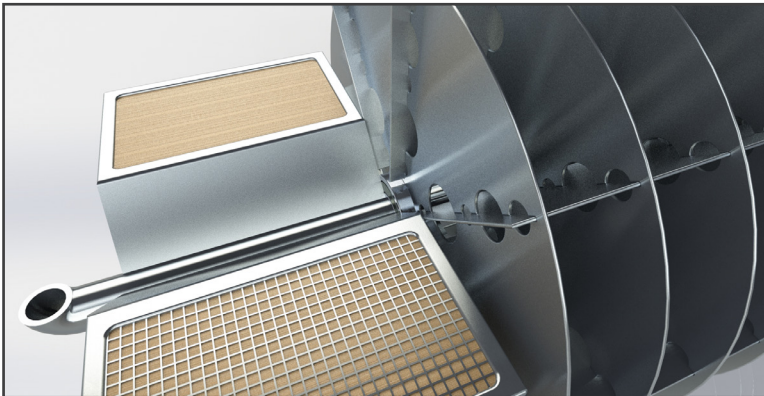
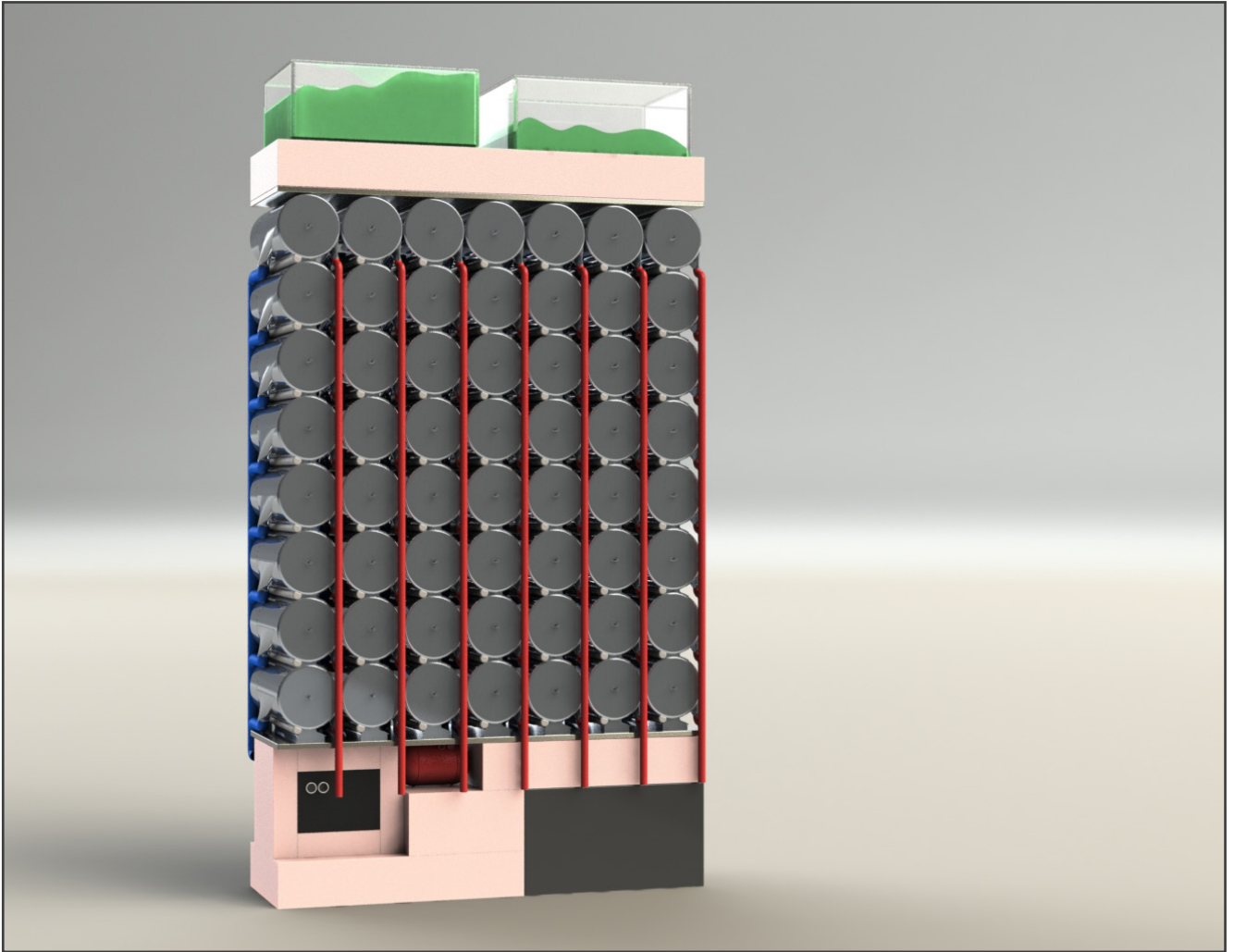




Automated cricket farming vending machine viability check

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Product Design Engineering 2025354

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2017



University
of Glasgow

**THE GLASGOW
SCHOOL OF ART**

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I. Glossary

Entomophagy - the human use of insects as food.

Invertebrates - Familiar examples of invertebrates include insects; crabs, lobsters

Moulting - In many invertebrates the manner in which an animal routinely casts off a part of its body, either at specific times of the year, or at specific points in its life cycle.

Pinhead - newborn cricket

Nymph - a nymph is the immature form of some invertebrates, particularly insects, which undergoes gradual metamorphosis before reaching its adult stage.

Algae - term for a large, diverse group of photosynthetic organisms

Spirulina - a biomass of cyanobacteria (blue-green algae) rich in protein that can be consumed by humans and other animals.

Feed conversion (kg dry feed/kg live weight) - or feed conversion rate is a ratio or rate measuring of the efficiency with which the bodies of livestock convert animal feed into the desired output

Ovipositor - a long, needle-like or sabre-like egg-laying organ of the female cricket.

Gear ratio - is defined as the input speed relative to the output speed

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III. Executive Summary

This report outlines the reasoning behind the design of a cricket vending machine and validates its social and technical aspects by showcasing experiments, calculations and relevant data.

The product overview section presents the outcome of the project. In order to develop a deeper understanding of the product design, the report explores all of its aspects in detail.

The problem with the manner in which food demand is met at present is discussed in detail in the introduction, making it clear that there is a lot of room for improvement and novel ideas. The question of why crickets are a good dietary (food) alternative is also addressed by examining their environmental friendliness and excellent nutritional value, thereby giving an overview of their relatively simple life-cycle.

To take the project a step further it was essential to understand how Western people feel about eating insects and what factors are favourable to encourage them to do so. Through a series of experiments and interviews it was concluded that under the right circumstances and in the very near future there is a potential that snacking on crickets will become more attractive and not be considered weird anymore.

For a successful cricket breeding machine design, the insects rearing requirements had to be investigated in depth. This report summarise the findings from a literature review together with personal insights from breeding more than 5 generations of crickets at university and experimenting on their life-cycle by adjusting different living condition factors.

Taking all the findings into account, a design solution is presented. A structural analysis was performed to justify the technical viability of the design and the choice of materials and manufacture.

The report gets into great depths of calculating the energy demand for the main parts of the system required to run the machine on a daily basis. This analysis shows that feed is the largest resource required which means that there is great potential for improving its efficiency by introducing a more self-sustainable feeding system (examples with Algae and Human food waste are given in the report).

One could think that maintaining a relatively high temperature, utilising an oven and a steam generator would require a great amount of energy. However, the report shows that with the use of suitable insulation and design optimisation the heat losses can be minimised to achieve an energy efficient solution.

It is also shown that rotating the farms (for cleaning purposes) is a small fraction of the energy demand. To prove that it was necessary to address the change of load in time due to cricket growth. Despite of the small energy input required for the motors delivering the rotation, it is interesting to see the change in torques over time, which is graphically presented.

At the end of the report all the necessary inputs per year and per day are calculated and converted to British Pounds to enable an estimate of running costs.

IV. Product Overview

The designed product is a scalable food producing, processing and vending machine. The examined size delivers an output of **1kg of live cricket weight** per day by harvesting one of the **56 cricket farms units**, each containing **2000 adult crickets** at the time of harvest.

To make this possible, a number of subsystem machines and processes are designed.

The two most important factors for cricket breeding are feeding them properly and maintaining the correct temperature. These are achieved through the **feed distributing system** and the **living areas heating system**. The living areas in the cricket farms are maintained clean by a combination of the farm unit's design and a **synchronous electromotor** which each of them with one revolution per hour enabling the disposal of waste at all times.

Hot pressurised steam is used to harvest the crickets after they have layed enough eggs to replace them. The steam is delivered from a **boiler** and slaughters them quickly while decontaminating the cage, thus preparing it for the next generation.

An outlet pipe goes through a filter which separates the dead crickets from the liquid, bringing the former to **an oven** and the latter back to the boiler.

