicles (Domestic RV Centre).

The Stirling’s Cycle system is simple to operate, and highly effective in temperature control. However, it is often costly and difficult to build.

The Compression system works by compressing a gas into a liquid, and then allowing the liquid to re-expand in the target chamber. The expanding gas absorbs heat from the environment, which can then be ported externally to be recompressed.

Each of these systems requires a continuous supply of electricity, which Devikulam lacks. These systems also have complicated and costly set up processes; that are not affordable, relative to the resources that Devikulam has available. Therefore we reached the conclusion that the utilisation of a passive cooling system will be most appropriate for this community, in terms of the resources that they have available, and the actual required temperature they need to preserve most farm products. For essential medicines, cooling is further enhanced via the implementation of a small-scale Peltier scheme.

**Case Precedence**

Refrigeration in developing communities is a relatively new idea. Problems such as housing, sanitation and power have often been discussed and solutions donated to communities. The realisation of the impact refrigeration, cold storage and cold cycles have had on western societies has led to a flurry of activity in the academic, scientific and engineering communities in the past decade (Grosser, 2007). Refrigeration is an inherently energy and resource intensive process, therefore we specifically targeted passive cooling techniques in an effort to increase the viability.
When conducting research into passive cooling techniques we came across a multitude of ideas. These included shading, selective insulation, evaporative cooling, thermal mass flooring and the icy ball refrigeration. Currently there is a lot of research being conducted into passive cooling techniques; however there is a lack of sufficient documented evidence relating to passive cooling.

**Case Study 1: Adam Grosser**
Many qualitative assessments have been made regarding the efficiency and practicality of such systems and many research papers have been published. However systems such as Adam Grosser’s sustainable fridge have not yet been implemented after being presented in 2007. Curious as to why this is the case, we came to the conclusion that it because of a lack of funding in the research and people are unable to generate a profit from their inventions.

Adam Grosser’s system works on the principle of absorption refrigeration. He has created an inner chamber that, when heated, will evaporate in the outer chamber cooling its immediate surroundings. This system is heated for 20 minutes and cools for 12 hours. Grosser outlines the impact of such a system on developing communities, however as yet there is no further implementation of this system.

![Figure 1 Adam Grosser, TED talks](image)

**Case Study 2: Sustainable Housing Project, Porto Rafti Greece**
This project focuses on developing housing projects which focus on green roofs and improved environmental characteristics of the residential buildings. In Porto Rafti, Greece the average daytime temperature is more than 30 degree Celsius in the warmer period of the year. Occupants use traditional compression air conditioners to reduce the temperature to 28 degrees Celsius. This puts stress on the annual loads and energy consumption for the household as well as the community.
The aim for the project in the case was to develop sustainable heat isolation building structure to reduce energy consumption. They have multiple measures such as green roofing, roof ponds and improved window thermo-isolation. Though there are interesting ideas about the improved thermo-isolation in the windows, the green roofing and the roof pond is more relevant to our project. It is found that a roof pond has 1.5 times reduced cooling loads than that of the green roof. However, the roof will be heavier and require stronger and more expensive structure to withstand the weight.

Relevance to our project:

Our refrigeration system will not contain windows. Also, we will be using the more effective “roof pond” as the case study suggested but instead of exposing the water mass directly to sunlight we will insulate the entire chamber bringing the temperature down, not to 28 degrees but 10 degrees Celsius. The strength of structure to support the weight of the water is less relevant to our project since we are not using as much water and the structure of the chamber is a lot simpler than any housing structure they implement their sustainable green housing on.

Case Study 3: Roof Pond Cooling in Thailand

Roof Pond cooling has been employed in northern Thailand with great success. It was used to store their fruits and vegetables. The chamber was 25m^3 in volume with the pond depth of 0.10m. They found that the pond water usually cooled to the minimum ambient night time temperature. They were able to work in an environment with a relative humidity level of 85~95%, which is far greater than the humidity experienced in Devikulam. Some of fruits (namely, Pear of the Pien Pu variety) gave the best results inside the chamber; their storage life being extended from 1 week to several months. This is promising for our project as we are storing similar foodstuffs. The team’s economic analysis of the system indicated that it was very promising.

There have been other applications where Champignon mushrooms (which can only grow in winter in Thailand) were being cultivated inside the Chamber during other seasons in a similar chamber. This method helped extend the production season considerably, and increased the farmer’s income. This projects goals and results are very promising and we have incorporated similar ideas into our solution.
**Design Requirements**

We have arrived at the following design criteria through an analysis of the case studies presented and by analysing what the community needs.

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Rationale</th>
</tr>
</thead>
<tbody>
<tr>
<td>Refrigerate</td>
<td>The solution must be able to refrigerate a chamber of varying size allowing for an increase in the longevity of the foodstuffs and medicine stored within</td>
</tr>
<tr>
<td>Pest Resistance</td>
<td>The chamber must be pest free so that the foodstuffs and medicine are not destroyed</td>
</tr>
<tr>
<td>Must be built from local materials</td>
<td>This is to encourage local industries and reduce cost in manufacturing</td>
</tr>
<tr>
<td>Economically Viable</td>
<td>This is so the project can be funded by either the local community or funding from the World bank or a similar organisation</td>
</tr>
<tr>
<td>Has to be a reliable and easily maintained machine</td>
<td>The system should not require extensive technical knowledge to be able to be used over a prolonged period of time</td>
</tr>
</tbody>
</table>

Secondary requirements for the chamber that should also be taken into account:

- Be easily accessible by the community, in terms of its location and its internal layout.
- Be easily maintained by the community, with little or no maintenance to the structure once completed, and an acceptable amount of periodical upkeep in terms of cleaning and organisation.
- Be relatively simplistic in its design, such that its construction should not warrant extensive professional knowledge, nor should the implementation be extensive in regards to both time and finance.
- Be waterproof in its design, so that the stored goods may be kept in a low-humidity environment.
- The aim is to construct a chamber capable of operating for a minimum of 20 years, with a post-operational assessment to check the current integrity of the chamber, so as to determine the appropriate end-time strategy for possible re-use of the facility, or recycling of the materials.
Design Options

Design Options for Cooling Module

Option 1: Absorption

Overview
The absorption refrigeration system utilises the effect that while gases (or liquids) are expanding, they will absorb heat. Hence they will cool their environment.

One of the advantages of this system is that it can achieve very low temperatures which other refrigeration systems cannot achieve. Other advantage is that this system has no moving parts; allowing for easy maintenance. However, this system is inherently dangerous because it operates under high pressure. It is also inefficient in small scale implementation compared with other cooling systems such as compression refrigeration.

Physics
There are two phases in the system; charging and cooling phase.

Charging phase
Refrigerant–absorbent solution inside the hot ball is heated, which causes the absorbent to lose its solubility and puts the system under high pressure. This releases the refrigerant gas and evaporates it into the cool ball. Gas under high pressure experiences an increase in its boiling point. Since the cool ball is relatively colder than the hot ball, the refrigerant gases will condensate inside it.

Cooling phase
After the charging phase is complete, the heat is removed and the cool ball is placed inside the chamber with the hot ball outside. The reduction in temperature drops the system’s pressure back to normal, which reverses the increase in the refrigerant’s boiling point and the absorbent regains its solubility. This will cause the refrigerant to re-evaporate in the cool ball, cooling the chamber in the process. The refrigerant gases are then reabsorbed into the absorbent, allowing the phases to repeat in cycles.

Possible materials
The most important materials in this system are the refrigerant and the absorbent. Some different types of refrigerant and absorbent are as follows:

<table>
<thead>
<tr>
<th>Materials</th>
<th>Advantage</th>
<th>Disadvantage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ammonia (refrigerant) + water (absorbent)</td>
<td>Ammonia’s Boiling point of $-33^\circ$C at atmospheric temperature</td>
<td>Ammonia Gas is toxic to the environment</td>
</tr>
<tr>
<td>Water (refrigerant) + Lithium Bromide (absorbent)</td>
<td>Water is Non-toxic to the environment</td>
<td>Requires the initial pressure of the system to be near vacuum</td>
</tr>
<tr>
<td>CO2 (refrigerant) + Water (absorbent)</td>
<td>CO2 is less toxic compared to ammonia</td>
<td>Cooling effect is generally weaker than ammonia</td>
</tr>
</tbody>
</table>
Option 2: Peltier Cooler

Overview

Peltier cooler uses a thermoelectric effect, known as the Peltier effect, to cool the environment.

One of the advantages is that, if the materials are chosen correctly, the temperature can drop to low temperature quickly. Also, the system is robust as it has no moving parts. The efficiency however is very low, and multiple modules and junctions are required to experience a noticeable effect.

Physics

Heat emission or absorption occurs when a current flows through a junction between two metals with different Peltier coefficient. This occurs because energy required for electrons to travel through metal is different for each metal. As the electron changes its medium from metal A to metal B, the required energy needed to travel also changes. To match the required energy, electrons will either absorb or emit heat energy.

The Peltier effect is governed by the following equation:

\[
\dot{Q} = p_{1-2}I
\]

Where

\(\dot{Q}\) = rate of heat emission/absorption

\(p_{1-2}\) = difference in peltier coefficient from metal 1 to 2

\(I\) = current

This shows that the equation is vector sensitive; if you reversed the current, the junction would reverse its role (heating to cooling and vice versa). This also applies if you swapped the order the material was set up.

Possible materials

Peltier coolers can use any combination of conductors and semiconductors to achieve a cooling effect. Some of the more popular combinations are listed below:

<table>
<thead>
<tr>
<th>Material combination</th>
<th>Advantage</th>
<th>Disadvantage</th>
</tr>
</thead>
<tbody>
<tr>
<td>copper – Bismuth Telluride</td>
<td>Has a very high (p_{1-2}) value which implies that it has a high rate of heat emission/absorption as well.</td>
<td>Both copper and Bismuth Telluride are costly, especially when multiple junctions are used as recommended.</td>
</tr>
<tr>
<td>Copper-nickel</td>
<td>Much cheaper to manufacture compared with other popular Peltier modules; hence the rate of heat emission/absorption would be low.</td>
<td>(p_{1-2}) Value is relatively low compared to other popular Peltier modules.</td>
</tr>
</tbody>
</table>
Option 3: Night Radiation Cooling

Overview
Night radiation cooling uses the night sky to cool a thermal sink, which then can be used to cool a chamber during the day.

The major advantage of night radiation is that it does not require electrical or thermal energy. It just needs to make sure that the thermal sink is exposed to the night sky, allowing it to cool. The system is robust and straightforward to implement due to its simple design. Unfortunately, the system cannot reduce the temperature of the chamber down to zero degrees (which is our main goal). Even the most efficient ones could only bring the temperature down to 6 degrees.

Physics

There are two phases for night radiation cooling; Night and Day.

Night
During the night, a large thermal mass is exposed to the night sky which establishes a thermal gradient between the two. By the laws of thermodynamics, when there is a temperature gradient between the two bodies, both bodies will try to achieve the same temperature. The night sky is an infinite heat sink, with a temperature significantly lower than the thermal mass which has been absorbing heat during the day; hence the thermal mass will try cooling itself down to the same temperature as the night sky by radiating the absorbed heat. This succeeds in getting the thermal mass cooled down to 10 degrees.

Day
During the day, after the thermal mass has been cooled, it is insulated from the solar radiation to prevent the water from heating up by the sun. This establishes a new thermal gradient between the thermal mass and the chamber and hence cools the chamber down to roughly 10~20 degrees via similar concept.

It should be noted that this type of cooling is most effective during the dry seasons, as water content in the sky dictates the emissivity of the atmosphere, which is directly proportional to the amount of radiation from the sky to the earth

Possible materials
In general cases, night radiation can use any form of thermal mass to achieve cooling. However water is the best thermal mass we can use. It’s not only a very good heat sink, but also it is practically free, and easy to implement as well as having a similar specific heat capacity to the food mass in the chamber.
Option 4: Compression

Overview
The system induces a cooling effect by mechanically expanding the refrigerant gas.

