University of Toronto
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APS111 & APS113
Conceptual Design Specification (CDS)

Team #	01	Date	11/05/2015

Project Title	Maintaining Food Quality For Home Delivery
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_x_ Cover Page
_x_ Executive Summary
_x_ Project Requirements
_x_ Alternative Designs
_x_ Proposed Conceptual Design
_x_ Conclusion
_x_ Reference List
_x_ Appendices

_x_ Turnitin Submission (one team member submits the team's assignment to Turnitin)

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EXECUTIVE SUMMARY

The proposed design is based on the needs and wants described by C&N Associates in their design brief. The company is mainly involved in the import/export of goods, manufacturing of novel systems and management consultation, all of which are aimed at being beneficial for people and for the planet. In their statement they expressed that the current packaging system used in the food industry inadequately preserves food texture, and thus want a new solution that will keep food hot without degrading food crispiness and crunchiness.

We expressed the client's wants in engineering terms, and based on research, defined the client's need as a system that is able to keep food at the desired temperature during transportation while simultaneously preserving food texture and flavour. We then determined people and organizations that would have a vested interest in our design. The most important of which were the Health Canada who are interested in the safety and hygiene of the system; and the kitchen staff, who are concerned with the effectiveness and ease operation of the system.

Through brainstorming, our team began to delineate what the design must be able to do to solve the important aspects of the problem. We determined that the functional basis is to hold energy constant, leading to the primary function of being able to retain the quality, texture and taste of the food. This can be done through the secondary function which is to prevent the relative humidity in the package from reaching the dew point. Through the black box method our team decided which objectives the design should achieve and by means of an objective-tree, they were narrowed down to specific, measurable goals. The most important objective is that the system should maintain a low moisture content, keeping food texture and flavour in its original state. Constraints were then chosen based on regulations and codes from the Canadian Food and Drug branch of Health Canada in conjunction with those defined by the client. The most important constraint is that the design shall not transfer any substance from the materials to the food at any temperature as this could harm the user. Finally we defined the service environment. The city of Toronto was chosen because the design will primarily be used in this area, it is most significant that there is a large temperature variation throughout the year from average low of 2.5 °C and average high 12.5 °C. We also included a description about the people who are going to be in direct contact with the design, which are mainly elderly and people with disabilities. It is essential to have a thorough understanding of who they are and the interaction they will have with the packaging system, as their needs are the reason for this project.

Our team then began to move to the solution space. We first expanded the solution space and brainstormed over 38 possible solutions. With many creative ideas, we began to narrow down the solutions by eliminating those that did not meet the functions and constraints. Then using multi-voting the 5 best designs were chosen. After an evaluation of their ability to meet the objective goals, a weighted decision matrix determined that a ventilated polystyrene unit with insulated carrier that houses silica gel would best meet the clients wants and needs. To evaluate this, the most important test that needs to be conducted is water vapour transmission rate which will play a key role in telling us and the client how well the system controls humidity. This will determine whether we will move forward with this design, or generate alternative solutions.

1.0 PROJECT REQUIREMENTS

This section details all of the factors that will narrow the design space in section 2 and 3. Specifically, the problem statement defines the gap and the client needs in engineering terms. Then the factors that affect the design will be described, as the service environment and the stakeholders. These help define the functions, objectives and constraints, in other words the specific details of what the design must be and do in order to solve the problem.

1.1. PROBLEM STATEMENT

The main purpose of packaging food is to preserve it against physical damage, chemical changes and microbial growth [1]-[2]-[3]. It is crucial that the packaging provides an effective barrier against moisture, gases and contaminants from the external environment [2]-[4]-[5]. However, the food delivery industry also needs a system that keeps food warm for long period of time while not altering food texture and flavour.

Crispness and crunchiness are the two most textures that clients are expecting in the food, and people of all cultures appreciate that [6]-[7]. Besides that elderly people do not have an perfect sensory system, therefore the food smell, taste and texture are essential to increase their appetite and food intake [8]-[9]. Therefore, it is important to select a packaging material that can effectively keep food crispness for a long time [2]-[3]-[6].

It is known that crispy food has a lower moisture content than the environment that surrounds it. As a result, the system will progress to a thermodynamic equilibrium. In other words, there will be water loss or gain from one surface to another. Therefore moisture will migrate towards the crispy food, affecting its appeal and mouthfeel [6]-[10]-[11]-[12]. In order to preserve food originality, the food delivery industry need a system to prevent foods from getting soggy, losing flavour and changing texture.

Our client also wants hot food kept above 60°C during food transportation as is required to prevent the growth of pathogens [13]-[14]-[15]. Currently there is a lack of systems that keep food warm for a long period of time while simultaneously maintaining its appeal and mouthfeel [1]. Most sealed packages keep food hot for an acceptable amount of time, but in doing so they also trap moisture from the food inside the system which majorly contributes towards humidity accumulation and thus sogginess [16]-[17]. Therefore the traditional packaging system is unsatisfactory.

People want high quality food. Therefore our client needs a packaging system that is easily transported and operated, fits in their budget, keeps food hot until the customer receives it and, most significantly, does not alter food’s texture and flavor. It is important that consumers enjoy the experience of eating their meal.

1.2. IDENTIFICATION OF STAKEHOLDERS

People or organizations that have a vested interest in the design.

Table 01: Stakeholders (listed in order of importance)

Stakeholder	Interest	Impact On FOC'S
Health Canada	Ensure no transfer of harmful chemicals from packaging to food [18]	Design should contain food without transfer harmful chemicals.[C5]
Manufacturer of the Design	Concerned about the design specifications as they will be responsible for its production [19]-[20]-[21]	Design should be able to be produced with their know-how [O4] [C2]
Ontario Ministry of Health and Long-Term Care	Ensure right balance of nutrition for Canadian citizens [22]	Food appealing and tasty, so people will be willing to eat [F2]
Kitchen Staff	Manipulation of the design without a lot of effort and previous experience [23]	Take minimum steps for food packaging and be intuitive to operate [O4] [C1]
Packaging manufacturers as the Crown Packaging, which is the largest competitor in Canada	Avoid the entrance of a new competitor in the market [24]	Offer innovation in order to avoid food getting soggy and then obtain a good market share [O1]

1.3 FUNCTIONS

The fundamental requirements the design must meet to preserve and keep food with its original flavour and texture.

1.3.1 Functions Basis:

F1. The functional basis of this design is to hold energy constant.

1.3.2 Primary Function:

F2. Retain the original state in terms of quality, texture and taste of the food.

1.3.3 Secondary Functions:

F3. It will keep the food within the required temperature range, i.e. hot foods above 60 degrees and cold foods below 6 degrees.

F4. It will prevent the relative humidity in the container from reaching the dew point and control the quantity of moisture.

F5. It will securely contain the food and provide relevant separation.

1.3.4 Unintended Functions:

F7. Expand the social experience of volunteers.

F8. Provide a container for the user to store there delivered meal in the refrigerator.

1.4. OBJECTIVES

Table 02: Objectives and their goals - listed in order of importance - [Appendix A]

No.	OBJECTIVES	METRICS	GOALS
O1	Low moisture content	Percentage score obtained from equation in "Appendix C"	A score of 50%
O2	Low heat transfer	Amount of heat that each material transfers per second	Less than 11.63 J/s [Appendix D]
O3	Cost should be minimal and lower than the current system	Cost of component materials per unit	The cost per unit should be below $0.21 [25]-[26]
O4	Should require minimal steps to operate	Count the steps to package or open the system.	2 steps

1.5. CONSTRAINTS

Some restrictions that are imposed on this design by the law are as follows.