After fat and spices are added in the oven. The final output has a a tasty crunch.

The cricket machine is intended for the market in the near future, where eating insects would be still a novelty for people, but not unusual.

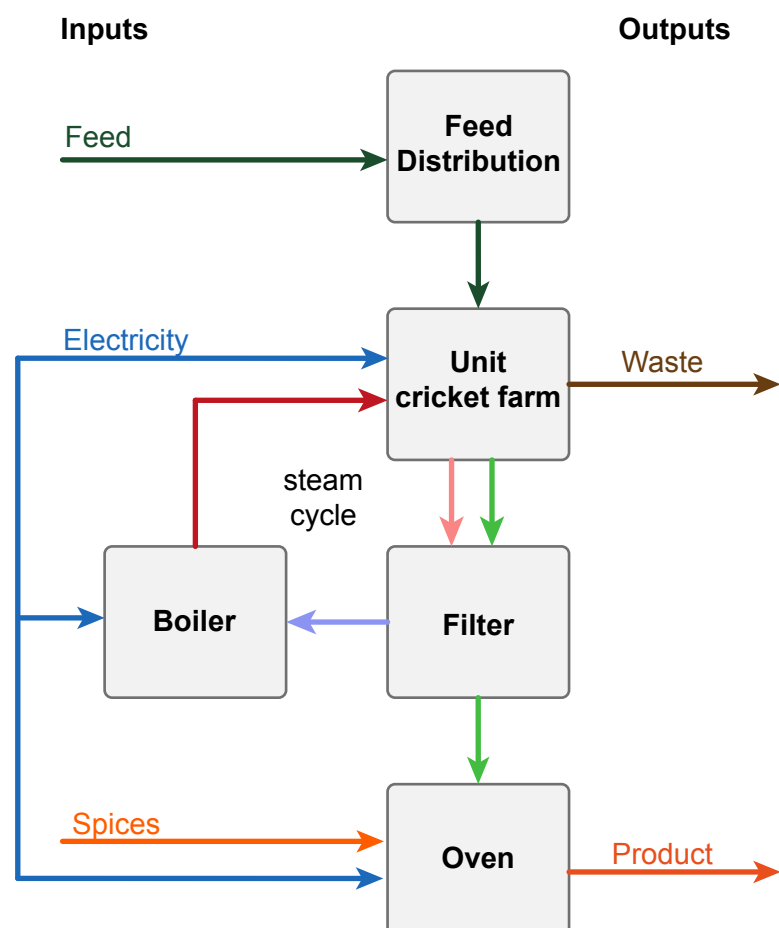


Fig. 1 - System Diagram

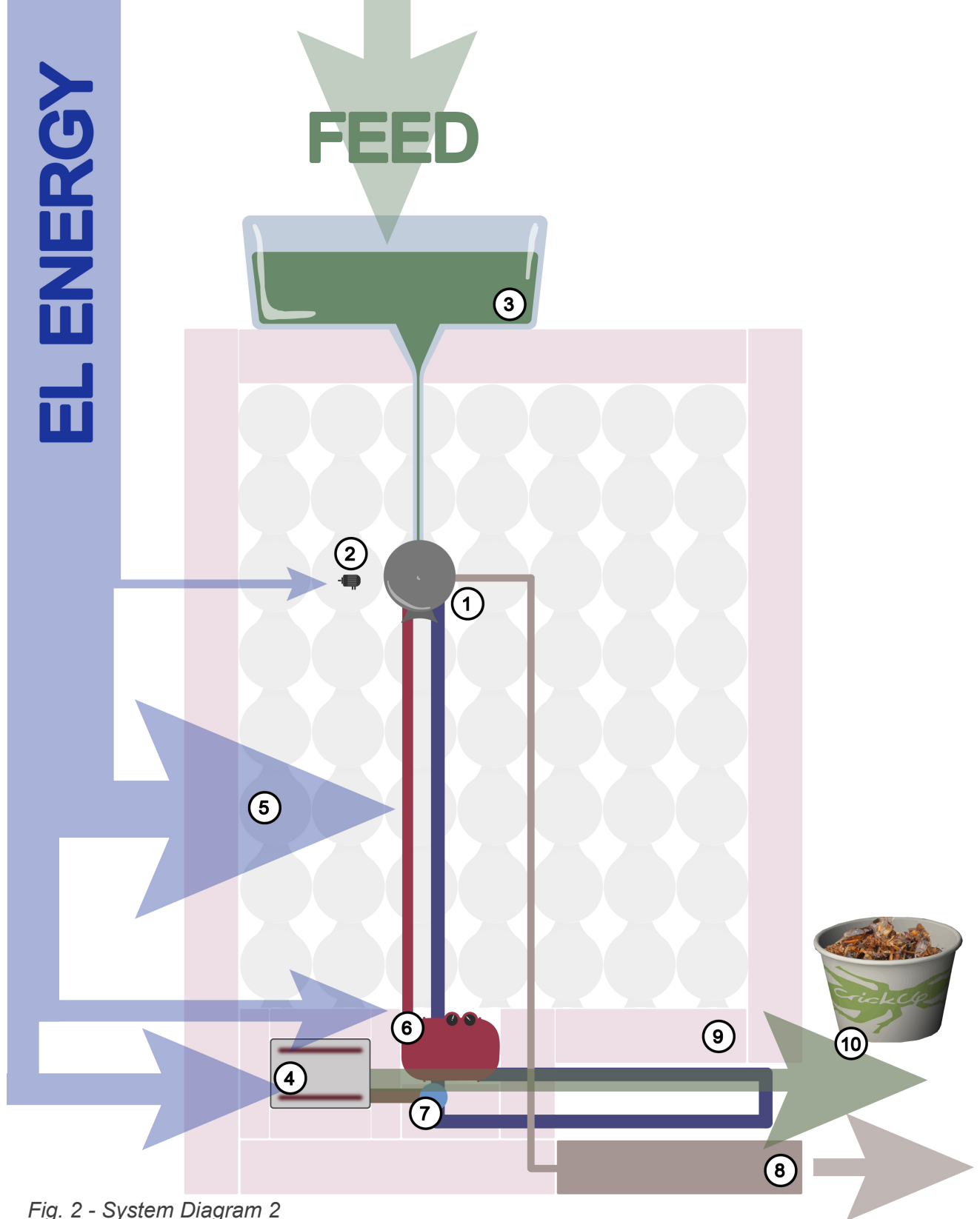


Fig. 2 - System Diagram 2

- | | |
|---|--|
| ① Unit farm, 2000 crickets x 56 | ⑥ Boiler and hot pipe |
| ② Synchronous motor, 1RPH x 56 | ⑦ Filter separating crickets and water |
| ③ Feed storage tank, 1 month x 2 | ⑧ Waste |
| ④ Oven, 220°C, 6 minutes | ⑨ Polyurethane Foam |
| ⑤ Heater for farm area of 1m ³ | ⑩ 0.5kg roasted crickets a day |

1. Introduction

This chapter is going to give background information about the problem with world overpopulation and current food production. It is also going to briefly present the proposed solution - entomophagy (the human use of insects as food) and explain why crickets are the insects of choice.

Problem

The world population at the moment stands at 7.3 billion. Predictions suggest the number will rise to 8.5 billion by 2030, 9.7 billion by 2050 and 11.2 billion by 2100 (United Nations, 2015). This means doubling the meat consumption in the next 30 years (Gardner, 2013). Current methods of meeting the food demand are simply unsustainable and have a vastly negative impact on the environment.

18% of the Greenhouse gas (GHG) global human induced emissions are from livestock production. The number includes transport of livestock and feed. A literature review suggests that producing 1 kg of beef has the most negative environmental effect equating to 14.8kg of CO₂. 1 kg of pork releases 3.8kg CO₂ into the atmosphere, chicken 1.1kg (Fiala N., 2008). And it is not just about the Carbon Dioxide, the charts below (see fig. 3) show the difference in water and feed