The biggest advantage of this system is that it has the potential to cool down a chamber to zero degrees in. It’s also very efficient for the amount of cooling it can achieve. The mechanical units in the system are complex however, making it difficult to train the locals in maintaining the compression refrigeration device.

Physic
The compression refrigeration system is designed such that the compressor and condenser are situated outside of the chamber, while the evaporator is placed inside the chamber.

Cooling agent vapour would first be pumped into a compressor, inducing heat and pressure to the vapour. Gas under high pressure experiences an increase in its boiling point, and as this compressed vapour flows down the condenser where its gets air cooled, the agent condenses into liquid. This liquid cooling agent is then pumped into an evaporator where it will expand the liquid into a gas quickly. This swift evaporation causes the expanded gas to quickly pump through the pipe between the expander and the compressor, inducing a cooling effect across that section of the pipe and cooling the chamber in the process. The newly expanded gas is pumped back into the compressor where the cycle continuous.

Possible materials
The most important materials in this system are the refrigerant. Some different types of refrigerant and absorbent are as follows:

<table>
<thead>
<tr>
<th>Refrigerant</th>
<th>Advantage</th>
<th>Disadvantage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Freon</td>
<td>Superior stability, not flammable at room temperature. Is nontoxic to human</td>
<td>Contains CFC, which damages the ozone</td>
</tr>
<tr>
<td>1,1,1,2-tetrafluoroethane</td>
<td>Less harmful to nature compared with Freon</td>
<td>Can emit toxic gases when experienced with 250 degrees temperature</td>
</tr>
</tbody>
</table>
Option 5: Stirling Cycle

Overview
The Stirling Cycle refrigerator uses mechanical work, through a piston, to expand a heated gas, allowing it to boil under low pressure, and hence create a cooling effect. This system is primarily used in cryogenic coolers; however we decided to investigate the practicality and efficiency of such a system for household refrigeration.

The advantages of this system lie in the short time that mechanical work must be done on the piston to produce a significant cooling over an extended period of time, the temperatures that can be achieved are sub 0 and the machine is very compact and robust. The disadvantages are that the system must be pressurised and use pure helium.

Physics

Initially the helium is compressed and heated by the hot reservoir. It is then adiabatically expanded, not allowing any heat dissipation. This causes the Helium to immediately cool and begin to boil at a very low temperature. As it is insulated from the hot reservoir it draws energy from the cold reservoir cooling it.

Possible materials

<table>
<thead>
<tr>
<th>Material</th>
<th>Advantage</th>
<th>Disadvantage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Helium</td>
<td>Low boiling point and inert</td>
<td>Difficult to transport to community</td>
</tr>
<tr>
<td>Chamber Insulator</td>
<td>Only requires mechanical work</td>
<td>Difficult and costly to construct</td>
</tr>
</tbody>
</table>
## Analysis Table of Different Cooling Methods

<table>
<thead>
<tr>
<th></th>
<th>Absorption</th>
<th>Night Radiation</th>
<th>Peltier Cooler</th>
<th>Compression</th>
<th>Stirling</th>
</tr>
</thead>
</table>
| **Cooling rate** | • Good for large scale applications  
• Fast Cooling rate            | • Slow Cooling Rate           | • Highly inefficient          | • Good for small scale  
• Can freeze                                      | • Can be easily controlled   |
| **Cost**         | • Chemicals and chamber are costly ($1600 AUD)  
• Cost is negligible  
• Materials can be sourced from the local community | • Cost is negligible          | • Materials used are expensive  
• Only required in small quantities. | • Complex machinery  
• Costly Machinery and maintenance (11,075.82 AUD) | • The chamber and working fluid are very costly |
| **Reliability**  | • No moving part  
• Can explode due to high pressure | • No moving parts  
• Sensitive to weather conditions | • No moving parts  
• Can overheat | • Moving parts  
• Good Reliability   | • Moving parts  
• Good Reliability |
| **Power Source** | • Diverse range  
• Requires constant fuel for charging phase | • No power source | • Requires electricity  
• Requires transformer  
• Battery powered | • Requires electricity  
• Requires mains power | • Human |
| **Operation and maintenance** | • Minimal since there are no moving parts  
• Straightforward operations  
• Inspections for leaks and swelling required | • Straightforward operation  
• Minimal maintenance  
• Monitoring of the system is required to check for leaks | • Straightforward maintenance and operation  
• Plug and play | • Operation is straightforward  
• High level of maintenance | • Difficult to source parts  
• Technically easy to maintain |

|                  | **Total** | 18 | 22 | 21 | 17 | 18 |

| **Favourable**   | 5         | 4  | 3  | 2  | 1  |    |

*The categories are ranked in descending order of importance.*
**Design Options for Chamber**

**Alternative Design – Below Ground**

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimises utilisation of space above ground.</td>
<td>Implementation costs are higher as large scale excavation is required.</td>
</tr>
<tr>
<td>Is better for insulation when the chamber is sited</td>
<td>Construction time is increased as excavation is both labour and time intensive.</td>
</tr>
<tr>
<td>10 metres below the earth’s surface.</td>
<td>Requires more elaborate security protocols and evacuation proceedings.</td>
</tr>
<tr>
<td>Much greater protection from pests and airborne</td>
<td>Structure needs to be reinforced to a greater degree to cope with pressures from the surrounding earth acting upon the walls.</td>
</tr>
<tr>
<td>diseases.</td>
<td>Adequate ventilation is more difficult to achieve.</td>
</tr>
<tr>
<td></td>
<td>Excavation can only occur at certain times of the year (non-monsoonal seasons.)</td>
</tr>
<tr>
<td></td>
<td>More difficult to provide power/ lighting to the chamber.</td>
</tr>
</tbody>
</table>

**Design Options for Chamber**

**Option 1: Chamber and Night-Radiation Heat Exchanger**
The first option is the standard installation for the design, and is the cheapest in terms of cost and labour time. When operational, it has the ability to cool the chamber to approximately 10 degrees Celsius, and it shall be able to hold the chamber at this temperature. Time taken to install is approximately 4 weeks.

**Option 2: Chamber and Peltier-Effect Heat Exchanger**
This option combines the standard installation, with the installation of the Peltier-Effect Heat Exchanger, which takes approximately 2 days to install. This Heat Exchanger must be installed by a professional, due to its high-tech nature. However this option takes approximately the same amount of time as option 1, as the Peltier-Effect Heat Exchanger can be installed during the later stages of the chamber construction. It is more expensive in terms of labour time as it requires a professional to install.

**Option 3: Chamber with both Night-Radiation and Peltier-Effect Heat Exchangers**
In terms of labour cost and time, the implementation of option three is identical to that of option two. The only difference between these options is that the Night-Radiation Heat Exchanger is operational in option three, as it requires daily maintenance to remove and replace the roof insulation, also to keep the volume of water constant.
Design

The design for the Cool Storage system refrigerates a container using natural means.

The Cool Storage solution is divided into three primary components:

1. The Night Radiation Cooler

   The Night Radiation Heat Exchange method relies on the radiation of heat from the water to the atmosphere to transmit heat from the chamber. During the day, water is pumped within the chamber to establish a new thermal equilibrium, by absorbing heat from within the chamber. During the night the water is allowed to radiate heat to the atmosphere and hence cool.

2. The Peltier Effect Heat Pump

   The Peltier heat pump utilises the Peltier effect by creating a junction between materials with differing resistivity. This creates a heat current across the junction. The system is powered by a 24V solar panel or battery that powers a Peltier plate.

3. The Chamber

   The chamber is specifically designed to store agricultural produce and medicine. It is sufficiently insulated from the daytime ambient temperatures by the perlite, polyurethane and bud brick exterior skin. The chamber is designed to incorporate the Night Radiation and Peltier Effect Cooler in one structure.

We believe that this solution adequately fulfils all the primary criteria, and most of the secondary criteria.
<table>
<thead>
<tr>
<th>Parameter</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capacity Dimensions (Length, Height, Width)</td>
<td>(1800,1750,1800) mm</td>
</tr>
<tr>
<td>Stable Temperature (With Peltier Installed)</td>
<td>Approximately 0-1 degrees Celsius</td>
</tr>
<tr>
<td>Stable Temperature (Without Peltier Installed)</td>
<td>Approximately 10 degrees Celsius</td>
</tr>
<tr>
<td>External Access Points</td>
<td>1</td>
</tr>
<tr>
<td>Waterproof</td>
<td>Yes</td>
</tr>
<tr>
<td>Heat Insulation Efficiency</td>
<td>90% Efficient</td>
</tr>
</tbody>
</table>
**Night Radiation Cooling (Primary cooling)**

Whilst searching for cooling mechanisms we found that most employed complex machinery or dangerous chemicals. Many options were rejected on this basis. However Night-time radiation seemed ideal. It only requires natural, renewable resources and is powered by the night sky.

For any refrigeration cycle a hot body must be put into contact with a cold body. The Hot body then cools down and the cold body heats up until they are at the same temperature. This is the Zero\textsuperscript{th} Law of Thermodynamics. Heat transfer takes place through convection, conduction and radiation. The three forms of energy transfer can be mathematically modelled using the following formula (A A M Sayigh, 2000):

\[
mc \frac{dT}{dt} = q_r + q_c + q_e
\]

If further cooling is desired then work must be done on the cold body to pump heat away. This process is energy intensive because of the entropy of the system. As the temperature of an object decreases the entropy decreases. “A familiar demonstration of entropy is the mixing process of two jars of balls, red balls and black balls. Mixing is easy but un-mixing is tedious. Ipso facto, heating is relatively easy – strike a match - but cooling requires real effort - build a refrigerator.” (Guy K.White, 2002). Therefore it takes far longer to cool the body than to heat it. By utilising a number of heat transfer mechanisms it is possible to speed up the process.

**Figure 2: This is the basic model of a heat engine**

In the Night-time radiation system the hot body is the chamber and the cold body is the night sky. The key feature of using the night sky as the cold body and not a refrigerant is the sky act as an infinite heat sink. It does not require extra work to be put in to absorb more heat. The night sky I able to act as an infinite heat sink as it is in contact with space. Space is at, almost, 0 Kelvin, hence the atmosphere tries cools. As the sun heats the atmosphere, the inherent heat locked into the planet’s atmosphere is 300K (30°C) during the day. Therefore during the night the sky radiates heat to space and the land tries to reach a thermal equilibrium with the sky. Therefore night time temperatures are far lower than daytime temperatures.

Using a medium with a high specific heat capacity and high heat loss due to radiation a heat pump can be created. We have decided to use water as the radiator and absorber to create a heat pump. This system is known as the pond cooler. The roof of the chamber is filled with water during the
night and it loses heat due to radiation. During the day the water is insulated in the chamber so that it is not heated due to solar radiation. Hence the contents of the chamber are chilled by the water which absorbs the heat from the contents as it is cooler than the chamber.

This system is able to lower the temperature of the contents by up to 20° from the ambient day temperature. Temperatures achieved in Thailand have been as low as 6°C. This system is not highly efficient and is very sensitive to water content in the sky. Water content in the sky dictates the emissivity of the atmosphere, which is directly proportional to the amount of radiation from the sky to the earth. We have used the following mathematical models to predict the cooling created by night sky radiation.