C1. The system shall be able to open with no external tools besides fingers. [27]-[28]

C2. The system shall not utilize any external packets or sachets that can be accidentally ingested.

C3. The container shall follow proper Canadian food storage codes (Appendix "B") [29].

C4. The container shall have a “consume before” label telling the user when the meal safe to eat until [29].

C5. The design shall not transfer any substance from the materials to the food at any temperature [30]-[31].

1.6. SERVICE ENVIRONMENT

This section will introduce the environment that the design is inserted. It is going to describe aspects that are important about the physical environment, as the city of Toronto, and will also define relevant conditions about living things that will interact with the design, as users and volunteers.

1.5.2. PHYSICAL ENVIRONMENT

The design is going to be mainly used in Toronto, Ontario, Canada.

1.5.2 (a) Temperature [32]

Average annual temperature:
- Average high: 12.5 °C
- Average low: 2.5 °C

Coldest month: January
- Average high: -2.1 °C
- Average low: -10.5 °C

Warmest month: July
- Average high: 26.8 °C
- Average low: 14.8 °C

1.5.2 (b) Precipitation [33]

Annual average:
- Snowfall: 115.4 cm
- Rain: 792.7 mm

1.5.2 (c) Wind [34]

Average wind speed: 16 km/h.

1.5.3. LIVING THINGS

1.5.3 (a) User [35]

Most of the people who will utilize the design are elderly, adults with disabilities, people recovering from surgery or illness and people with chronic illness who wish to remain in their own house. Generally, they are aged over 60, but younger people with disabilities also receive the service. Most of them do not have the physical ability to manipulate objects.

1.5.3 (b) Volunteers [35]

People who deliver the food that Meals on Wheels provides for the community. They are going to do the service using their own car, so they do not have an appropriate vehicle to deliver food. They are people from different ages and all of them have the physical ability to manipulate objects.

1.5.3 (c) Microorganisms [3]-[11]-[12]-[13]

Microorganism are responsible for the food spoilage. It is crucial to keep the food in the right temperature, water activity and pH. In our design is extremely important to keep the food above 60°C, thus microorganism will not be able to grow.

2.0 ALTERNATIVE DESIGNS

This section introduces the designs that our team created in order to provide a solution for our design brief. These designs work in order to preserve food originality during the delivery process. Among 38 different designs our team used multi-voting to reduce the list of 5 possible designs. Finally we used a Weighted Decision Matrix to select the most feasible design.

2.1 Moisture Absorbing Packaging

Design is composed by a container and a lid. The container is made of expanded polystyrene, which would provide the required thermal insulation. The lid is composed by poly(ethylene terephthalate, 1,4-cyclohexane dimethanol) (PETG) and a moisture absorbing desiccant film [36]-[37], which would be attached to the lid. Therefore this design is able to keep food hot and absorb the high moisture content.

Figure 01: Container of design #1

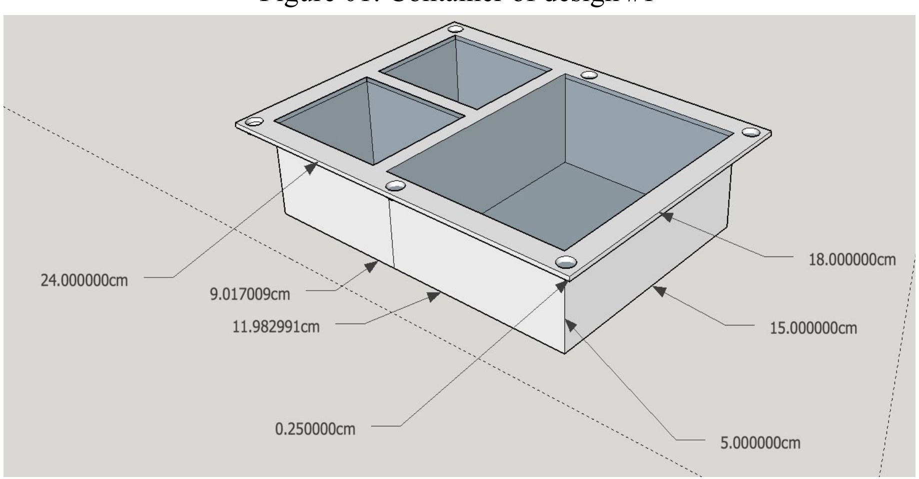


Figure 02: Front of the Lid of design #1

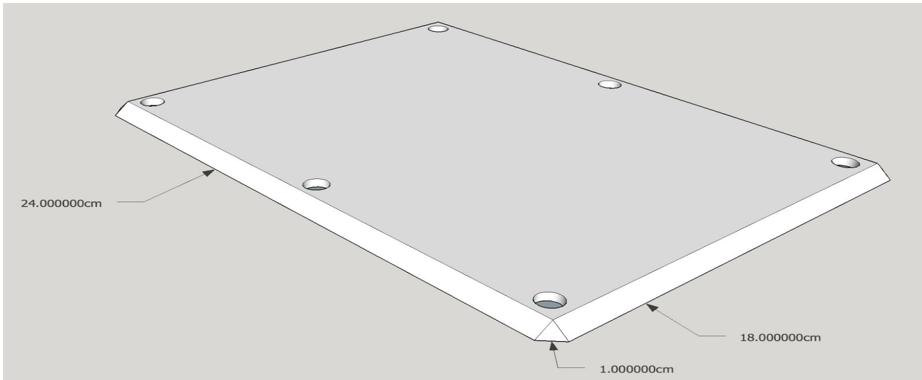


Figure 03: Back of the Lid of design #1

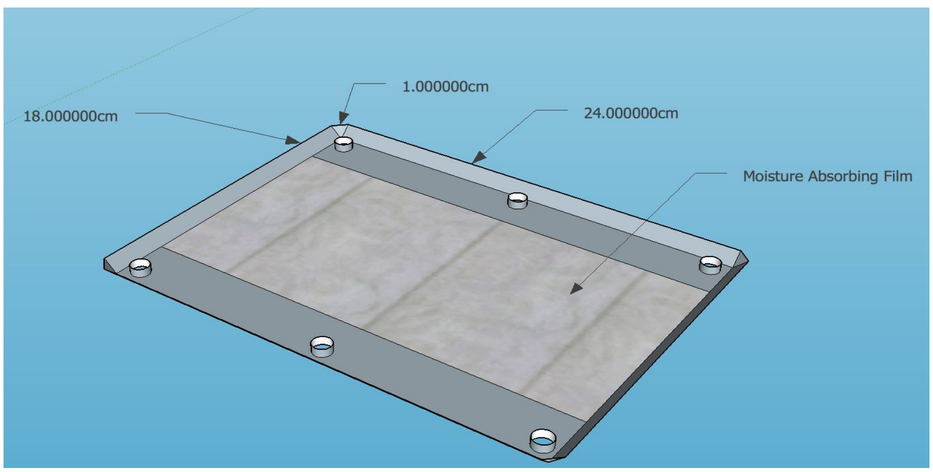


Table 03: Performance by design #1 on objectives [Appendix E]

Objective	Description	% Achieved
O1 - Low moisture content	100% of absorption of moisture. 0% of ventilation. According "Appendix F" this designs receives a score of 50%	100%
O2 - Low heat transfer	Heat transfer of 6.86 J/s	100%
O3 - Inexpensive	Cost per unit is $0.47 CAD	45%
O4 - Few steps to operate	Requires 3 steps to package and 2 steps to open	67%

2.2. Convert moisture to heat inorganic packaging

This design can be divided to two parts: the lid and the container. The lid has a hand holder which is easy for user to hold and carry and two buckles on either side. The container has two rooms for foods, which is made of expanded polystyrene, which can contain food while keeping the two room separated. one room is for drying and heating, which using 50%Cao & 50%CaCO3 [38]-[39]. Another room is for humidifying, food can be put in two rooms according to the need.