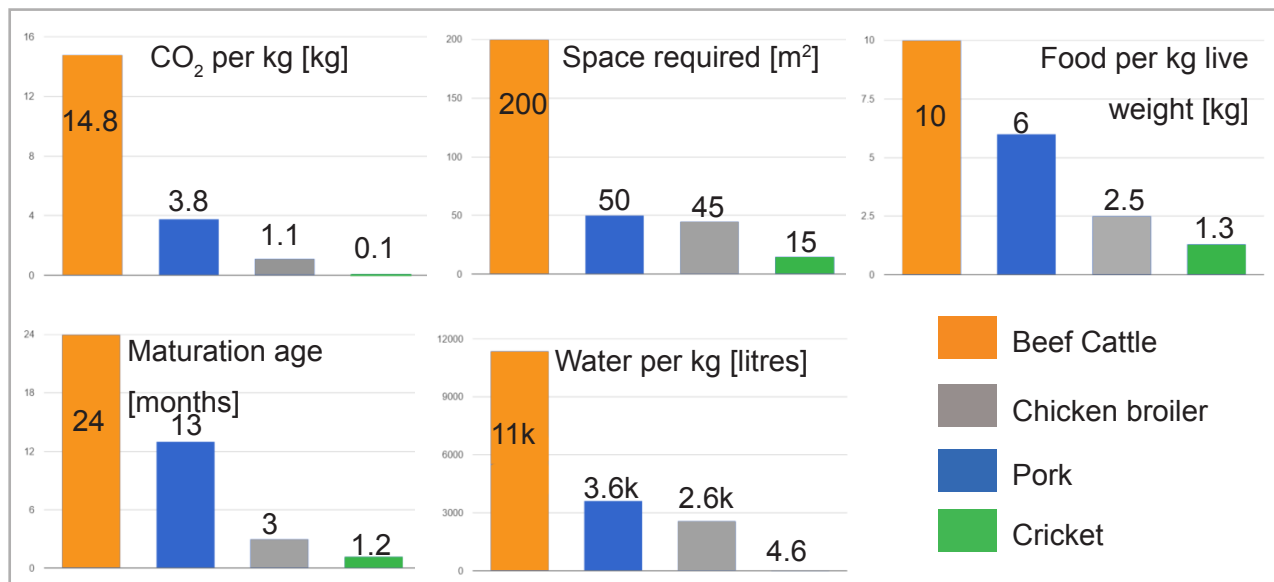


Fig. 3 - Comparison of different animals for food.

demand as well as space and time required to get 1 kg of live weight.

If edible weight was to be considered, the difference in numbers would be even more dramatic since only 60% of a cow is edible, whereas one can eat 100% of the cricket (90% with no legs.)

With the current rate of population growth and global warming, it is evident that the ways of feeding people need to change.

Entomophagy

There are numerous publications focusing on the nutritional value of insects as food. Not only are they proven to be a much more efficient and environmentally friendly source of food, but they are also incredibly protein rich and provide all the necessary macro and micro nutrients for a healthy human diet. (van Huis, A., 2013.)

People eat insects on a daily basis in many parts of the world (predominantly Asia and Africa). However, until recently, Western countries have never seriously considered entomophagy an option. Lately, environmentally aware people or ones looking for clean protein have started consuming insect based protein power bars, usually made with cricket flour, nuts and dates.

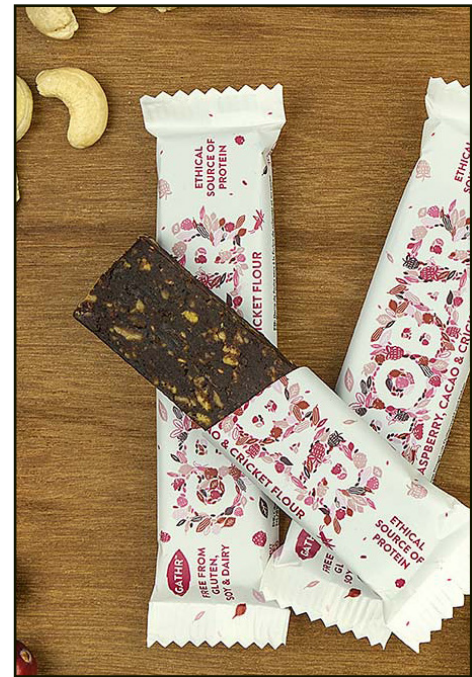


Fig. 4 - Cricket Protein Bar
(gathrfoods.com)

Crickets

Crickets starting to normalise on the health food market was only one of the reasons for choosing them for this project. The truth is that their nutritional content and relatively easy breeding requirement and life-cycle make them a safe bet for taking entomophagy further.

Nutritional value

100 grams of fresh crickets (when they are dried nutrition varies) contain: **121kcal** from which **12.9g of protein** (including all essential amino acids), **5.5g of fat**, **5.1g of carbohydrates**, **75.8mg calcium**, **185.3mg of phosphorous**, **9.5mg of iron**, **0.36mg of thiamin**, **1.09mg of riboflavin**. (Asnath Maria Fuah et al., 2015)



Fig. 5 A and B - Female Adult Cricket (frozen)

Life-cycle

The cricket life-cycle will be discussed in greater detail later, when discussing the design specification of the final product, since it greatly depends on a big number of factors, predominantly temperature. All the quoted values and experiments are based on a breeding temperature of 30°C.

It takes **56 days** from laying an egg to its development into an adult having the ability to lay an egg. That number has been the driver of the **56 farms** design.

It takes **13 days** from laying an egg to hatching a Pinhead - a small ant sized baby cricket.

In the stage the pinhead develops into a Nymph and moults (shedding its exoskeleton) 7 or 8 times until it becomes an adult. It takes **30-35 days**.

After the last moult, having grown wings, the cricket is considered an adult. 2 days of adulthood need to pass before cricket start mating and 7 more days until they start laying eggs.

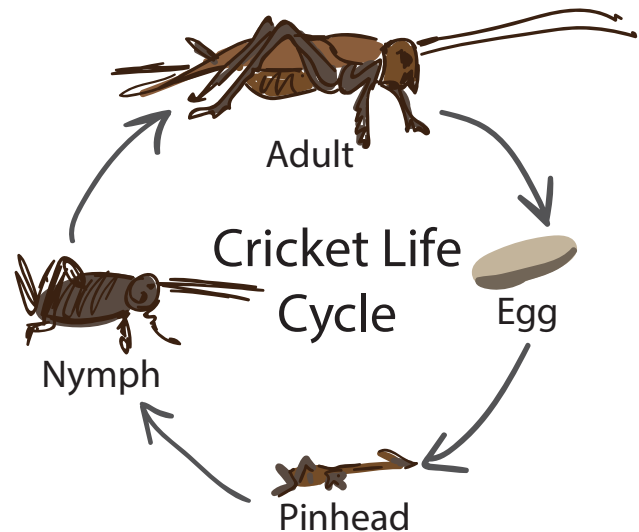


Fig. 6 - Cricket Life cycle illustration

2. Determining the Product Design Specifications

In order to design a successful product to farm insects and sell them to people, both of these stakeholders need to be considered. What do consumers want and what is best for the crickets inside the machine are two really important questions that require to be looked at carefully.

Customer requirements

Educational aspect

It is important to understand the attitude of Western people towards eating insects. A good way to reach out to more people and ask them about their opinions is giving them an online questionnaire.

The first result (Fig. 7, on the next page) show how people react to the thought of eating insect without being given any information on the topic. Giving 1 as an answer indicates a total rejection of the idea, whereas choosing 10 means that one is very positive about the idea.

The questionnaire then proceeds to explain all the benefits related to eating insects. After educating the randomly selected participants, the question is being asked again. Figure 8 shows that the opinions have greatly changed.

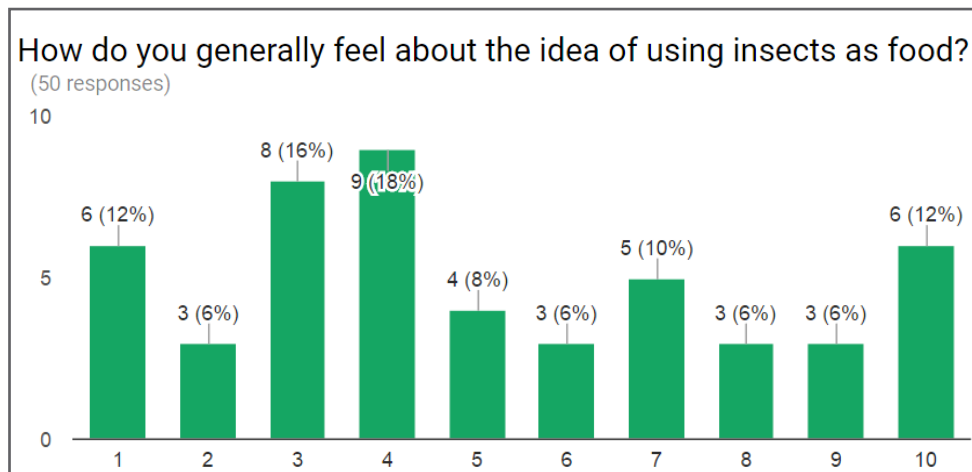


Fig. 7 - Questionnaire responses (1)