**Calculation**

![Figure 3](http://www.myweather2.com/)

The Following Models are sourced from:
R. Dobson, ‘Thermal modelling of a night sky radiation cooling system’, University of Stellenbosch

\[
R = e_r (\sigma T_{pond}^4 - S)
\]

- \(R\) = radiative cooling \(W/m^2\)
- \(e_r\) = roof pond emissivity \(0.93 < e_r < 1.0\)
- \(T_{pond}\) = roof pond temperature
- \(S\) = globe thermal radiance
- \(\sigma\) = Stefan – Boltzmann Constant
$S = e\sigma T^4$

$T = \textit{ambient air temperature}$

\textit{Emissivity} of the sky can be approximated by the Berkeley Equation (A A M Sayigh, 2000):

$$e_{sky} = 0.741 + 0.0062T_{pd}$$

To calculate the $T_{pd}$, dew point temperature, the following approximation was used:

$$T_{pd} = T_{\text{Ambient}} - \frac{100 - \text{Relative Humidity}}{5}$$

$$R = e_r \sigma (T_{pond}^4 - e_{sky} \sigma T_{AMB}^4)$$

Therefore for the Values stated at the beginning the pond will reach a temperature of 5.52°C as heat loss due to radiation goes to 0.

<table>
<thead>
<tr>
<th></th>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>Jun</th>
<th>Jul</th>
<th>Aug</th>
<th>Sep</th>
<th>Oct</th>
<th>Nov</th>
<th>Dec</th>
</tr>
</thead>
<tbody>
<tr>
<td>Relative Humidity</td>
<td>0.77</td>
<td>0.77</td>
<td>0.76</td>
<td>0.71</td>
<td>0.66</td>
<td>0.66</td>
<td>0.77</td>
<td>0.71</td>
<td>0.76</td>
<td>0.81</td>
<td>0.84</td>
<td>0.8</td>
</tr>
<tr>
<td>Dew Point Temperature</td>
<td>0.154</td>
<td>0.154</td>
<td>4.152</td>
<td>6.142</td>
<td>8.132</td>
<td>7.132</td>
<td>7.154</td>
<td>6.142</td>
<td>5.152</td>
<td>4.162</td>
<td>3.168</td>
<td>1.16</td>
</tr>
<tr>
<td>Ambient Air Temperature</td>
<td>20</td>
<td>20</td>
<td>24</td>
<td>26</td>
<td>28</td>
<td>27</td>
<td>27</td>
<td>26</td>
<td>25</td>
<td>24</td>
<td>23</td>
<td>21</td>
</tr>
<tr>
<td>Emissivity of the Sky</td>
<td>0.74</td>
<td>0.74</td>
<td>0.77</td>
<td>0.78</td>
<td>0.79</td>
<td>0.79</td>
<td>0.79</td>
<td>0.78</td>
<td>0.77</td>
<td>0.77</td>
<td>0.76</td>
<td>0.75</td>
</tr>
<tr>
<td>Stefan - Boltzman Constant</td>
<td>5.67E-08</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temperature of Pond</td>
<td>0.29</td>
<td>0.29</td>
<td>0.35</td>
<td>0.38</td>
<td>0.41</td>
<td>0.39</td>
<td>0.39</td>
<td>0.38</td>
<td>0.36</td>
<td>0.35</td>
<td>0.33</td>
<td>0.30</td>
</tr>
</tbody>
</table>

As can be seen from the temperature of the pond the water will cool sufficiently during the year to dramatically cool the chamber.

The recommended size specifications for the night radiation cooling are:
Peltier cooler (Secondary Cooling System)

Once we had settled on the Night Radiation cooling system we decided a secondary cooling system is necessary to be able to safely store medicines and items that need to be frozen. As the secondary cooling mechanism the Peltier Cooler was seen as the most viable option.

The Peltier cooler is a cooling system which uses the thermoelectric effect called the Peltier effect. When two different metals are connected at a junction and a current is passed through them, the junction begins to emit or absorb heat depending on the direction of the current. The Peltier effect can be modelled by the following equation:

\[ \dot{Q} = pl \]

Where:

\[ \dot{Q} = \text{rate of heat emission/absorption} \]
\[ p = \text{difference in peltier coefficient} \]
\[ l = \text{current} \]

This is a vector equation; if the current is reversed, the junction would reverse its role (heating to cooling and vice versa). This also applies if you swapped the order the materials.
Metals
Electrons speed up or slow down under the influence of contact potential difference. Since different materials have different influence on passing electrons, it will have its speed changed accordingly. This means that electrons will have different level of kinetic energy for each individual material. If two different metals are joined together and have a current flow through it, it will create an energy difference in the junction (since the velocity of the electron will change from one material to another). But because of the law of conversation of energy, this extra (or devoid) energy must come from somewhere; that is through emitting and absorbing heat.

Materials
Although Peltier coolers can work with any metal as long as they are of different types, it seems to work most efficiently with Copper and Silicon Semiconductors. This is due to the fact that the combination has the greatest Peltier coefficient difference for its cost.

Note that a signal Peltier cooler requires multiple junctions for the cooling effect to be significant.

Peltier coolers are not being used as the primary source of cooling, but rather it is used to aid the night radiation cooling. The Peltier cooler that will be used is a pre-made, semiconductor type cooler with 50x50x4.3mm 15.6A/15.4V 150W 127 couples. There will be 5 Peltier modules placed on the floor to achieve the most effective supportive cooling (approx. 5 degrees of additional cooling), and will use the water that is being used by night radiation cooling as a heat sink. The power supply for this system will be solar panels (since the additional cooling is only required during the day) and can be placed anywhere sunlight shines the most. The power source and the module will be connected via wires running underground, slipping through the gaps made for the insulation layers.
Figure 4 G Gromov, RMT Ltd
As can be seen from these diagrams the Peltier Cooler requires a current of 2.2 Amps and will pump 0.2 Watts of energy.

Figure 5 The Peltier Cooler
**The Chamber**
The following sections comprise our design solution for a chamber that will serve as the core component of the refrigeration system. We created our own compound layer for the external skin of the chamber to insulate the contents. For the standalone chamber the primary structural material is Perlite.

**Perlite**
The term ‘Perlite’ refers to naturally occurring siliceous rock which has exceptionally low density (light weight) and tough physical strength. When heated it can expand to twenty times its original volume, hence transportation costs can be reduced (Perlite.net 2011).

![Perlite Image](image)

*Figure 6 Different Forms of Perlite*

<table>
<thead>
<tr>
<th>Compositions of Perlite</th>
<th>Percentage (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Silicon</td>
<td>33.8</td>
</tr>
<tr>
<td>Aluminium</td>
<td>7.2</td>
</tr>
<tr>
<td>Potassium</td>
<td>3.5</td>
</tr>
<tr>
<td>Sodium</td>
<td>3.4</td>
</tr>
<tr>
<td>Iron</td>
<td>0.6</td>
</tr>
<tr>
<td>Calcium</td>
<td>0.6</td>
</tr>
<tr>
<td>Magnesium</td>
<td>0.2</td>
</tr>
<tr>
<td>Trace</td>
<td>0.2</td>
</tr>
<tr>
<td>Oxygen (by difference)</td>
<td>47.5</td>
</tr>
<tr>
<td>Net Total</td>
<td>97.0</td>
</tr>
<tr>
<td>Bound Water</td>
<td>3.0</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>100.0</strong></td>
</tr>
</tbody>
</table>

*(Perlite.net 2011)*
Advantages of Perlite

Perlite is cheap, costing around $50 American per ton (The Institute for Planetary Renewal).

It is transported in compact form and expanded on site by heating (NSW Department of Primary Industries).

Perlite is environmental friendly as it does not contain asbestos (InspectAPedia 2011).

Chemically inert (Perlite.net 2011).

Due to its closed cell structure, perlite does not absorb moisture and is air tight.

Perlite insulation has low thermal conductivity through a range of densities. The recommended density range is 48 to 72 kg/m³. Within this density range, the chamber will be kept at the designated temperature determined by the cooling system, which would be around 0°C for storage of agricultural goods, prawns, and other perishable goods.

Research of Common Construction Materials/ Materials Required
To make better use of Devikulam’s natural resources, the insulating chamber incorporates layers of clay and cow droppings. As an abundant natural resource, clay is easily obtainable at the village and also widely accepted as a raw material, as several farmers have implemented chambers using clay. Clay is flexible, strong, fire resistant, and rot/termite proof. It has high thermal resistivity and can serve as an air purifying substance by absorbing moisture. It also diffuses vapour and shields high frequency electromagnetic radiation. (Colours by Nature)

Figure 7 Layers of Wall: Perlite, Polyurethane, Air Gap and Mud Brick

Size specifications:
The recommended size for the chamber will be 15m³, with dimensions of around 3m×2m×2.5m. In our recommended design, the existing government housing is used as the external shell. In which case the size of the chamber can be adapted to whatever size the government house is.
Chamber Construction

Overview:
Construction of the chamber is to be approached methodically through a multiple-phase process.

The core material we will be using as the main insulator, polyurethane, has limited availability. It is also worthwhile to note that the layers of material we put on for insulation are labour intensive. Therefore for the refrigeration programme to be a success, we will have to work with the local Non-Governmental Organization (NGO), Pitchandikulam Forest. They will assist initially with the manufacture, arrangement and transportation of the essential materials. More importantly, their community outreach programme will be utilised to make collaboration with the community easier.

Initially the local population will be consulted to determine adequate sites for further inspection. If the proposed site is deemed satisfactory then primary construction shall commence, beginning with the transportation of materials and essential personnel to the site. At this point several aspects of the construction can run concurrently, as outlined in the Gantt chart below. Once the system is complete, it will be closed to the general public for two weeks. This is to perform a post-construction analysis of both the chamber and its cooling systems to ensure all operational standards are met.

<table>
<thead>
<tr>
<th>Week</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
</tr>
</thead>
<tbody>
<tr>
<td>Research and consultation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Physical Site Analysis</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Foundation Preparation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pouring of Concrete Foundation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Erection of Walls</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Brick Manufacturing</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Application of Polyurethane</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Erection of internal walls</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Roof Assembly</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shade Construction</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Implementation of Night Radiation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Implementation of Peltier Scheme</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Disposal of Waste</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Post Construction Analysis</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Phase 1 – Research and Consultation: 2 Weeks
The detail pertaining to the research/consultation component of this phase is Devikulam-specific and can be found in the implementation section.

Physical Site Analysis:
Many important factors come in to the proper selection and preparation of a site to house the system. Once the community has proposed a number of sites that meet the social constraints of the community, it is the task of the committee, in collaboration with the project engineer to determine which site is physically optimal for construction. It is highly recommended that the system should be
implemented in the immediate vicinity of a water body, or at least close to a readily available supply of water. The integrity of the earth at the site must be appropriate, so that the operation of the chamber is not jeopardised due to eventual damage to the foundation. The chamber will increase traffic flow in the area. Therefore a site must be chosen that does not present a risk of degradation to any significant sites and ecosystems in the vicinity.

**Phase 2 – Primary Construction of Chamber/Cooling Systems: 4 Weeks**

**Foundation Preparation:**
This component of the construction can begin once the site has been chosen and agreed upon by the community. If an existing government-housing structure is be used, then this step is unnecessary.

A 5x5m square pit is to be dug 250mm into the earth. This is to house the foundation of the structure. As this volume is relatively low, it is to be removed with shovels and should only take 8-10 hours. The excavated dirt is to be relocated at the discretion of the community elders. If no suitable location is nominated, it will be evenly distributed about the area. Once the pit has been completed, the ground is to be compacted with a roller.

**Pouring of Concrete Foundation:**
If a government-housing structure is being utilised, this step is unnecessary.

Wooden guides for the cement are to be cut and placed at the bottom of the pit to the required specifications of the foundation. The concrete mixture is then mixed on site, and poured to the specified depth. It will take approximately 2 weeks of curing before the walls can be safely assembled upon the foundation. Excess mixed-concrete is to be set aside for disposal at the completion of the project.