Figure 04: front view, left view and right view of the design

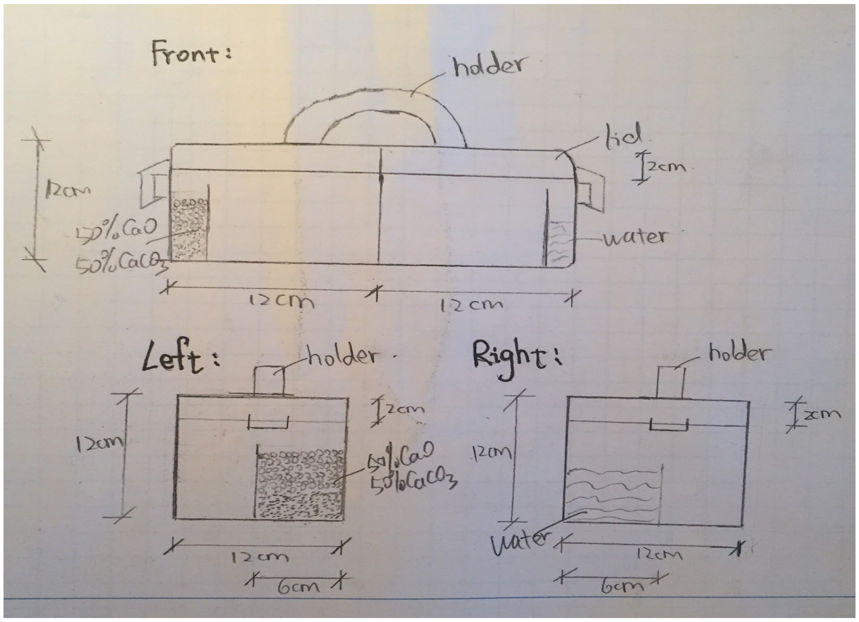


Table 04: Performance by design #2 on objectives [Appendix F]

Objective	Description	% Achieved
O1 - Low moisture content	80% of absorption of moisture. 0% of ventilation. According "Appendix C" this designs receives a score of 40%	80%
O2 - Low heat transfer	Heat transfer of 0.183J/s	100%
O3 - Inexpensive	Cost per unit is $0.114 CAD	100%
O4 - Few steps to operate	Requires 4 steps to package and 2 steps to open	50%

2.3. Ventilated polystyrene unit with insulated carrier that houses silica gel

This system utilizes two components: 1) the insulated carrier already in use by meals on wheels to keep multiple carrying units hot 2) individual unit that carry one meal, which are ventilated to reduce moisture build up. The lower half of the container is a rectangular prism with dimensions 25x15x4 cm and the lid is a portion of a cylinder that has a base of a chord of a circle with radius 8 cm and a chord height 4 cm. The individual container will have 12 holes spaced 1 cm apart at the top of the container to allow moisture to escape. Silica gel on the inside of the insulated carrier will collect the moisture that leaves individual units.

Figure 05: Inside view of container and compartments

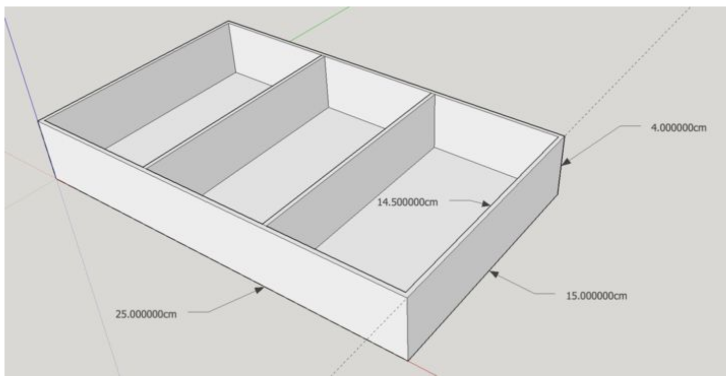


Figure 06: Top view of lid

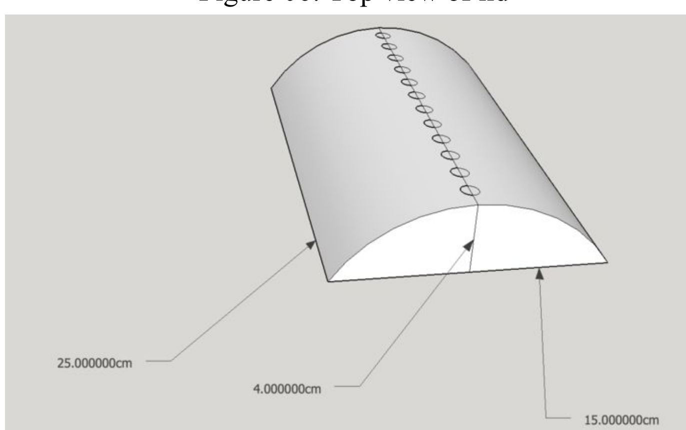


Table 05: Performance by design #3 on objectives [Appendix G]

Objective	Description	% Achieved
O1 - Low moisture content	Silica gel is received percent score of 85% ventilation scored 3.8%	88%
O2 - Low heat transfer	Heat transfer of 2.52J/s	100%

O3 - Inexpensive	Cost per unit is $0.039 CAD	100%
O4 - Few steps to operate	Requires 2 steps to package and 2 steps to open	100%

2.4. Polypropylene container with preservation bag

This design consists a heat preservation bag and a disposable container [40]. The container is made of polypropylene, which has a good heat-resisting ability.[41]-[42] Besides, there are screw grain between cover and the body of the container so the cover can be simply closed and opened by rotating. The special lid is designed to control the humidity. There are holes on the lid which allows steam get inside. Then the steam would be absorbed by an absorbent wool. [43] The insulation bag is made by EPE foam and oxford fabric. [44]-[45]-[46] The bag prevent the heat loss, thus keep the origin taste of food.