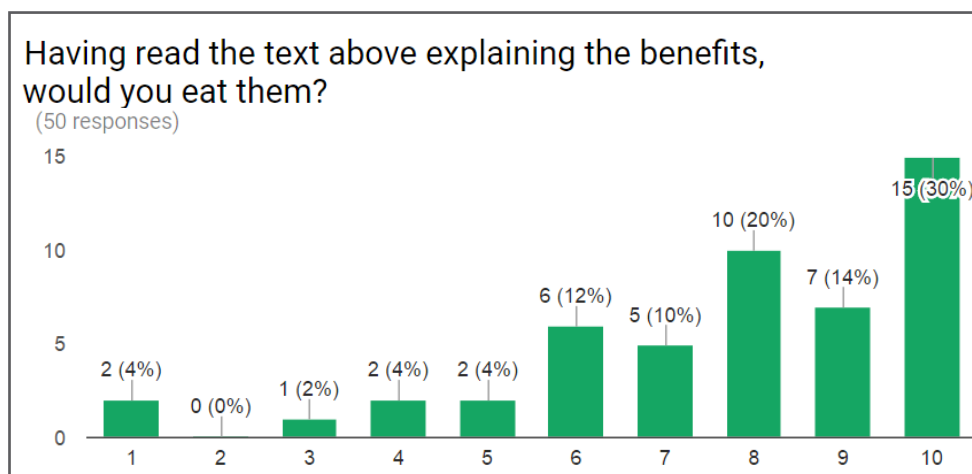


Fig. 8 - Questionnaire responses (2)

It is concluded that **the more information you give to the consumer the more open they become towards the idea of entomophagy.**

Social Aspect

The next experiment consisted of asking people to eat insects in different environments - at university, at home, at a public space (Appendix A, 1.). What made a great impression was that people in groups were much more open to eat an insect compared to when they were approached individually. It could be concluded that the trend follows the same graphs as above - Fig. 7 showing people's response to the idea when by themselves and Fig. 8 when in a group - influenced to try by the pro-entomophagy ones.

This led to the decision to design **a cricket vending machine for the public space**, differing to the initial idea to design it for the private home.

Overcoming phobia

Another potential barrier to entomophagy worth mentioning is the phobia of insects. The author of this report, had a really bad phobia of insects at the start of the project. However, through sustained effort and self-led exposure therapy, it was overcome to the extent that they can tolerate to have crickets on their face. (see appendix A, 2.)

Cricket requirements

In order to design an automated cricket farm, one has to be knowledgeable and understand the requirements for the successful breeding of healthy insects. Referring to scientific literature on the matter initially and then building a non-automated farm (fig. 9) to breed crickets and learn from the experience first hand were the two necessary steps taken towards that goal.



Fig. 9 - Author's cricket farm

Breeding

Temperature

The cricket life cycle varies greatly with temperature - faster development in warmer environment. A change from just 30.5 to 31°C results in a 10 day shortening of their life cycle and one day shortening of their hatching period. Thus, by controlling the temperature the output of the machine can be amended in accordance with the demand. (Clifford, C.W. & Woodring, J.P., 1990)

The insects can survive temperatures just a few degrees above 0°C. However, temperatures below 20°C are not advised for breeding due to greatly slowing down their life cycle.

Furthermore, temperatures above 35°C are lethal. 30°C is considered to be the optimum for breeding, despite of the fact that life cycle is a faster at slightly higher temperatures.

The **cricket farm living area temperature is to be maintained at approximately 30°C** and kept above 25°C and below 35°C at all times.

A heating mat covered with sand was used to heat the experiment farm with. A thermostat was utilised for control.

Light regime

It has been shown that **light does not play a significant role in cricket breeding**.(Clifford, C.W. & Woodring, J.P., 1990.). Cricket were kept in the dark - when container lid was closed. It has been noticed that crickets get scared when the lid is opened from the sudden increase of light. Personal experimenting also shows that they prefer hiding in the darkest spots available.

Feeding

The initial idea of this project was to combine the cricket farm with an algae farm so that the system is even more self-sustained, providing its own food. Due to the complexity of this undertaking and the scale of the project this idea was discarded. However, crickets were fed Spirulina (a type of algae) successfully.

After considering a few in depth studies about cricket feed it was decided to choose **Poultry feed as the main food source** since it is cheap and readily available. It also gives a good conversion ratio (kg dry feed per kg live weight) of 1.3 (Lundy & Parrella 2015).

Human food waste is also a great possibility with even better feed conversion ratio (Asnath Maria Fuah et al. 2015). Although this would increase the efficiency of the process, it will also complicate the system by introducing the requirement of preventing rotting of fresh food.

Rearing density

Studies suggest that density is another important factor for cricket breeding. The rearing group should neither be too large nor too small. Crickets in dense groups grow faster compared to when reared singly. However, too much overcrowding decreases the general well-being of the group. (Chauvin, 1958).

It was later determined that the minimum crawl space i.e. surface area per cricket is 2.5cm^2 (Patton, 1978). This allowance of living area gave the minimum rate of mortality and the maximum growth index after hatching. However, it is the optimised minimum so a bit more would be better.

The aim of the cricket living area design is to give 4cm^2 per cricket or more. Having 2000 crickets per unit farm yields **8000cm^2 of surface area per unit.**

Oviposition

Female crickets lay eggs 7 days after they have started mating with a rate of 95 eggs a day per female. (Asnath Maria Fuah et al., 2015.). 50 to 60% of the eggs hatch. (Clifford, 1990.).

Egg laying trays have to be provided with a damp, relatively soft, egg medium so that the female ovipositor can lay an egg inside. Breeding has been done successfully using damp soil so it remains as the medium of choice.

It is important that the medium is protected with a mesh on top, otherwise male crickets dig in and eat a big percentage of the eggs.

Cleaning

It is important to maintain the rearing areas clean to prevent virus or parasite problems. Frequent removal of trash/litter storage is required. Keeping the egg laying trays separate from the main rearing compartment when not in use is also important. (Clifford, C.W. & Woodring, J.P., 1990.)

Many different ideas were tested for maintaining the living area clean at all times. The current design utilises a slow rotation of the units, while a jet of **hot steam** is used to decontaminate

every unit farm after harvesting, thus preparing it for the next generation.

Harvesting

Initially, crickets were placed in the fridge where they hibernate and then moved in the freezer, to be slaughtered peacefully in their sleep. This would require a freezer integrated in the vending machine.

However, it was later found that insects destined for human consumption should be first sterilized in hot water, which also agrees with the welfare of farmed insects. (Erens, Jesse et al., 2012). This led to the choice of **hot steam** being used for cleaning and harvesting purposes.

Experiments proved it is working successfully for both (fig 10)



Fig. 10 - Using a steam cleaner for slaughter

Cooking

Although harvesting crickets in this manner automatically cooks them (i.e. boiled), experimenting showed that oven roasted crickets with very little oil and spices makes them very tasty (see appendix).

Three roasting temperatures were tested (180°C, 200°C and 220°C) to investigate the required times for roasting and the difference in taste quality. It turned out that roasting them at **220°C for six minutes** gave the best results. Cricket mass decreased in half after roasting. (See Appendix B, 1)