**Erection of Perlite/Concrete Walls:**
If a government-housing structure is being utilised, the erection of the perlite walls is unnecessary. However, any doors other than the primary door and all windows must be removed and bricked in with the concrete blocks. Perlite is then utilised to seal any fractures and provide insulation. The original concrete roof is to be removed at this point; resulting waste is to be set aside for later disposal.

When building from scratch, the concrete blocks are to be built to the specified dimensions. The adhesive mixture will be mortar. Care must be taken at this stage to build the walls as perpendicular to the foundation, and as square with each other as possible. This improves the integrity of the structure and prolongs the operational life of the chamber. It is important to place a gap in the external wall for the door, as noted in the specifications.
Brick Generation:
The custom made cow dung/grass and cow dung/terracotta bricks are to be manufactured on site through the utilisation of a brick press and local materials. To construct the cow/dung terracotta brick, the terracotta pots are inverted into the cow dung, whilst an air cavity within the pot is maintained. The entire brick is then compressed in the press and allowed to cure. The cow dung/grass bricks are simply a homogenous mixture of the aforementioned materials, to be compressed and allowed to cure.

Application of Polyurethane:
The polyurethane comes in compressed form, and is sprayed onto the concrete walls to act as an insulator. It is situated between the concrete and cow dung/grass layers. Because the foam will expand to approximately 10-20 times its initial size, application is to be done by a competent worker with prior experience with the material, such as a design team member or the engineer. It is to be laid out into strips to ensure that there is enough space for the foam to expand laterally up and down the wall, as well as outwards.

Erection of Internal Walls:
Once the cow dung/grass bricks have properly cured, they can be laid in place to the specified dimensions. These walls are to be erected directly against the polyurethane on the internal side, and as parallel as possible to the external walls. Once again a gap must be left to house the door to the structure, as specified in the design notes. These bricks are to be interconnected with the traditional adhesive mud mixtures.

Roof Assembly:
The roof comprises a combination of bamboo woven matting, reinforced with cement to provide a rigid, waterproof ceiling that can support the weight of the water above. During construction the bamboo matting is to be supported from below by temporary supports whilst the cement cures. Once this occurs these supports can be removed. The bamboo matting is to be woven by village volunteers who are skilled in the craft. This process should occur approximately 3 weeks into construction, to allow adequate time for the concrete foundation to cure to enough strength and for the mortar in the walls to harden.

Shade Construction / Application:
Similar to the bamboo matting, the Palmyra leaf shields are to be woven locally and stored until construction of the roof is complete. At this point the shields can be leant up against the external walls of the chamber, to act as a radiation barrier. The door can also be installed at this point in time.
Implementation of Night-Radiation Scheme:
Once the concrete within the roof assembly has cured, the water can be gradually added to the heat sink. Initially it is to be filled to a low depth of 5-10 millimetres, so that an initial check for leakage can be done. Any leaks found are to be sealed with perlite.

Implementation of Peltier Scheme:
The Peltier scheme is the last component to be installed, once the roofing structure has been completed. Due to its relatively small size, installation time is relatively short. However, it must be installed by a person with prior experience with the system, due to its electronic nature. The shelf unit is first bolted to the ceiling. The Peltier plates are then attached to the top panel, and connected to the power source.

Disposal of Waste:
At the conclusion of the project there is expected to be a collection of waste resources, such as unused, mixed concrete/mortar, bamboo/leaf fragments, bricks and perlite. Resources such as the bamboo/leaf fragments and bricks/perlite can be recycled for other local projects, such as the construction or insulation of other local structures. The unused, mixed concrete/mortar will have to be disposed of appropriately, at the discretion of the community elders. The waste skip is expected to be trucked to the nearest landfill, should no other suitable location be found.

Phase 3 - Post-Construction Analysis: 2 Weeks
During the 2 weeks of post-construction analysis and evaluation. The chamber, night radiation, and Peltier components are to be checked against the following criteria:

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Action If Failure</th>
</tr>
</thead>
<tbody>
<tr>
<td>The ceiling must be completely waterproof.</td>
<td>All leaks and weak-points must be re-sealed with perlite, with polyurethane reinforcement.</td>
</tr>
<tr>
<td>The chamber must be free from pest-intrusion.</td>
<td>Access protocols are to be updated, as well as a re-check of all walls and floors for cracks.</td>
</tr>
<tr>
<td>The door must provide effective insulation.</td>
<td>Insulation behind the door will be increased, along with a more effective seal around the edges made from fibres.</td>
</tr>
<tr>
<td>The Peltier plates must dissipate heat to the heat sink effectively.</td>
<td>The Peltier plates are to be re-adjusted to a more effective position, optimally closer to the heat sink.</td>
</tr>
<tr>
<td>Evaporation levels of the water body should be less than 5% of the total volume per day.</td>
<td>The adjustment times of the terracotta/cow dung bricks are to be re-evaluated to reduce exposure time to the atmosphere.</td>
</tr>
</tbody>
</table>
Implementation

Implementation Overview
The core design embodied within this report breaks down into 3 constituent sub-designs:

- The Chamber
- The Night-Radiation Heat Exchanger
- The Peltier-Effect Heat Exchanger

In terms of construction, the Night-Radiation Heat Exchanger is integrated within the chamber design, so that these two components must be constructed concurrently. The Peltier-Effect Heat Exchanger greatly improves the refrigeration capabilities of the design, but is optional in the sense that it can be combined with the existing system at a later date, or not at all.

Community Consultation/Site Determination:
A four person committee is to be formed with the sole task of liaising with the population, to determine locations which are most adequate to house the chamber, with respect to social context.

The committee is to be comprised of a design team member, a representative from Pitchandikulam Forest, and two elders from the community.

A general meeting of the community is to be undertaken. At the discretion of the elders of the community, it may be either a single, large gathering of the entire community, or several smaller meetings to different social groups, such as the Most Backward and Dalit Classes, residing in the village and in the colony. Every member of the community will be given the chance to suggest possible sites, and provide reasons why such a site should not be utilised. The criteria for an adequate site are given below, the site:

- Must be localised for optimum access for the community as a whole, its location should not favour access to a particular group of people.
- Must not be sited upon private property without the express permission of the owner.
- Must not be sited upon grounds of religious significance.
- Must not dramatically alter the social dynamic of the immediate area, any citizens who feel that such a site critically impinges on their rights and routines have a right to provide valid reasons against the site proposal.

Ideally, the design utilises a government-built house to take advantage of the existing structure, materials, so as to reduce construction costs. If such a location cannot be found, or if it is not in a
location suitable due to the above reasons, then the structure will have to comprise a chamber built from scratch.

**Post-Project Considerations**

Upon completion of the project, it is expected to be operational for approximately 15 to 20 years. In that time, considerations such as the following will have to be taken into account to ensure both a smooth integration of the project into the community, and an appropriate post-operational strategy:

- Periodic check-ins with the community to assess the integrity of both the chamber and the heat exchange.
- Periodic check-ins to assess current usage rates and what is being stored, local response surveys on its impact and assessment of the immediate environment to incorporate adaptations into the existing design for future deployment in other areas.
- An appropriate end-time strategy to either re-allocate use of the space should the refrigeration aspect become non-functional, or an effective demolition strategy to maximise re-use of its resources, and to minimise damage to the environment.

**Maintenance Strategy**

Day to day maintenance of the system entails the removal and replacement of the terracotta/cow dung bricks that shield the water pool, so as to utilise the in-built Night-Radiation system. This is to occur roughly every dawn and dusk. The door is also to be locked over night at these times.

Structural analysis is to be performed periodically by the managing organisation, Pitchandikulam Forest, approximately every time a survey is distributed to the community (see next section.) The structure must exhibit minimal cracking (penetrating less than 30mm into the walls). The ceiling must be completely waterproof. There is to be minimal pest intrusion. In terms of buckling and levelling, walls and beams should not deviate more than 3 degrees from their original positions. The piping should only exhibit intermittent corrosion at most, with corrosion permeating no more than 2mm into the pipe.
Chamber Design:

### Tests

- Checking of foundation for:
  - Sinking
  - Levelness
  - Cracking

- Checking of walls for:
  - Cracking
  - Levelness
  - Insulation Integrity

- Checking of ceiling for:
  - Cracking
  - Buckling
  - Insulation Integrity

- Checking of doors for:
  - Pest-Infestation
  - Cracking

- Checking of Internal Storage Lockers for:
  - Pest-Infestation
  - Cracking

### Possible Actions if Failure

- Repair of foundation
- Condemnation of structure (Demolition and extraction of brick and insulation for recycling)

- Repair of walls
- Replacement of Walls
- Replacement of insulation
- Condemnation of Structure

- Repair of ceiling
- Replacement of ceiling
- Replacement of insulation
- Addition of support pillars
- Condemnation of Structure

- Repair of doors
- Replacement of doors
- Extermination of pests

- Repair of lockers
- Replacement of lockers
- Extermination of pests
- Reallocation of space for different storage (non-perishables)

Night Radiation Cooling System:

### Tests

- Checking of pipes for:
  - Corrosion
  - Leaking
  - Damaged seals at connections

- Checking of evaporation pond for:
  - Leaking

- Checking of pump system for:
  - Leaking
  - Metal Fatigue
  - Corrosion

### Possible Actions if Failure

- Replacement of Pipes
- Removal of System

- Sealing of pond
- Removal of system

- Replacement of Parts
- Removal of system

Should the integrity of the chamber be found to be satisfactory, the chamber space may be re-allocated for non-perishable food items or other miscellaneous storage, if the cooling systems are found to be no longer operational.

**Source of Materials**

A core design requirement of the Engineers Without Borders design brief was to minimise the utilisation of materials from non-local suppliers. This is primarily to promote local industry and reduce implementation costs. The two primary components of the design achieve this...
requirement to different extents. The storage chamber certainly, which by virtue of its low-tech design, satisfies this requirement. Alternative building materials can be sourced from the immediate area.

The heat exchanger is less flexible in its design, although it does seek to maximise the use of local materials where possible. Many of the metal components within it are sourced from various companies in Chennai, a large city in the State of Tamil Nadu. Unfortunately it is not feasible to source many of the components directly from the area surrounding Devikulam.

<table>
<thead>
<tr>
<th></th>
<th>Sourced locally</th>
<th>Out sourced</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chamber</td>
<td>Cow Dung</td>
<td>Perlite</td>
</tr>
<tr>
<td></td>
<td>Clay</td>
<td>Concrete Blocks (Cement)</td>
</tr>
<tr>
<td></td>
<td>Terracotta Pot (Kular)</td>
<td>Polyurethane</td>
</tr>
<tr>
<td></td>
<td>Bamboo</td>
<td>Timber</td>
</tr>
<tr>
<td>Heat Exchanger</td>
<td>Night Radiation (Water)</td>
<td>Peltier Module</td>
</tr>
</tbody>
</table>

Table of components for system

Environmental Impact
The environmental impact of this project is directly affected by how it is implemented.

Environmental Impact & Benefit for each material

Polyurethane:
Polyurethane is a chemically inert material. The material itself is non-toxic to the environment hence it will not damage the environment during its lifecycle. The polyurethane, being the primary thermal insulator, ensures that the produce will not perish. This will reduce the amount of organic rubbish, which alludes to fewer solid wastage problems, reduces the release of methane, and induces better hygiene. Polyurethane however is not bio-degradable and it’s not recyclable; meaning that during the end of its lifecycle, the polyurethane will become a solid waste, which will have negative impact on the environment.
**Night Radiation**

Night radiation can cool the chamber up to 10 degrees Celsius, which is cool enough to store agricultural produces and extend its freshness. However because the water will be heated after the radiation is complete, the problem of disposing the warm water becomes an issue.