Figure 07: Container

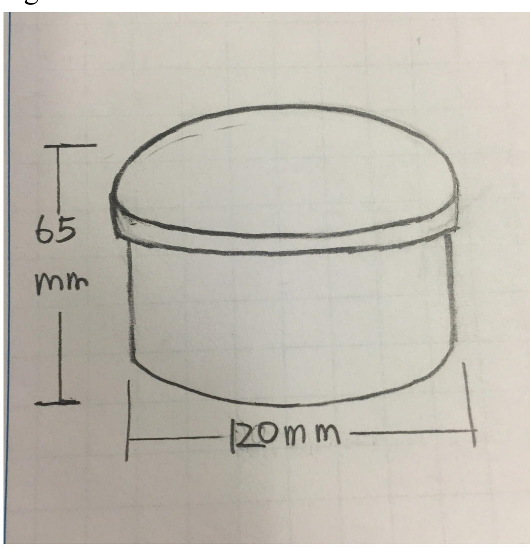


Figure 08:Screw Grain

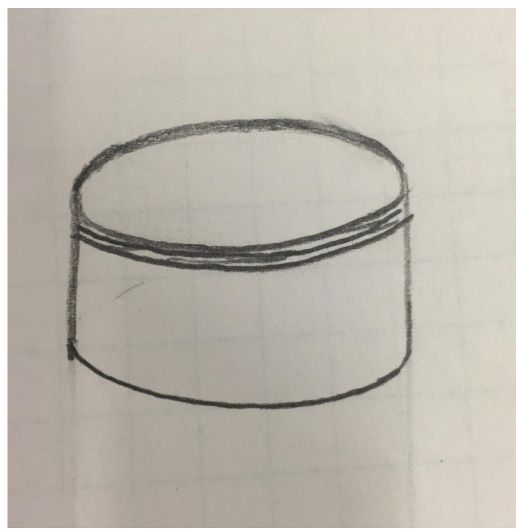


Figure 09:Holes

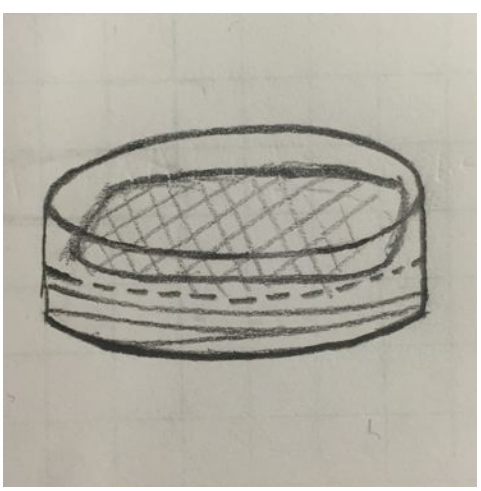


Figure 10: Absorbent wool

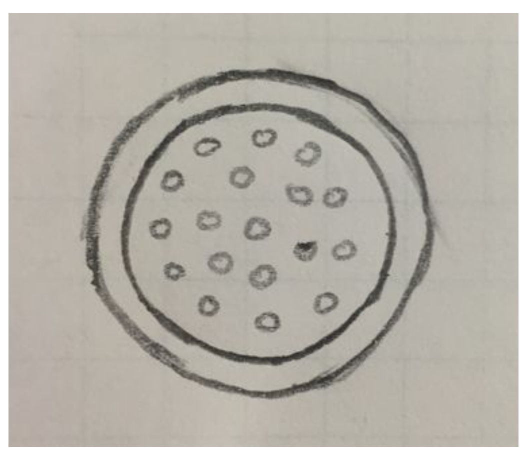


Figure 11: Insulation bag

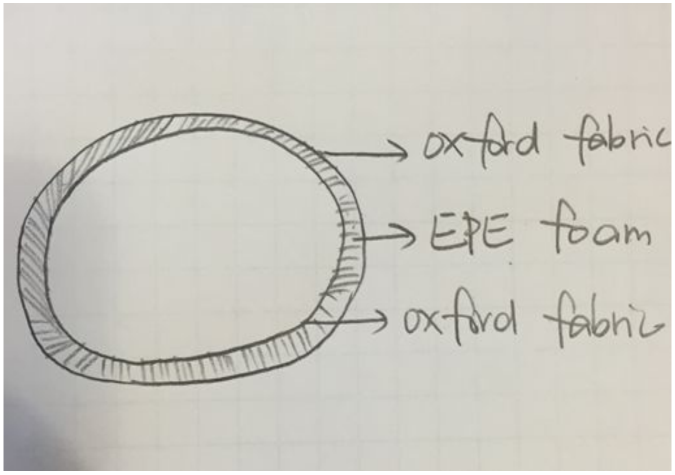


Figure 12: Insulation bag

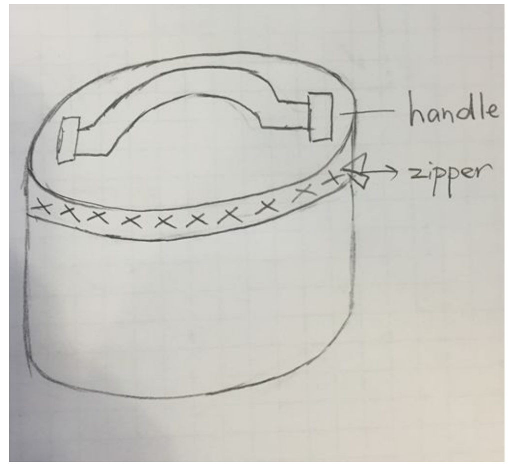


Table 06 : Performance by design #4 on objectives [Appendix H]

Objective	Description	% Achieved
O1 - Low moisture content	The absorbent wool could absorb 80% of moisture. 0% of ventilation. According "Appendix F" this designs receives a score of 50%	80%
O2 - Low heat transfer	Heat transfer of 2.737 J/s	100%
O3 - Inexpensive	Cost per unit is $0.13 CAD	100%
O4 - Few steps to operate	Requires 4 steps to package and 3 steps to open	40%

2.5. Precipitation Analogy model:

This design was developed through an analogy with the natural process of precipitation. The lid is a dome-shaped to allow the condensation of water vapour. The droplets then slide down the lid and out through the openings. The base provides storage for hot and cold foods. The base and lid are made out of ‘Expanded polypropylene’ (EPP). This material is a good insulator as it has air trapped in between the polymer chains[47]-[48]-[49]. This material is also light, resistant to cracks and hydrophobic[47]-[48]-[49].