Fig. 11 - Roasted Crickets on toast

3. Design Solution

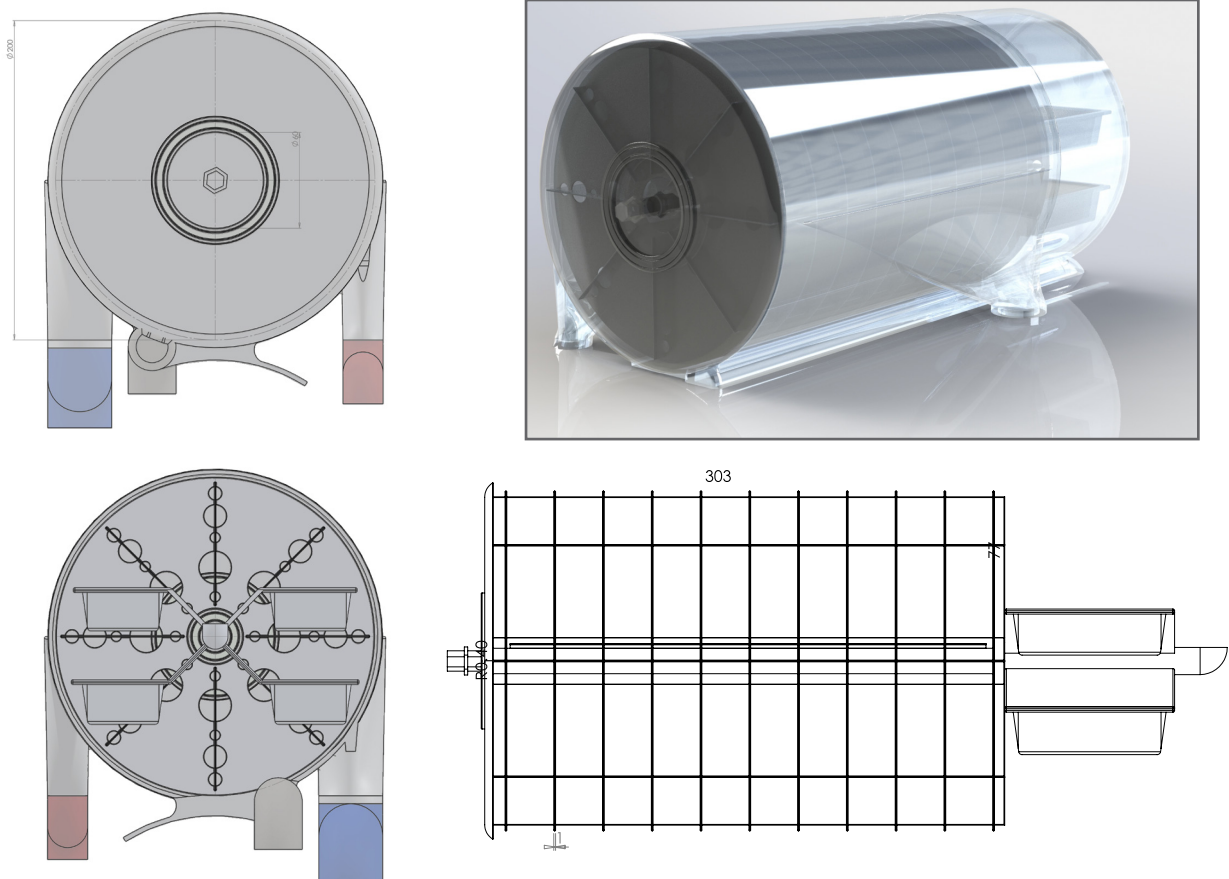


Fig. 12 - Unit farm drawings

The novelty in the automated cricket vending machine design lies in the rotating farming unit. This provides very large surface area for its small volume. The dimensions of the unit were driven by the surface area needed for 2000 crickets which was decided to be not less than 8000cm^2 .

The unit is divided in 11 circular plates for **living area**, perforated to allow free movement, and 8 perpendicular rectangular squares, providing a total surface area of 8327cm^2 . There is a feeding pipe running through the centre of the unit providing the necessary nutrition. The living area rotates with 1RPH coaxially to the **feeding pipe** via two ball-bearings and a synchronous motor. The rotation is slow enough not to be noticed by the insects, and gravity is utilised to collect the waste in an outlet pipe through which it gets disposed.

The **egg laying/hatching area** is opened only when crickets are ready to lay eggs, right before harvesting. It consists of **4 egg laying trays** containing damp soil and a mesh on top.

Hot steam harvesting takes place after a sufficient amount of eggs have been laid (approximately 2 to 3 hours). 13 days later the hatching area opens to the living area and the new generation moves in.

The two areas are united with the casing which contains the waste pipe at its bottom side, thereby enabling the stacking of the farms on top of one another possible.

Materials and structural verification

Aluminium

CES material selector together with experimenting with crickets themselves were used to determine the main unit farm material.

Since it is a machine with strong environmentalist character, low CO₂ footprint and recyclability were very important features. Resistance to corrosion and formability were also important due to the geometry of the unit.

Aluminium and a few types of thermoplastics appeared as the most suitable choice. **Aluminium** was chosen due to cost, longevity and high heat conductivity which helps to thermally unify the area of the machine the farms are in.

Manufacturing

Extrusion seemed like the obvious choice for the case of the unit, therefore Aluminium grade 6063 was chosen due to its extrusion friendly and corrosion resistance qualities.

The grade of Aluminium, the shape of the casing and the method of manufacturing suggest wall thickness of 3mm (Appendix B, 2). It is important to verify whether the units can structurally withstand the loads of the farms stacked on top of them.

Structural Verification

A linear elastic finite element analysis is performed to verify the structural viability of the cricket unit design in the most conservative case - having 7 fully loaded unit farms stacked on top.

Geometry

To enable a quick and reliable analysis the geometry is simplified to a cylinder defined by a 200mm diameter and 400mm depth.

Material properties

For the purposes of this analysis the following aluminium material properties are used:

Young's Modulus = 69×10^3 N/mm²; Poisson's Ratio = 0.35; Density = 2700 kg/m³; Yield Strength = 240 N/mm²

Support

A surface defined by a 40° section of the cylinder's diameter is restrained in all 3 translational degrees of freedom to model the support conditions of the cricket units (see fig. 13)

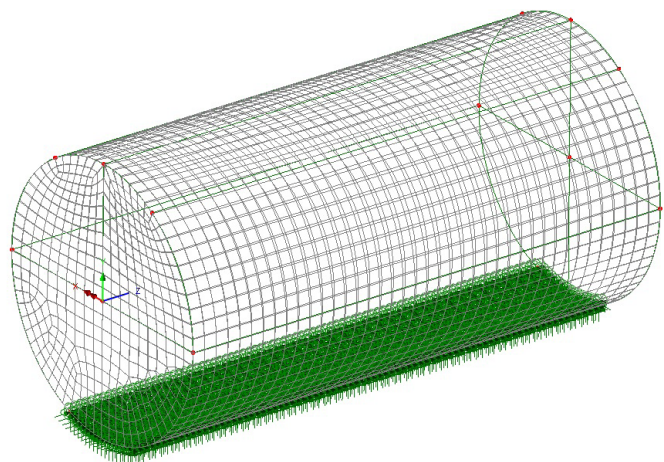


Fig. 13 - Support Conditions

Loading

The cricket units are stacked on top of each other. Therefore, only the bottom unit is investigated in this model, as it is expected to be most heavily loaded. The load is applied transversely to the cylinder wall as a 15kPa static uniform pressure applied on a surface defined by a 65° section of the cylinder's diameter (see fig. 14). To account for the variability of loading over the unit's design life a safety factor of 1.35 is used on all material loads and a factor of 1.5 on the cricket loading.

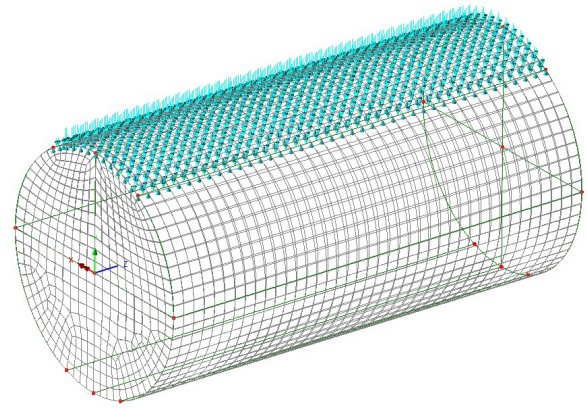


Fig. 14 - Nature of Load Application

A breakdown of the loading from a single unit: (1.5 Factored Loading)

Item	Material	Load (N)
Casing	Aluminium	55
Shaft (feed pipe)	Aluminium	4
Living area (rotating part)	Aluminium	18
Egg laying trays	Gravel	2
Crickets	Insects	15

Results

The magnitudes of displacement show maximum deflection to be much less than 1mm. Considering that the gap between the casing wall and the rotating living area units is 2mm, this deflection can be comfortably allowed for in the design.

Stresses are also well below the threshold of 240MPa. (Aluminium Yield Strength)

It could be concluded that the choice of material and construction is a viable one even more unit farms are added to the design.

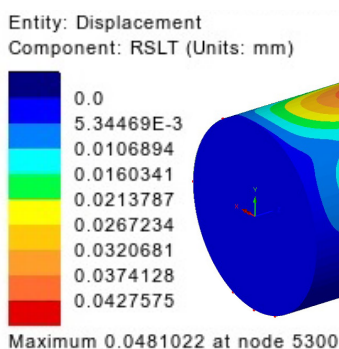


Fig. 15 - Displacement

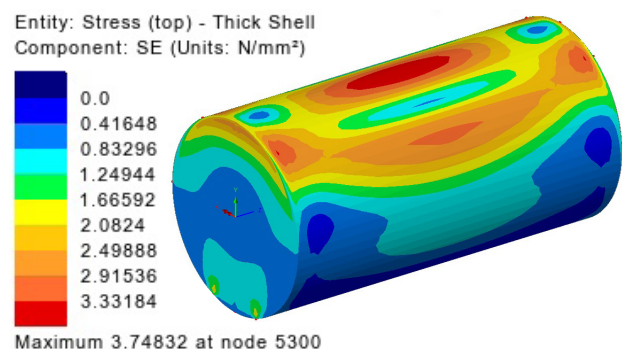


Fig. 16 - Stresses

Control

Autonomously operating a complex system with several subsystems and living organisms requires an integration of multiple sensors in a **coherent automatic feedback control system**.

The report does not get into the details of the closed loop diagrams illustrating the control system. It outlines its importance with examples in the proposed design.

Temperature control

Maintaining efficient cricket breeding depends greatly on maintaining the right temperature. Switching the heating on and off at the right time, although simple, is crucial for the design.

A good design solution was to use aluminium and to maintain the same temperature across all the living farms space so that only few sensors are required instead of 56 - if controlling every farm unit separately.

As explained earlier, this particular insect life cycle can slow down or speed up depending on demand i.e. if there are holidays the temperature can be lowered as if to "pause" itself for some time. This is a very significant feature when living beings are what is dealt with.

Cricket managing

It is important to know the rate at which crickets grow as well as the time it takes for a sufficient number of eggs to be laid.

Both of these considerations could be taken care of simply by monitoring the change of weight. 4 weight sensors (pressure mats) under each egg laying tray are responsible for getting 3000 eggs measured.

Having the living area spun by a synchronous motor makes monitoring the growth an easy task. The motor maintains the same angular velocity and when the load changes, the torque changes thus drawing more power. This is looked into more detail further in the report.

Feed

It is natural that feed demand changes with cricket growth. Combining the feedback from the synchronous motor power draw change with the feed distributing system is important in order to minimise waste of resources.

Pressure

Hot steam is used to harvest the crickets and decontaminate the farm. The jet is delivered from a boiler through a distributed flow inlet pipe, across the living area of the cricket farm. Building pressure in the unit before exiting helps cleaning and harvesting processes. Having a controlled valve at the outlet pipe can serve for this purpose. Pressurised steam is very dangerous - it should be controlled meticulously.

4. Energy for system operation

One of the objectives of this report is to investigate whether producing food in this way is energy efficient. Energy calculations were performed to address this consideration.

Feed and electricity constitute the main energy demand.

Feed

As mentioned in the previous chapter Poultry Feed will be used to feed the crickets at that stage of the project which gives a feed conversion ratio of 1.3 i.e. **1.3kg** of feed required for **1kg** of live weight.

Price

Average market price for chicken feed is £7 per 25kg which yields **0.28 pence per kilogram**. (Mole Valley Farmers, 2017)

Since the machine is producing 1 kg of crickets a day, it could be safely concluded that it requires 1.3 kg of feed to maintain that rate amounting to **0.36 pence per day**.

This could be rounded up to **40p** a day to include losses which yields **£146 a year**.

Volume

It is important to decide how often the feed storage containers should be refilled to determine their size.

To find the volume required, by already knowing the mass, it is required to find the density of the feed. This was done by measuring the mass of 25ml feed. (Fig. 17)

25ml of feed = 18 grams

$$25ml * \frac{1300g}{18g} = 1805.5 = 1.8l$$

The volume for a **month's supply** is then **54l with a mass of 39kg**.

It could be safely assumed that storing food for at least a month is not a problem. The current design has two containers, a month's worth of feed each.

Distribution

Feed is to be distributed in the feed pipe along the living area via an Archimedes screw. It could be attached to the electromotors spinning the unit farm. The amount of feed delivered should be controlled to correspond to the demand changing with cricket growth.



Fig. 17 - Measuring density of feed

Electricity

It is very difficult to estimate all the electricity uses in a design at this stage. For that purpose the report concentrates on the electricity used for heating and for rotating the farm units. When calculating the total energy there are *Others*, approximated systems not taken into account.

Electrical Energy into Heat

Apart from feed energy, electricity is consumed to heat up the oven for roasting the crickets once a day for 6 minutes at 220°C, as discussed earlier. Also all living areas should be maintained at roughly 30°C, not going above 35°C or below 25°C. Last but not least - water should be heated up to 125°C to steam harvest the crickets and decontaminate the area.

Total electrical energy for heating = Electricity to run the boiler + Electricity to run the Oven + Electricity to heat the farming area.

The oven uses **8cm** of **Polyurethane Foam** with thermal conductivity of **0.003 (W/(m·K))**, for insulation, the living space utilises a **15cm** thick layer of the same material.

Electricity to run the boiler

To calculate the energy required to boil water from 30°C (considering the boiler is in the heated up cricket living area) and turn it into steam of 125°C, the amount of fluid in at least one of the states of matter should be known.

The volume of water required could be reversed engineered from the volume of steam necessary.

The maximum volume of steam required can be estimated to be filling the full pipe length to the farm unit furthest away from the boiler. It is the volume of the unit plus the inlet and outlet pipes.

Volume of the living area (cylinder with a radius of 10cm and a length of 30cm) is **9425cm³**.

Maximum length of the inlet pipe with a radius of 7.5mm is 2150mm which gives a volume of **380cm³**.

The outlet pipe has a radius of 15mm and maximum length of 2250mm, so its volume is **1590cm³**.

The total volume is **11,395cm³**.

Knowing that steam has 1700 times the volume of its corresponding amount of water, it can be calculated that the volume of water needed boiling is **6.7cm³** of water which equals to **6.7grams** of water.

In order to be able to raise the pressure above 1 bar if necessary (this will be controlled by sensors and valves), the energy required for **10 grams** instead of 6.7 is calculated.

The heat loss to the surrounds is not taken into account in this case due to very small surface area and a short period of heating.

Calculating the energy is done in three steps:

(1) energy necessary to heat up water from 30°C to 100°C using the following equation:

$$Q = c_p m \Delta T \quad (\text{Lienhard, 2008})$$

Where c_p is the specific heat capacity of water 4.184 J/gK, m is the mass of water 10 grams and ΔT is 70°C.

$$Q_1 = 2928.8J$$

(2) energy required to turn water at 100°C to steam at 100°C using

$$Q = mL \quad (\text{Lienhard, 2008})$$

Where L is latent heat of vaporisation 2266 J/g, m is still 10 grams.

$$Q_2 = 22660J$$

(3) energy to get the steam up to 125°C using the equation from (1) with c_p being the specific heat capacity of steam which is 1.865 J/gK and ΔT is 25°C.

$$Q_3 = 466.25J$$

Total energy

$$Q_{boiler} = Q_1 + Q_2 + Q_3$$

$$Q_{boiler} = 26055.1J = 26055.1Ws$$

If the water is turned to steam for **1 minute** it will require **434 W**

$$E_{boiler} = 434.3W * \frac{1}{60}h = 7.23Wh$$

Electricity to run the oven

As indicated in the previous chapter, the oven needs to maintain 220°C for 6 minutes and 8cm of Polyurethane Foam is used for insulation. However, to calculate the energy required to generate and maintain the heat, the volume and surface area of the oven need to be known.

Firstly, the space required to roast 2000 crickets needs to be calculated. An experiment was conducted in order to estimate the surface area required. (Fig. 18 on the next page)

It showed that 30cm² is required to roast 20 crickets. Therefore, 3000cm² will be then required for the daily roast.

In order to understand what would be the best overall shape of the oven, the different volumes and surface areas were calculated trying out various oven levels. To keep them to minimum, a square footprint was chosen. Variations with different levels were calculated (see appendix) and a 4 level oven with height of 18.5cm and a square base with a side 27.4cm was chosen. This results in 13899cm³ volume and 3529cm² surface area.



Fig. 18 - Roasted crickets on graph paper

To find the energy required to heat the oven up the following equation is used:

$$Q = \rho V c_p \Delta T \quad (\text{Lienhard, 2008})$$

Where ρ is air's density 12578g/m³, V its volume 0.0139m³, c_p is specific heat of air approximated to 1 J/gK and ΔT is 190°C.

$$Q = 33212J = 33212Ws$$

If the oven is heated up for 10 minutes the energy required is **55.4W**

The rate of heat loss when heated up via conduction could be calculated having chosen the insulating material and its thickness of 0.08m.

$$\dot{Q} = kA \frac{\Delta T}{x} \quad (\text{Lienhard, 2008})$$

Where k is thermal conductivity of polyurethane foam 0.003, A is the oven surface area of 0.353m², ΔT is 190°C and x is the insulation thickness of 0.08m.

$$\dot{Q} = 25.2J / s = 25.2W$$

Heating up is for 10 minutes, while maintaining the temperature for 5 more, total oven energy per day is:

$$E_{oven} = 55.4W * \frac{1}{6}h + 25.2W * \frac{1}{12}h$$

$$E_{oven} = 9.23Wh + 2.1Wh = 11.33Wh$$

The graph shows it takes the oven 10 minutes to heat up and more than 2h to cool down.

Electricity for heating up the living areas

The volume of the living areas, containing all the 56 unit farms is **1m³**.