**Peltier Modules**

Peltier Modules, unlike other conventional refrigeration device, does not use chemical refrigerants which in normal cases harmful to the environment. Thus, like the polyurethane, it will not damage the environment during its lifecycle. Also just like polyurethane, its additional cooling effect will prevent spoilage of produces. Since the Peltier Module is mainly made from copper and bismuth p-type and n-type semiconductor, it will not bio-degrade into nature at the end of its lifecycle. However these materials are recyclable, allowing us to reuse some of these metals without exploiting natural resources.

**Mud Brick**

The mud brick acts in the same way the polyurethane do, in that it thermally insulates the chamber, keeping the cool inside. This ensures that the produces remains fresh and extends their useableness. However, unlike the polyurethane, it is bio-degradable; thus it will not become a solid waste during the end of chamber’s lifecycle.

**Government Building**

The chamber will use the concrete government building which will provide the main structure for the chamber. By using these buildings as a scaffold, it reduces the materials exhausted in making the chamber. This helps stabilise the amount of natural resource within the Devikulam environment which otherwise, may have led to resource depletion if this chamber idea was to be implemented to a large scale. During the end of its lifecycle, rather than destroying the building, it can be further modified to provide a comforting home with proper thermal insulation, meaning there is no material wastage.
Overall
The chamber itself is designed to use the natural materials around Devikulam as much as possible. The materials are either bio-degradable or non-toxic to prevent any possibility of damaging the environmental aspect of Devikulam. The role that the chamber takes also adds benefits to the environment, as it may reduce spoilage waste caused by rotting produces by keeping it fresh inside the chamber.

Cultural Impact

Industry level
Our storage system on this level will have a significant impact on the prawn industry. Currently, the prawns produced are kept on ice for one day only. If the prawns are not sold or consumed within a day, spoilage occurs and the food has to be thrown away. The refrigeration system will allow farmers to store their prawns for an extended period of time. This suggests opportunities for more generated income from the farmers, as they are now able to sell more of their goods with the same volume of prawn over a longer period. Additionally, this also leads to a longer consumption period for the villagers.

On the other hand, the agricultural products such as rice and tapioca and other farm products are pre-sold to local wholesalers or the government upon harvest (EWB forum 2011). The refrigeration system, when mass produced, is likely to enable more production of products, as the process of production is now independent of the rate and times in which they collect their goods.

Within the village
The community may benefit remarkably from the sanitation provided by the refrigeration system, as pathogens within the produce are less likely to survive at a lower temperature. Also, it provides a physical barrier from flies and ants.

As a permanent effect, there is likely to be an increase in productivity, because rather than having to process food every day in order to have fresh food stock, they can process a larger volume in one day and consume that food in a significantly extended period of time. Fruit storage period is also increased significantly due to the reduction in temperature from almost 40 degree Celsius to around 10 degrees. Therefore, the refrigeration system has an overall impact upon the daily patterns and activities of the residents— creating more free time for the residents to partake in other aspects of their living. However, it will be important to do further investigation on current community values and methods of these sorts of activities, as processing food on a daily basis may be the resident’s current preference.
Opportunities:
Our design is expected to provide opportunities, to compensate the costs outlined previously. They will primarily arise after the cooling systems have been implemented.

First, we are providing a spacious compartment with significantly lower temperature when compared to the outside environment. This encourages the agricultural producers to increase their volume of production as the surplus will not be spoiled within a few days, as has happened previously. We aim to facilitate an increase in the capacity for which the local farmers can produce and hence, increase the employment opportunities in Devikulam required to fulfil the increased capacity.

Secondly, opportunities will arise from the further involvement of Pitchandikulam Forest (PF) with the local community. As PF strengthens its relationship with the village through the implementation of the project, we are looking to put them in charge of the refrigeration system. We will also source local volunteers to carry out the construction so the residents in Devikulam will value and appreciate the system.

Finally, to compensate the short term cost of this project, we plan to consolidate the resident’s knowledge about this type of technology. Hence a profitable opportunity is that the villages surrounding Devikulam could become potential “customers” for residents in Devikulam to sell such technology. It will be important for Pitchandikulam Forest to seek people with interest in the system within the village, to so that these people may be taught about the construction of the system.

Community Response
The community response is to be gauged through a series of periodic surveys following the completion of the chamber. There will be a total of five surveys, spread over the chamber’s operational lifetime of 15 to 20 years. The final survey will determine what the community wishes to do with the space once it no longer performs as a refrigeration system. The surveys are to be transcribed into the local language, and distributed manually by the chamber manager to residents who use the chamber. These surveys are then to be analysed by the project’s post-construction managers, Pitchandikulam Forest, to determine if there needs to be any change to protocol.

Survey 1 – 3 months after completion

- How often do you use the chamber?
- Do you have enough space to store your goods?
- Is the chamber hygienic?
• Have you noticed any pests or insects in the chamber?
• Did any of your goods spoil in the chamber?
• Do you have any problems accessing the chamber?

Survey 2 – 1 months after completion

• How often do you use the chamber?
• Is the chamber hygienic?
• Have you noticed any pests or insects inside the chamber?
• Have you noticed any damage to the chamber?
• Have there been any issues with sharing the chamber?

Survey 3 – 5 years after completion

• How often do you use the chamber?
• Is the chamber hygienic?
• Have you noticed any pests or insects inside the chamber?
• Have you noticed any damage to the chamber?
• Have there been any issues with sharing the chamber?

Survey 4 – 10 years after completion

• How often do you use the chamber?
• Is the chamber hygienic?
• Have you noticed any pests or insects inside the chamber?
• Have you noticed any damage to the chamber?
• Have there been any issues with sharing the chamber?

Survey 5 – 15 years after completion

• Was the chamber effective in preserving your goods?
• What would you like to use the space for in the future?
• Did you have enough space to store your goods?
• Was the chamber hygienic?
• Would you like the chamber to be removed?

Community Consultation Reflection
We anticipate a number of difficulties when we consult with the community, before and after construction. Before construction it will be difficult to generate public awareness of the project, and public motivation. This concept of large-scale refrigeration is a foreign technique for the area that, when coupled with the inherent fear of the unknown that change brings, may cause mistrust amongst the community for the project. This is why a successful collaboration of the project development team with the existing NGO, Pitchandikulam Forest, is paramount. This NGO already has an outstanding reputation with the local community, as it has worked in the area previously.
After construction it will be difficult to get the surveys filled out. Although they are short, they do take up time which detracts from local activities. Overcoming this problem would involve offering an incentive to do the survey; unfortunately there is not enough money in the budget to finance this. When talking with the community, representatives should speak as clear as possible, and avoid the use of technical language.

**Education Strategy**

This project is reliant on its successful integration into the society, as it cannot benefit the community if it is not used. Because of it this, it is crucial that the local population is properly educated on what chamber is, how it can improve their life, and how to use it. The briefing of the population on the nature and operation of the chamber is to happen during the research phase of the construction implementation, as the population needs to know what this chamber is and how it affects them before they can decide on where it is to be placed. The chamber manager, who will be appointed to perform maintenance on the chamber, will receive additional briefing.

The general information distributed to all the villagers about the existence of the new storage system relates to its nature, and how they can use it. We propose building two of these systems; one for the colony and one for the village. People who wish to gain access will be informed of which chamber belongs to which social class, to prevent conflict during use between the two social classes. It is likely that the residents will not have used a refrigeration chamber before, so it is important to teach some key functionality rules, such as closing the doors when entering and leaving the chamber. Also, they will need to know to stay in the chamber for as short a timeframe as possible, and to limit their number of access times daily, in order to allow maximum efficiency for the refrigeration system to operate.

Appending to this general information, the people of Devikulam will need to be aware that this is for storing food and medicine only; it is not designed for anything. This will be community property, determining which section belongs to which household will need to be undertaken by the village elders. Furthermore, cleanliness for the chamber will have to be looked after for sanitation purposes. Here, it is an opportunity for creation of employment by means of a chamber keeper to provide management, to keep the chamber clean, to limit access times, as well as to make sure that the people accessing do not interfere with other people’s property and vital operating equipment (like the single phase heat exchange) as part of OH&S guidelines for the chamber.

Key information relating to what cannot be stored, access times, and proper maintenance of the chamber can be found in other sections of the report.
What Cannot Be Stored

The chamber is designed so that it may store foodstuffs in individual lockers, in a manner that is secure. The lockers will be separate entities, so that there should be no cross-contamination from different lockers. As such the following items are prohibited for storage within the chamber, unless such an item is deemed to be safe.

<table>
<thead>
<tr>
<th>Prohibited Item</th>
<th>Exceptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Liquids</td>
<td>• Medications</td>
</tr>
<tr>
<td></td>
<td>• Commercially available drinks with approved seals.</td>
</tr>
<tr>
<td>Explosive/ Highly Flammable Materials</td>
<td>• Aerosols</td>
</tr>
<tr>
<td></td>
<td>• Cooking Fluids</td>
</tr>
<tr>
<td></td>
<td>• Gasoline</td>
</tr>
<tr>
<td></td>
<td>• Pressure Containers</td>
</tr>
<tr>
<td></td>
<td>• Matches</td>
</tr>
<tr>
<td>Oxidisers/Organic Peroxides</td>
<td>• Bleach</td>
</tr>
<tr>
<td></td>
<td>• Fertilisers</td>
</tr>
<tr>
<td>Corrosives</td>
<td>• Drain Cleaner</td>
</tr>
<tr>
<td></td>
<td>• Batteries</td>
</tr>
</tbody>
</table>

Hazards Sourced from Airsafe.com

Such items are forbidden, as they present a hazard to both the chamber and users. They can also influence the nature of the foodstuffs, rendering them inedible.

End of Life Strategy

There are several alternative options to pursue once the chamber has reached its designated life-expectancy. Upon 15 years of operation, the entire system is to be assessed by a professional to determine if it is capable of extended use, and if failing that, what can be altered or recycled.

Project Adaptability

The project’s viability for utilisation in other areas and climates depends primarily on the availability of resources, and the climate of the target area. In climates of greater humidity or colder ambient air temperature, the Night Radiation System will be much less efficient; however the Peltier-Effect will be functional in most climates. The chamber itself will maintain its structural integrity and insulation qualities regardless of its location, granted that the location features a stable foundation to build upon.
Map of the tropical regions with similar climatic conditions as Devikulam.

In the above image all the coloured regions will have similar conditions as the refrigerator situated in Devikulam, hence the models we have used will yield similar results.

<table>
<thead>
<tr>
<th>Component</th>
<th>Successful Adapting Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chamber</td>
<td>• Solid earth foundation to build on</td>
</tr>
<tr>
<td></td>
<td>• Available Materials</td>
</tr>
<tr>
<td>Night Radiation Cooling Scheme</td>
<td>• Similar Climate</td>
</tr>
<tr>
<td></td>
<td>• Access to a water-body</td>
</tr>
<tr>
<td></td>
<td>• Available Materials</td>
</tr>
<tr>
<td>Peltier Effect Cooling Scheme</td>
<td>• Available materials</td>
</tr>
</tbody>
</table>
Evaluation

This report was commissioned to develop a practical, sustainable solution to one of the many problems Devikulam faces as a developing community. The key goals of the project were based upon the design requirements set forth by Engineers Without Borders in the design brief. Such goals were to make the project:

- Practical in terms of cost and construction times.
- Beneficial to local industry.
- Reduce spoilage of perishables.
- Provide equal opportunities for both social classes in the village.