Figure 13: General shape of container

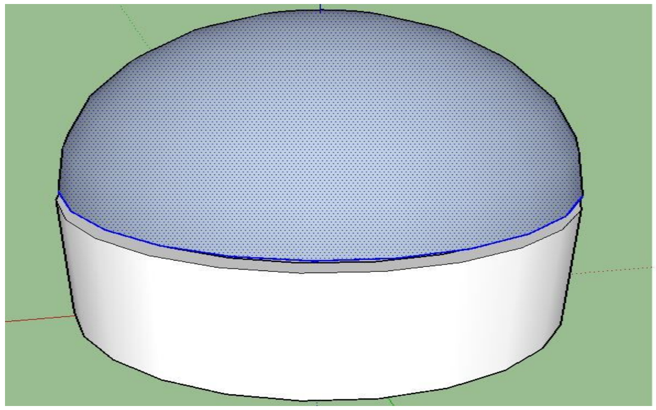


Figure 14: Condensed water leaves the package

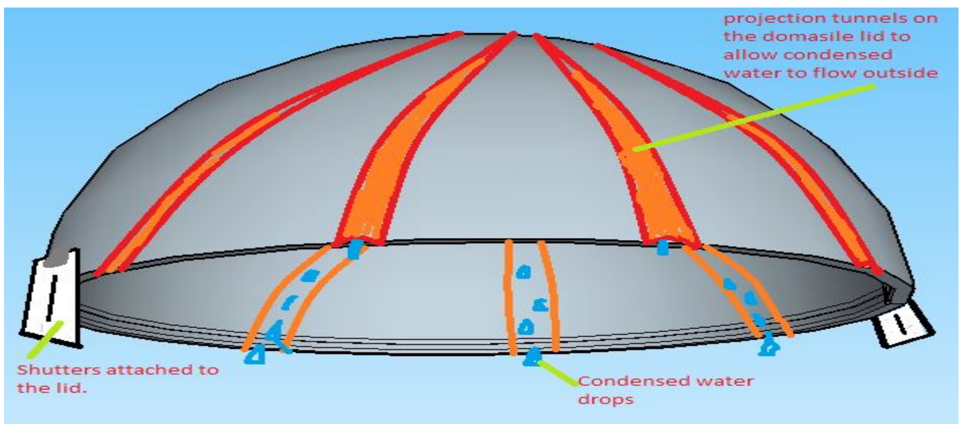


Figure 15: Operation of lid in 2D

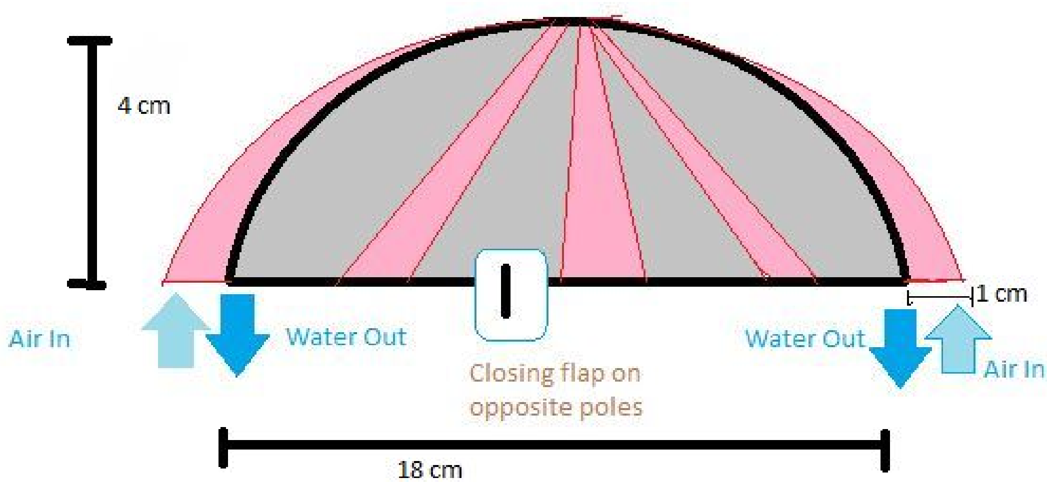


Figure 16: Inside view of base

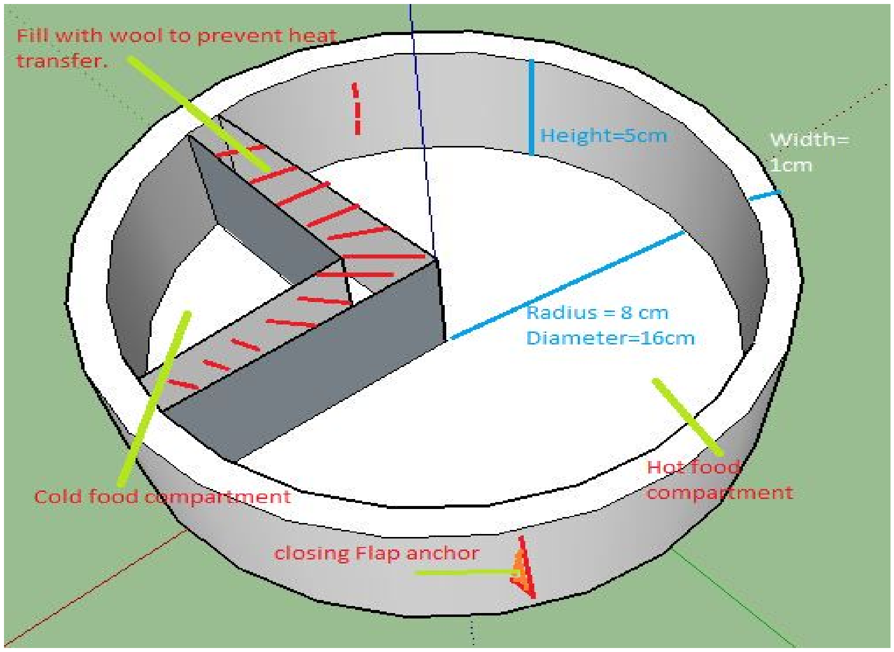


Table 07: Performance by Design #5 on Objectives [Appendix I]

Objective	Description	% Achieved
O1 - Low moisture content	Wool is attributed an absorption percentage of 80% and holes in the lid are rated with a ventilation percentage of 3.125%	46.25%
O2 - Low heat transfer	Heat transfer of 0.711 J/s	100%
O3 - Inexpensive	Cost per unit is $0.17 CAD	100%
O4 - Few steps to operate	Requires 2 steps to package and 2 steps to open	100%

3.0 PROPOSED CONCEPTUAL DESIGN

Upon moving to the solution space our team began to brainstorm as many ideas as possible, and came to a total number of over 38 designs. Many of these however, did not adhere to the constraints or have the proper functions, and the number was reduced to 9. After that our team used multi-voting to narrow the total number of designs to the 5 best. After an analyses of the degree to which these alternative designs met the objectives, their percentage scores were put into a weighted decision matrix to determine the best design [Appendix J]. Design 3 and 5, ventilated polystyrene unit and cloud precipitation analogy design respectively, had the highest scores, however design 3 seemed more feasible and simpler, thus a better solution.

3.1. PROPOSED DESIGN:

Ventilated Polystyrene Unit

This design uses two methods to keep the relative humidity low. A combination of a ventilated unit and a silica gel desiccant to remove water vapour from inside the meal-containing unit.

Ventilation and Vapor Collection
- 12 one cm diameter holes for ventilation at the top of lid
- Cylindrical shape guides rising water vapour to holes, allowing it to escape
- The existing insulated carrier will be modified to hold silica gel, drawing more water vapour out of the individual unit
- Silica gel must be replaced every time

Heat Transfer and Insulation
- The packaging is made out of polystyrene with a density of 1.05 g/cm^3 [50] and a thickness of 2.5 mm
- Heat transfer of 2.52 J/s [Appendix I]
- The individual unit will be stored inside the existing insulated carrier during transport

Cost
- Outer surface area is 955.8 cm^2 [Appendix I]
- Volume of plastic required per unit is 238.95 cm^3
- Cost per unit is $0.039
- Use of modified existing system will help reduce costs