Surface area is **7.6m²**

As mentioned earlier, there is 0.15m insulation using polyurethane foam with thermal conductivity of 0.003

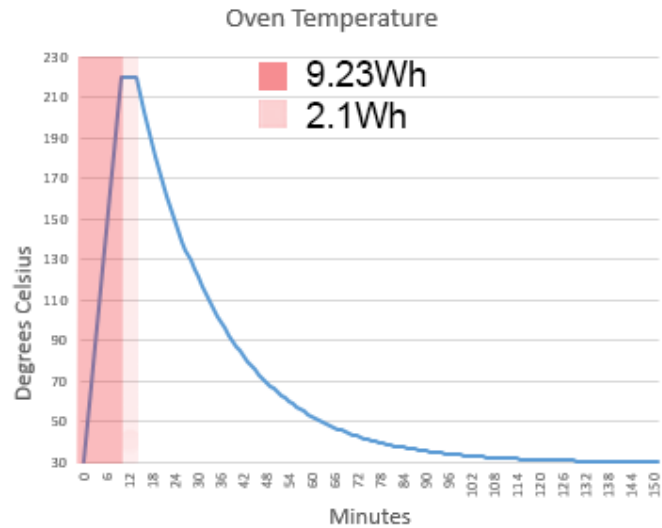


Fig. 19 - Oven temperature change

Temperature to be maintained at 30°C when outside temperature is 22°C. Knowing the volume and density of air needed heating up is simple calculating the energy required to heat it up (9800J). However, this needs to happen only once at the beginning, so to calculate the daily input of energy is much more important to know how much heat is being lost to the environment thus calculating the amount of energy needed to maintain the desired temperature.

$$\dot{Q} = kA \frac{\Delta T}{x}$$

Where k is thermal conductivity of polyurethane foam 0.003, A is the surface area of 7.6m², ΔT is 8°C and x is the insulation thickness of 0.15m.

$$\dot{Q} = 12.16J / s = 12.16W$$

Supposedly the living area heater will run all the time (24h in a day) which gives **291.84 Wh**. But it important to take into account the heat dessipated from the oven into the cricket area. Will it affect it at all? Or it would overheat and the living area would require cooling?

Oven effect on the living area temperature

It is important to be reminded that the living area should not go above 35°C or below 25°C.

Since the heat transfer greatly depends on the temperature gradient, describing the heat transfer from the oven to the living area was made using an excel spreadsheet, to plot the variables for a period of 151minutes, which is the time it takes for the oven to heat up and then cool down - return to 30°C (equilibrium) for about two hours.

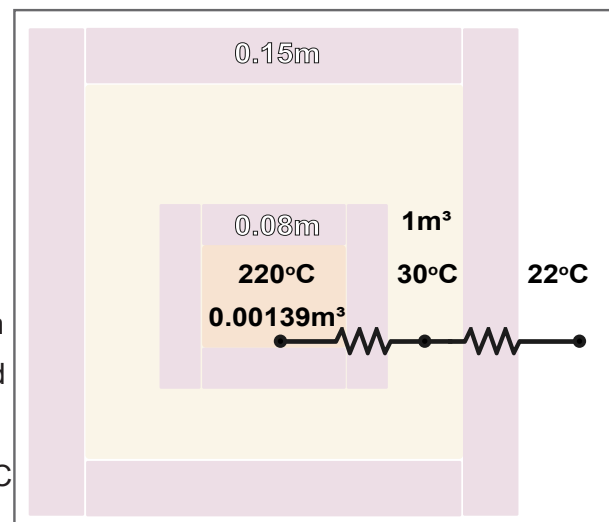


Fig. 20 - System heat resistance diagram (not to scale)

Then using the heat transfer equation from above and calculating how the heat coming from the oven minus the heat going out of the whole system affects the living area temperatures, where the farms are, if the living area heating element is switched off right when the oven is turned on.

Due to the initial dip in temperature, resulting from the heater being turned off and the rate of heat loss to the outside, which is greater than the oven contributes for that period, the farm temperature does not exceed the maximum allowed. (Appendix B, 3 - the graphs combined)

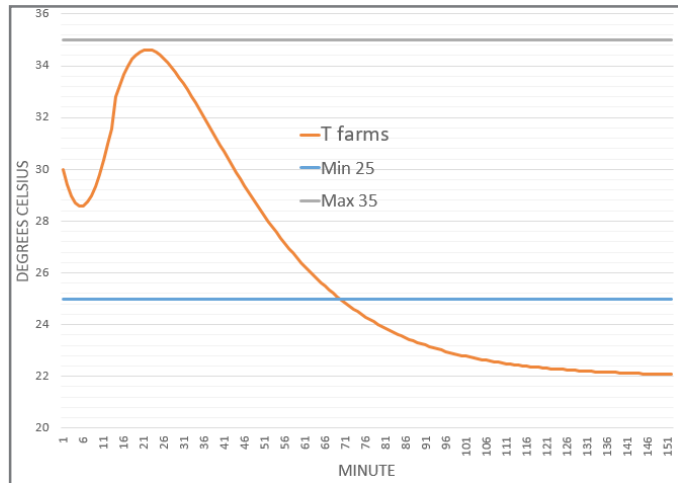


Fig. 21 - Farms area temperature change

Furthermore, it could be also seen that there is no need to switch the main hearing back on at least for an hour. Therefore the energy consumption for a day is for 23h not 24h.

$$E_{farm} = 12.16W * 23h = 279.7Wh$$

Electrical Energy into Mechanical Energy

Every cylinder rotates with 1RPH (0.0167rpm; 0.001745rad/s) for the entire cricket life cycle. It disengages from the motor during harvesting. Since it is such a low speed, and the torque required is not very large, it is sensible to have 56 separate motors controlled electronically rather than one more powerful motor and a lot of mechanics to translate the rotation across all farms.

The motor of choice is an AC synchronous electromotor due to its long life, simplicity of running and longevity.

To calculate the required Power input the efficiency η , as well as the output power required, need to be known.

$$P_{in} = \frac{P_{out}}{\eta} \quad (\text{Serway, 2003})$$

$$P_{out} = \tau\omega \quad (\text{Serway, 2003})$$

Where ω is the angular velocity of 0.001745rad/s, τ is the sum of all the torques involved in N.mm. In this case the torque to overcome moment of inertia where is the angular acceleration, which for the very small angular velocity is taken as 0.05 s.

$$\tau = I\alpha \quad (\text{Serway, 2003})$$

$$I = \frac{mr^2}{2} \quad (\text{Serway, 2003})$$

Where m is the mass rotating which is 1kg at the beginning and 2kg before harvesting, (see Appendix B, 4.). r is the mass radius, which is constant 0.1m.

There are also friction torques at the both end of the rotating mass where there are two ball bearings. They share the total load, but have different sizes. The friction torques can be found:

$$M_r = Ff \left(\frac{d}{2} \right) \quad (\text{www.roymech.co.uk})$$

Where f is friction coefficient of the bearings 0.003, d is the inner diameter 15mm for the smaller and 50mm for the bigger bearing. F is the load which is half the load of the whole cylinder:

$$F_1 = F_2 = \frac{mg}{2}$$

It could be seen that the load depends on the mass, consecutively the friction torque at the two ball bearing depends on mass, same for torque to overcome moment of inertia. Once again this was all calculated in a spreadsheet and the changing load taken was into account - see fig.22.