Through research into common refrigeration techniques, it was found that refrigeration is a costly process, especially on the scale that the design team aspired to. The design team decided early that smaller, personal refrigeration units would be impractical in terms of cost and efficiency, and as such it was necessary to build at a larger scale for the project to ever be successful within the community. This approach consequently promotes increased interaction between the social classes, which may or may not be well-received in the community. The report’s recommendation to build two separate chambers for each of the social classes is open to change, as it is subject to peer review, budget limitations and consultation of the community before construction. The two-fold cooling approach is an innovative collaboration of two different thermodynamic phenomena; their combination will hopefully lead towards new innovative designs and research into the application of low-cost refrigeration for developing communities. Even though the initial implementation costs are high, this is relative to smaller-scale projects, the cost is perceived to be reasonable in respect to the cost of erecting similarly sized structures in the area, such as temples, shops and schools.

**Fiscal Evaluation**

This section includes the breakdown of monetary costs involved in the project implementation. In this section, Cost Analysis is carried out in a per-chamber basis. All prices and costs are in Australian Dollars.

**Cost of materials**

Estimation of costs includes two main areas, namely start-up costs and ongoing costs (George 1998 cited in Construction Experts Inc. 1998). The start-up costs of implementing this solution are
comprised of the cost of obtaining the material, transporting the material, and the construction of the cooling system. The ongoing costs come from maintenance needs (Ansems 2008).

**Start-up Costs**

<table>
<thead>
<tr>
<th>System Component</th>
<th>Material</th>
<th>Price per mass ($/tonne)</th>
<th>Density of Material (kg/m(^3))</th>
<th>Price per volume ($/m(^3))</th>
<th>Maximum Amount (m(^3))</th>
<th>Maximum Price ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chamber</td>
<td>Perlite</td>
<td>50-560(^a)</td>
<td>80-150(^b)</td>
<td>4.84</td>
<td>13.025</td>
<td>52.1-1094.1</td>
</tr>
<tr>
<td>Chamber</td>
<td>Cow Dung</td>
<td>0</td>
<td>-</td>
<td>0</td>
<td>4.410(^b)</td>
<td>0</td>
</tr>
<tr>
<td>Chamber</td>
<td>Clay</td>
<td>0.13</td>
<td>1500(^c)</td>
<td>0.195</td>
<td>2.205</td>
<td>0.43</td>
</tr>
<tr>
<td>Chamber</td>
<td>Concrete Blocks (Cement)</td>
<td>39.95(^d)</td>
<td>2400(^e)</td>
<td>95.88</td>
<td>4.9</td>
<td>474.6</td>
</tr>
<tr>
<td>Chamber</td>
<td>Polyurethane</td>
<td>-</td>
<td>-</td>
<td>166.7(^e)</td>
<td>0.898</td>
<td>149.7</td>
</tr>
<tr>
<td>Chamber</td>
<td>Terracotta Pot (Kular)</td>
<td>0(^f)</td>
<td>-</td>
<td>0</td>
<td>33.073(^h)</td>
<td>0</td>
</tr>
<tr>
<td>Chamber</td>
<td>Bamboo</td>
<td>0</td>
<td>-</td>
<td>0</td>
<td>8.06</td>
<td>0</td>
</tr>
<tr>
<td>Chamber</td>
<td>Timber</td>
<td>$220(^i)</td>
<td>500(^j)</td>
<td>110</td>
<td>0.03</td>
<td>3.3</td>
</tr>
<tr>
<td>Refrigeration</td>
<td>Peltier Module</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>145(^i)</td>
</tr>
<tr>
<td>Refrigeration</td>
<td>Night Radiation (Water)</td>
<td>0(^f)</td>
<td>-</td>
<td>0</td>
<td>2.5 m(^3)</td>
<td>0</td>
</tr>
<tr>
<td><strong>Total Cost Without Perlite and concrete layer</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>$298.43=14,891.72 INR</td>
</tr>
<tr>
<td><strong>Total Cost With Perlite</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>825.13-1867.13</td>
</tr>
</tbody>
</table>

*The prices in this table are overestimated. The amount need per chamber is calculated by finding the volume needed of each material in each chamber.

a: Prices change due to supply and demand each year, mostly ranging from $49 to $559 per tonne (USGS 2009). In rare cases, prices of perlite reach more than $1000 per tonne, but this will not be taken into account due to its infrequency.

b: The density of expanded perlite is about 80–150 kg/m\(^3\) (The Perlite Institute Inc. n.d.) Assuming maximum value, around 0.31 m\(^3\)×150 kg/ m\(^3\)=46.5 kg of perlite is needed for each chamber. Two of these chambers will require 93 kg of perlite, which is 0.093 tonne.

c: The density of clay is no more than 1500 kg/ m\(^3\) (DH Gate Factory 2011).

d: The prices of different masonries and concrete blocks are listed by Masonry Advisory Council (2010)

e: Polyurethane is obtained in the form of sprays. Our team has bought polyurethane as a material for our prototype from the company FoamIt (http://www.sprayfoamdirect.com/). Evidenced in our
own experiment, a $15 spray can provide 0.09 m$^3$ of polyurethane. This is equivalent to around $166.7$ per cube meter.
f: Terracotta are used for tea in India and are readily available as it is mass produced, hence the negligible cost.
g: Concrete has a density of 2400 kg/ m$^3$ (Glenn Elert 2001). The thickness of the concrete layer is 50 mm and the layer has dimensions 2m×3m.
h: The cow dung and clay are mixed in a ratio 3:1 by volume. Then, this mixture is mixed with terracotta pots in a ratio near 1:5. This forms the glass hollow mud brick layer.
i: Each Peltier Module is around $29$, and each chamber requires 5 of them.
j: The price of timber varies about $220$ per tonne and the density of Timber is on average 500 kg/m$^3$ (Wood and Timber Trade Online 2010; Stargrow n.d.)

In conclusion, if government housing is available, then there is no need for an extra perlite layer and bottom concrete layer, so that the maximum materials cost for the chamber is around $298$. If existing structure is not available, perlite would have to be used and the maximum cost ranges from $825$ to $1867$. However, it should be well noted that, although a possibility, it is quite rare for the price of perlite to exceed $100$ per tonne, and hence the cost of perlite per chamber is normally just under $200$ per chamber. Taking this into account, on average, the refrigeration system should cost no more than $1020.40$ as a maximum.

**Cost of Transportation**
Transportation cost is negligible because all materials are available on site or available for purchase in the city centre. The materials will be transported by trucks that are already travelling between the village and the city, thus producing negligible cost for transportation.

**Cost of Establishment and Construction**
The establishment and construction of the project will be monitored and instructed by practicing engineers. Local contractors will also execute the building processes of the project. This project is a form of humanitarian engineering, and thus will be carried out in cooperation with a humanitarian organization which would recruit volunteer engineers and contractors. The organization will be Pitchandikulam Forest. This is outlined more specifically under the section “Timeline Breakdown & Implantation Opportunity”. There will be at least one engineering project manager and 2 contractors. The contractors will receive aid from local volunteers. Note that the Glass Hollow Mud Bricks are a major component of the volunteer’s work, which was included in the table above (Cost of Attainment). The project will take no more than month as the cement and concrete need to be monitored before it is completely settled, which takes around a month. Hence the total cost involved from Construction will be the cost involved in providing the volunteers with food, shelter, and living supplies. These costs should be covered by the humanitarian organization.
Ongoing Costs

Cost of Maintenance
The maintenance of materials will be done simultaneously with the maintenance of the whole system, and will address with an education plan as discussed below.

Systems Maintenance Cost & Profit generated from education
The profit generated from education is equivalent to the cost eliminated from having the local residents understanding the maintenance and operational issues.

Without teaching the locals about maintenance procedures, in each maintenance check, engineers or technicians will be sent to the village. In this case, there will be two maintenance checks in the first year, one in the second year, and a final one in the fourth year. The four of them will cost (as a maximum) around $26,000.

<table>
<thead>
<tr>
<th>Activity</th>
<th>Cost per Unit ($/Unit)</th>
<th>For</th>
<th>Final Cost ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Travel Airfares</td>
<td>1000/Person/Flight</td>
<td>2 Person, 2 Flights</td>
<td>4000</td>
</tr>
<tr>
<td>Payment to Engineers/Technicians</td>
<td>1000/Person/Week</td>
<td>2 Person, 1 Week</td>
<td>2000</td>
</tr>
<tr>
<td>Miscellaneous costs &amp; tolerance</td>
<td>N/A</td>
<td>N/A</td>
<td>500</td>
</tr>
<tr>
<td><strong>Total Cost</strong></td>
<td>N/A</td>
<td>N/A</td>
<td><strong>6,500</strong></td>
</tr>
</tbody>
</table>

Alternatively, an education program will be implemented. One or two instructors will be educating the local residents about maintenance procedures after the system is built. The instructors will be volunteers with a humanitarian engineering background, again recruited by Pitchandikulam Forest. The volunteers will be instructing the local residents in a way outlined in the implementation plan in the next section. The only cost involved in this case comes from the financial support (to provide food, shelter, and living needs during the program) necessary for the engineering volunteers, which is estimated to be less than $720. Further, an extra surplus of materials will be supplied to the village, in order to provide the village with materials for repair. Most of such materials will be concrete blocks. This should cost no more than $350 per chamber. This cost will be covered by the cooperating organization. Hence, the profit generated from education is $26,000 - ($720+$350) = $24,930.

Relocation Cost
The systems will be built upon government buildings. However, there may be existing families residing in those buildings. Hence, there would be relocation costs involved. As it is unclear how much money the families in the government housing use on a daily basis, the project team and Pitchandikulam Forest will negotiate with such families in person. The project team should
compensate enough money for the family to move into another house, and provide them with extra privilege to use a slightly larger part of the chamber if they wish so. The relocation cost can vary greatly, depending on negotiation with the family. Nevertheless, the project team will limit relocation cost up to $600.

**Fiscal Charts**

**Start Up Costs Option 1 - With Government Housing**

![Pie chart showing start-up costs with government housing]

Total Start Up Cost with Government Housing: $298.43 = 14,891.72 INR

**Start Up Costs Option 2 - Without Government Housing (Low Perlite Price)**

![Pie chart showing start-up costs without government housing]

Total Start-Up Cost with low cost perlite: $825.13
Start Up Costs Option 3 (Rare)-Without Government Housing (High Perlite Price)

Total Start-Up Cost with high cost perlite: $1867.13

With government housing, each refrigeration system will cost less than $298. If government housing is not available, or more chambers need to be built on free grounds, the system will cost less than $1020. Cost involved in the educational program and relocation process is estimated to be under $1670, and this should be covered by the funding organization, Pitchandikulam Forest.

Risk Evaluation

Pre-construction risk:

Workers
Participants who are building the chamber may be subjected to various hazards, such as:

- Heavy objects
- Unorganised workplace
- Working in high elevation, etc.

The risk corresponding with these hazards can simply be minimised by introducing the workers to good workplace practices with accordance with the OH&S guidelines. These can include proper lifting techniques, uses of harness for high elevation work and a guideline on how to maintain the workplace in good working order. These introductions would not only lower injuries in the workplace, but it would also give the locals with valuable work experience and knowledge for other
field of employment, gives them an opportunity to expand on this implementation on their own and with fewer causality, hence escaping from entrenched dependencies. A certified engineer or a member of the PF would be responsible in introducing these practices.

Another hazard that the workers will be facing is with the polyurethane spray. Although polyurethane is nontoxic and chemically inert, it is flammable in its chemical stage and the user may also feel slight discomfort if they inhale too much of the fume released. Also, Polyurethane can only be mechanically removed once set, which can cause irritation to the affected person if any, got on their skin, or even their mouth. The works will be recommended to wear long sleeved shirts, gloves, mask and work in a well-ventilated area when using polyurethane.

**Civilians**

Locals can be affected by the same hazards and risk as the workers if they are in too close proximity with the work place. To ensure the locals can be within a safe distance away from the workplace, temporary barrier or a warning line should be drawn around the area which is deemed hazardous. Signs should also be placed around the workplace to notify the locals of some of the hazards they may be exposed to if they enter the workplace.