Figure 17: Base of container and compartments

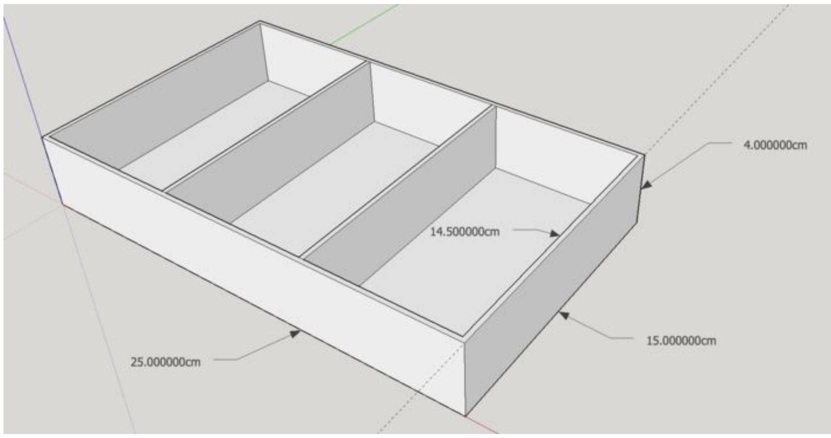


Figure 18: Top view of lid

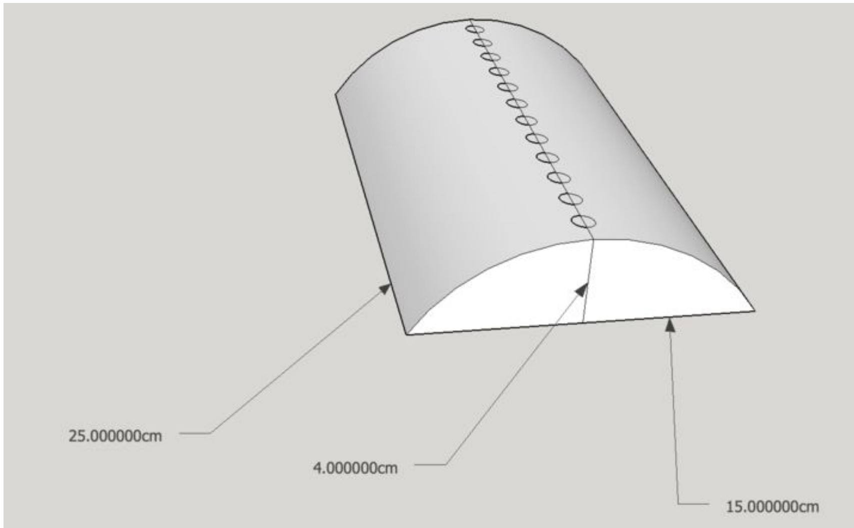
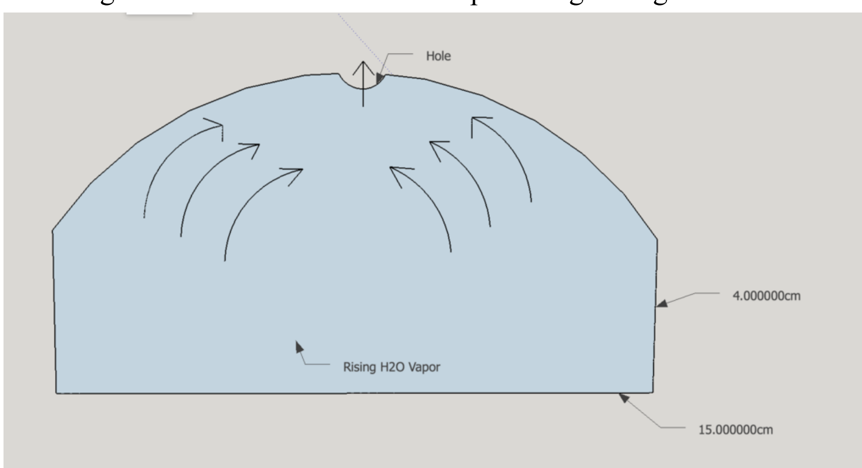


Figure 19: Movement of water vapor rising through container



3.2. METRICS

The primary objectives for this design are those directly affiliated with keeping food texture and quality constant, and thus hold energy constant. Therefore the two objectives that will be tested are the ability to keep moisture content low and the efficacy of the insulation.

3.2.1 Methods for Measuring Humidity within a Sealed Package

- ASTM D7709-12 - A test designed to measure the water vapour transmission rate of pharmaceutical bottles and blisters but is suitable for "most types and sizes of other consumer packages." [51]

3.2.2 Methods for Measuring Efficacy of Insulation

- ASTM D3103-14 - A test designed to determine the “thermal insulation quality of a package” which is suitable for packages “with multiple energy sources” [52]

3.2.3 Methods for Determining Food Quality After Packaging

- ASTM E460-12 - A test to quantify the “sensory attributes” of food after packaging and hence the overall effectiveness of the design on the food itself. [53]

4.0 CONCLUSION

C&N expressed their desire for a solution that would prevent hot meals from going soggy during delivery. Our team concluded that they are in need of a system that is able to keep food hot while preserving the qualities of food’s texture and taste. The system must perform the base function of holding mass and energy constant, all while remaining within the constraints defined by the client and those enforced by Canadian legislation. Our team formed 4 objectives that measured the quality of solutions that we came up with and we determined that the ventilated polystyrene unit would best fit satisfy the client. This can be verified through the metrics above, thus determining the future of this project.

5.0 REFERENCE LIST

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APPENDICES

APPENDIX ‘**A**’:
This appendix contains information on objective arrangement procedure in terms of their respective importance in relation to the problem.

PAIR-WISE COMPARISON TABLE
This evaluation system involves rating one objective compared to others as more important (1) or less important (0). A goal was established for every subsequent objective and a means to measure it (metrics). Listed below is a concise list of all evaluations.

Table 08: PAIRWISE comparison table

	O1	O2	O3	O4	sum
O1	-----	1	1	1	3
O2	0	-----	1	1	2
O3	0	0	-----	1	1
O4	0	0	0	-----	0

‘1’ stands for **more important**
‘0’ stands for **less important**

APPENDIX ‘**B**’:
This appendix provides information on the food storage codes mentioned in the constraints section of the document.

Describes the Canadian Food Storage Codes[29]

1.Frozen foods shall be kept at temp of 0°C or below.

2. Hazardous foods (includes foods already prepared or to be served cold) stored at temperature of 4°C.

3. Cooked foods to be served hot shall be stored at temp of at least 60°C

4. Foods intended to be stored after having been cooked shall be able to be cooled from 60°C to 20°C in less than 2 hours and from 20°C to 4°C within 4 hours.

5. Cooked foods stored at 4°C shall be reheated until internal temp of 74°C is reached.

APPENDIX '**C**'

To be able to measure the capability to remove moisture from the system, 2 main factors will be taken into consideration: the effectiveness of the moisture scavenger and the amount of ventilation. These two will be given equal weight in an equation modelled after the equation for weighted average. Based on the first of 2 figures below, the following percentage ranges have been assigned (using the row entitled 'Capacity for Water at 77℉/25℃').

High: 66-100%
Medium:33-66%
low: 0-36%

A specific percentage value will be decided using the graph labelled 'Figure 2: Equilibrium Capacity (H_2O) of Various Adsorbents' which has specific values for the mass of water absorbed at increasing relative humidity. For the amount of ventilation, a system that has no lid and a completely open top will be given a value of 100%, and the other percentages can be calculated by dividing the total area of the holes by the total area of the lid.

For example a lid with area of 100 cm^2 and the sum of the area of the holes is equivalent to 15 cm^2, then the percentage will be 15/100 x 100% = 15%.

The equation is as follows: $(\textit{percentage of absorption}) \times (0.5) + (\textit{percentage of ventilation}) \times 0.5$

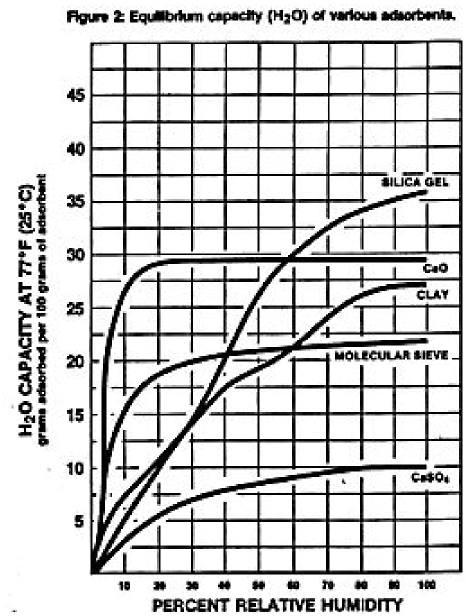
The goal for this objective has been determined to be 50%. This reason for this is that if one of the above criteria is 100% and the other is 0%, for example, if a system with an open top is used without an absorbent, than the maximum score that can be reached is 50%.

Figure 20: Properties of Absorbents [52]

Properties of Adsorbents

Property	Molecular Sieve	Silica Gel	Montmorillonite Clay	CaO	CaSO4
Adsorptive Capacity at low H20 Concentrations	Excellent	Poor	Fair	Excellent	Good
Rate of Adsorption	Excellent	Good	Good	Poor	Good
Capacity for Water @77° F, 40% RH	High	High	Medium	High	Low
Separation by Molecular Sizes	Yes	No	No	No	No
Adsorptive Capacity at Elevated Temperatures	Excellent	Poor	Poor	Good	Good

Figure 21: Equilibrium Capacity (H_2O) of Various Absorbents [52]



APPENDIX ‘**D**’

In order to select a material that provide thermal insulation it is necessary to calculate the quantity of heat that that is lost according some specifications.