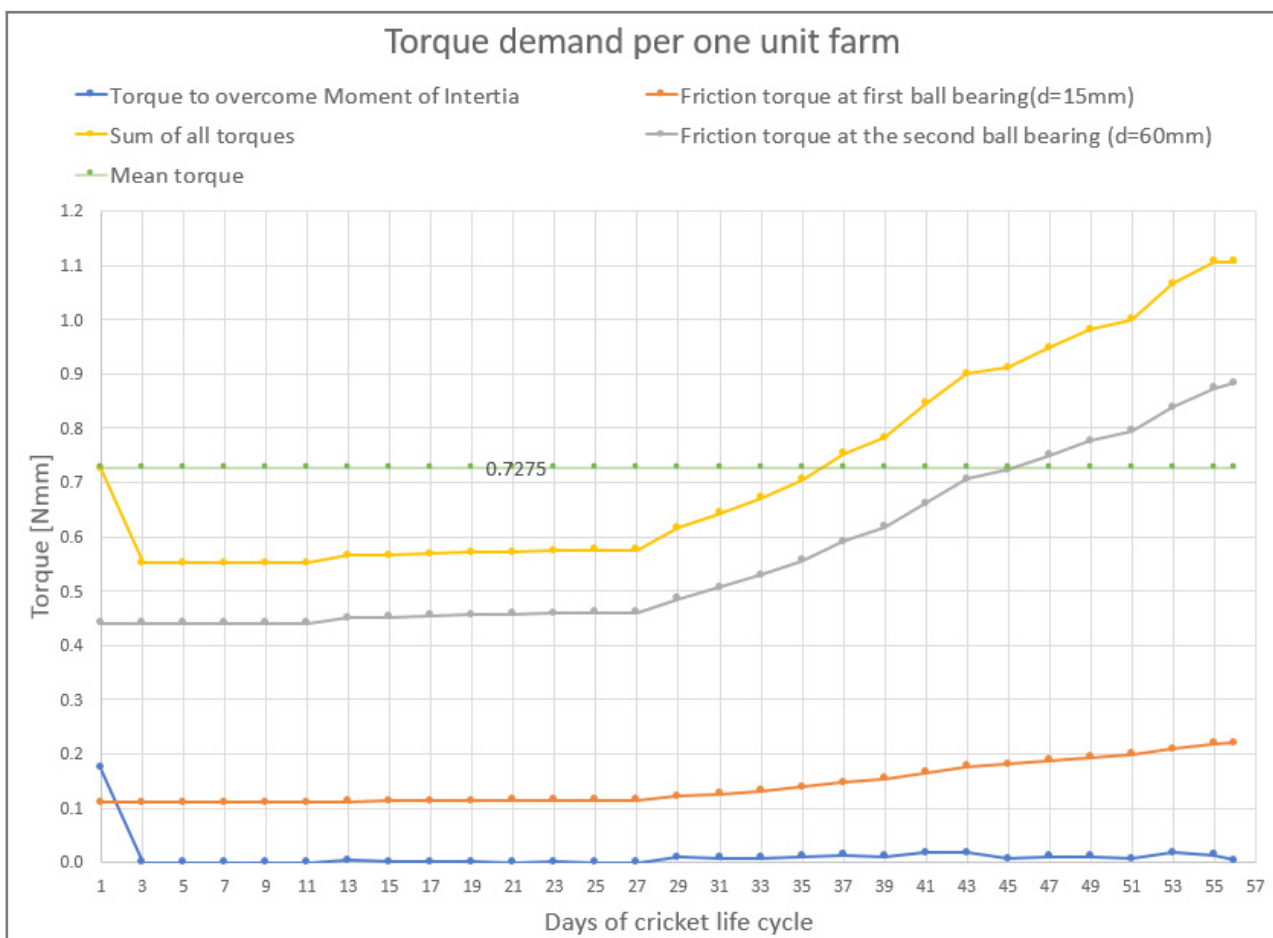


Fig. 22 - Torque demand change depending on cricket growth

There are 56 farms, each of them on a unique day, so it could be concluded that the mean torque value multiplied by 56 is the torque required per day.

$$0.7275Nmm * 56 = 40.74Nmm$$

Plugging it into the power output equation this gives: 0.001745rad/s

$$P_{out} = \tau\omega = 40.7Nmm * 0.001745rad / s$$

$$P_{out} = 0.071mW$$

Gearing efficiency

Looking at a conservative case, a 250rpm motor needs to be geared down 15 000 times to provide 1 rotation per hour. Maximum gear ratio of a worm gear is 75, which means that 3 gears will be required e.g. 25 x 25 x 24 = 15 000.

Worst case scenario - taking the minimum efficiency of a gear 0.2 to the power of three would give a motor efficiency of 0.008

$$0.0711/0.008 \text{ } 8.9mW \times 24h = 213mWh = 0.2Wh$$

$$P_{in} = \frac{P_{out}}{\eta} = \frac{0.071mW}{0.008} = 8.9mW$$

Taking that the motors rotate all the time:

$$E_{mot} = 8.9mW * 24h = 0.213Wh$$

Total Energy to run

Total electrical energy is

$$E_{el} = E_{boiler} + E_{farm} + E_{oven} + E_{mot} + E_{oth}$$

Additional energy will be required that has not been taken in into consideration in this report

- heat recovery ventilation, vending mechanisms, user interface touch screen, lights and etc.

Conservatively it is approximated to half the calculated energy giving daily electricity consumption of:

$$E_{el} = 298.47Wh + \frac{298.47Wh}{2} = 447.7Wh$$

For one year:

$$447.7Wh * 365 = 163.4kWh$$

It will be easier to add this to the feed if it is converted to pounds.

Average price for a kWh as of today is 12p (ukpower.co.uk) giving **£19.6** per year, **5p a day**.

From feed calculation it can be concluded that to harvest 1 kg of crickets a day, 0.5kg when cooked (see appendix), it requires:

$40p + 5p = 45p$ cost to run the machine per day, excluding servicing and maintenance, which technically should not happen often at all.

5. Conclusion

To conclude, it could be said that energy demand for the machine look very optimistic, in spite of always taking the conservative side with estimations.

Crickets are easy to farm and an automated system should make it even easier.

It might be optimistic, but not necessarily naive, to think that with the right marketing and engineering the world could be a better place.

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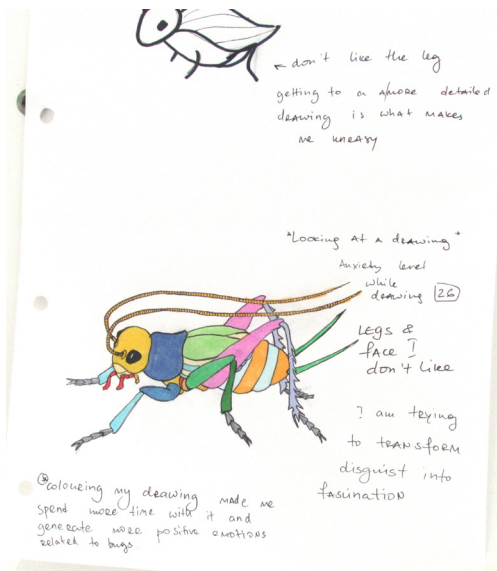
V. Appendices

Appendix A

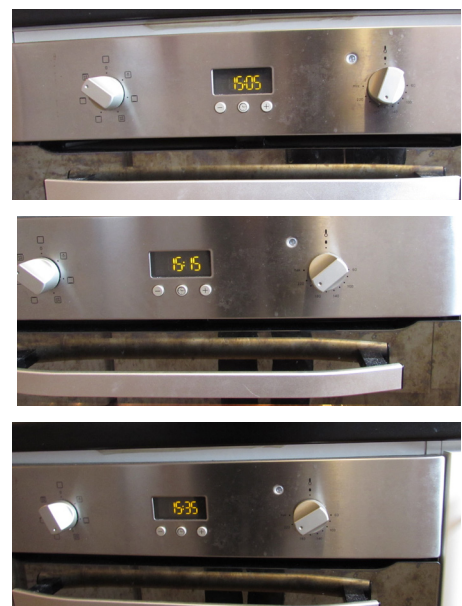
Appendix A ,1. Group testing of eating insects.



Appendix A, 2. Overcoming phobia with exposure therapy.



Appendix A, 3. Testing cooking temperatures 180°C, 200°C, 220°C

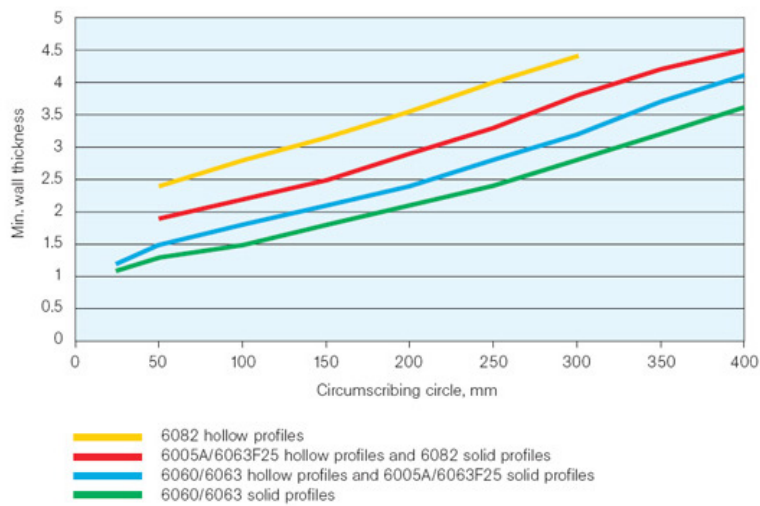


Appendix B:

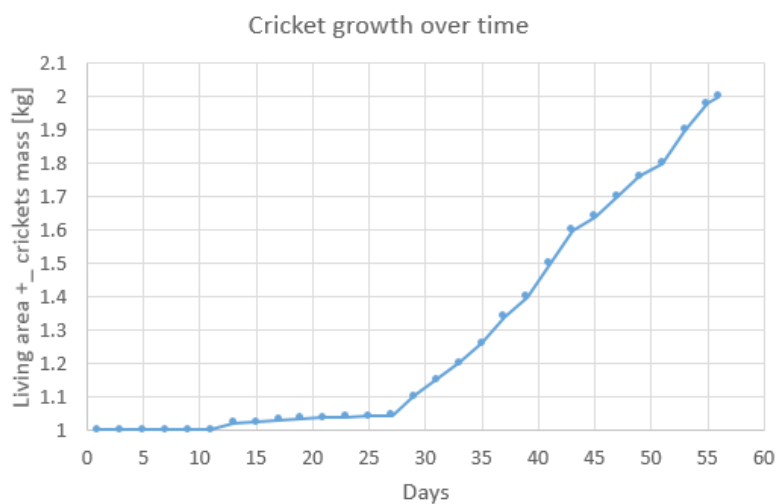
Appendix B, 1. Weight before and after roasting.



Appendix B, 2. Aluminium Extrusion Design Requirements



Appendix B, 4. Cricket Growth



Appendix B, 3. Combined graph of temperature changes