**Post construction risk:**

**Workers**

A couple of workers who have built the chamber should also be allocated to inspect, maintain and run the chamber. This is because the maintaining person may be exposed to similar risks faced during the construction of the chamber. Hence by employing a person who has been introduced to good workplace practices, the injury rate can be lowered. This also gives opportunity to spread this knowledge with other locals of the community by employing some of the maintaining person who has not yet earned experience with good workplace practice. This will give that person the opportunity to learn these practices from his/her own community.

**Civilians**

Civilians who use the chamber are exposed to several new hazards which include:

- Lack of ventilation
- Dim lighting, etc.

The risks involved with these hazards can be minimised via future improvements on our current design should they seem necessary and urgent; such as ventilation shaft, lights for night time storage etc. This implementation will be left for the locals to decide. By doing this, the local can gain a sense of ownership for the chamber and allows them to make their own decisions on how they wish to fix these problems. This will help the community escape entrenched dependency and allows for safe usage of the chamber by the locals.
Civilians are also posed with a threat that the whole chamber may collapse. This risk however is minimised with the employment of maintainer and inspectors mentioned above. These people have the responsibility of identifying and repairing any potential threats to the chamber itself.

Other hazards that the locals are exposed to are the possible clustering of the chamber due to overstocking of goods, and being burnt by the Peltier plate. The risked involved with this can be controlled by implementing signs and other notification to inform the user of any dangers they must be aware of, as well as reminding them to use the chamber responsibility.

**Wild Life**
One of our cooling chamber’s main jobs is to keep the pests out. This makes Devikulam’s previous pest control options (such as rat traps, poisons etc.) obsolete and no longer needs to be implemented. These pest control options are considered hazards to the local wildlife in Devikulam; hence by getting rid of these hazards, we coincidently reduce the risk of wildlife being injured within the Devikulam community.
<table>
<thead>
<tr>
<th>Risks</th>
<th>Hazards</th>
<th>Likelihood</th>
<th>Consequence</th>
<th>Risk Rating (pass is &lt;5)</th>
<th>Control Measures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Back strains</td>
<td>Bricks, isolation materials for the roof, overworking</td>
<td>1</td>
<td>2</td>
<td>2 (pass)</td>
<td>Educate proper lifting techniques and work practices. Employ more people to reduce work load</td>
</tr>
<tr>
<td>Hit from falling objects</td>
<td>Bricks, isolation materials, tools, belongings</td>
<td>1</td>
<td>3</td>
<td>3 (pass)</td>
<td>Remove loose items when working in high elevation. Establish a safety perimeter to restrict civilians from walking under zones which heavy objects are most likely to fall</td>
</tr>
<tr>
<td>Exposure to unwanted</td>
<td>Polyurethane, mud bricks, chemical gases (if implementing absorption)</td>
<td>3</td>
<td>1</td>
<td>3 (pass)</td>
<td>Wear long clothing or overalls. Wear masks and gloves when appropriate</td>
</tr>
<tr>
<td>food materials</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shock</td>
<td>Peltier module</td>
<td>1</td>
<td>2</td>
<td>2 (pass)</td>
<td>Ground electrical source and checking that power is off when installing.</td>
</tr>
<tr>
<td>Food spoilage</td>
<td>Dirt, cross contamination, pest</td>
<td>2</td>
<td>2</td>
<td>4 (pass)</td>
<td>Visual notification and reminder about hygiene when using the chamber and on good food storage practices</td>
</tr>
<tr>
<td>Air quality</td>
<td>Dust, dirt, rare access to chamber</td>
<td>1</td>
<td>2</td>
<td>2 (pass)</td>
<td>Implement ventilation during future developments.</td>
</tr>
<tr>
<td>Tripping/falling</td>
<td>Loose items, water puddles, disorganised lounge, working in high elevation, moving in the dark</td>
<td>3</td>
<td>1</td>
<td>3 (pass)</td>
<td>Allocate spaces and areas for each specific item, inspection rooster to check for leaks, use of safety harness when working in high elevation, provide lightings for night works.</td>
</tr>
<tr>
<td>Entire structure collapsing</td>
<td>Reckless people’s actions (e.g. vandalism), water, wind</td>
<td>1</td>
<td>3</td>
<td>3 (pass)</td>
<td>Weekly inspection and maintenance rooster. Possibly employ security</td>
</tr>
<tr>
<td>Burns</td>
<td>Peltier module</td>
<td>1</td>
<td>2</td>
<td>2 (pass)</td>
<td>Proper heat sinks to divert temperature, visual warning.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Likelihood</th>
<th>Consequence</th>
<th>Risk Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>not severe</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>very severe</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>not likely</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>very likely</td>
<td>3</td>
<td>6</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Likelihood</th>
<th>Consequence</th>
<th>Risk Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>not severe</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>very severe</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>not likely</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>very likely</td>
<td>3</td>
<td>6</td>
</tr>
</tbody>
</table>
Ethical Evaluation

Ethical Issues in Construction
The construction portion of the design implementation is of critical importance, as its successful completion is paramount to the longevity and effectiveness of the project. Employment of the local population is necessary for both the construction of the chamber, and the effective assimilation of the project into the local social context. The proposed construction work is planned to utilise volunteer workers to undertake primary construction of the chamber, with supervised guidance by professionals. This raises the ethical question of payment to volunteers for such services, as this construction will undoubtedly detract from other, paid employment that these workers could be approaching during this time of construction.

Humanitarian work is optimised to run on as small of a budget as possible, due to financial constraints. This means that there is no financial compensation to these volunteers available as most financial resources are directed towards the procurement of materials. However, the volunteers will be offered preferred space within the chamber as a token of their efforts, along with a meal every work day and a safe working environment. Preferential space means they will be offered lockers closer to the entrance for easier access.

Ethical Issues in Site Determination
As discussed in the chamber construction research section of the report, every citizen will have the right to provide arguments against a proposed site location. Due to the function of the chamber as a storage device, and its physical size, its location will present a definite alteration to the livelihoods of those who live nearby it. This is because it will greatly increase traffic to the area, whilst taking up a large space. This issue comes down to what is good for the community as a whole, and the decision to designate a proposed site will have to take into account the benefits to the larger community, in terms of accessibility. The negative impacts the site will have for the minority will have to be heavily outweighed by the positive impacts for the majority, this is at the committee’s discretion.

The site determination with respect to accessibility for the whole population is an issue as well. The community is divided into two distinct areas, the colony and the village, based upon social classes. These classes, whilst cordial to one another, attempt to minimise interactions with each other where possible. Thus it will be difficult to determine a site which not only meets the physical demands of the design, but will also minimise the average travel time for all users, whilst being located in a as neutral of a social area as possible.
Ethical Issues in Access Protocols
Access to the chamber is limited to certain hours, as outlined in the chamber use section, to enhance the insulating capabilities of the chamber and also to reduce the risk of theft. But during these access hours certain access protocols need to be implemented so as to reduce inter-social-class interaction as much as possible. Whilst this may not be ideal, it is to preserve the status quo of the social context as much as possible, which helps to increase the social acceptance of the project within the area. This report suggests that an optimised access protocol is at the discretion of the community elders, as they have a greater understanding of the social dynamic in the region. This will lead to an informed decision pertaining to who gets to access the chamber at what times.

Another issue with access is to determine who has the right to store their goods within the chamber. Due to the physical size of the chambers adapted from government housing, it would be impractical to accommodate the entire village population’s storage needs, because storage space per capita would be too small to be effective. Preferred use of the facility will be given to those who volunteered in its construction, and those who stand to benefit most from the increased storage space, in terms of increased profits on market export. Whilst this restricts access for smaller farmers, it favours the net increase in wealth for the community. This allocation process is again at the discretion of the community elders.

Ethical Issues in Communal Chamber Use
A communal project such as this is based upon an element of trust, and respect for other people’s property. Because of this it is paramount that effective security protocols are implemented during the day-to-day operation of the chamber so that people’s property is not compromised. The chamber door will be locked at certain hours, to ensure that adequate time is spent refrigerating the chamber, and to minimise theft where possible. But during access hours when the door is open, protection is minimal. The design contributes lockers to reduce cross-contamination of goods, and to provide a modular breakdown of the storage space to highlight individual supplies. Due to budgetary reasons locks cannot be provided free of charge. Because of this it is highly recommended that users of the chamber use their own locks to increase the security of their stored supplies. It would be ideal to provide locks for the lockers free of charge, but it is not possible without sacrificing the quality of other aspects of the chamber, like its insulating ability.
**Future Design Adaptations**

In the future we would like to improve the efficiency of the refrigerator by improving the interface between the night radiation cooler and the chamber. We will achieve this by lowering copper pipes from the roof into the chamber and exiting them through the concrete base. Other ideas we have are for different power sources for the Peltier Effect including thermocouple producers.

**Team Reflection**

There is no doubt that ForeSense, as a team, has gained invaluable experience from this project. Specifically, the project enabled us to execute and exercise our own original ideas into innovative solutions. From the judgment criteria of the project, our team grasped a general idea towards the aspects necessary to consider in design implementation. The strength of this project lies within its clearly outlined goal (to design a feasible solution for issues faced by a group of people) yet open-ended steps and choices for us to undertake and develop.

Nevertheless, there were many challenges that ForeSense face, from which we learned more about the way we work and how we could improve it. In particular, the largest obstacle we faced were achieving deadlines and scheduling meetings. One thing we could improve on is our sense of priority and attitude towards teamwork, as we have initially underestimated the scope of this project. The team would benefit more if we make clear of each person’s role and initiatives more formally.

Nonetheless, although all the members of Team ForeSense undertook an overloaded amount of units, each team member were performing and presenting his best endeavour. We realized that working in a team creates extra dimensions of motivation and duty from each member, in which each of us competes to make the best contribution to teamwork while supporting each other’s work.

Overall, the project work has definitely been a positive experience for the team. It was both inspiring and exciting to be able to produce work with real applications in an engineering context.

This project has been both enlightening and difficult, from its conception to completion. We have found that the difficulty lies not in the subject matter, but rather the communication between team members, and in accomplishing the appropriate degree of detail. Upon completion of the preliminary report, we decided to re-adjust our group structure, in terms of who was researching and writing what, which I believe has led to an improvement in efficiency major problem was the compilation of the final submission. I feel that as a group we under-estimated the time it would take to properly stitch the individual segments together and compile references. Because of this it was always a push to get the final submission compiled in the days before submission. Another key issue was our propensity to explore and adopt new ideas to implement, often well into the later development stages of the report. This meant that our writings were often fragmented, and work.
already developed was rendered obsolete. Whilst some work could be re-applied as alternatives, fragmentation of the idea structure caused a distinct lack of control in what was being written, and confusion especially on my part as to what I should be working on.

This project design has been based upon the assumption that every criteria and will be met in its implementation. In practicality this assumption will not hold, as the project will likely encounter delays due to the transportation of resources, availability of resources, shortages of labour and weather restrictions. We hope that the design’s stringent construction process (which seeks to run tasks concurrently only when resources are already on hand) will allow for the project to continue on to completion, despite any unforseen setbacks. In case of delays, it is labour costs that will mostly influence the budget, the re-negotiation of these costs will need to be undertaken should such an incident occur.

Anirban Ghose

This has definitely been a very interesting project. Admittedly 6 weeks ago I thought it would be far more formulaic and straightforward than it really was. I found the range of options that we were made to contend with sometimes overwhelming, however being able to sit down and discuss these ideas with a group of people made it so much easier. The nature of our project, the physics and technicality behind it, created obstacles in two ways, Firstly it was our lack of understanding and secondly it was the inability to convert the high tech problems into low tech solutions. Overcoming this took some real time and effort and I believe this is what made our solution very late in maturing.