Specifications:

The initial temperature of the food is 70 °C
The atmosphere inside the insulated carrier is around 68°C and 70°C because it receives heat from the packaging with food and lose heat to the external atmosphere.
For calculations we are using:

T_o = 70°C (inside packaging)
T_f = 68 °C (big delivery box)

In order to calculate the level of insulation that each material provides we will calculate the amount of heat (thermal energy - joule) that is necessary to decrease 1000 g of water from 70 °C to 60°C.

That amount is:

$$Q = m.c.\ \Delta T$$

m = 1000 g
c = 1 cal/g °C
ΔT = (60-70) °C

$Q = 1000.\ 1\ .\ 10 = -10000$ cal

1 cal = 4.186 J

Therefore, Q = - 41860 J

Assuming that the delivery time takes 2 hour, our design needs to lost 41860 J in 2 hours to reduce the temperature in from 70°C to 60 °C.

If it loses 41860 J in 2 hours, how many Joules the design loses in 1 second?

41860 J --- 3600 s (2h)
x --- 1 s

x = 11.63 J

Now it is necessary to calculate the amount of heat that each material loses. We will use the formula below:

$$\dot{Q} = k\ .\ A\ .\ \Delta T\ /\ L$$

$\dot{Q}$: the amount of heat per an unit of time (kcal/h)

k: thermal conductivity of the material (Kcal/h.m.°C)
A: external area of the packaging that is in contact with the atmosphere (m^2)
ΔT: variation of the temperature (°C)
L: thickness of the packaging (m)

For calculations:

1 kcal/h = 1.16222 J/s
1 W/mK = 0.859845 Kcal/h.m.°C

For this calculation we will assume that all material will build the same container, which has the following specifications:

A: 0.09m^2
L: 0.0025 m
ΔT: 70 °C (internal temperature of the packaging) - 68 °C (temperature inside the big delivery box)

In order to select a good material it is necessary to choose one that the $\dot{Q}$ is less than 11.63 J / s.

Appendix ‘**E**’

Description of the performance of Design #1

<u>O1:</u>

The design does not have any hole, so the percentage of ventilation is zero. The moisture absorbing film provides 100% of absorption. Therefore, according to Appendix 'C' this design has a scores 50%.

<u>O2:</u>

Container:

$\dot{Q} = k \cdot A \cdot \Delta T / L$

k = 0.03 W/mK = 0.025796 Kcal/h.m.°C
A: $0.0675 m^2$
L: 0.0025 m
ΔT: 2 °C

$\dot{Q}$ = 0.025796*0.0675*2/0.0025 = 1.4 Kcal/h = 1.63 J/s

Lid:

$\dot{Q} = k \cdot A \cdot \Delta T / L$

k = 0.15 W/mK = 0.13 Kcal/h.m.°C
A: $0.0432 m^2$
L: 0.0025 m
ΔT: 2 °C

$\dot{Q}$ = 0.13*0.0432*2/0.0025 = 4.5 Kcal/h = 5.23 J/s

Design:

$\dot{Q} = \dot{Q}_{container} + \dot{Q}_{lid}$ = 1.63 + 5.23 = 6.86 J/s

<u>O3:</u>

Container:

The cost of EPS (expanded polystyrene) is $2880 for 1000 kg, which means $2.88 for 1kg.

The volume of material used to produce the container is 0.000108 m^3. The density of the material is 32.037kg/m^3. Therefore the mass of the container is:

$m = \rho V = 0.000108 \times 32.037 = 0.00346$ kg

The cost of the container would be:

cost = 0.00346*2.88 = $0.01

Lid:

$3 for 1$m^2$

The area of the lid is 0.048m^2

Therefore the price of the lid would be around $0.15. However it is necessary to add the moisture absorbing film, which probably would increase the lid's cost to $0.35.

Design:

The final cost of the design is going to be around $0.36 USD. Converting this amount to CAD the design is going to cost:

CAD = 1.3 x 0.36 = $0.47

The objective goal is $0.21 CAD, therefore this design meets 45% (0.21/0.47) the objective.

<u>O4:</u>

In order to package the design it is necessary:

1) Hold the container
2) Place the lid in the right place
3) Push down the lid in order to pin with the container

In order to open the design it is necessary:

1) Hold the container
2) Pull up the lid

The objective is 2 steps for each operation. As this design requires 3 steps to package, it meets 67% (⅔) the objective.

Appendix ‘**F**’

Description of the performance of Design #2

O1:
80% of absorption of moisture. 0% of ventilation. According "Appendix C" this designs receives a score of 40%

O2:
The specific heat of $CaCO_3$ is 0.8951J/（g*℃）
The specific heat of CaO is 0.15J/（g*℃）

The formula of specific heat: Q=c*m*delta(t);

Our goal temperature is from 70℃ to 60℃ so delta(t)will be 10℃

Q=(150.7*0.15+121.95*0.8951)*10=1317.62J

Q per second = Q/(3600*2)= 0.183J/s

O3:

The drying room is 2cm*10cm*6cm=120m^3
75% is filled with CaO and $CaCO_3$,120*75%=90cm^3

Mass of CaO = density of CaO* volume = 3.35*90/2= 150.75g= 0.33165lb
Mass of $CaCO_3$ = density of $CaCO_3$* volume =2.71*90/2= 121.95g= 0.268lb

The price for a ton of calcium carbonate is $90(US dollar), for calcium oxide is $80(US dollar), so the cost of the material of one drying room is:
0.09/2*(150.75*80+121.95*90)/1000000=$0.001036(US dollar).

The length, width and height of the outside is 24cm,12cm,12cm.The thickness is 0.5cm.

The volume of poly is 0.001152m^3 The density of the material is 32.037kg/m³. Therefore the mass of the container is:
$m = \rho V = 0.001152 \times 32.037 = 0.0369$ kg

The cost of the poly of the container would be:
0.0369 *2.88 = $0.11(US dollar)

So the total cost will around $0.111(US dollar) =0.111*1.3=$0.114(Canadian dollar)for all of the material for one container.

O4:

Steps to package:

(1) Hold the container's hand holder
(2) Open the buckle and lift the lid
(3) Renovate the drying room and humidifying room
(4) Close buckle

Steps to open:

(1)Hold the container
(2)Open the buckle and the lid

Appendix '**G**'

This appendix contains calculations pertaining to the alternative design #3.

Outer surface area of container:
2x25x4= 200 cm^2
2x15x4=120 cm^2
25x15=375

total: 200+120+375= 695 cm^2
Outer surface area of lid (a chord of circle with radius of 8 cm and a chord length of 15 and a height of 4m)
$A = \frac{R^2}{2}$ x(**ϴ**-sin**ϴ**)

ϴ=arcsin((15/20)/8)
ϴ=1.215 rad

$A = \frac{(8)^2}{2}$ x(1.215-sin(1.215))x2
A=17.8 cm^2

25x1.215x8=243 cm^2

total=17.8+243=260.8 cm^2

Volume:
=total surface area x thickness
=(695+260.8)x(0.25)=238.95 cm^3

O1

Silica Gel has a 'high' capacity for water at 77℉ (25℃) and could hold 35.5 g per 100 g of absorbant, therefore, it received a percentage score of 85%. The total area of ventilation is:
12x(π)$(0.5)^2$ = 9.42 cm^2 9.42/243=3.87%

(85)(0.5)+(3.87)(0.5)=44.4%

44.4/50=88.8%

O2

k(polystyrene)=0.033 W m^{-1} K^{-1}[53]

$\dot{Q}$ = (0.033 W m^{-1} K^{-1})*(0.09558 m^2)*(2K)/0.0025m = 2.52 J/s

2.52<11. therefore achieves 100%

O3

ρ=1.05 g/cm^3 [53]
V=238.95 cm^3
m=ρm
m=(1.05 g/cm^3)(238.95 cm^3)
m=251 g

Cost of polystyrene = $0.05 (USD) per lb

0.05 (USD) x 1.3 = $0.065 (CAD) per lb

251 g= 0.553 lb

0.553 lb x 0.065 ($/lb)= $0.0359

$0.0359>$0.21 therefore achieves 100%

O4

The number of steps it takes to open this design is as follows:

1. Pull lift tab
2. open container

Total number of steps = 2

Appendix ‘**H**’

This appendix contains calculations pertaining to the alternative design #4.

Outer surface area of the container:
(0.06)^2 x (3.14)*(2)=0.0226m^2
(0.12) x (3.14) x (0.065)=0.0245m^2
0.0226+0.0245=0.0471m^2

Thickness of container: 0.001m= 0.1cm
Thickness of the insulation bag: 1cm
Weight of PP: 0.946g/cm^3

Weight of one container:
(0.1cm x 471 cm^2 x 0.946g/cm^3=44.6g

Weight of one insulation bag:
the weight per insulation bag is the weight of oxford fabric plus EPE foam per unit, which is 10g.

Cost per unit:
price of the EPE foam: 1.5CAD/m^2
price of the PP plastic: 1.16CAD/kg
price of the oxford fabric: 2CAD/m^2

the cost per unit=the cost per container+the cost per bag
=0.05CAD+0.08CAD
=0.13CAD
Due to there are also other materials needed for the design such as zipper, the cost per unit will be 0.5 CAD.

Calculating thermal insulation for design#4 using the following formula:

$$\dot{Q} = k \cdot A \cdot \Delta T / L$$

$\dot{Q}$: the amount of heat per an unit of time (kcal/h)

k: thermal conductivity of the material (Kcal/h.m.°C)
A: external area of the packaging that is in contact with the atmosphere (m^2)
ΔT: variation of the temperature (°C)
L: thickness of the packaging (m)

For calculations:

1 kcal/h = 1.16222 J/s
1 W/mK = 0.859845 Kcal/h.m.°C

K value for EPE foam = 0.025 kcal/h.m.°C [54]
A = 0.0471 m^2
L = 0.1 cm = 0.001 m
T = (70 - 68)°C = 2°C

$$\dot{Q} = (0.025 \text{ kcal/h.m.°C}) \times (0.0471 \text{ m}^2) \times (2\text{°C})/0.001 \text{ m}$$
$$= 2.355 \text{ kcal/h}$$
$$= 2.737 \text{ J/s}$$

Steps to package:

1. Put food into the container.
2. Close the container,
3. Put the container into the insulation bag.
4. Close the insulation bag.

Steps to open:
1. Open the insulation bag.
2. Take the container out.
3. Open the container.

Appendix ‘**I**’

This appendix contains calculations pertaining to the alternative design #5.

O1:
Humidity Control Calculations:
Number of holes in the lid=8
Shape of the holes= Semi-circular
Radius of one hole= 1 cm
Area of one hole= (0.5*pi*(1)^2)cm^2=1.571cm^2
Area of 8 holes=8 * 1.571cm^2 = 12.566 cm^2
Area of base container opening = pi * (8cm)^2 = 201.062cm^2
Percentage ventilation=((12.566 cm^2)/(201.062cm^2))* 100 = 6.249815672%=6.25%

Wool can absorb water equal to 35 percent of its mass. Keeping in mind the high absorptive quality of wool, wool is allocated an absorption value of 80% (This value has been arbitrarily assigned to wool for all calculations).
Keeping in mind the reduced contact surface of wool with air in this design, the value of 80% is multiplied by a factor of halve resulting in a final percentage of absorption of 80%.

Total calculation of performance in dealing with moisture = ((80)*0.5)+((6.25)*0.5) /0.5 = 86.25%
O2:
Calculating thermal insulation for EPS:
Thermal insulation value (K) for EPS is found to be:

$\dot{Q} = k \,.\, A \,.\, \Delta T / L$

$\dot{Q}$: the amount of heat per an unit of time (kcal/h)

k: thermal conductivity of the material (Kcal/h.m.°C)
A: external area of the packaging that is in contact with the atmosphere (m^2)
ΔT: variation of the temperature (°C)
L: thickness of the packaging (m)

K value for EPS = 0.034 W/mk [55]
A = (2*pi*lrb * htb)+(pi*lrb^2) + (2*pi*lrl^2)

Substituting value yields = 1046.2cm^2=0.10462m^2
L = 1 cm = 0.01 m
T = (70 - 68)k = 2k
$\dot{Q}$ = 0.034W/m.k * 0.10462m^2 * 0.01m * 2k =7.11x10^(-5) J/s = 0.711 J/s.

O3:
Cost calculation for a single unit:
Note: For simplicity purposes the shape of lid is assumed to be a perfect semicircle.

EPS (Expanded Polystyrene) cost per tonne is $1880.

Calculating volume of EPS used in one unit:
i r b = inner radius of base = 8 cm
l r b = larger radius of base = 9 cm
htb = height of base= 5cm

Volume of base container = (1 cm * pi* lrb^2) + (htb*pi*(lrb^2 - irb^2))
Substituting values and solving yields: 254.469 + 267.0354 = 521.5044

l l r = Larger lid radius = 9
s l r = smaller lid radius = 8
h t l = height of lid = 4 cm

Volume of lid = ((4/3)*pi* llr^3) - ((4/3)*pi* slr^3)
Substituting values yields= 3053.6281 - 2144.661 = 908.9675 cm^3

Total volume = volume of lid + volume of base container = 521.5044 + 908.9675 =1430.472 cm^3

Calculating mass of the container:
density = mass / volume
mass = density * volume
Average density of ESP used = 2 pcf (pound per cubic foot) = 32.037 kg/m^3 = 0.032037g/cm^3

mass of used EPS = 0.032037g/cm^3 * 1430.472 cm^3= 45.83 grams.

Cost of EPS per tonne/1000Kg = $2880 [56]
Cost of EPS per unit = (2880/1,000,000) * 45.83g = US$0.1319 per unit = US$13.2 cents per unit
=CAD$17.3 cents per unit

O4:
Steps of operation:
Steps to Package:
1. Open the lid
2. Fill with food
3. Close the lid

Steps to Open:

1. Open the lid
2. Extract food

Steps to open = 2
steps to package = 3
Thus as steps required in both processes are less than the required metric amount/limit, this objective gets a percentage of 100%

Appendix ‘**J**’

Decision making

Table 09: Weight of objectives

Objective	Rank (From Pairwise Comparison)	Weighted (Determined through consensus)
O1	1	40%
O2	2	30%
O2	3	20%
O3	4	10%

Table 10:Comparison between objectives and designs

Objective	Design 1	Design 2	Design 3	Design 4	Design 5
O1	100%	80%	88%	80%	86.25
O2	100%	100%	100%	100%	100
O3	45%	100%	100%	100%	100
O4	67%	50%	100%	40%	100

Combination of two tables:

Table 11: Weighted Average Table

Objective	Design 1	Design 2	Design 3	Design 4	Design 5
O1	0.40x1	0.4x0.8	0.40x0.88	0.40x0.8	0.40 x 0.86.25
O2	0.30x1	0.3x1	0.30x1	0.30x1	0.30 x 1
O3	0.2x0.45	0.2x1	0.20x1	0.20x1	0.20 x 1
O4	0.1x0.67	0.1x0.5	0.1x1	0.10x0.4	0.10 x 1
Total	0.857=85.7%	0.87.0=87.0%	0.952=95.2%	0.86=86%	0.945=94.5%