I believe the chilled chamber will only be appreciated for its usefulness once it has been put into practice. I envisage farmers and housewives alike sharing the chamber to reduce waste and increase productivity in their lives. The prawn industry as well will benefit from this chamber as the prawns that are wasted on a daily basis have a second chance at being shipped or sold elsewhere.

This project is undoubtedly complex to implement. It has many stages and checks that need to be performed so that the integrity of the chamber is sound. The number of bricks and the sourcing of polyurethane will present problems however these logistic issues can be overcome with sound planning. Also being able to utilise one of the abandoned government houses will simplify the project.

Overall our team has come together at the critical times to design a solution that we all believe can provide real benefit to this community.
Michael Holmes

This project has been both enlightening and difficult, from its conception to completion. I have found that the difficulty lies not in the subject matter, but rather the communication between team members, and in accomplishing the appropriate degree of detail. Upon completion of the preliminary report, we decided to re-adjust our group structure, in terms of who was researching and writing what, which I believe has led to an improvement in efficiency. Major problem was the compilation of the final submission. I feel that as a group we under-estimated the time it would take to properly stitch the individual segments together and compile references. Because of this it was always a push to get the final submission compiled in the days before submission. Another key issue was our propensity to explore and adopt new ideas to implement, often well into the later development stages of the report. This meant that our writings were often fragmented, and work already developed was rendered obsolete. Whilst some work could be re-applied as alternatives, fragmentation of the idea structure caused a distinct lack of control in what was being written, and confusion especially on my part as to what I should be working on.

Despite this, the opportunity to work on an actual hypothetical project in its entirety has been a great learning experience. I have never quite fathomed how much complexity must go into such a report. For example, a wall structure cannot just be built; it requires a plan to lay the bricks and mortar, for the site to be levelled, etc. I now understand how much depth must be included for many abstract tasks we take for granted daily.

Andy Chen

Information gathering, I would argue, had been the hardest part. We are working with technology not yet well established so it was quite a challenge coming up with solutions without much reference to look at. Beyond that, the team work sometimes face difficulty when technology doesn’t help as much as we hope it would. For example, our online document-share system SkyDrive, failed to allow us to re-download the document for editing at a point of time.

We overcame these issues by a more extensive research and also with help with the EWB forum for information about Devikulam we could not find on the internet. Issues about document-sharing were also resolved by a more diverse way to share our document and not reply on a single mean.

I think we did well that we had regular meetings and all of our members are informed and up-to-date of in terms of progress. However it is frustrating at time when we had little progress in a
meeting that we just did not come prepared enough. Also the timing of the meeting may need to be revised that sometime we take too long for the meeting to actually start.

Nevertheless this course has been the most “team work” I have ever involved in for a single project. Much I learnt to know my own capacity and others to work as a team, and sometimes see what I complain about other people happening to myself so I learn to do my best for my part and help others because at some point, the roles will reverse.

**Kelvin Hsu**

In undertaking this particular project from the EWB challenge, I have not learned the technical knowledge I anticipated to learn 2 months ago. Instead, I learned about the more valuable skills necessary in an engineering career—or any career, for that matter.

Needless to say, one of them involved teamwork and communication skills. These skills are, and will always be, two of the most difficult yet powerful skills one can acquire in undertaking a project. This may be my nth time working in a team, yet the nature of an engineering project team introduces new parameters to how teamwork should be carried out for an innovative solution. As formulating an engineering solution is a fairly complex process in itself, much organization than usual is required. Our team members must be well aware of what other members are doing and when tasks should be done as most of our work are not separate entities to be put together in the end but stages of a particular sequence of our solution. One solution may also depend on other. The cost analysis, for example, is strongly dependent upon the materials chosen to be used in our system. Any small changes to the materials used, or even amount used, can create significant changes in the cost analysis.

This particular project is also the most research extensive project I have encountered in my academic years. As we are required to create an innovative solution that is cost effective, practical, possible, useful and harmless, we are open to as many choices as our imagination takes us. In order to assess every possibility fairly, many facts that seemed trivial to us and easily accessible before becomes extremely important and yet difficult to find, such as the prices of certain materials only found in India. I realized that not everything known to the human race is available on internet. Some information are simply not available, or simply too difficult to find. Furthermore, not all researches from our hard work can be used in our project as we learn more about the issue and possible solutions. Due to such reasons, research can be the most frustrating task in a team project, yet rewarding when that certain piece of information is finally found.
Personally, I have had doubts about our own abilities to undertake these particular projects. As a first year university student, I am well aware that I do not have enough technical knowledge about engineering to design any amazing solution. Because of this, I often find myself staring at the task requirements—having no idea where to start or what to do, because it seems impossible for some student with mere high school knowledge to create a design that can actually improve people’s lives in a distant land. However, my teammates were rather optimistic about the project and enjoyed the process of finding a suitable solution for Devikulam. They were able to narrow the problem down to something I could get my head around without being too overwhelmed. Nevertheless, I could not always follow my team as quickly as I wanted to. Because new ideas come up quite frequently from different members, it was difficult to comprehend most of the ideas properly before I can contribute any constructive comments upon the idea. This also demonstrates the difficulty of communication and teamwork—sometimes the person (in this case, myself) simply just doesn’t understand the material despite of the communication methods. As a result, during the initial stages, there were limits towards how much I can contribute to the teamwork. Nevertheless, as the tasks became clearer to each of us, we were able to split up the task accordingly and focus on individual designs concurrently before we put them together. In the end, I was able to put in my best effort towards the initial design of our chamber and the final financial analysis in our project.

The project has been a rewarding experience and, surprisingly, it is more on a personal level. This project enabled me to understand what it is like to be an engineer and what factors are involved in an engineering project. It also helped me to understand the real significance of engineering to the society. The course assessments were also particularly challenging. While frustrating, it was definitely rewarding after some positive and constructive feedback and reassurance from our tutors. In general, I felt more like an engineer after I undertook the EWB challenge project.

James Lee

This report has taught me many different things about being an engineer and helped in developing key characteristic of a good engineer, such as communication skills, research skills etc. however there were a few instances where it got extremely difficult. One instance was when our poor communication made us confused in what our final design was going to be like; hence we were forced to waste hours in pin pointing exactly which direction we were going. Another instance was that the researches that we were allocated were sometimes fruitless. (Trying to search up Peltier coefficient was the most difficult research by far). And by far the most difficult part was when the prototype would just fail all together as we were forced to abandon it. Through these hardships however, I have gained valuable resources and experiences for future projects.
Works Cited


Appendix

Prototype: Polyurethane
A proof-of-concept experiment was conducted to test our prototype: Polyurethane

Aim:
To observe how effective Polyurethane acts as a thermal insulator.

Method:
1. The following materials were collected;
   a. A can of expanding polyurethane foam
   b. 2 cardboard boxes (29cm x 36cm x 12.5cm)
   c. 2 blocks of ice (20cm x 13.5cm x 3cm)
   d. Measuring cup
2. One of the boxes was evenly sprayed with expanding polyurethane foam. Only one layer was required as the foam expands up to 3 times its own volume
3. This box was left for an hour to give it time to expand and harden
4. The 2 blocks of ice were placed on a table under the sunlight. One of the ices was enclosed with a polyurethane layered box, while the other was enclosed with the normal cardboard box.
5. This set up was left under the sun for 2 hours
6. After 2 hour, the ices were removed from their respective boxes and the volume of melted ice water for each ice block was measured and recorded with a measuring cup.
Results:

The volume of the ice block = 20 cm * 13.5 cm * 3 cm = 810 cm³ = 810 ml

The Set up – Each Boxes contain 1 block of ice each

Percentage of ice melted will be derived by the equation: \( \%_{melt} = \frac{\text{melted volume}}{\text{volume of ice block}} \times 100 \)

<table>
<thead>
<tr>
<th>Box Type</th>
<th>Melted Volume</th>
<th>Percentage of ice melted</th>
</tr>
</thead>
<tbody>
<tr>
<td>Polyurethane</td>
<td>66.2562 ml</td>
<td>66.2562 ml / 810 ml = 8%</td>
</tr>
<tr>
<td>Without polyurethane</td>
<td>133.4928 ml</td>
<td>133.4928 ml / 810 ml = 16.5%</td>
</tr>
</tbody>
</table>

Conclusion:

From the results, we can see the differences in the percentage of ice melted between the 2 ice block was 8%. This may not seem much, but we have also observed that the percentage of ice melted in the normal cardboard box was 16.5%, implying that the box's thermal insulation had improved by more than 50% by using polyurethane.

This leads to a more crucial discovery: because ice melts relative to its surrounding temperature, ice melting slower in an enclosed space compared to another enclosed space, then that enclosed temperature must be cooler. This experiment thus shows great evidence that the temperature inside the polyurethane box was cooler by more than 50% compared with the normal cardboard box under the sun; which is vital for storing our perishable goods.

A visual representation of the difference the volume of ice melted. Clearly there is a noticeable difference.
System Dimensions:

Cooling Chamber:

An Isometric view of our cooling chamber

Cooling Chamber front view

The Door will be placed on the middle the wall. The door itself is made from timber with a 1 inch polyurethane layer
Cooling chamber sectional view

The interior of the chamber, the steps are placed to allow some produces to be stored in a higher, cooler part of the chamber.

Cooling Chamber Wall layers

Layer from left to right: Perlite (250mm), polyurethane (1 inch), air gap (1 cm), mud brick (250mm)
Cooling chamber top view

The top view. Notice that there is an insulation material to cover the water during day time. There are also 4 Shadings to enhance the cooling effect.

Mud steps

The steps are made from mud bricks with equal increments of height and length per interval.
Cooling chamber roof section

The layers are from top to bottom: water (10cm), cement (1cm) timber (50mm), bamboo reinforcement (150mm) and timber again

Peltier Cooler

Isometric view of the Peltier box
**Peltier Cooler top view**

Top view: allows for 5 squares Peltier module to be installed

**Peltier Cooler Section View**

The door of the Peltier box is made from a wood-polyurethane-wood layer, and the box is made from perlite. The top is made from wood-polyurethane layer.
FORE-SENSE Constitution

Names

As of the 23rd of August, 2011, the following students will be a part of team FORE-SENSE:

- Anirban Ghose (311193218)
- Michael Holmes (311246044)
- Ju Heon Lee (311247156)
- Andy Chen (311268781)
- Kelvin Hsu (311215068)

Aims

The goal is to develop a solution, as the part of the EWB framework, to improve the livelihoods of the people living in the local region of Devikulam. This will be done through employing skills developed through Mechatronic Engineering in a unique and effective way to aid in developing or maintaining the proposed solution.

Team Roles

- Anirban Ghose: 1) Team Representative. Representing the team when presenting the team’s work. 2) Layout. Editing the project to look more presentable.
- Michael Holmes: Proof reader, Editor
- Ju Heon Lee: Secretary. Records all ideas, brainstorming and other noteworthy events which have occurred during the meeting. It will also be secretary’s job to bring the prior meeting’s minutes.
- Andy Chen: 1) Communication guy. In charge of all communication linking and updating. All group members will send notes, summary and other citation to Andy for archiving. 2) Layout. Editing the project to look more presentable.
- Kelvin Hsu: Proof reader, Editor

Team Rules

1. Decision making in the team is unanimous, where everybody must take a vote in each decision (if a team member is absent, their vote will forfeit.)
2. In the case of conflict, the argument will not last for more than 3 days. If persisted, the first person to leave the meeting forfeits his idea.
3. Each time a person fails to get something done by the assigned deadline, a strike will be recorded. The ratio of strikes will determine the price each member has to pay for the party.
4. If anyone deviates from the task at hand, the team representative has the authority to bring them back on track by any means of force.

Team meeting protocol:

There will be a formal team meeting on every Monday from 12pm – 1pm. All team members must attend this meeting except in times of emergency.

Signature: