IPD GRADUATION PROJECT

DESIGN OF AN **ODOUR BAITED MOSQUITO TRAP FOR MALARIA PREVENTION** IN AFRICA

HENRY FAIRBAIRN
4578716
TUDELFT
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Graduation Report

MSc Integrated Product Design

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Delft University of Technology

Faculty of Industrial Design Engineering

Landbergstraat 15, Delft,The Netherlands

Henry J.R. Fairbairn

4578716

Supervisory Team

Chairman:	***JC Dielh***
Mentor:	***Henk Kuipers***
Supervisor:	***Florian Muijres***
Mentor:	***Antoine Cribellier***

Figure 0.1: (Estimated) Approximately 800 Mosquitoes captured during Concept testing.

Figure 0.2: 'Bug Dorm' Cages each containing male and female Anopheles mosquitoes. Mosquitoes used for testing are starved of a blood meal to promote host seeking behaviour.

Figure 0.3: Female mosquitoes are separated for testing. They are removed from the 'Bug Dorm' by gentle sucking into the pipe. A gauze prevents targets from passing all the way through the pipe. Captives can be gently blown into the release pot for testing teh next day.

0.1
ABSTRACT

If used alongside insecticide treated bed nets, an innovative odour baited mosquito trap with a high capture performance could contribute massively to the prevention of malaria in Africa and the eradication of the disease. This report outlines the research and design processes carried out by Henry Fairbairn, with the support of a supervisory team from consisting of members from the Technical University of Delft and Wageningen University and Research.

The SolarMal Project was the first trial to investigate the impact of odour baited mosquito suction traps as a tool for vector control and malaria prevention.

Results from the clinical study show that the implementation of mosquito traps across the island of Rusinga, Kenya, lead to a 30% reduction in cases of malaria and 70% reduction in the Anopheles population (Homan et al. 2016). However, further research into mosquito escape behaviour showed the Suna-Trap, used in the SolarMal Trial, had a poor capture performance with less than 4% of approach flights resulting in capture (Cribellier et al. 2018). A study by N.Tubben found that the majority users in were unable to maintain the Solar powered mosquito trapping systems after the project. To be an effective tool for prevention of malaria, it must be possible for users in Africa to sustain the working condition of the trap to continue to reduce biting and even prevent resurgence.

Based on findings from this research and an iterative R&D process outlined in this report, it was possible to design an concept for an innovative mosquito trap with a high capture performance which is suitable for further lab testing and field testing.

A number if concepts were tested in order to highlight how variant factor effect performance compared to the Suna-Trap. Each concept tested should include as few variables compared to the benchmark Suna-Trap to clearly conclude on how the variant effects performance.

Although the testing is not thorough enough to make any scientific conclusions, there is enough data to make a conclusion as to whether incorporating the feature into a new design will increase the capture rate. High performing principals can be further tested in the future. From evaluations of the hypotheses it can be concluded that the additions of heat and moisture increase the capture rate in comparison to a standard Suna-Trap under lab conditions.

The addition of hot water and a heating element above the trap canopy showed the most notable improvement compared to the BG Suna-Trap in terms of capture performance. It is thought that the additional heat and moisture in the trap prove more attractive to the target vectors increasing the number of approach flights resulting in more flights into the capture zone.

Considering the context factors as well as performance factors highlighted in the research, the final design aims to provide a high performance mosquito trapping solution of which is suitable for use in Africa.

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PROJECT OVERVIEW

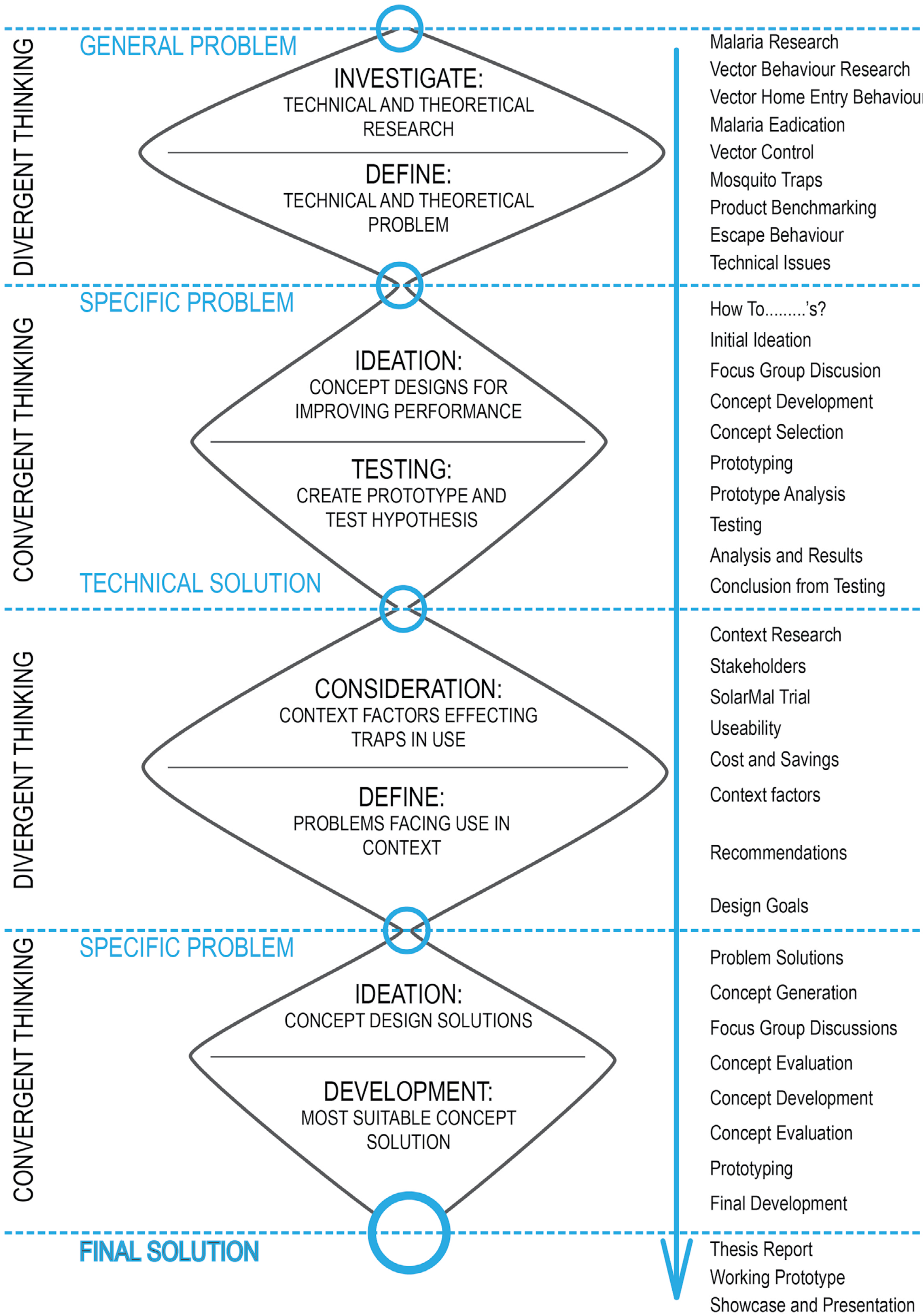


Figure 0.4: 'Illustration of project overview showing the design process and tasks performed.

0.3
TABLE OF CONTENTS

1.0

Chapter 1: The Brief

This ‘brief’ chapter outlines the initiation and overview of this Integrated Product Design graduation project.

1.1
INTRODUCTION

If used alongside insecticide treated bed nets, an innovative odour baited mosquito trap with a high capture performance could contribute massively to the prevention of malaria in Africa and the eradication of the disease. This report outlines the research and design processes carried out by Henry Fairbairn, with the support of a supervisory team from consisting of members from the Technical University of Delft and Wageningen University and Research.

The World Health Organisation (WHO) estimate that there were a total of 216 million malaria cases worldwide in 2016 resulting in 445,000 deaths (World Malaria Report. 2017). Although Malaria had been eradicated from many areas of the world, 91% of the estimated 445000 deaths caused by malaria in 2016, occurred in Africa (World Malaria Report, 2017). The direct costs from illness, treatment and premature death estimated at around $12 billion a year, not taking into account the indirect cost of loss of potential economic growth (CDC - Impact of Malaria. (2018).

Over 1 billion ITN's have been distributed in Africa and are accredited as a major factor of the 60% reduction in malaria since 2000 and the 6.2 million lives saved since 2013 (Malaria Consortium). The use of bed nets, especially Insecticide Treated Bed nets (ITN's), have been so effective in the control of malaria vectors as the majority of female biting mosquitoes are nocturnal and predominantly bite at night when hosts are asleep (Malaria Consortium. 2018).

In more recent years, mosquito resistance to the insecticides used is causing the ITN's to be less effective and up to three quarters of endemic countries have reported resistance of vectors. Resistance has been reported to detract from the effectiveness of all insecticides used in ITN's and some mosquito populations have shown resistance to multiple insecticides (World Malaria Report. 2015).

It wasn't until 2012 a trail was conducted to investigate whether the mass trapping of mosquitoes could contribute to reduction in cases of Malaria. Odour baited mosquito suction traps were implemented across the whole island of Rusinga, Kenya, to reinforce the nationwide strategy of malaria prevention through combined methods of vector control using long lasting insecticide treated bed nets (LLINs) and early treatment of malaria cases (Hiscox, 2016). The project spanned over three years and results from the clinical study show that the implementation of mosquito traps across the island lead to a 30 % reduction in cases of malaria after the three years. Fewer cases of malaria were recorded in households with a trap compared to those waiting for a trap to be installed. Trapping host seeking mosquitoes interrupts the reproductive cycle of the vector leading to a population reduction. The effects of mass trapping across Rusinga resulted in 70% reduction in the Anopheles population (Homan et al. 2016).

However, further research into mosquito escape behaviour showed the Suna-Trap, used in the SolarMal Trial, had a poor capture performance with less than 4% of approach flights resulting in capture (Cribellier et al. 2018).

Based on findings from this research and an iterative R&D process outlined in this report, it was possible to design an concept for an innovative mosquito trap with a high capture performance which is suitable for further lab testing and field testing. The resultant design solution and prototype are suitable for further testing and development before field testing.

This innovative odour baited mosquito trap design uses warm water and an electric heating element to increase the capture performance of the trap. These methods showed the most promising improvements in performance compared to the benchmark Suna-Trap in duel testing performed under lab condition at Wageningen Uiversity and Research.

The expected increase in approach flights do to the warm water is attributed to the addition of two close range cues promoting a response in vector host seeking behaviour. The heating element fitted around the rim of the inlet pipe aim to provide a localised heat source encouraging a higher number of vector approach flights into the capture zone thus increasing the capture performance.

The following pages describe and illustrate the background research, design and testing phase, context research and final design development conducted during this project.

1.2

INITIATION
THE BRIEF

This project is to be lead by a student of the Industrial Design Faculty of the Technical University of Delft in collaboration with the Experimental Zoology and Entomology departments of Wageningen University and Research acting as 'the client'. The aim is to work from knowledge gained from current research to design a mosquito trap with higher performance so as to be more effective as a tool for prevention of malaria. Not only does the prevention of the spread of the pathogens save lives, prevent illness and loss of productivity but saves economies vast amounts of capital which can be used for economic development.

The Solarmal Research project, headed by Prof Takken of Wageningen University and Research (figure 2), investigated the influence of odour baited traps on the mosquito population and spread of Malaria, in a context scenario. The experiment was conducted on the Kenyan island of Rusinga where traps, implemented alongside (the continued use of) insecticide treated bed nets (ITNs), were rolled out to homeowners across the whole island. The results of the three year experiment showed a 70% reduction in pathogen carrying species over the three years. Results also showed a 30% reduction in cases of malaria in houses equipped with a trap in comparison with those waiting.

The Suna-Trap was used in the experiment on Rusinga, as well as further testing at Wageningen University (WUR). Continued research at WUR, led by PhD researcher Antoine Cribellier, aims to better understand the flight paths of pathogen carrying mosquito species around these traps.

The 3D tracking of mosquito flight paths around the traps shows successful and unsuccessful captures. Of the recorded flight paths only 4% resulted in capture, highlighting the low capture performance of the trap. The original brief for this project had a strong technical focus towards improving the capture rate.

However, during early discussions, the need for context and user consideration to create a truly effective product was highlighted. A context appropriate design was necessary to create a product which could be used and maintained for an extended period of time in the field. This was incorporated into the brief highlighting the importance to not only investigate improving the capture rate but also the context and user related challenges posed by use in rural Africa. Improving the capture rate and performance of a trap in context could provide a product solution which is more effective at preventing malaria transmission and might contribute massively to the eradication of malaria, and other pathogens, in Africa.

Working from the results of performance research carried out at WUR and investigations into the use of the Suna-Trap in context - It should be possible to design a more effective mosquito trap with a higher capture rate which is suitable for future field testing in Africa.

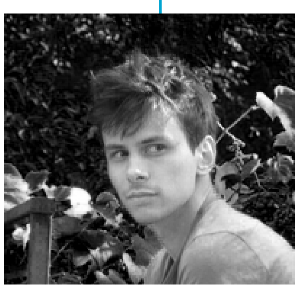
Figure 2: Professor Willem Takken pictured with a Suna-Trap installed on Rusinga Island.

1.3

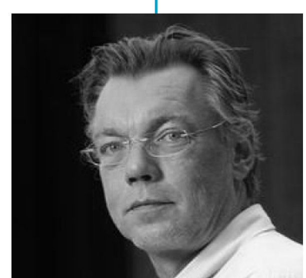
YOU AND WHO'S ARMY?

THE TEAM

HENRY FAIRBAIRN
PRODUCT DESIGN LEAD
MSc INTEGRATED PRODUCT DESIGN STUDENT
TU/DELFT



ANTOINE CRIBELLIER
PROJECT MENTOR
PhD CANDIDATE
EXPERIMENTAL ZOOLOGY
WUR



HENK KUIPERS
PROJECT MENTOR
ASSISTANT PROFESSOR
INDUSTRIAL DESIGN
TU/DELFT

FLORIAN MUIJRES
PROJECT SUPERVISOR
PhD CANDIDATE
EXPERIMENTAL ZOOLOGY
WUR

JC DIEHL
PROJECT CHAIRMAN
ASSISTANT PROFESSOR
DESIGN ENGINEERING
TU/DELFT

WAGENINGEN
UNIVERSITY & RESEARCH

TUDelft

1.4

A CUNNING PLAN
DESIGN APPROACH

This project poses two main challenges which are considered in the approach, the first being to improve the performance of the trap in terms of capture efficiency and the second is to design for the user and context in which the trap should be used. The approach taken to this project is one of two stages to account for the two challenges.

Through technical, theoretical and design research, the first stage aims to find a way to improve the capture rate. Having proved a principal for increasing the capture rate, the challenge faced in the second phase of the project is to incorporate this product principal into a concept aimed to be suitable for use in context where even the most simple prevention methods have struggled to make a lasting effect on the pressure from malaria.

The design approach taken to this project is an iterative one consisting of two main activities, research & design and concept development. The research & design process aims to investigate the theoretical, technical and context factors and understanding how they influence the design process.

The concept development process applies the insights gained from the R&D into product concepts and prototypes which can be tested and developed into a final concept solution.

Although the overall goal of the end solution is to eventually aid the control and ultimate eradication of Malaria, it is very unlikely to be achieved within the scope of this 20 week project. It is also not within the scope of the project to conduct any field research in Africa so it is imperative to make the best use of the resources available. Resources such as reports from field studies and conducting interviews with experts in the field as well as people from African communities where possible can highlight potential context and user related factors.

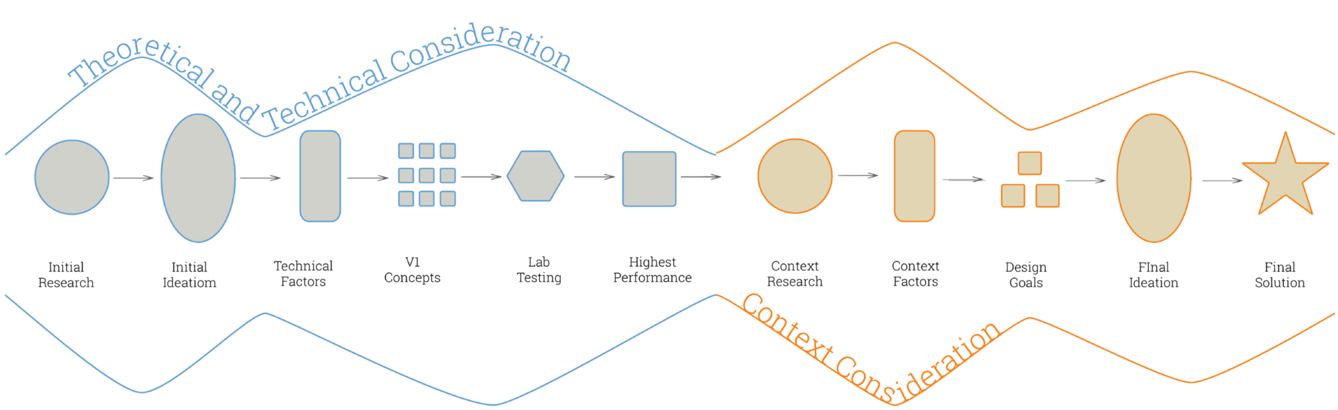


Figure 3: Illustration of design approach showing divergent and convergent phases as well as technical and contextual focus throughout the project. The two design iterations, separated by testing and context research can be seen within the approach.

1.5

TO DO LIST
OBJECTIVES

- Investigate mosquito host seeking behaviour and vector interaction around existing products in order to increase the capture performance of a mosquito trap.
- Conduct concept testing to answer design questions and gain proof of principal for any improvements to performance.
- Investigate and analyse the context factors which influence the use of traps in Africa in order to create an appropriate trap for sustained use.
- Considering all the insights gained, produce a final concept solution for an innovative trap suitable for field testing.
- Create working prototypes and test under lab conditions to confirm the performance and usability of the design.

1.6

THROUGH THE TELESCOPE
DESIGN GOAL

To develop an innovative concept for a mosquito trap which could eventually be used for vector control and malaria prevention. Based on the research and design in the initial phase, the concept aims for an increased capture rate in comparison to other products whilst remaining suitable for further research and testing. The final concept solution should be suitable for use in context providing a robust solution which is simple to use and possible to maintain in order to be most effective in preventing transmission on malaria. The final design and prototype should be suitable to initiate small batch production of products for further testing and development.

To develop an innovative concept for a mosquito trap with an improved capture rate which could eventually be used for vector control and malaria prevention in Africa.

The solution should be suitable for further testing and development towards a commercial product.

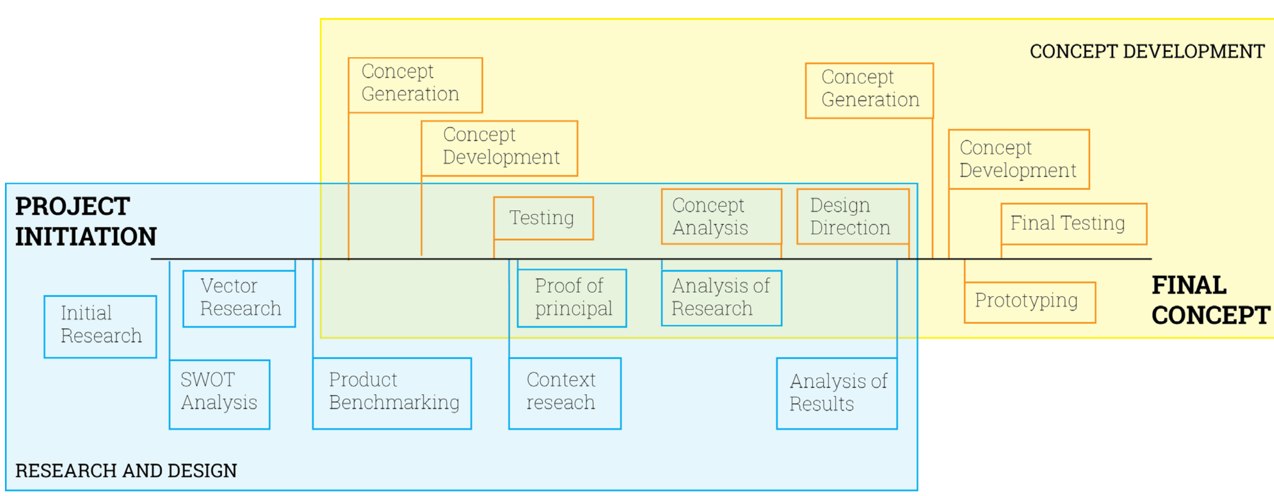


Figure 3: Illustration of objectives leading towards the goal, a final concept design.

2.0

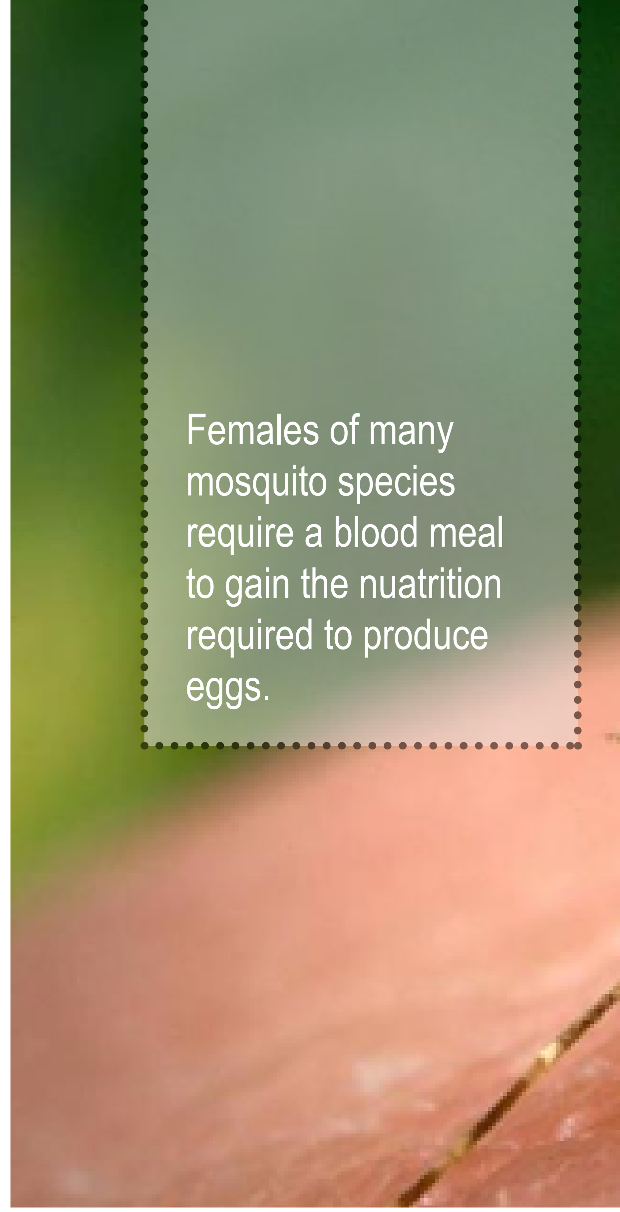
Chapter 2: The Little Biters

This chapter investigates the fundamental, experimental and field research into vector behaviour and control. It is important to understand the factors affecting the behaviour of mosquitoes, the primary vectors of Malaria, in order to better catch them!

Figure 4: 50 Female Anopheles Mosquitoes in a release pot prepared for research test.

2.1

THE LITTLE BITERS MOSQUITOES



The parasite which causes malaria is transmitted by mosquitoes, the most dangerous vectors of disease. Around 3500 species of mosquitoes have been found around the world, some of which are haemophagic - the females of the species and require a protein rich blood meal in in order to create eggs (Knols, 1996). Both male and female mosquitoes feed on plant sugars but females need a blood meal for the nourishment required for egg production (Foster and Walker 2009) and to do so, they must find a host.

Anthropophagic mosquitoes, those which bite humans, include those of the genus Culex, Aedes and Anopheles. These species are able to transfer pathogens between humans and are referred to as vectors of disease (WHO, 2018). When a female Anopheles mosquito takes a blood meal, it is able to contract the malaria parasite from an infected human. It is then able to pass the parasite on through its saliva when biting another human. Malaria remains one of the most important vector borne diseases in the world partly due to its high transmission rate.

The two characteristic which define a successful host species for successful transmission of malaria parasites are; a large population and a species which is highly likely to bite another person and ability to survive through the parasite development stage (Burkott. 1988). Of the 422 recognised Anopheles mosquito species only 70 are known vectors of the malaria parasite and of these only 40 are important, the most important being the Anopheles Gambiae.

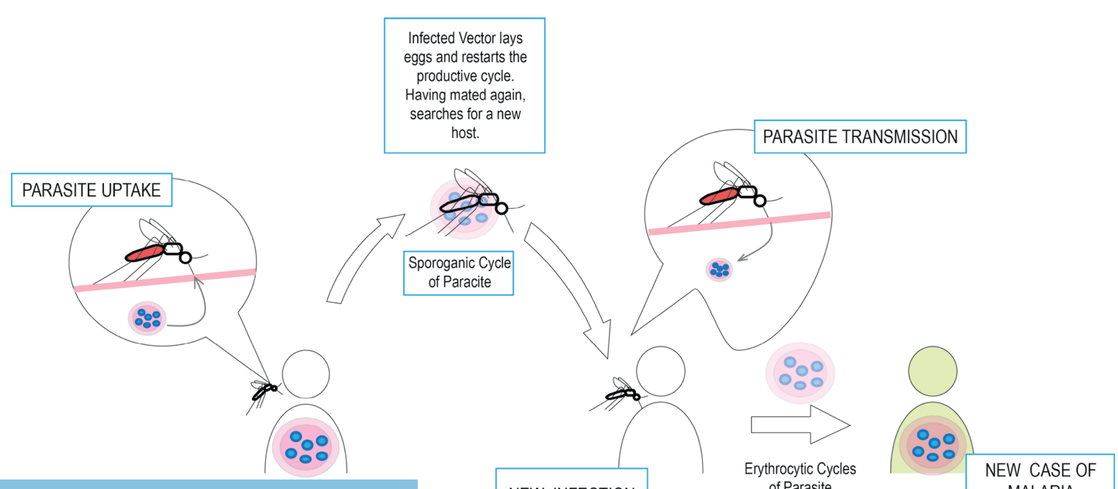


Figure X: 50 Female Anopheles Mosquitoes in a release pot prepared for research test.

Figure 5: Female Anopheles Mosquito taking a human blood meal.

2.2

THE MAIN OFFENDER ANOPHELES *GAMBIAE*

Anopheles Gambiae (An. Gambiae) often occur in high number and densities (Gilles & Coetzee 1987), they also have a high survival rate and a strong preference to human blood (White. 1974) making them a perfect host for the malaria parasite. They are the most prevalent species across Sub-Saharan Africa, which explains the high rate of parasite transmission in the region. An. Gambiae sensu stricto is one of the most anthropophagic mosquitoes in the world and has a strong preference to feeding on humans than other animals. It is said that an An. Gambiae s.s was found to pass through a herd of cattle in Nigeria to seek the human host (Gillies, 1988).

An. Gambiae are nocturnal and for the most part, endophagic insects – they are actively host seeking at night and tend to bite people when they are indoors and asleep. If successfully taking a blood meal, activity is suppressed by 2-3 days during oviposition with vectors often staying in the house for some time (Takken, Knols. 1999). Up to 12 ovipositions have been recorded for An. Gambiae s.s. In Tanzania (Gillies, 1988) illustrating how a mosquito is able to transmit malarial parasites to a number of people by repeated feeding throughout its lifetime.

2.3

THE HUNT
HOST SEEKING BEHAVIOUR

In order to take a blood meal, it is first necessary for female An. Gambiae to local a suitable hos. As they hunt in the dark, the olfactory system is this mosquito's key to host seeking. Different cues emitted by humans trigger different behaviours which allow the mosquito to orientate towards and land on a host (Takken, Knols. 1999). In the absence of a host cue, mosquitoes will fly upwind in a fairly straight line until they locate a plume of which they can follow (Takken et al. 1997). Finding a plume, the mosquitoes performing casting behaviour - convoluted flight paths passing across the plume in order to orientate towards the source (Spitzen, Takken. 2008).

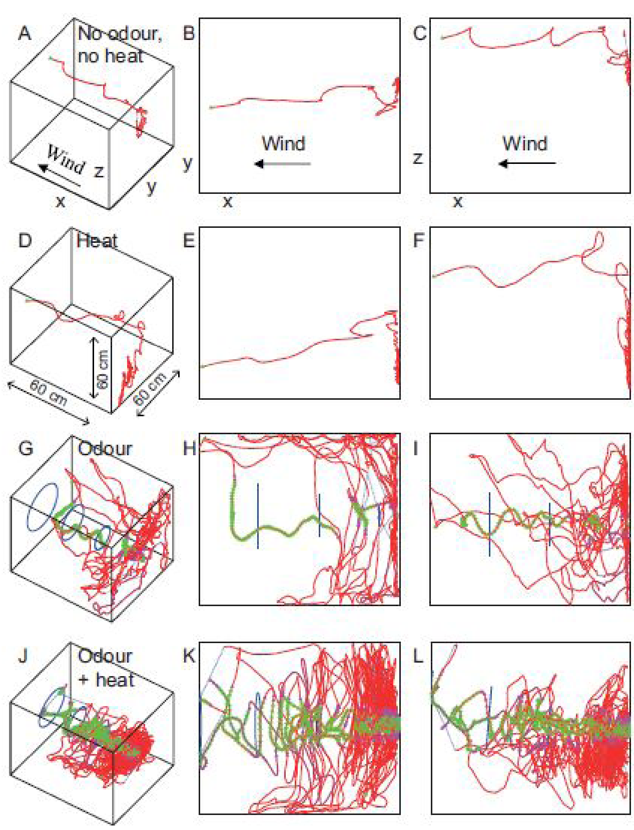


Figure 6: Visualisation of flight paths recorded during behaviour experiments carried out by J. Spitzen. The visualisation shows the convoluted flight paths performed by host seeking mosquitoes in response to different cues.

The major host cues in which mosquitoes respond too are;

- CO_2 - Given off by humans due to respiration. Elevated levels of CO_2 can be recognised by mosquitoes and, in the absence of other odours, acts as an activator (Takken, Knolls. 1991) Field experiments have shown that the presence of human odour and CO_2 increase the attractiveness of traps (Spitzen. 2018)

- Body Odour - Bacteria break down the acids in human sweat giving off volatile organic compounds (VOCs) (Shirasu. 2001). Anthopophilic mosquitoes respond to human body odour executing convoluted casting flight paths in and out of the plume whilst moving towards the source. Passing in and out of the plume allows to the vector to locate the direction of the source and orientate towards the target.

- Heat - vectors have heat sensitive receptors on their antennae provoking a response in behaviour when within a short distance (15-30cm) of the host, before the heat emitted fades into the background (Spitzen. 2018). Research has shown that, in teh presence of heat and odour, An. Gambiae decrease flight speed and, as shown in figure X J-L, perform more frequent crosswind flights. This suggests that the vector is assessing the target in order to find a suitable place to land and feed.

- Moisture - human body heat evaporates the sweat produced in order to cool down increasing the humidity around the body. Although there is little specific research, it is thought that vaporised moisture from sweat is a contributing cue to host seeking behaviour.

- Visual - An. Gambiae mostly hunt at night suggesting visual cues play less part in host seeking and come into effect when choosing a landing place. Test subjects have shown to land on dark areas (Carde. 2015).

Figure X: 50 Female Anopheles Mosquitoes in a release pot prepared for research test.

Host seeking process can be split into three categories based on the olfactory cues needed at each stage; long, mid and short range host seeking. The exact range at which a mosquito is able to pick-up on these cues is undefined as it depends on many environmental factors including wind speed and direction and geography of the land. Reports suggest a mosquito is able to identify minute increase in background CO_2 levels from over 200m (Takken et al. 1997).

Long Range 10m - 200m: Mosquitoes pick up on minute increases in background CO_2 levels. The insect then follows the plume upwind in a relatively straight line, performing casting behaviour if the plume is lost.

Mid-Range 1m-10m: Other human body odours are recognised and more convoluted flight paths are witness as further casting behaviour is exhibited to orientate towards the host.

Close Range 0m-1m: The olfactory system responds to different concentrations of all host cues. Combinations of human odour, heat and moisture start to play a part in finding a suitable place for landing. CO_2 has shown to play a part in close range orientation deterring mosquitoes from areas where concentrations are too high such as exhalation from the mouth. Hence why mosquitoes tend not to just fly into the mouth!

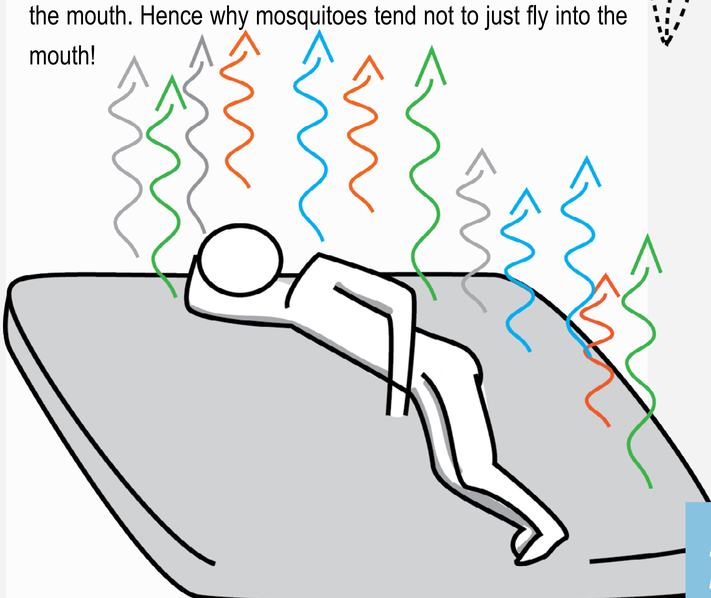


Figure 7: Illustration of mosquito host seeking behaviour in response to host cues in context.

2.4

THE SMELLY STUFF

ODOUR CUES

There are two common ways to use odours to control mosquitoes; repellents are used to reduce the attraction to humans whereas attractants are used to draw mosquitoes into traps.

Host odour cues sought by An. gambiae can be classified into two groups; carbon dioxide and body odours. The receptor systems used by mosquitoes to detect these odours when host seeking are located in the antenna and maxillary palps respectively.

Carbon dioxide is the most abundant compound in human breathe and research has shown that Anopheles mosquitoes can respond to pulses of co2 at increased levels above background levels (0.034 % or 330ppm)

Carbon dioxide and Octenol, the latter of which is an alcohol chemical which attracts mosquitoes, are the most used attractants. More recently, synthetic odours have shown to be as attractive as natural human odours when impregnated on clothing (A.Hiscox in an interview).

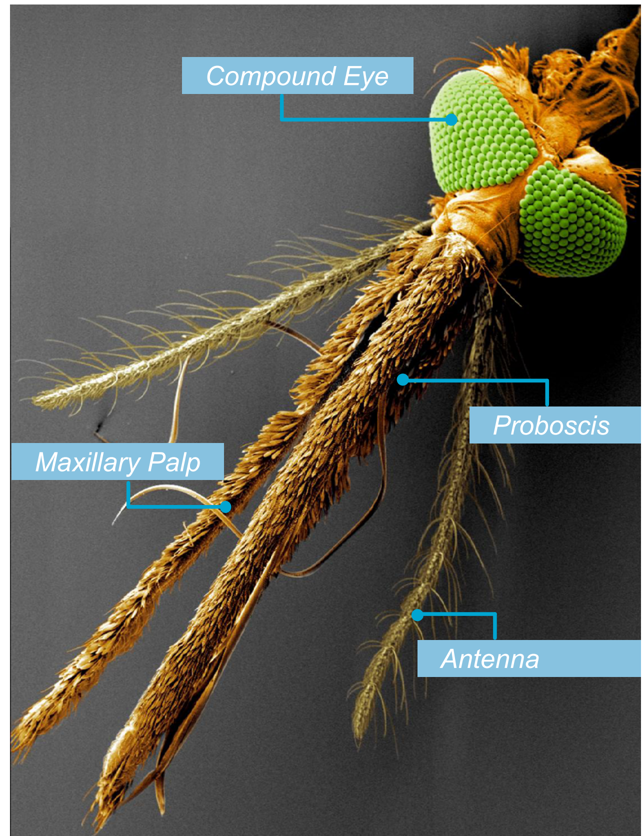


Figure 8: Magnified image of a female Anopheles mosquito's olfactory system.

MB Odour Blend

Mbita (MB) is a synthetic odour blend consisting of of 3-methyl-1-butanol, tetradecanoic acid, ammonia solution, (S)-lactic acid, and carbon dioxide. (Mukabana et al., 2012). Field testing in Tanzania, carried out by Wolfgang Mukabana tested the MB blend against a standard blend, natural human odour as well as blends IC1 and IC2.

Over 30 nights of trapping in the field, the MB blend was more attractive to to female An. Gambiae than the other odours and lure treated with natural human odour. It was also found that most of the vectors caught had not blood fed suggests that the synthetic odours mainly attract host seeking mosquitoes.(Mukabana et al., 2012)

2.5

THE INVASION

VECTOR HOME ENTRY

In many cases, the human target is sleeping during the night when An. Gambiae active so the mosquitoes must enter the home in order to reach their host target. Home entry is predominantly through the eaves of the home, the gap between the top of the exterior wall and the roof.

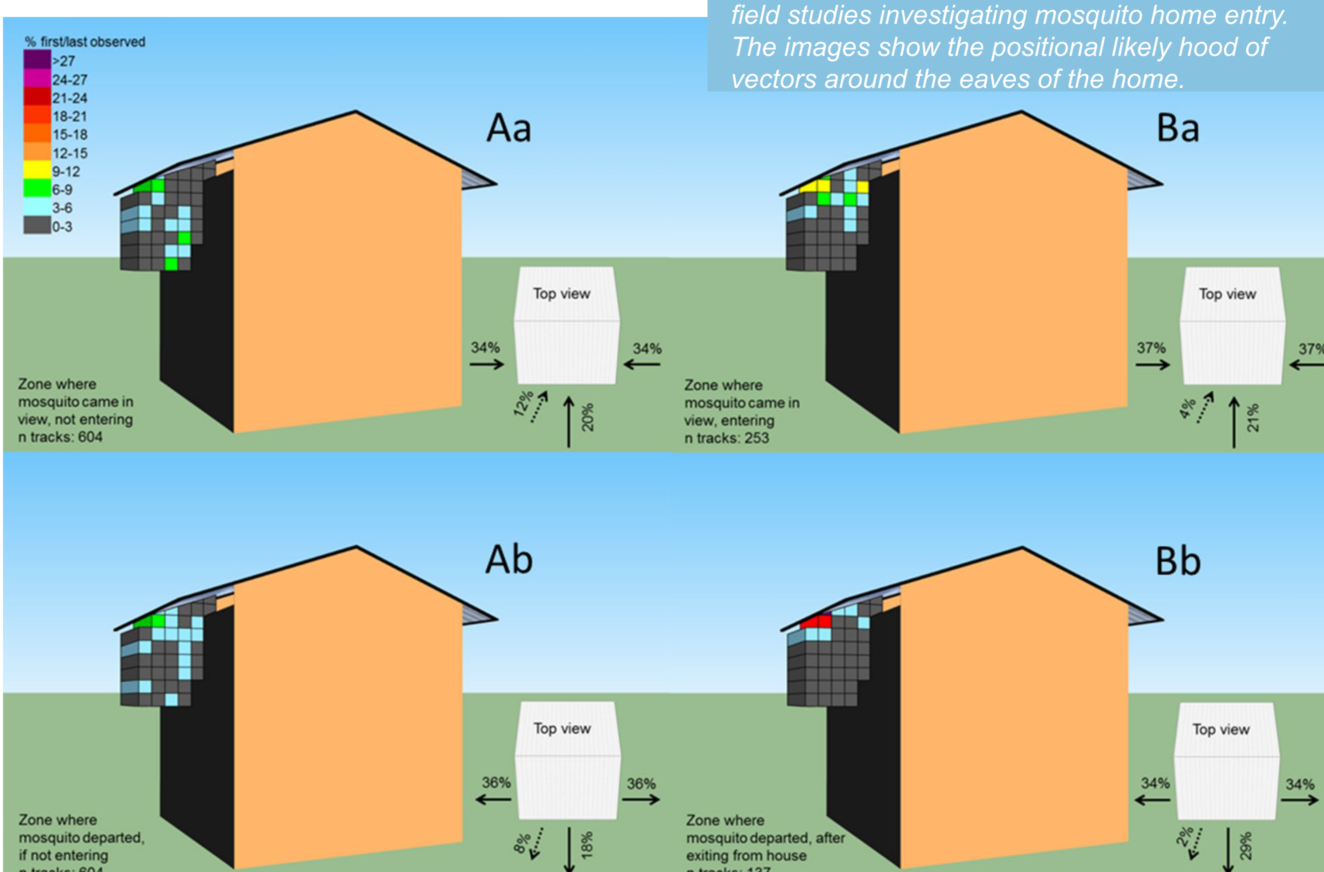
Semi field experiments conducted in Kenya recording the flight paths of mosquitoes around the eaves of a mock house. 3D analysis of the flight paths highlights characteristics of vector home entry behaviour. Odour plumes leave the home through the eaves attracting mosquito approaches.

The eaves of the home act as a bottle neck where mosquitoes attempted to enter the house. Convoluted flight paths and reduced speed, combined with mosquitoes leaving and re-entering the house results in a build up of a concentration of host-seeking vectors.

Heat maps are used to visualise the distribution of mosquitoes recorded showing the frequency distribution of where the target was at the start and end of recorded flight path. Results showed mosquitoes approaching at an altitude of approximately eave level. Mosquitoes which were recorded to pass into the house spent more than 80% of their time within 30sm of the eave. Results show reduced flight speeds on approach and more convoluted flight paths.

- 55% of the mosquitoes recorded either failed to enter the house or made a number of attempts before passing through the eave.
- 23% passed through the eave with an uninterrupted approach.
- Of the vectors which entered the house, almost 10% re-entered compared to the 12.6% which departed.

Figure 9: Visualisations of data collected from semi field studies investigating mosquito home entry. The images show the positional likely hood of vectors around the eaves of the home.



2.6

THE RETALIATION VECTOR CONTROL

At the end of the nineteenth century, it was discovered that the Malaria parasite was transmitted by mosquitoes. From this point, attempts could be made to control the vectors and eliminate the disease. The discovery of the use of DDT, in 1939, as an insecticide was crucial to controlling malaria during the second world war. With the use of chemical insecticides, the US launched the National Malaria Eradication programme and malaria was eliminated. Proceeding this, the WHO initiated the Global Malaria Eradication Program.

Although Malaria had been eradicated from many areas of the world through vector control, the technical challenges facing the Global Malaria Eradication Programme, especially in Africa, were unsurpassable. Much of the continent wasn't included within the plan due to logistical difficulties. Sub-Saharan Africa posed elevated logistical and distribution challenges and the WHO ultimately abandoned its aspirations for the programme in 1969. Until 1991, the organisation continued to focus on resolving these issues with research and development of new tools, advances in drug and vaccine development as well as vector control (WHO, 2018).

The estimated number of cases has decreased globally through vector and transmission control alongside improved healthcare systems and treatments. The WHO Global Malaria Report, 2014, stated a 47% reduction in malaria between 2000 and 2013 largely due to insecticide treated bed nets.

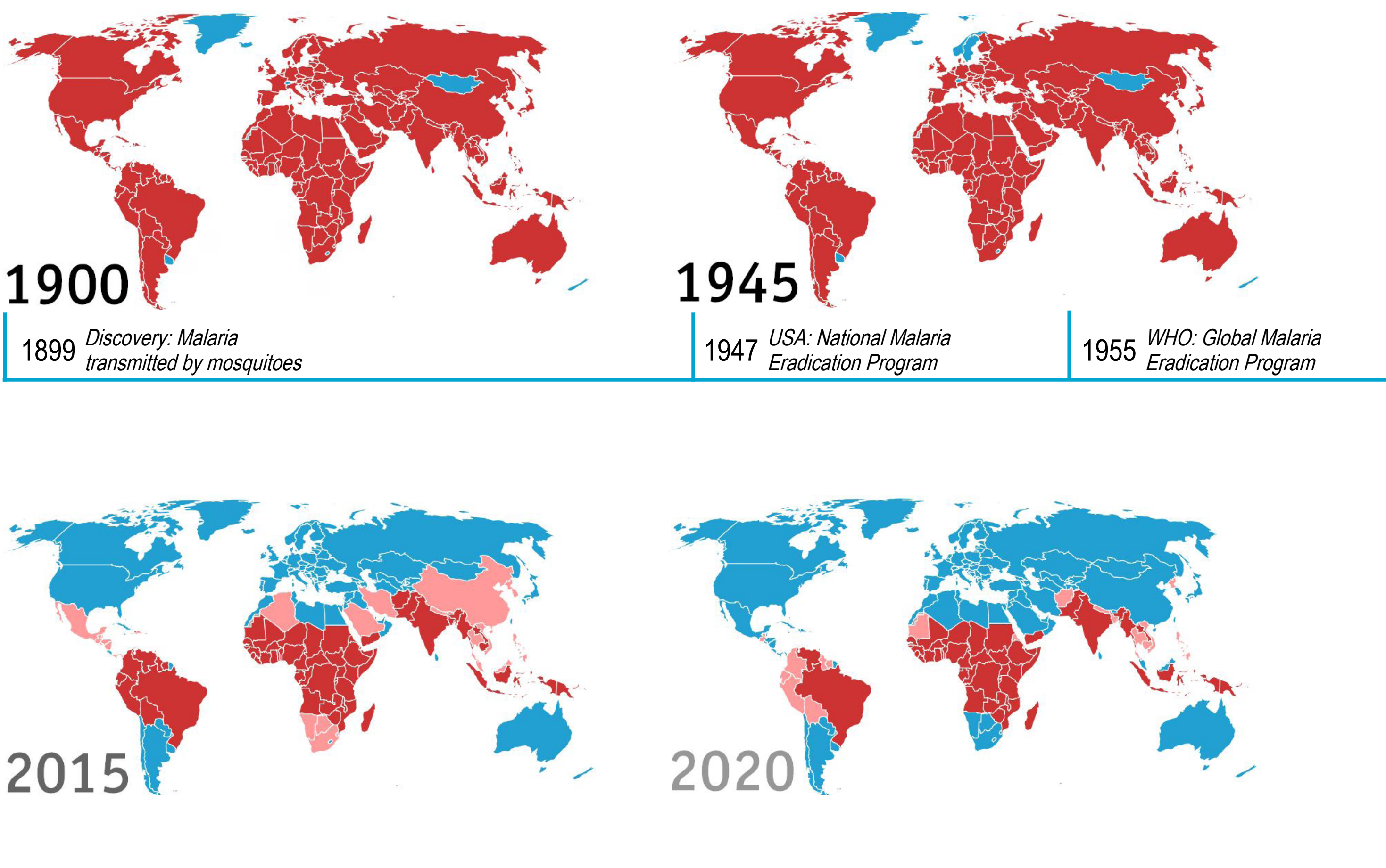


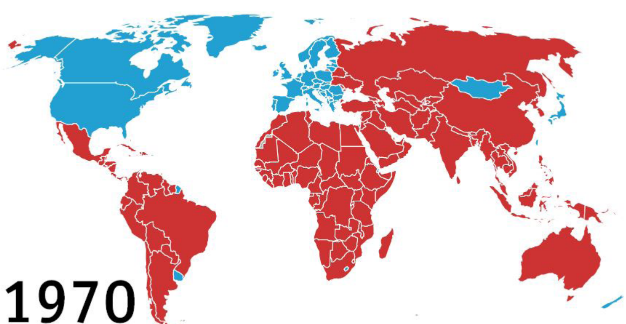
Figure 10: Data maps visualising the spread of malaria at different points in time. Annotations highlight notable developments in global vector and malaria control.

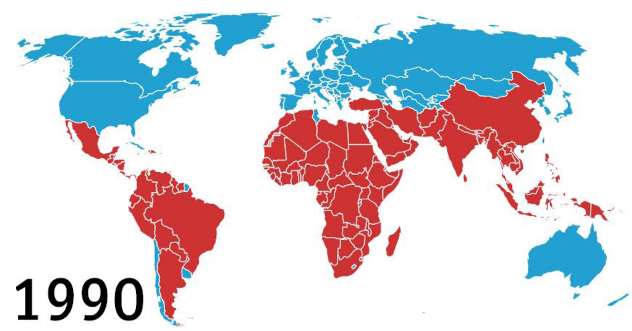
Malaria Prevalent

However, the lowest contributing region to the 18% loss is sub-Saharan Africa where some areas are experiencing an increase in prevalence in recent years (World Malaria Report, 2017). The malaria endemic is so prominent in Africa for a number of reasons;

1. The Plasmodium falciparum is the most dangerous of four malarial parasites and is most common in Africa;
2. social-economic boundaries hinder treatment and prevention as basic healthcare infrastructure is underdeveloped in many rural areas and the cost of getting treatment is high compared to earnings;
3. an abundance of Anopheles mosquitoes which, in many countries, are able to transmit the parasite all year round (CDC - Impact of Malaria. (2018).

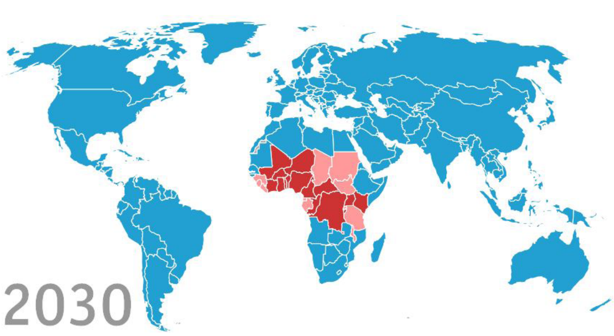
In 1898 British officer Ronald Ross, of the Indian Medical Service, demonstrated that bird malaria was transmitted by mosquitoes. By 1899 Italian scientists led by Giovanni Batista Grassi showed how human malarial parasites were spread by Anopheles mosquitoes in an experiment where mosquitoes fed on malaria patients in Rome were sent to London and infected two volunteers (CDC, 2018). From this point mosquitoes could be targeted to eliminate the spread of malaria.





1969 *WHO: Global Malaria Eradication Program ABANDONED*

Continued Research by WHO into medicines and vector control. 1991



Malaria Elimination

Malaria Eradicated

Species Sanitation

The bionomics of mosquito species are extremely important for vector control, an understanding of habitat, life cycle and breeding behaviour is necessary to control a specific vector (Takken 1991). For example, it is known that during their lifecycle mosquitoes require a water surface to lay their eggs upon, even when other environmental circumstances are favourable, and areas without available stagnant water are usually free of malaria (WHO 1989). From this principal a number of vector control methods are proposed:

1. The application of larvicides to destroy mosquito larvae in stagnant pools
2. Introduction of Biological agents in breeding sites
3. Local Environmental Management

Although this method of vector control has been successful in the past it requires intensive effort to continually monitor the environments, highlighting and dealing with breeding sights. This is simply not possible on large scales especially in areas such as Sub-Saharan Africa with a high number of widespread rural inhabitants, especially during the wet season where even small puddles offer breeding grounds for mosquitoes (Takken, 1991). Species sanitation and mosquito ecology decreased in popularity after the second world war when the insecticidal use of DDT was discovered.

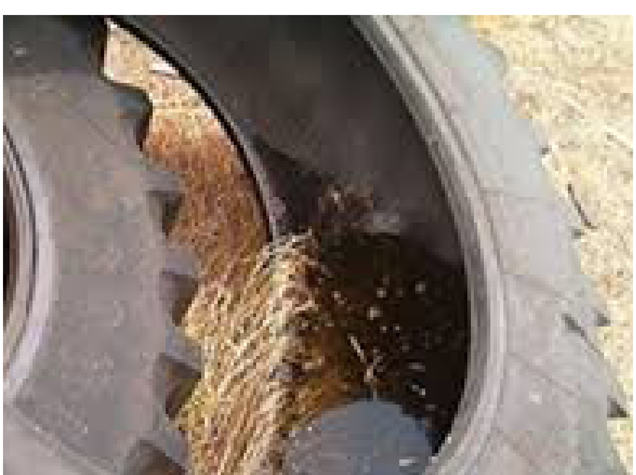


Figure 11: Small pool of stagnent water collected in a car tyre in Africa provides a breeding ground for mosquitoes.

Insecticides

> Regular exposure to DDT resulted in widespread resistance among mosquito populations. Therefore, eradication via DDT needs to occur within 3 years with no resurgence to be successful.

The WHO's 'Global Eradication of Malaria Program' which relied heavily on the use of DDT had much success, eradicating or dramatically reducing malaria in 37 countries. However, it was found that DDT was toxic to living organisms and the environment and was soon banned by Sweden in 1970 and the USA in 1972 (EXTOXNET 2018). Nevertheless, DDT is still used routinely in 19 countries, most of which are in Africa (Platt McGinn. 2002), In these countries where malaria is still endemic, DDT is used for indoor residual spraying of homes to prevent mosquito home entry and reduce populations (Sadasivaiah S et al. 2007).

Mosquito's resilience to DDT became apparent as early as 1946 and campaign managers of the Global Eradication programme where aware that regular exposure to DDT over 4-7 years tended to results in widespread resistance. Today, as well as many other insecticides, DDT resistance is widespread among the Anopheles species (Platt McGinn. 2002).

Figure 12: DDT drove the global malaria eradication program and was the most effective method of vector control until use was banned

Indoor Residual Spraying

As the name suggests, Indoor Residual Spraying (IRS) is a method where a coating of insecticide is sprayed onto the walls and other surfaces inside the home.

For several months after spraying, mosquitoes will be killed if they come into contact with the chemical insecticide when landing on a wall or surface (CDC 2018). However, it has been mentioned that endophagic mosquitoes tend to land and remain in the home after feeding. Thus, IRS generally kills mosquitoes after they have bitten a host (Takken, Knols. 1999). Although this prevents further the transmission of parasites from human to another, at least 80% of households within an area should be sprayed in order to be effective (CDC 2018).

Since massive reductions in the use of DDT a number of other, generally more expensive chemical pesticides have been developed, such as Pyrethroid.

However, IRS has not been as effective in many areas as poorer nations are unable to afford the continuous use of chemicals, logistics of spraying and follow up spraying in rural areas as well as the continued increase in vector resistance to the pesticides available.

Bed Nets

The use of bed nets, especially Insecticide Treated Bed nets (ITNs), have been so effective in the control of malaria vectors as the majority of female biting mosquitoes are nocturnal and predominantly bite at night when hosts are asleep (Malaria Consortium. 2018). After the Millennium Development Goals were outlined, injections of funding increased the coverage of insecticide treated bed nets (ITNs) in Africa from around 2% in the year 2000 to 55% in 2015.

Over 1 billion ITNs have been distributed in Africa and are accredited as a major factor of the 60% reduction in malaria since 2000 and the 6.2 million lives saved since 2013 (Malaria Consortium). Community-wide trials in several African settings have shown the use of ITN’s reduces illness, disease and death from malaria in endemic regions. Death due to malaria in children under 5 decreased by up to 20% in trials with ITN’s (WHO. 2018).

Investment in LLINs rose from 2004 to 2010 with mass distribution campaigns approximately every three years to maintain coverage. This comes at great cost and investment and funding are estimated to plateau or decline in coming years. It is thought that extending the life further, to five years, could save $3.8 billion over 10 years (CDC, 2018).

Figure 13: Indoor residual spraying of insecticides has been successful but maintaining coverage and vector resillience are a challenge.

Figure 14: Bed nets, especially long lasting insectiside treated nets are the most effective method of vector control in Africa,

Pyrethroid insecticides are the only chemicals approved for use on ITN's as they pose very low risk to humans and other animals. However, nets need to be retreated every 6 to 12 months to continue effectively killing mosquitoes and other biting insects.

Unfortunately the additional cost and the lack of understanding resulted in very low re-treatment rates across Africa (WHO. 2018). Developments have lead to the production of long-lasting insecticide treated bed nets (LLINs) with a lifespan of up to 3 years, more than three times that of standard ITNs.

In more recent years, mosquito resistance to the insecticides used is causing the ITN's to be less effective and up to three quarters of endemic countries have reported resistance of vectors. Resistance has been reported to detract from the effectiveness of all insecticides used in ITNs (World Malaria Report. 2015). While nets without treatment still provide a physical barrier between night biting mosquitoes and people, the mosquitoes remain alive and able to search for a new host.

Other issues include disuse and misuse. In many cases it has been found that although in possession of a bed net, individuals don't use them. Murindahi explains in an interview that bed bug infestations deter people from using bed nets as the bugs can be seen on the inside of the net, they then drop down on the sleeping host to feed.

Although bed nets have contributed to the reduction of malaria across Africa, the cost of maintaining coverage relies on funding and investment.

Already, mosquitoes have show resistance to all the chemicals approved for use in ITNs.

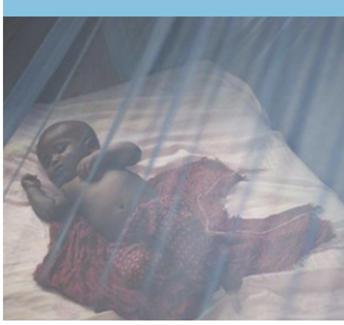
Misuse or disuse of nets hinders the effectiveness of the intervention.

Figure 15: Intfant sleeping under a bed net. Bed nets prioritised for young children as they are most vulnerable to malaria.

Species Sanitation	Pros	Cons
	• Biological control is environmentally beneficial • Measures can be taken around the home. • Specific populations can be targeted • Control of lavae is an effective way of controlling vector populations	• Difficult to implement over large areas and diverse environments. • Environmental control must be maintained to avoid resurgence. • Breeding sites are numberous as even a puddle in a tyre track can make a suitable breeidng site.

Insecticides	Pros	Cons
	• Insectised have been the most sucessful methods of vector control globally. • Can be applied over large areas . Applied in a mannor similar to crop spraying. • Numberous methods of use such as IRS and ITNs • New chemicals continuously being developed	• Mosquitoes become immune to the chemicals used. • Continuous application of insectised is both costly and detrimental to the environment. • Traces of DDT have been discovered in pregnant women.

IRS	Pros	Cons
	• Kills mosquitoes which land in the house. • Thought to reduce home entry. • Spraying allows for easy coverage of all areas of the home.	• Doesn't eliminate mosquitoes which do not land on treated walls. • Upkeep can be unaffordable as homes must be re-treated every 6 months. • Alone, it doesn't prevent a homeowner from being bitten by an infected mosquito.

ITNs	Pros	Cons
	• The most effective method of vector control since DDT was banned. • Can be prioritised for use by children under 5. • Provides a mechanical barrier between vectors and people when they are asleep. • ITNs and LLINs have been rolled out in huge numbers and contributed massively to reduction in loss of life.	• Vectors become resilient to the Insecticedes • If untreated, mosquitoes are not destroyed and can seek another host. • Nets become damaged or are misused. • ITNs require re-treatment which is ofen not performed. • LLINalso need to be re-treated or replaced every 3 years. • Only effective when the host is inside the net.

The vector control methods investigated have all shown to be effective methods of vector control and reduction in malaria. However the continuous development of resistance to insecticides in malaria vectors poses a problem to population control. The most effective way to control vectors has proved to b a combination of methods above. Controlling the vectors in the larval stage alongside the use of IRS and LLINs to control adult vectors is of up-most importance. Additional prevention methods which can be used in combination can contribute to speeding up the elimination process and eradicating malaria globally.

2.7

THE ARSENAL
MOSQUITO TRAPS

There is a market for mosquito traps in the warmer regions of the west where mosquitoes and other biting insects are a particular nuisance, such as the southern states of America.

A wide range of traps available in the west to attract, capture and kill mosquitoes. The most effective mosquito traps incorporate host cues to mimic human presence. Many commercial traps burn propane or require a specific canister in order to produce CO2. These larger traps are also popular in the hospitality sector with many, larger products are marketed to resorts, hotels and restaurants etc. However many of the traps available target 'biting insects' and not discriminate against mosquitoes for vector control but to prevent annoyance.

Mosquito traps have been used by researchers since the early 1900's for monitoring mosquito populations around the world. Traps allow the researchers to gather data on species prevalence in different areas preserving the bodies of the captures vectors for further analysis. The Mosquito Magnet (MMX, no longer in production), BioGents Sentinel and the CDC light trap have been used by researchers for trapping mosquitoes to determine species and population size (sources) as they are relatively cheap, light weight and portable.

In an interview, Dr A. Hiscox explains how mosquito traps are usually set for short periods ranging from hours to weeks. They are often moved from place to place during a research project and aren't permanent features for vector control (Interview with A.Hiscox Appendix X).

Chemical attractants can be added to the trap either impregnated into fabric or in a specialised depository system. This makes the traps more effective against targeted species. Although some traps incorporate a sticky surface of which mosquitoes adhere to upon landing, raps use an impeller fan to suck the mosquitoes into a catch bag where they desiccate. This preserves the integrity of the mosquito somewhat which helps with analysis of the catch in a research context.

Figure 16: Mosquito Magnet Patriot

Many of the highest selling traps target the Western market capturing mosquitoes and other biting insects primarily to reduce annoyance.

Traps such as the Mosquito Magnet burn propane to produce CO2 (and heat) to attract targets which are then sucked in.

These traps are expensive with the Mosquito Magnet Patriot costing $329.99 without a propane tank. This is followed by continuous cost of providing CO2, odours attractants and power from the mains supply.

The Suna-Trap by BioGents AG (Germany) is the only trap known to have been developed and used in a trial to test if mass trapping had an effect on cases of Malaria.

The trap consists of a central suction fan which creates an airflow through the trap. When attached to a 12V power supply, the ventilator rotates drawing air through the inlet pipe at a velocity of 3.1m/s, opening the shutter gate. Inside the trap, the air circulates under the conical cover becoming saturated with volatiles from the synthetic odour blend before being forced out of the trap through the perforated canopy at a base rate of 0.5m/s (Hiscox, Otieno et al. 2014).

Figure 17: Traps commonly used by researchers. Left: CDC LT. Middle - BG Suna-Trap. Right: BG Sentinel

2.8

CENTRE OF ATTENTION
THE SUNA TRAP

The Suna-trap was based on the design of a product from the BioGents range, the Mosquitito. This simple trap consists of a fabric (Nylon like) conical catch bag with a simple fabric cover. The product is suspended on a cord attached to the ventilator and inlet tube, positioned centrally in the fabric cover. On analysis of the Mosquitito, it was thought to be unsuitable for uses for the experiment on Rusinga for a number of reasons.

Figure 18: BG Mosquitito

CONSIDERATIONS

- The trap was thought not to be robust enough for field work in Africa as the traps were going to be in permanent locations rather than moved around.
- Odour was expelled through the conical catch bag which was made of a 'sort of nylon fabric' which was thought to become saturated with odour over time (however GSMS or other analytical methods were performed to determine whether/how much odour is absorbed). This resulted in elevated levels of mosquito activity around the base of the trap rather than the inlet pipe
- It was feared that the intended orientation and elevation the trap could be subject to flooding during the periods of heavy rainfall experienced in Rusinga.
- The Suna-trap was based on the design of a product from the BioGents range, the Mosquitito. This simple trap consists of a fabric (Nylon like) conical catch bag with a simple fabric cover. The product is suspended on a cord attached to the ventilator and inlet tube, positioned centrally in the fabric cover.

A number of design decisions were made during the redesign process to tackle these issues and were outlined in an interview with Alexandra Hiscox PhD who was involved with the redesign and SolarMal experiment.

DESIGN DECISIONS

- Firstly, the fabric cone was replaced with an aluminium replacement but this was found to be too heavy. It was also too expensive and there was an anticipated risk of theft due to the material value. A UV resistant plastic cone was chosen as it was thought to be robust enough to last up to three years on Rusinga Island.
- The base of the BG Mosquitito was not water resistant, but with the substitution of a plastic cone, the product could be turned upside down allowing the cone to serve as a water cover preventing the trap from becoming flooded. It also prevents water from entering the trap where is could potentially sustain the mosquitoes and prevent desiccation.
- Alteration of the cone shape was not considered due to a combination of time constraint and lack of need to do so.
- The Lycra type material used for the canopy was also changed to a plastic version thought to be more robust. The part could also be made from white UV resistant plastic to incorporate a black white colour contrast between the canopy and inlet pipe.
- The pattern of perforations of the plastic canopy and the length of the CO2 outlet pipe were deduced from results of duel testing. A pattern of more, smaller holes was preferable to fewer larger holes and a number of CO2 outlet tube lengths were tested before determining the optimum length.

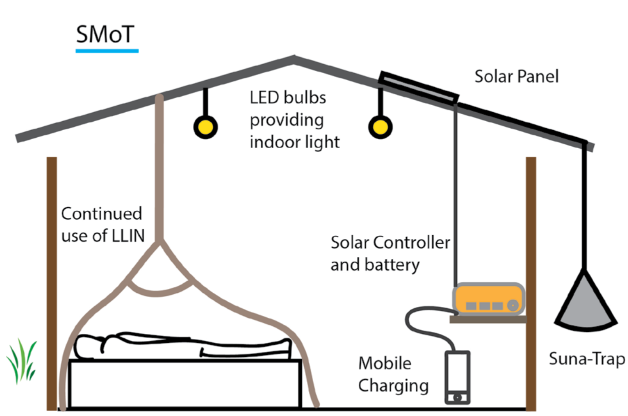
POWER SUPPLY AND CO2

The trap requires a 12V 0.28A supply and over 10 hours will use 0.036kWh of power. The trap can be powered using a solar panel making it suitable for use in homes without a grid provided power supply. A battery is required to store energy gained during the day and a controller is necessary to provide the power to the trap at night when needed.

A CO2 release tube is situated close to the inlet pipe. CO2 can be provided via a canister or via another source such as a fermenting mixture of yeast and sugar (maolasses).

Figure 19: Lifting the cone of the trap reveals the catch bag and fan and odour inside.

Figure 20: Illustration of the SMOT system installed on Rusinga Island during teh SolarMal trial.



2.9

BEST IN CLASS PRODUCT BENCHMARKING

During the initial research phase of this project, many mosquito trap solutions currently available were investigated in detail. For further information on the range studied please see Appendix X.

After development of the Suna-Trap, testing was conducted in semi-field experiments to establish whether the new trap design performed as well as existing products in terms of number of captures. The Suna-trap outperformed the CDC LT (CDC it not fitted with odour as protocol intends) when unlit and equally to the lit trap. Although outperforming the MMX in lab testing, the Suna-trap performed equally well as the MMX under semi-field conditions. It is thought the the wide odour emission area of the suna-trap is less effective at spreading odour in the field due to wind and other atmospheric conditions (A.Hiscox. 2014).

Many of the commercially available traps, targeting the western market (often advertised to attract and kill tiger mosquitoes in the USA) were excluded from the product benchmarking as it was clear they are not suitable for use in less developed countries where access to propane or CO2 tanks and an electricity grid are unlikely. The mosquito magnet patriot, a popular product has been included to highlight the unsuitability.

The Suna-Trap by BioGents AG (Germany) is the only trap known to have been developed and used in a trial to test if mass trapping had an effect on cases of Malaria. Testing has shown that the Suna-trap performs as well as if not better than other traps under semi-field conditions. However, rather than just assume this product as the benchmark solution, it is important to analyse other products on the market to gain a better understanding of solutions available and evaluate the benefits and pitfalls.

BG SENTINEL

BG SUNA

CDC LIGHT TRAP

MM PATRIOT

MMX TRAP

Figure 21: Mosquito traps analysed and compared in product benchmarking.

1. From the research conducted to far it is important it is clear that a high capture rate is important for effective control of adult vectors.
2. The traps must be easy to transport and distribute across rural Africa. Once on location the traps should be
3. Simple to install in order to to minimise the overall installation time of the SMoT.
4. The traps must be robust and survive in a permanent location for a period of three years (robust and weatherproof)
5. Create a positive user interaction encouraging the user to maintain the trap. How well each trap meets these essential criteria will reveal which trap is most suitable.

The comparison chart below shows the scores representing how well each trap is though to meet the proposed requirement. It is clear that the biogents products are most suitable for use as tolls for malaria prevention in Africa. The traps are scored out of 7 for each factor and the highest total score represents the most suitable solution.

- The standing orientation and light weight, collapsible base make the Sentinel a good tool for researchers in the field. However it is felt that it is not robust enough for permanent situation on location.
- Although the capture rate is lower compared to the Sentinel due to the hanging orientation, the Suna-Trap is more suitable for permanent installation in the field and is well protected from external factors such as adverse weather.
- The CDC light trap scored highly for ability to transport and install but, due to its lack of ability to incorporate and odour and frailty, it is less suitable for long term use in the field. Although the capture performance is comparable to the Suna and Sentinel, the MMX is difficult to transport, distribute and clean. Production has also ceased so it is no longer commercially available. The Patriot trap is robust and has a good capture rate but is expensive, bulky and CO2/propane requirements cannot be met.

	FACTORS 1	2	3	4	5	TOTAL
Sentinel	3.5 / 7	5 / 7	5 / 7	2 / 7	2 / 7	**17.5 / 35**
Suna	3 / 7	1.5 / 7	4 / 7	5 / 7	4 / 7	**17.5 / 35**
MMX	3 / 7	1 / 7	5 / 7	3.5 / 7	0 / 7	**12.5 / 35**
CDC LT	2 / 7	6 / 7	5 / 7	1 / 7	3 / 7	**17 / 35**
Patriot	4 / 7	0.5 / 7	1 / 7	4 / 7	1 / 7	**0.5 / 35**

Figure 22: Comparison of mosquito traps investigated evaluating each product against the factors highlighted. Receiving a score out of 7 for each category a total score for each trap can be used to rank the products.

2.10

BATTLE PLAN

TOOL FOR PREVENTION

Although ITNs and LLINs have proved to be prolific methods of vector control issues including mosquito resistance, coverage and product lifetime are withholding the eradication process.

Figure X below shows a generalisation of mosquito home entry behaviour based on understanding of reseach. If the inhabitance of the home sleep under a bed net they should be protected from the biting, potentially infected vectors. Assuming it is properly treated and in good condition, the vectors should be killed when they come into contact with the net. However, if the mosquito avoids contact with the net or has resistance to the insecticide it is then able to leave the home in search of an alternative target.

As the addition of odours and CO2 have improved the performance of traps, it is thought they could contribute to the prevention of malaria transmission and the reduction in vector populations.

Semi-field experiments performed with Anopheles mosquitoes were performed to investigate if the placement of an odour baited trap outside the home reduced home entry. Mosquitoes approaching the (eaves of the) home would be distracted by the trap and be captured. A control test was performed with a CDC LT placed inside the home, the number of mosquitoes caught provide an indication of home entry level. Further tests were performed with the addition of a Suna-Trap placed outside the home. In this scenario less vectors were caught inside the home indicating a reduction in home entry.

Mosquito Approach and House Entry With Insecticide Treated Bed Net

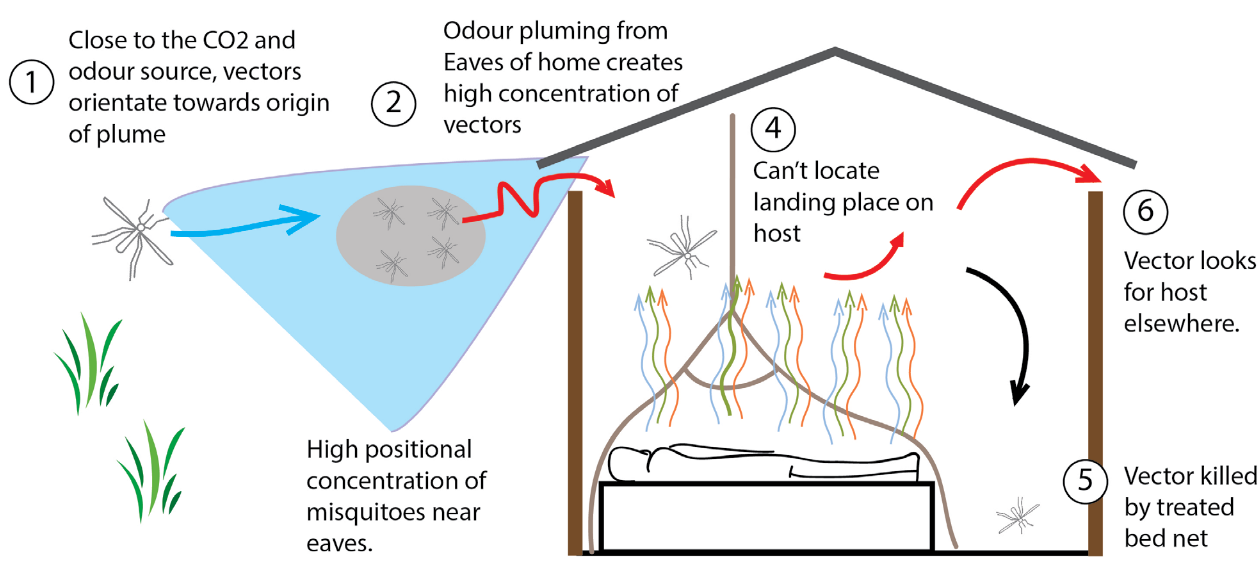


Figure 23: Illustration of the expected mosquito host seeking behaviour in context with the intervention of a bed net.

Over 32 nights of testing, 200 mosquitoes were release within the semi-field environment in each test. In control tests without the installation of the Suna-Trap, a mean of 84.1vectors were caught in the CDC LT. Results of tests conducted with the Suna-Trap installed outside the home showed a mean value of 54.7 female captures inside the house at night. As the traps cannot be expected to prevent 100% of vectors entry into the home it is essential that traps are used alongside ITN's.

Reducing the number of mosquitoes in the home at night prevents annoyance as well as biting when not under the the net. Mosquitoes host seeking activity often commences before inhabitants go to bed and unprotected by the net. This provides and easier opportunity for mosquitoes to successful bite a host.

The prevention of vector home entry, especially before inhabitants have gone to bed can reduce annoyance as well as biting. During the night, when inhabitants are under the mosquito net, vectors which enter the house and are not killed can then leave the house and seek another target. Looking for the next best target, mosquitoes leaving the house may approach the trap and get captured.

As the traps are baited with a human odour mimic, mosquitoes should not gain a resilience over time making the trap a key tool for talking malaria in the long term by helping to eliminate insecticide resilient vectors.

Mosquito Approach and House Entry with Suna

Ignors synthetic odour but returns to trap

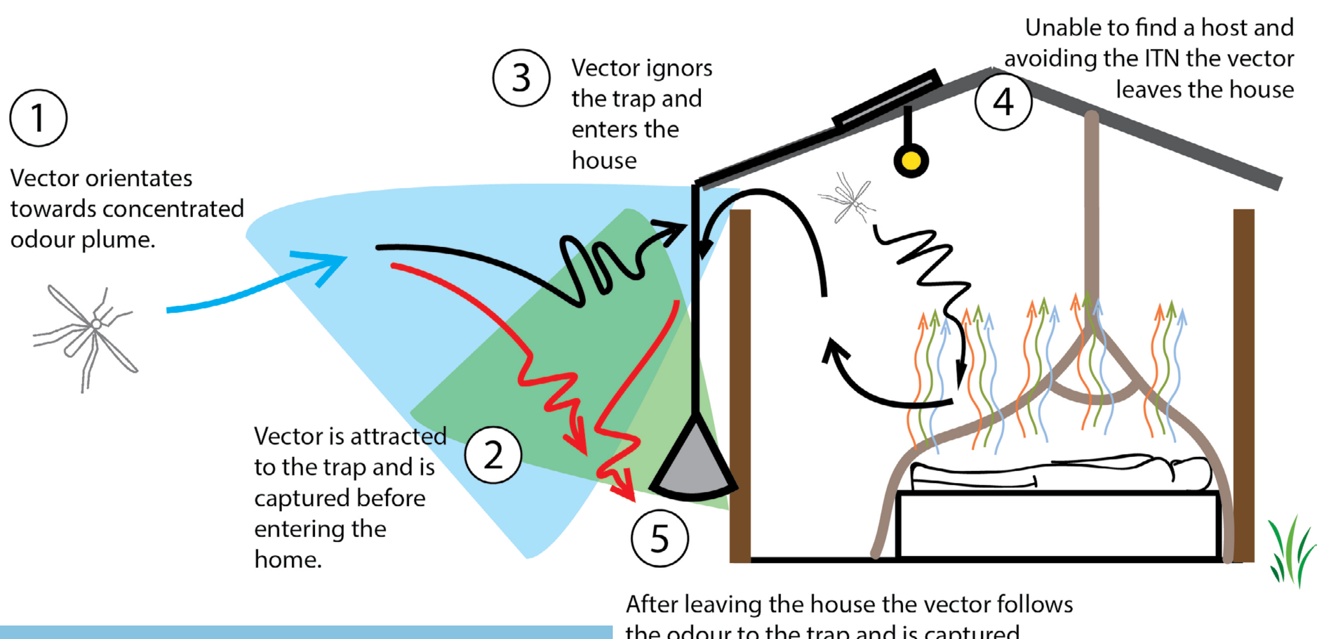


Figure 24: Illustration showing expected mosquito host seeking behaviour around a home with the intervention of bed net and odour baited trap.

2.11

THE GREAT ESCAPE
VECTOR FLIGHT RESEARCH

Antoine Cribellier, researching mosquito escape behaviour at WUR, investigated the flight patterns of Anopheles mosquitoes around the Suna-Trap in both handing and standing orientations. Vector flight paths were recorded using infrared cameras. 3D flight paths were created from the recordings and show the behaviour of mosquitoes around the trap. Of the total flight paths recorded, the number which results in capture gives and indication of the capture rate. Flight paths that do not result in capture show how approaching targets are able to avoid capture.

A total of 530 mosquitoes were recorded flying around the trap resulting in the reconstruction of over 2500 3D flight paths which can be further analysed. From the torturous flight behaviour of the subjects in the vicinity of the trap, two distinct and typical behaviours were found;

- Mosquitoes typically approach the trap from above flying towards the ground as they close in.
- In the close vicinity of the trap, the vectors change their direction and speed flying directly upwards away from the trap.

There are differences between the flight patterns of vectors around the suna-trap in each orientation.

The Suna-Trap in the hanging orientation captured more of the approach flights recorded. However, in the standing orientation, the trap is more attractive leading to more approach flights and higher number of captures.

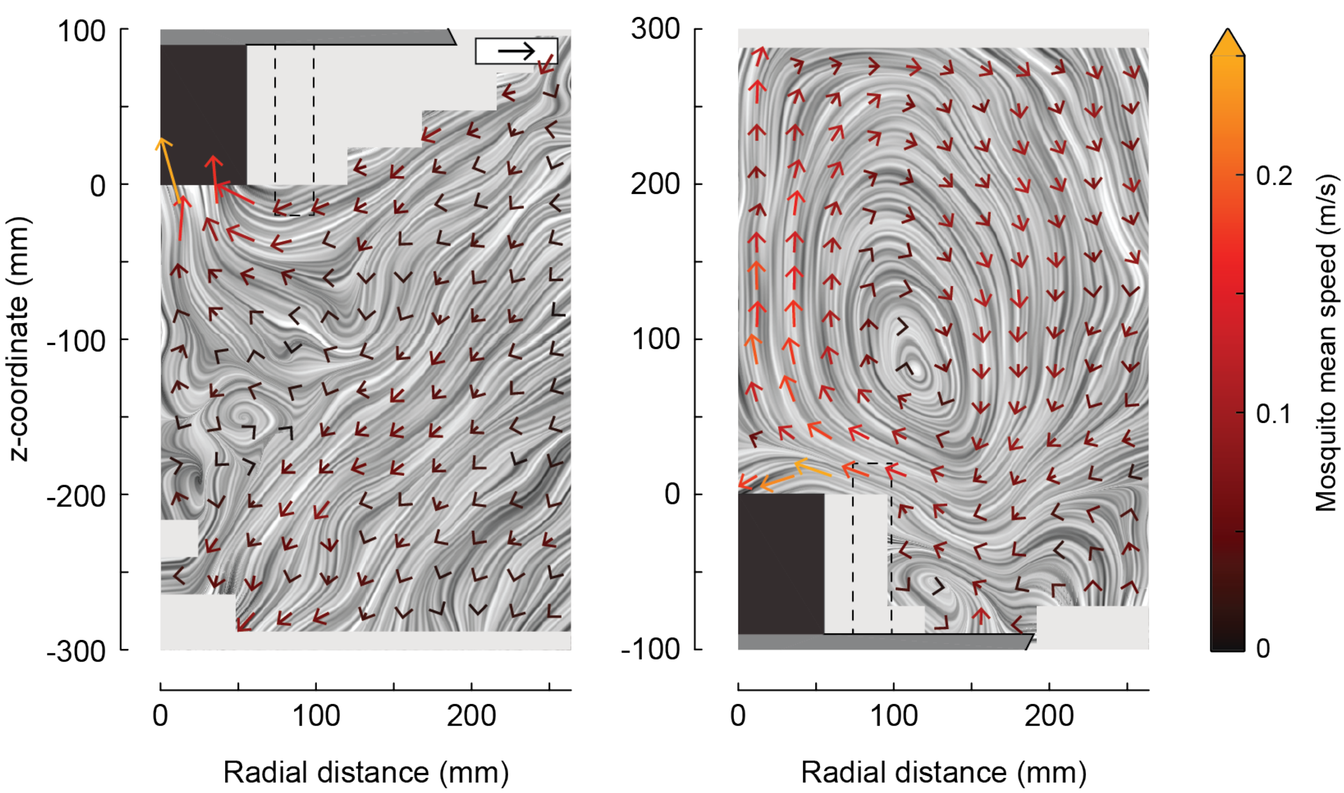
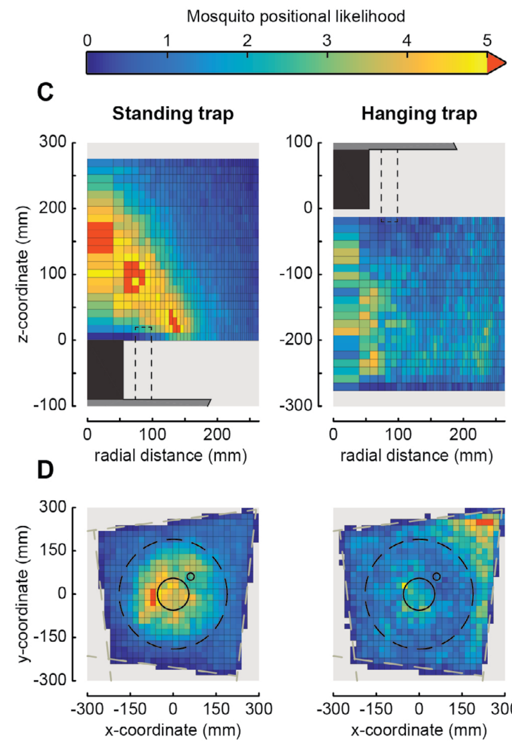


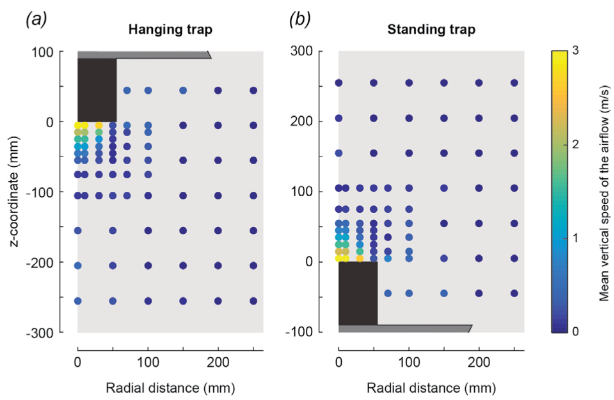
Figure 25: Vector flight oath maps by Antoine Cribellier visualise mosquito approach and escape flight patterns around the Suna-Trap in both standing and hanging orientations. In both situations vectors can be seen approaching fro above and escaping in a vertical direction. (sourced from A.Cribellier.)

Figure 26 (below): Vertical velocity of airspeed measured around the Suna-Trap using a hot wire sensor.

Figure 27 (right): Positional likelihood of vectors during the research by Antoine Cribellier.

(both sourced from A.Cribellier)





Mean vertical airflow calculations, taken at 76 locations using a hot wire measurement set-up, show a small area of high downward vertical airspeed which will be referred to as the capture zone. Mosquito flight paths entering areas where the airspeed is above 2m/s downwards into the inlet pipe resulted in capture. The results show very similar characteristics of the capture zone in each orientation.

Figure X visualises the positional likelihood of the vectors around th trap. it is clear tat the standing orientation results in a higher positional likelihood of mosquitoes around the vicinity of the capture zone. The images of the standing trap show high concentrations of vectors sound the capture zone confirming the attraction to the trap.

Of the 2570 flight paths recorded, only 87 resulted in capture. From all the approach paths made by the mosquitoes, less than 4% resulted in capture. Many mosquitoes re-approached the trap after initial evasion resulting in the generation of more than one flight path from that particular target. The end result is an estimated capture performance of 10% of total mosquitoes attracted to the trap will be caught. Improving the capture performance of the trap could result in a more effective tool for malaria prevention.

2.12

LESSONS LEARNT
THE CONCLUSION

Anopheles *gambiae* are the main vector of malaria in Africa, where the heaviest burden from malaria is heaviest. This species is nocturnal mostly hunting at night when hosts are asleep. High numbers of vectors and continuous development of resistance to insecticidal control make elimination of disease transmission an especially difficult challenge in Africa. Mosquito traps baited with human odour mimics could contribute to the future elimination process across the continent by reducing vector home entry, biting and ultimately malaria transmission.

Vectors are attracted to baited mosquito traps which mimic human presence with the emission CO_2 and synthetic odours (Muakabana et al., 2012) . Placing mosquito traps outside of the home has proven to reduce home entry in semi-field experiments.

Further analysis of the benchmark Suna-Trap show a low capture performance of around 10% in lab conditions and a capture rate of less than 4% of approach flights. The high positional likelihood of vectors around the inlet of the Suna-Trap in the standing orientation suggests that the combination of odour and CO_2 is attractive to the mosquitoes. Nevertheless, in close range of the traps, vectors appear to change their flight behaviour escaping from the fairly small capture zone. Unable to sense close range host cues associated with a human target, the mosquitoes accelerate vertically away from the trap avoiding capture (Cribellier et al,. 2018).

Increasing the performance of the trap, catching more mosquitoes thus further preventing home entry could have a considerable effect on reducing malaria transmission when used alongside an ITN.

Increasing the attractiveness of the trap to make it more competitive against the attraction of the eaves of the home could help reduce home entry, It is also important to address the capture rate of the trap, increasing the number of captures which result from vector approach flights. Research into the vector flight dynamics around the trap shows targets avoiding the capture zone and escaping capture. Increasing the number of flight paths into the capture zone could be attempted in two main ways; either increasing the capture zone or attracting more flight paths into it (or a combination of both).

3.0
Chapter 3: The First Move

Considering insights gained from the previous chapter, this initial design phase aims to incorporate behavioural factors and generate concepts for an increased performance.

Figure 28:: Using a hot wire sensor to investigate airspeeds experienced around new trap concept design.

3.1

THE DRAWING BOARD
CONCEPT GENERATION

In the previous chapter, investigations revealed the poor performance of the Suna-Trap in laboratory conditions. A more effective trap, catching higher numbers of vectors specifies a more useful research tool and potential tool for malaria prevention.

Understanding vector host seeking behaviour and flight patterns around the Suna-Trap revealed a number of possible wayt o increase number of captures.

Improving the attractiveness of the trap and especially vector attraction to the capture zone might be achieved by the addition of close range host cues such as heat and moisture. As well as making the trap more attractive and hence more competitive against the attraction of the eaves, the capture rate of approach flights made by targets could be achieved by either increasing the capture zone and/or causing more flights into the zone.

With a focus on improving the capture performance of the benchmark Suna-Trap product a number of How' To's were proposed;

- How to introduce heat to the product?
- How to introduce moisture to the trap?
- How to direct vector approach using the odour?
- How to Increase the capture zone?
- How to increase flights into the capture zone?
- How to alter the airflow inside the trap to improve attractiveness?

INITIAL IDEATION

Addressing the challenges posed by the 'How To's', an intensive ideation process commenced in which a number of innovative ideas were generated. Divergence of the design process allows for a large number of ideas to be explored through mind mapping and sketching

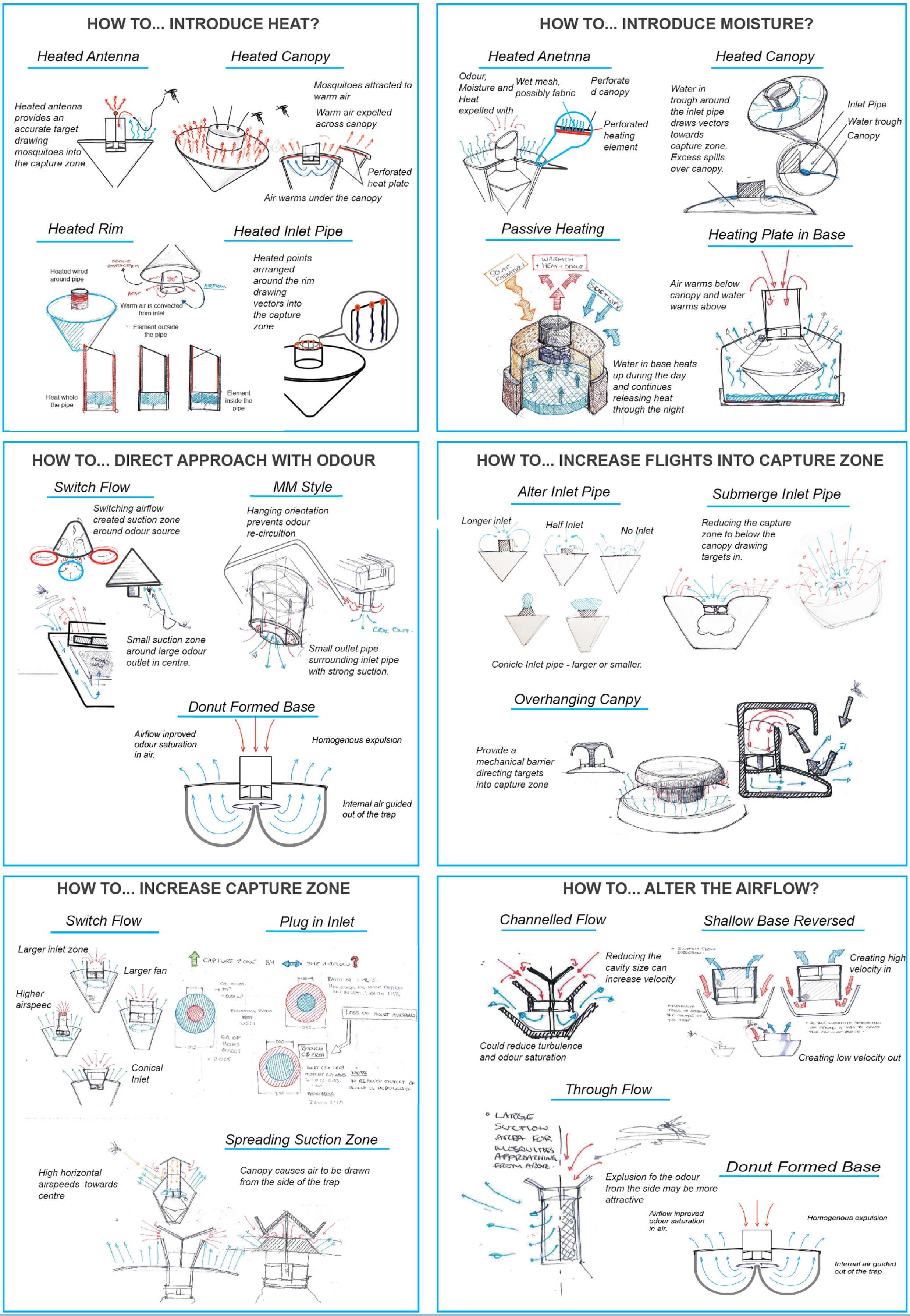


Figure 29: Summary of initial ideation showing the ideas generated in response to the 'How To's'.,

3.2

JOINING FORCES
FOCUS GROUP DISCUSSION

On the firth of April 2018 a Focus Group Discussion was held at the Experimental Zoology (EZO) Department at Wageningen University and Research led by Henry Fairbairn, design project leader from TU/Delft. And attended by; dr.ir. Florian Muijres, assistant professor; Jeroen Spitzen from the department of Entomology; and Antoine Cribellier - a researcher in the EZO department.

The rough concepts generated in the ideation process were presented to the group and discussed as they were introduced. Positive and negative aspects were deliberated as the ideas were evaluated. Hypothesis of expected performance were drawn so as design directions could be further developed based on the knowledge and expertise of group members.

(Full summary found in Appendix)

Hot To... Introduce Heat?

DISCUSSION: A number of ideas were discussed relating to introducing heat, a close range host cue which encourages landing behaviour. The main ideas shown in figure X include; adding a heated antenna, a heated plate under the canopy, heating elements in and around the inlet pipe as well as heating the inlet pipe itself. The position of a heating element was discussed as the air flow of the product could reduce the rate of convection of heat into the surrounding air.

POSITIVE: Adding a heating element to the trap could provide the close range host cue needed to draw th target vectors closer the trap. Adding an element near the rim of the trap was most popular. It is thought the warmer air in this localised area could provoke landing behaviour causing low velocity flight into the capture zone resulting in a higher capture rate of approach fligths.

NEGATIVE: If a heating element is too close to the capture zone the warm air could be sucked straight into the trap and not released so cannot attract the mosquitoes as intended. The energy requirements of electrically powered heating elements were also anticipated and heating metal plates was expected not to be practical or energy efficient.

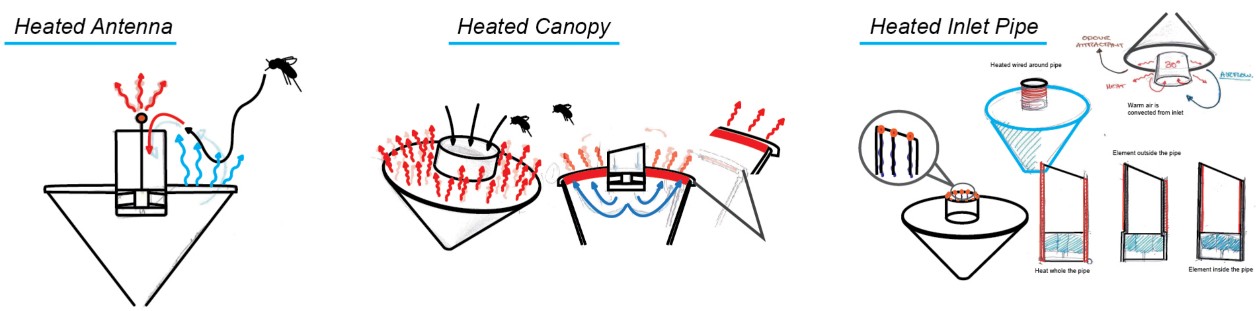


Figure 30: Ideas for introducing heat discussed during focus group.

How to... Introduce Moisture

DISCUSSION: Although it may not address the issue of vector escape, it was thought that applying moisture and heat together in the design would mimic a sweating person making the trap more attractive however it doesn't address the escape factor. Ideas to add water across the canopy, into the base and around the inlet of the trap were Moisture vapour can be detected by mosquitoes in close range of a host so it is necessary to heat the water and increase evapouration.

POSITIVE: The addition of moisture (vapour) should make the trap more attractive to targets. xxxxxThe idea to have a pool of warm water in the base of the trap was thought to be both a practical and suitable solution to providing heat and moisture cues which, mixed with odour, create a strong attractant. Taking advantage of the specific heat capacity of water, it could be possible to combine conductive and insulating materials encouraging passive heating during the day whilst retaining and slowly releasing the heat at night.

NEGATIVE: Heating the water was discussed as it was thought it would be necessary to create vapour from water around 36 degrees in order to mimic a human. Using a heating element could have an excessive energy demand depending on the amount of water in the trap. Too smaller amount of water and it may evaporate too quickly requiring constant refilling whereas a larger volume of water would take longer to warm up however, it could retain heat for longer.

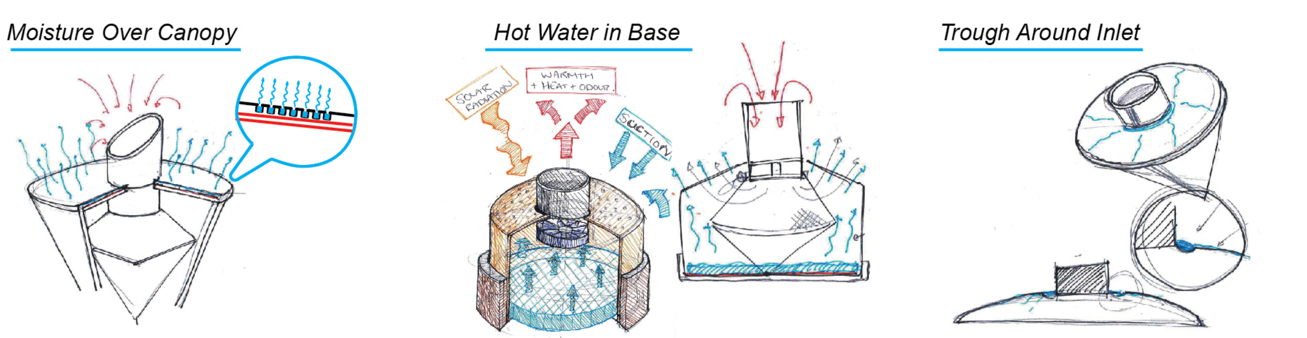


Figure 31: Ideas for introducing moisture discussed during focus group.

How to... Direct Approach with Odour

DISCUSSION: Comparing to features of the MMX trap, the idea of switching the airflow in this way would provide a strong plume of odour surrounded by a capture zone. Targets would have to cross to reach the source of the odour.

POSITIVE: Altering the airflow within the product also sparked interesting discussion. Turbulence in inside the product is thought to increase saturation of odour in the air before it is expelled through the canopy so but increasing this factor could create a stronger odour making the trap more attractive to the target vectors. 'The Donut' idea of which the base is drawn up in the centre was an interesting concept and could improve odour saturation as well as aid more homogeneous expulsion across the canopy (figure).

NEGATIVE Doubts were cast as to the discussion as to the possibility of the circular airflow being too strong and much of the odour saturated air being sucked directly into the trap, reducing the attractiveness. This was also an issue raised to the idea of reducing the length of the inlet pipe to bring the capture zone in line with the (horizontal) plane in from which the odour is expelled (figure).

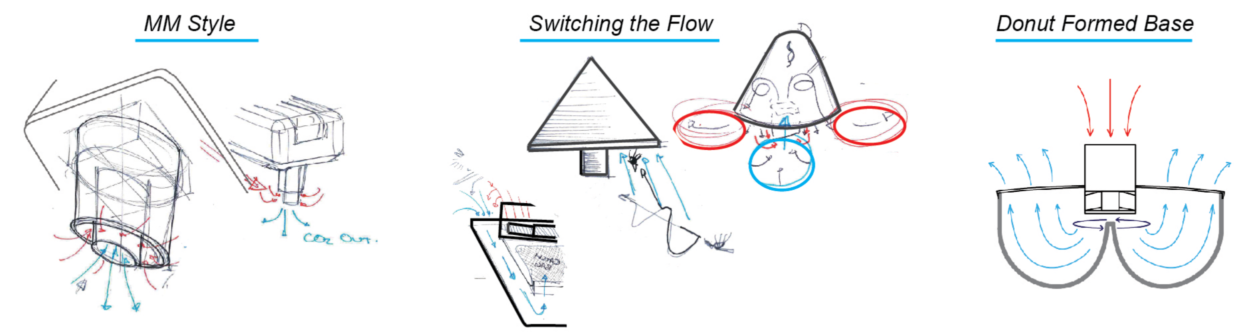


Figure 32: Ideas for directing approach with odour discussed during focus group.

How to... Increase the capture zone

DISCUSSION: Increasing the size could increase the number of flights into the capture zone. Ideas discussed included altering the inlet pipe to produce a wider area of suction. This could also be achieved by widening the inlet and adding a plug to the centre to maintain a high vertical suction velocity. The addition of a canopy aims to alter the suction zone to draw air from around the inlet rather than from above.

POSITIVE: Increasing the scope of the capture zone by sucking air in from the side could mean influencing more flight paths. The canopy and plug methods could both achieve this. The plug idea crates a wider capture sphere whilst maintaining a high vertical suction velocity.

NEGATIVE: Increasing the inlet without adding a plug or increasing the fan size will result in reduced suction. The addition of the canopy to alter the airflow prevents capture of flight paths directly above the inlet.

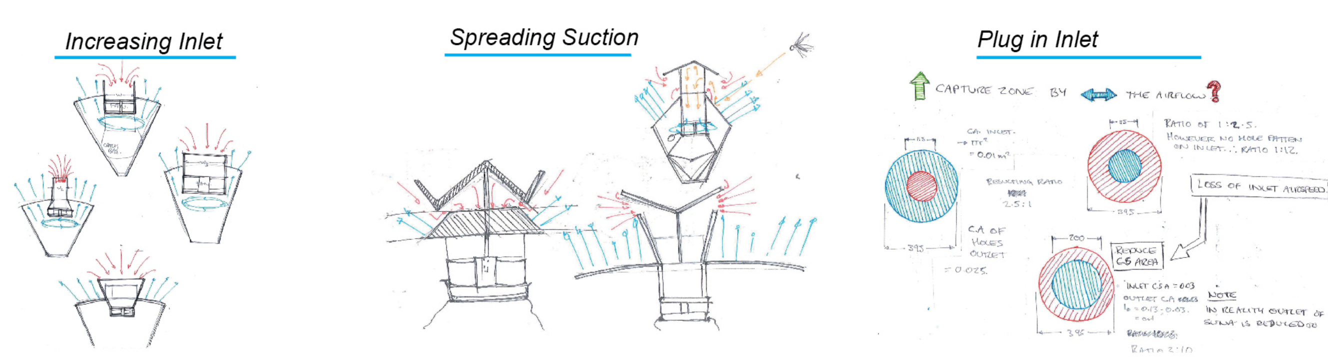


Figure 33: Ideas for increasing the capture zone discussed during focus group.

How to... Increase flights into the capture zone

DISCUSSION: Two main ideas were discussed as potential solutions to increasing flights into the capture zone. Altering the height of the inlet tube aimed to bring the capture zone closer to the canopy form which the attractant odour is expelled. The relative position of the capture zone could also be lowed beyond the canopy. An overhanging lid was a highlight of the discussion. Working directly from the escape research of A.Cribellier, this concepts incorporates a mechanical barrier which guides the targets into the capture zone.

POSITIVE: Removing the inlet pipe and submerging the fan into the trap could result in high capture rate of flights close to the canopy. The overhanging canopy was well received amongst the focus group. The canopy forms a mechanical barrier which intercepts targets as they try to escape vertically and direct thee flight path towards the capture zone.

NEGATIVE: The height of the inlet was defined through testing and is optimal. reducing the heigh probably results in less odour escaping making the trap less attractive. The overhanging canopy could also result in more odour being recirculated and not expelled from the trap. The low pressure zone under the canopy could deter the targets from entering.

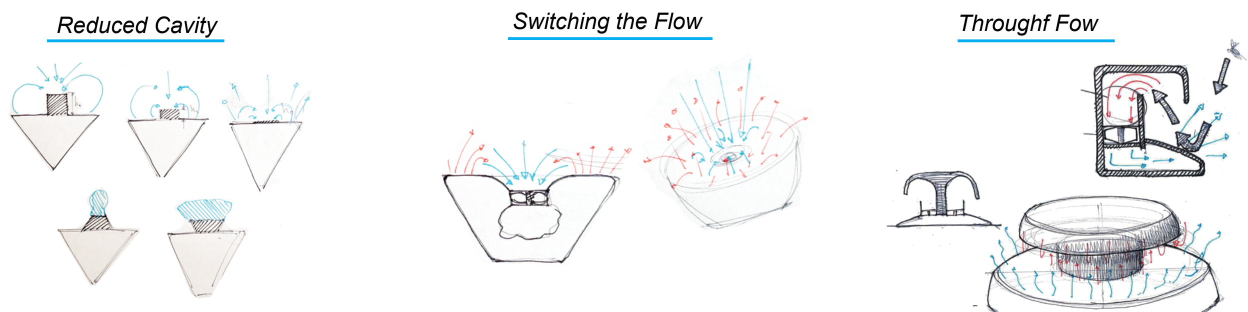


Figure 34: Ideas to increase flights into the capture zone discussed during focus group.

How to... Alter the airflow inside the trap

DISCUSSION: Detail of the airflow within the trap is unknown but it is thought that turbulence inside caused by fan helps saturate the air with odour before it is expelled. Altering the airflow could further improve the saturation of odour in air. It could also help with the homogeneous expulsion of odour scented air across the canopy.

POSITIVE: 'Donut Base' was again discussed in this category. It is thought that the 'cyclonic' airflow induced inside the trap helps saturate the air with odour before it is expelled. This should make the trap more attractive and increase capture rate. Other ideas included reducing the volume inside the trap which would result in less turbulent airflow and higher air velocities.

NEGATIVE: Reducing the cavity whilst switching the flow could reduce odour saturation in the air especially if expelled at high velocity. The expulsion of air out of the side or the bottom of the trap, might make the trap more attractive but doesn't address the capture rate.

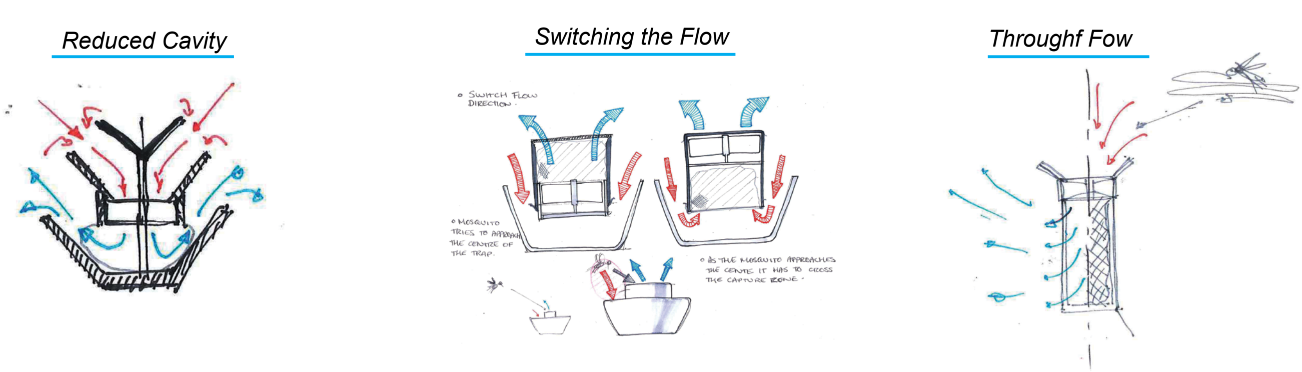


Figure 35: Ideas for altering the airflow discussed during focus group.

3.3

THE AMMUNITION CONCEPT SELECTION

A number if concepts should be tested in order to highlight how variant factor effect performance compared to the Suna-Trap. Each concept tested should include as few variables compared to the benchmark Suna-Trap to clearly conclude on how the variant effects performance.

However, due to time constraints the number of concepts should be limited to test the most interesting concepts (in terms of vector control research) and those with highest expectations.

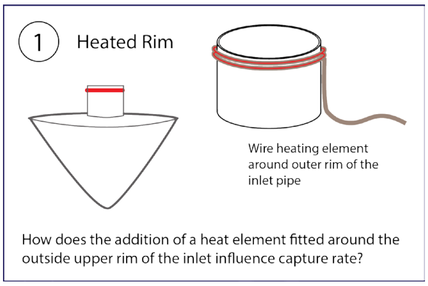
A number of concepts were to be selected at this stage of the project to investigate if any of the propositions resulted in increased performance compared to the Suna-Trap. The results aim to provide an understanding of how the fundamental principal behind each concept effects the resultant performance in each trail.

> To highlight which features influence the capture rate, each concept should minimise the number of variables from the control, the Suna-Trap.

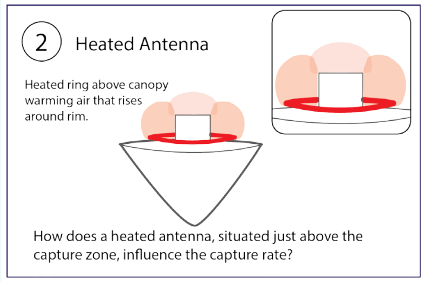
The main factor deciding which concepts were tested was time. With a preliminary plan it was decided that 9 concepts could be developed, prototyped and tested within the time frame. From then factors which contributed to selection included;

- Relevance to research questions – How likely the concept would provide a credible answer to the respective research question.
- Expected result – How much of an effect it was thought the concept could produce
- Feasibility of prototyping - the possibility of developing the concept to a working prototype with the available time and facilities.
- Could provide insight into research question – Whether the concept evokes behaviour in line with current research.

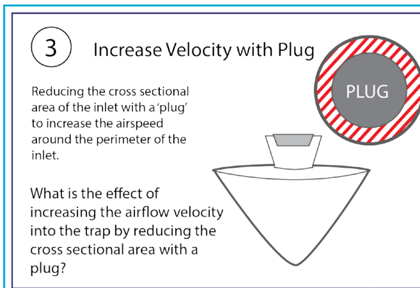
Based on the factors outlined, 9 concepts were highlighted, each aimed to answer a more specific research question with the scope of the one of the four main questions.



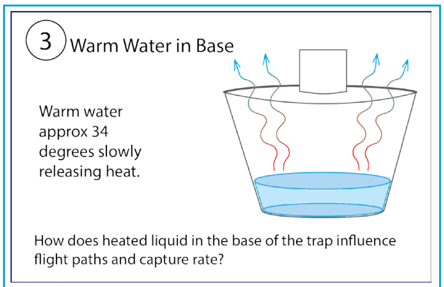
Introducing a heated element to outside the rim of the inlet pipe will warm the surrounding air providing a close range host cue that will attract mosquitoes into the capture zone resulting in a higher capture rate.



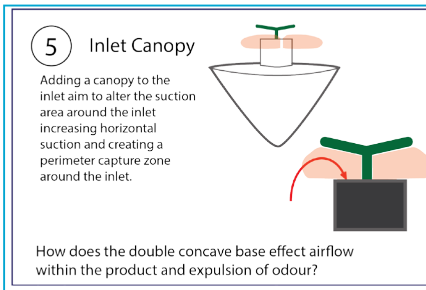
Adding a heated element, elevated from the canopy, will increase the temperature of air flowing from the areas of the canopy closest into it and the inlet pipe resulting in a higher capture rate.



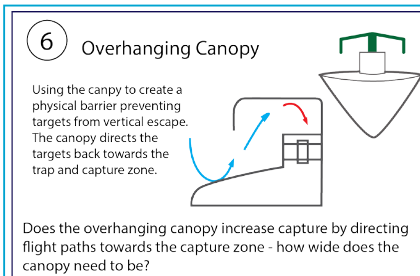
Increasing the width of the inlet pipe and adding a plug to the centre will create a stronger, wider-reaching capture zone. Its wider influence will result in a higher capture rate.



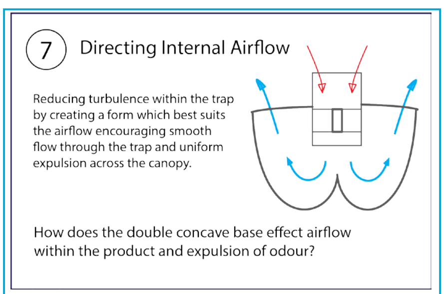
Adding heated water to the base will warm the turbulent air inside the trap as well as provide vapour, incorporating a second host range cue, resulting in a higher capture rate.



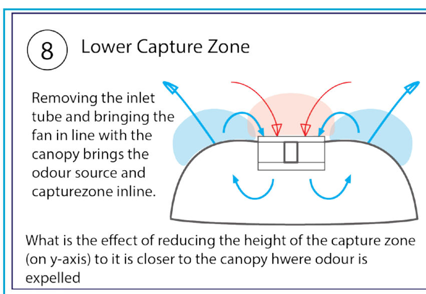
Adding a small canopy above the inlet pipe will alter the dynamic of the capture zone dragging more air in from the side of the rim rather than from directly above resulting in a higher capture rate.



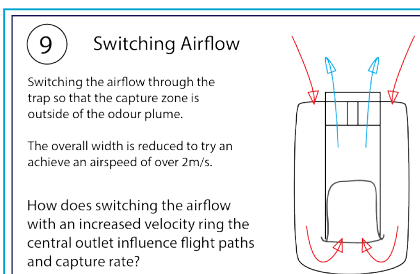
The overhanging canopy will provide a mechanical barrier directing mosquitoes towards the capture zone and preventing vertical escape resulting in a higher capture rate.



The shape of the base will aid the saturation of odour in the air and cause it to be homogeneously expelled across the perforated canopy resulting in a higher capture rate.



Removing the inlet pipe so the capture zone is closer to face from which odour is expelled will lead to more captures as the targets approach the source of the odour resulting in a higher capture rate.



Switching the airflow will provide a more direct odour source. Mosquitoes approaching or retreating from the odour source will have to cross the surrounding suction zone. This will result in a higher capture rate.

Figure 36: Final concepts selected for testing with the expected hypothesis for each concept.

3.4

THE PREPARATION: DEVELOPMENT AND PROTOTYPING

The 9 concepts selected were further developed and prototypes were created for each. Parts were constructed in the workshop at the TU/Delft using the facilities and materials available. Parts from the suna trap were utilised where possible to reduce varience between the prototypes.

The prototypes constructed are shown below.

1. Concept 1 - Heated rim of inlet
2. Concept 2 - Heated element above canopy
3. Concept 3 - Plug in Cone inlet
4. Concept 4 - Heated water in the base
5. Concept 5 - Small canopy above inlet
6. Concept 6 - Overhanging Canopy
7. Concept 7 - Donut shaped base
8. Concept 8 - Lower Capture zone
9. Concept 9 - Reversed Flow

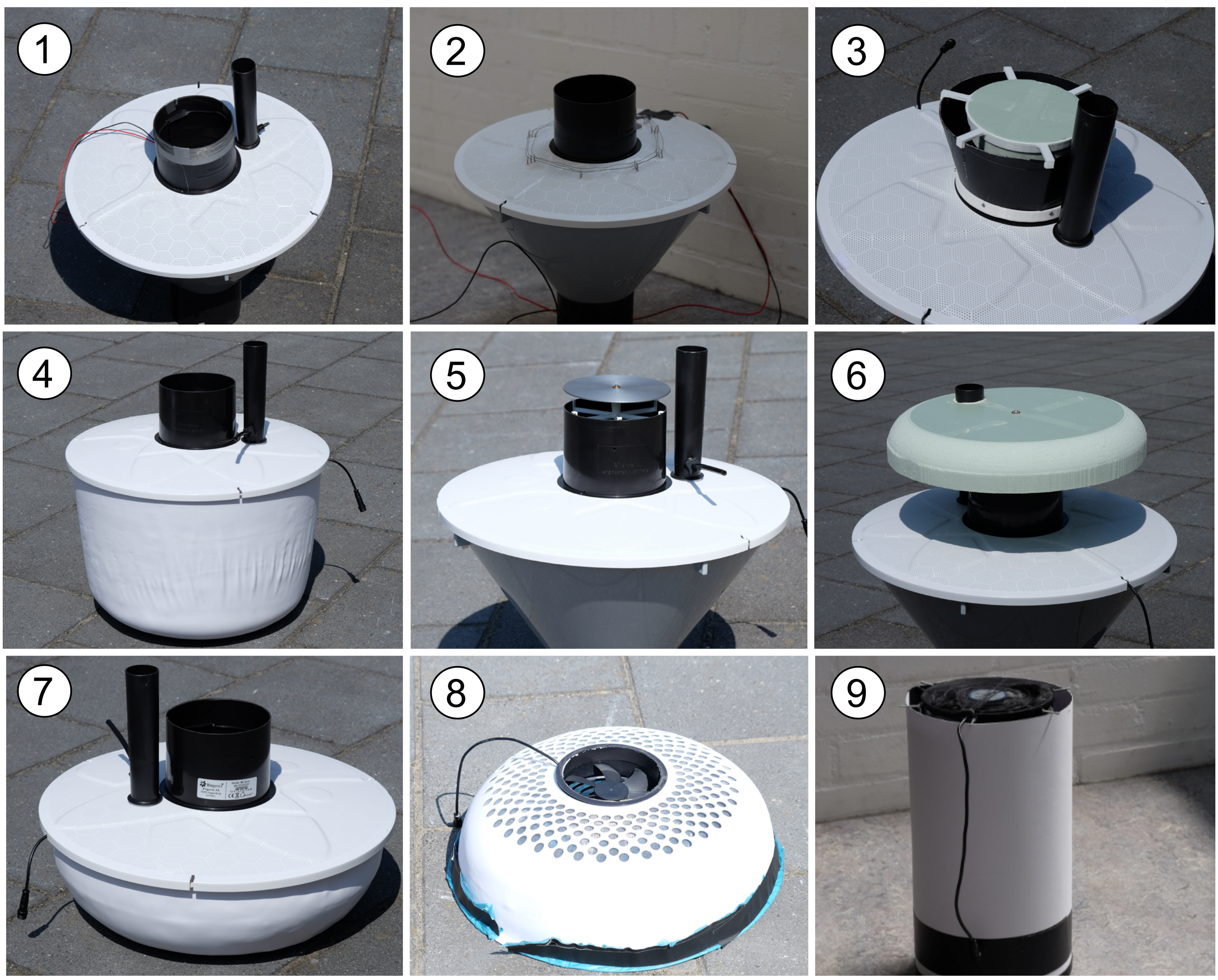


Figure 37: Prototypes developed for concepts 1 - 9.

In order to further investigate the performance of each concept is if first necessary to develop prototypes representing the principals to be tested. Retrofitting additional components to the Suna-Trap minimises unintended variation between the prototypes.

The 'Heated Water', 'Donut Base' and 'Reversed Flow' traps all required custom bases which were vacuum formed. Accurate foam patterns were created using a CNC milling process. 2mm thick (material) was then warmed and vacuum formed over the patterns. For the 'Reduced Capture Zone' concept, a new canopy was also vacuum formed to ensure odour dispersal.

The Inlet Canopy and Overhanging Canopy were retrofit to Suna-Traps with a 3D printed bracket. The bracket holds a vertical shaft in the centre of the inlet on which the canopy can be attached.

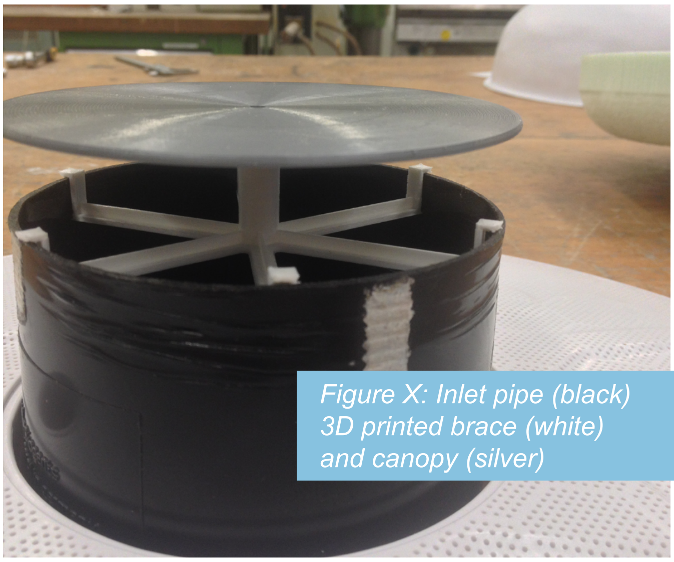


Figure X: Inlet pipe (black) 3D printed brace (white) and canopy (silver)

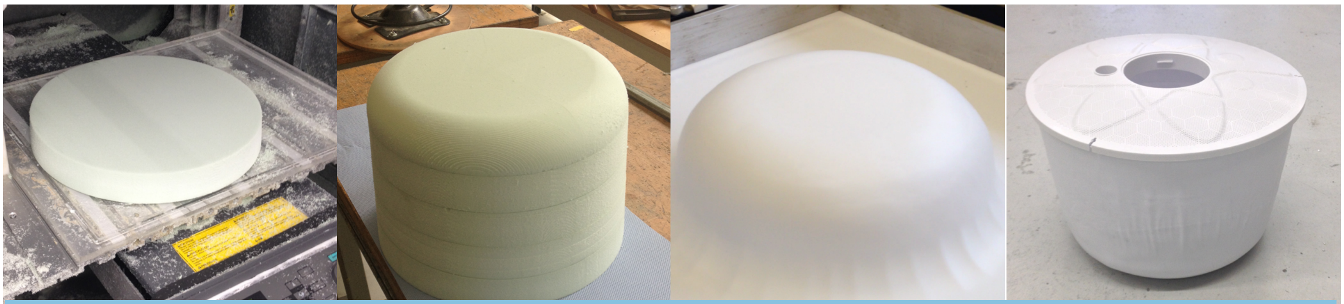


Figure 38: Production of vacuum formed parts. 1) CNC Milling of pattern. 2) Build up of layers for pattern. 3) vacuum forming of plastic over patter. 4) Base for Concept 4 with Suna-Trap canopy.

Figure 39: Parts created for prototypes 1-9

Concepts 1 and 2 require the addition of a heated element. Initial investigations into heating elements in products such as hair-dryers and fan heaters showed Nichrome wire as a popular material as its high electrical resistance causes it to heat up quickly. Coiling the wire creates a higher surface area of heated wire per cm3 of air causing the surrounding air to heat up more quickly.

Rough hand calculations were made to find out the diameter and length of wire which required. It was necessary to investigate through trial and error, what lengths and diameter of wire would produce air temperatures of around 36°C when within the traps airflow.

Tests were carried out to see how the elements perform in practise by measuring the temperature of the circulating air around the trap (Figure X).

It was found that if 2 meters of 0.5mm diamerter nichrome wire with 0.8A of current passing through at 12v produced a local temperature around body temperature when wrapped around the inlet. When positioned above the canopy lower increases in temperatire were found in the key areas but it was thought the degree of increase was enough to test.

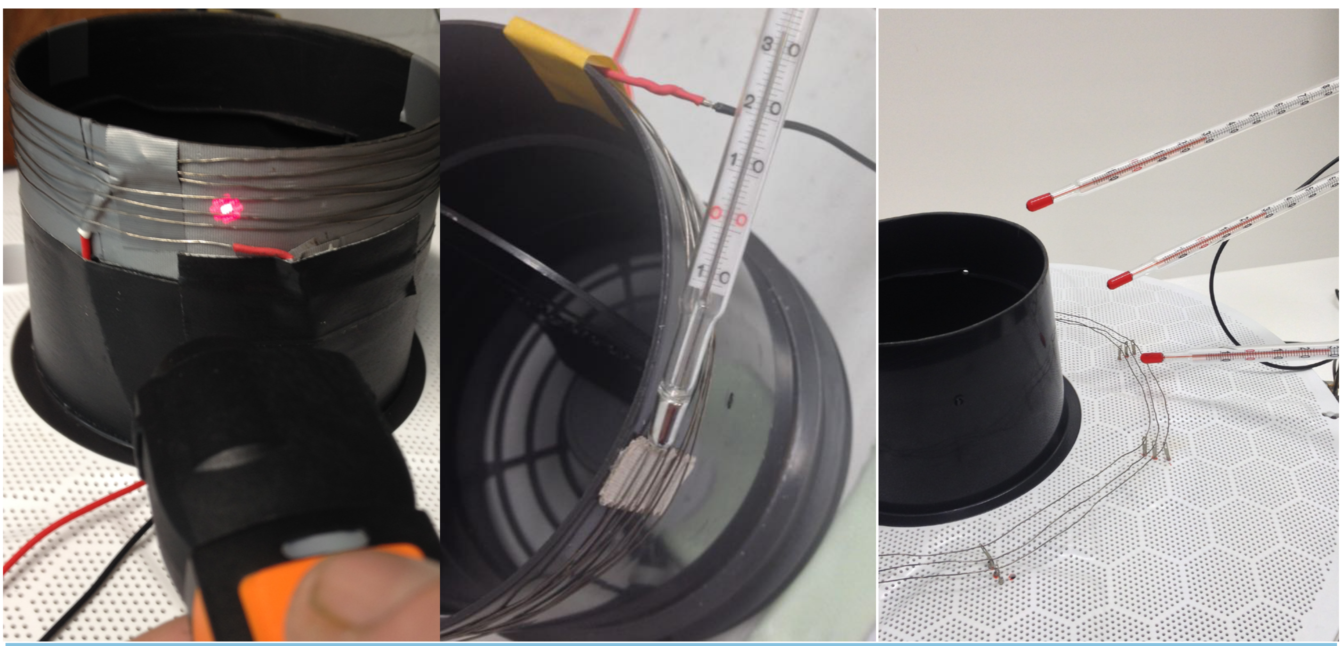
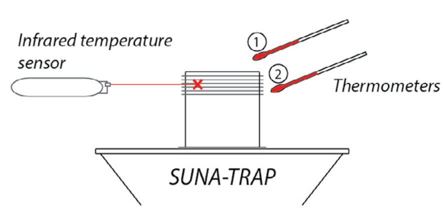


Figure 40: Heat tests analysing the effect of heating elements in concepts 1 and 2.

HEAT 1

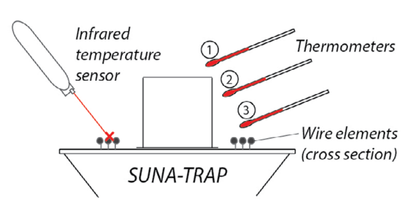
TIME (minutes)	IR Temp (°C)	POINT 1 (°C)	POINT 2 (°C)
0	25 (°C)	25 (°C)	25 (°C)
5	47 (°C)	33 (°C)	34 (°C)
20	49 (°C)	34 (°C)	36 (°C)
15	50 (°C)	35 (°C)	37 (°C)
20	49 (°C)	36 (°C)	38 (°C)



	Wire	Point 1	Point 2
Temp Increase (°C)	24	11	13

HEAT 2

TIME (minutes)	IR Temp (°C)	POINT 1 (°C)	POINT 2 (°C)	POINT 3 (°C)
0	25 (°C)	25 (°C)	25 (°C)	25 (°C)
5	27 (°C)	25.5 (°C)	25.5 (°C)	26.5 (°C)
20	28 (°C)	25.5 (°C)	26.5 (°C)	26.5(°C)
15	28 (°C)	26(°C)	26.5 (°C)	27(°C)
20	28 (°C)	26.5 (°C)	26.5(°C)	27.5(°C)



	Wire	Point 1	Point 2	Point 3
Temp Increase (°C)	3	0.5	1.0	3.0

Figure 41: Results form heat tests

Having evaluated the prototypes in the workshop, minor adjustment could be made the build quality to improve the intended performance.

It was

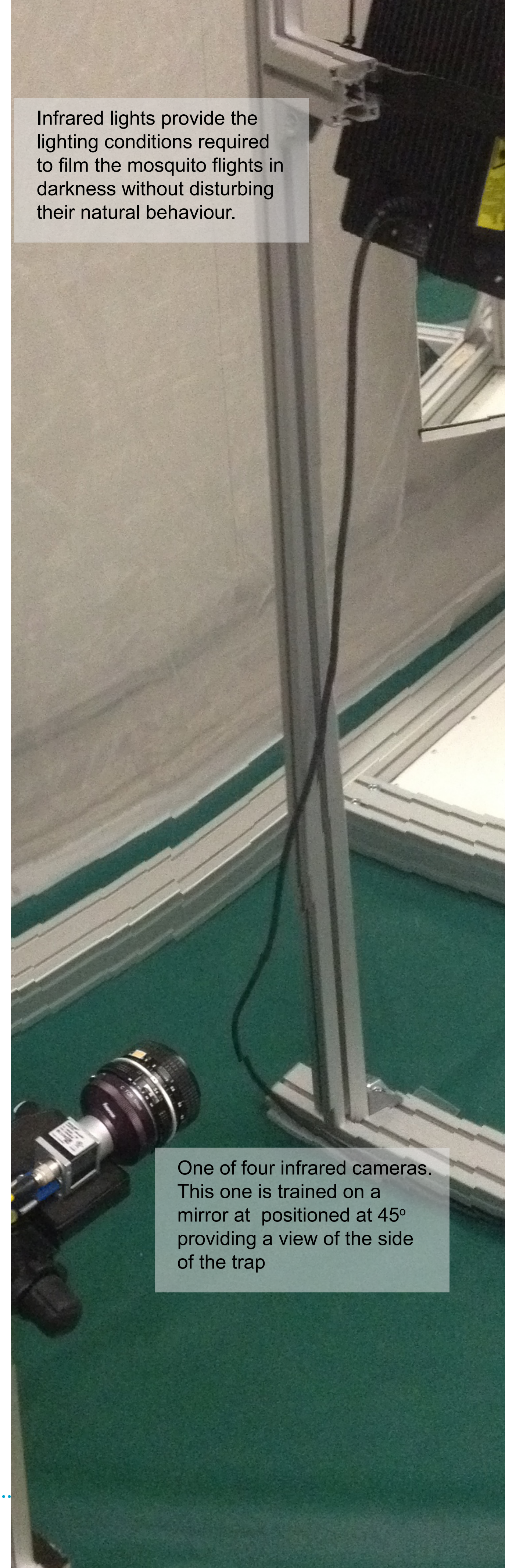
The 9 prototypes were now ready and transported to Wageningen University for testing with live vectors.

Figure 41: Measuring airspeeds at points around the trap concepts for analysis.

4.0

Chapter 4: The Proof

In this chapter the concepts developed are put to the test! Trailed in lab conditions with live targets, the performance of each concept was tested and evaluated to determine a winning principal for improving the capture rate.



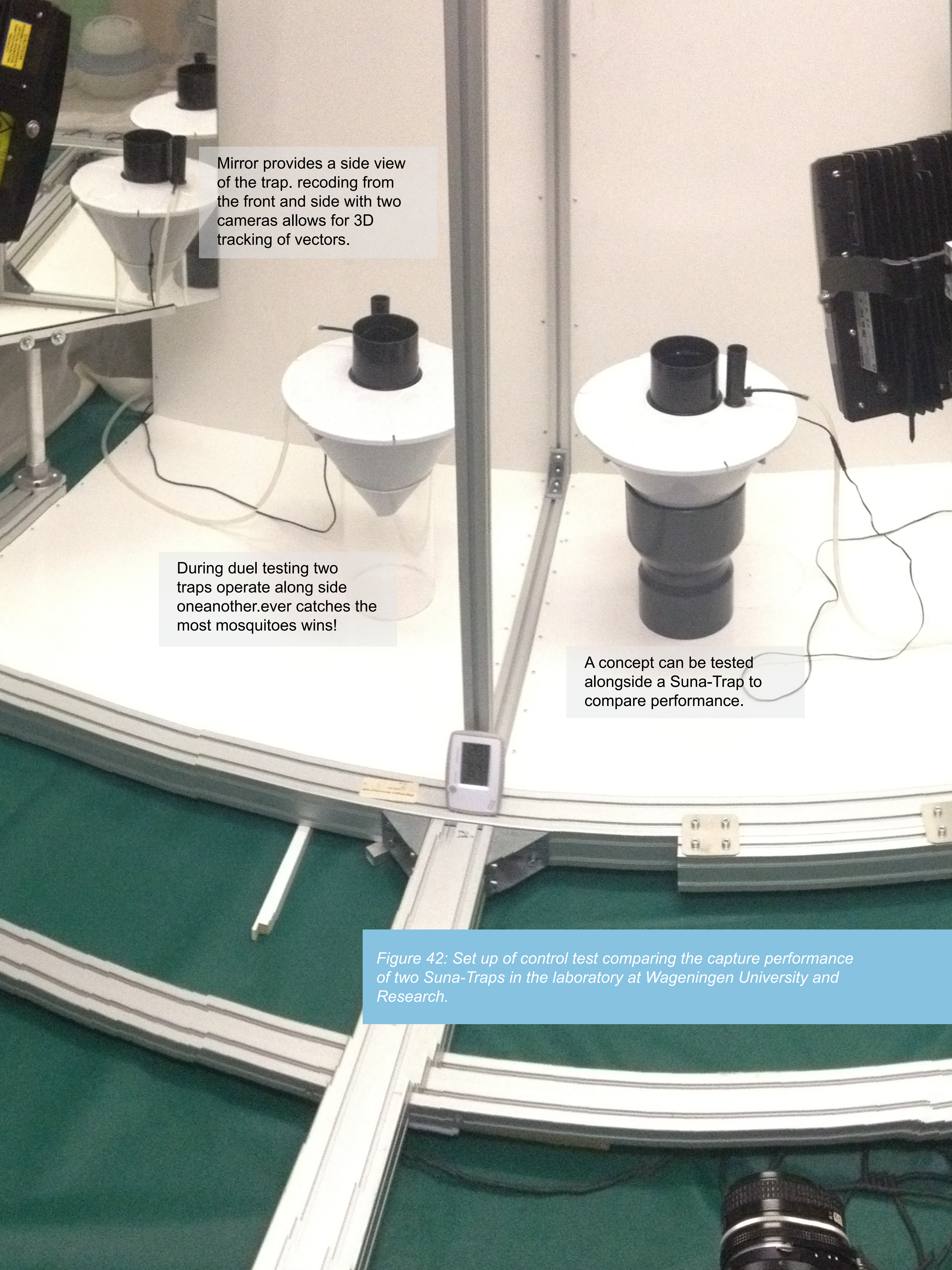


Figure 42: Set up of control test comparing the capture performance of two Suna-Traps in the laboratory at Wageningen University and Research.

4.1

THE OFFENSIVE CONCEPT TESTING

Aim

The aim of the testing is to discover which of the concepts out performs the benchmark Suna-Trap and prove a principal for increasing the capture rate. By comparing the capture rates of each new concept it should become clear which solutions offer the highest performance in terms of captures.

Objectives

- To test each concept in a duel choice test against the Suna-Trap where traps are tested simultaneously in the same environment and the captures are compares.
- Each concept should be tested 6 times in order to generate a p-value which indicates the outcome of the data relative to the hypothesis.
- The flight paths of the approaching mosquitoes should be recorded and tracked in order to better understand the approach and escape behaviours of the insects in the vicinity of the trap. This will allow for more conclusive analysis of each concept.
- All the results of the test should be recorded analysed and evaluated. The data from different concepts tested can be compared to determine the highest performing features.

Method

1. Two traps placed symmetrically in the set up.
2. IR Lights, cameras and traps are turned on
3. Under 'Moonlight Conditions' 50 Female An. Gambiae in release cage added to set up.
4. Vectors are realeased from outside of the set up and left for 20 minutes.
5. At the end of each test the traps are covered and turned off.
6. The catch bags are removed and placed in the freezer to kill the catch.
7. Capture numbers for each trap are recorded.

Planning

A plan for the experiments was constructed to test the concept 6 times within the allotted three weeks allowing some time for additional testing in case of any technical failures or external factors leading to a non-test.

Test slots were allocated to the available days, these coincide with the artificial daylight cycle of the test vectors of which are active between 08.00 and 13.00. Each concept was to be tested in a different time slot to allow for bias that might occur due to time of day.

During the experiments, concepts were to be tested on each side of the set up in case of any environmental variables which might effect the results. The odour impregnated strips where also switched between the left and right side of the set up between tests of each prototype to avoid any potential bias that may occur.

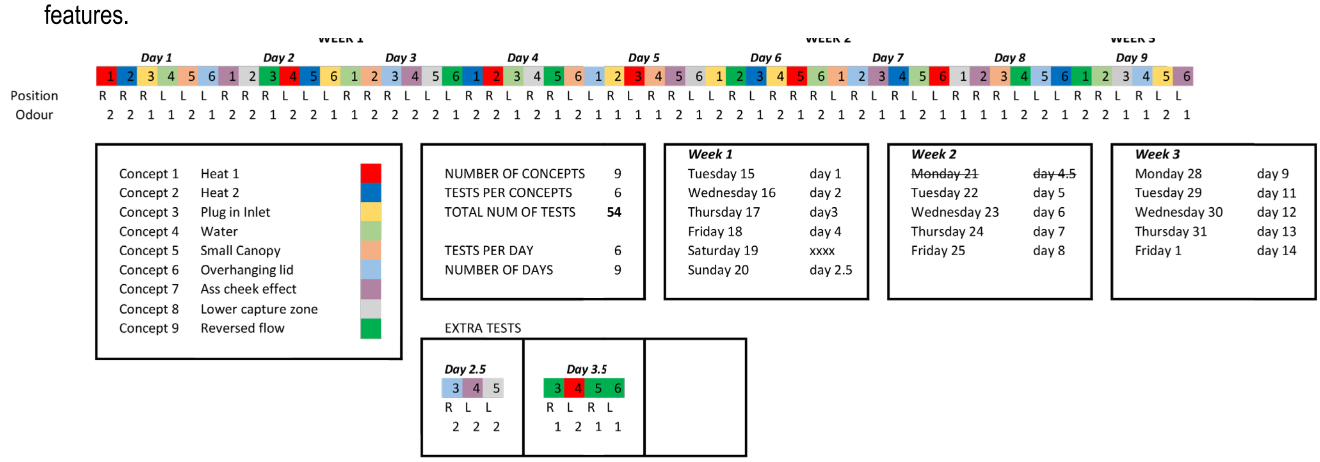


Figure 43: Schedule of testing

Setup

- A filament lamp situated close to and directed at the ceiling provides moonlight conditions.
- Infrared lights shining on the traps provide conditions for filming with infrared cameras without disrupting the test.
- 2 Infrared cameras are situated at the other and of the test tent facing each facing a trap. Flanking these are two more cameras facing towards mirrors positioned at a right angle between the trap and orientated at roughly 45 degrees. This provides the second camera with a clear view of the trap from the side. Paths recorded from the front and side view cameras can be combined to produce a 3D vector flight path.
- Each trap is situated on an adjacent, white plastic surface with white plastic wall boards behind each trap and separating the two providing a clear background for the camera view improving the ability to track recorded flights. The traps are placed so the centre of the inlet pipe, in line with the rim, is approximately 30cm from each wall and 55cm from the floor.
- CO2 used in the traps was provided by via canister at 250ml per minute (check)
- A radiator on a timer and thermostat was used to maintain the required temperature at relevant times of day
- Humidifiers were also used to maintain the correct environment for mosquito host seeking behaviour

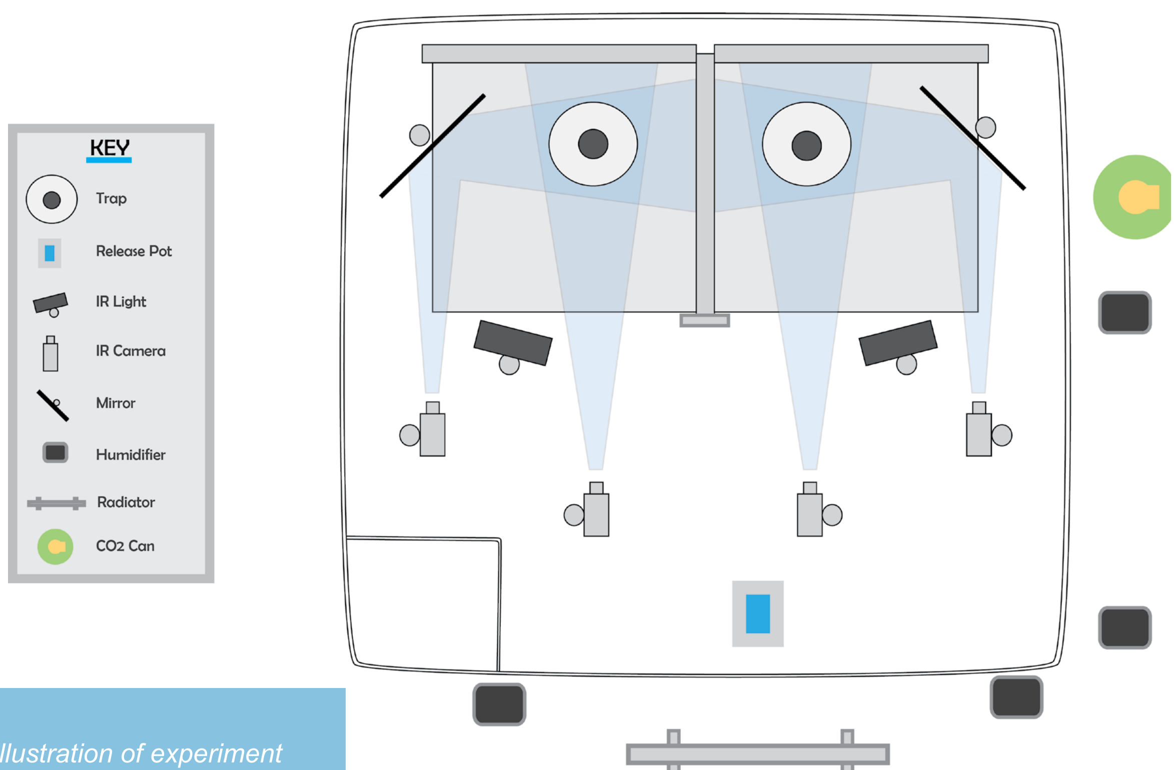


Figure 44: illustration of experiment set up.

4.2

THE AFTERMATH

RESULTS AND FINDINGS

Results were gathered and analysed progressively throughout the course of the experiment. In each test the number of target vectors captured were recorded providing a figure for the number of captures in each trap as well as the total number of captures for the test. From this data it is most interesting to analyse the percentage of total captures in the concept trap.

- If the two traps being tested perform equally well the capture percentage with be 50% for each trap (midline).
- A concept outperforming the Suna-Trap would result in a mean percentage of total captures above the 50% .
- The opposite can be said for a poor performance in comparison.

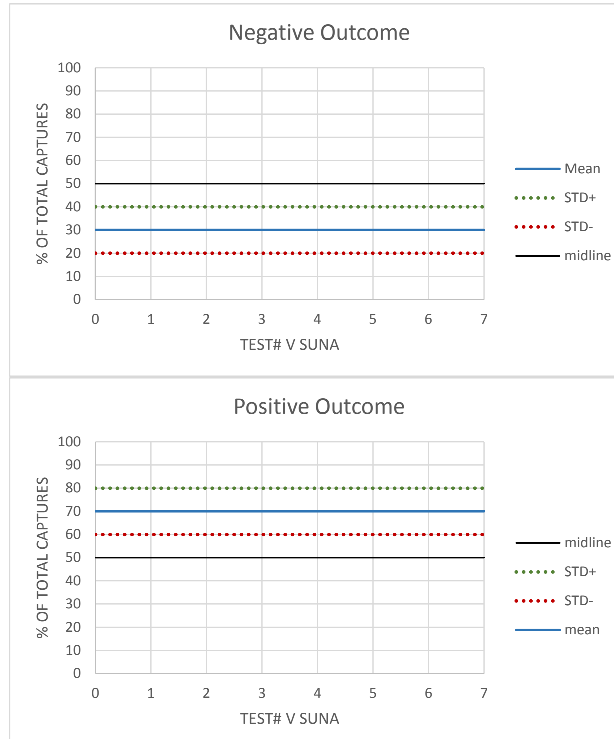


Figure 45: graphs showing hypothetical positive and negative results of concept testing.

INITIAL RESULTS

Plotting the mean capture % of each concept on a graph, as shown in figure X, shows a comparison of performance against the Suna-Trap. It can be seen that concepts 1,2 and 4, where heat and moisture are incorporated, performed best against the Suna-Trap. It could also be seen that the reversed flow concept performed very poorly even with further prototype development.

Analysing the diference between the mean % of total captures from the each concept and the point at which performance is equal to that of the Suna-Trap, 50%. It is clear from the graph shown in figure X that concepts 1,2 and 4 have the highest perfrmance and concepts 3, 6 and 9 performed far worse than the Suna-Trap.

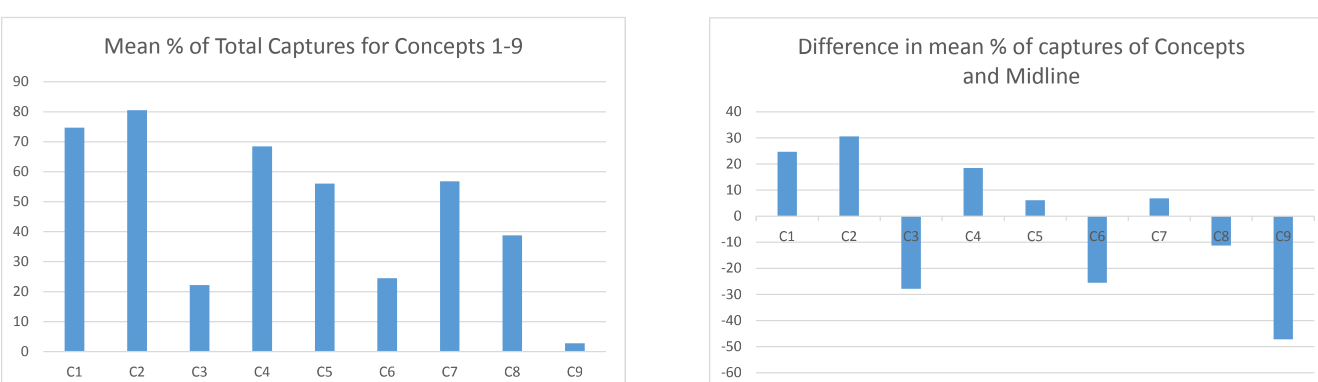


Figure 46: (left) Mean of total captures for each concept 1-9. (right) Difference in mean captures from the mid line showing comparative performance to the Suna-Trap.

Positive Outcomes

Concept 1

In the first test we could see an immediate increase in capture rate with the concept 1 catching 91.67% of the total captures, trapping 22 targets compared to only 2 captures contributed by the Suna-Trap. The following results showed a lower capture rate than the first test but still out performed the control trap. After 4 tests, it was conclusion that further tests would provide similar results and the current data was enough to draw a useful conclusion.

Concept 2

Concept 2, featuring a Nichrome wire heating element positioned above the canopy, repeatedly outperformed the Suna-Trap over the first three tests with a consistently high capture percentage in each test. This resulted in a mean capture percentage of just over 80% in duel choice experiments capturing an average of four times more than the control, a 400% improvement in capture rate.

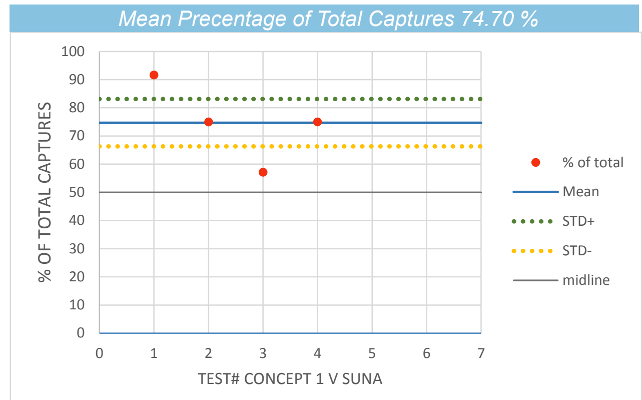
Concept 4

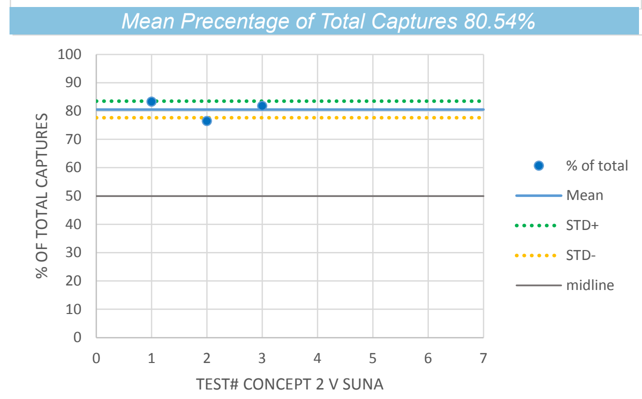
Featuring hot water in the base of the trap also, showed to have a positive effect on the capture rate in the first three tests resulting in a mean capture percentage of just over 68%. The number of captures seen in the data show reliably high performance compared to the Suna-Trap and did not need to be tested further in this way.

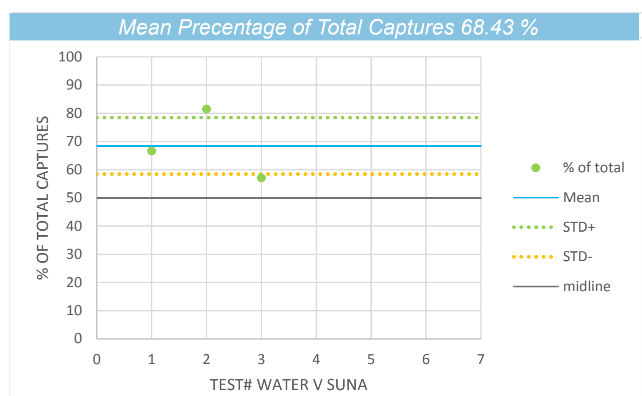
Concept 7

The application of the donut shaped base performed better than initially expected with all but one of the test results showing an improved performance with a mean capture percentage of 56%. Although this seems a minor improvement, the average capture percentage is just over 64%, a notable improvement.

Concepts 1,2 and 4 providing the addition of moisture and/or heat in the trap result in a higher capture numbers.







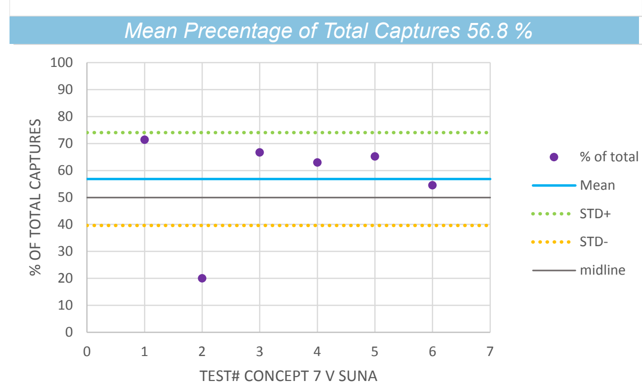


Figure 47: Scatter graphs showing positive results from initial testing. Top to bottom - Heat 1, Heat 2, Hot Water, Donut Base.

ADDITIONAL TESTING AND RESULTS

The following phase of experiments test concepts 1, 2 and 3 against each other. Three combinations were defined;

- Heat 1 v Heat 2,
- Heat 1 v Water and
- Heat 2 v Water.

It was possible to test each concept against each of the remaining two concepts four times, providing just enough data to make a preliminary conclusion as to which of the three top performing concepts was most effective.

Although there is only a small data set, the outcomes are fairly conclusive in terms of being convinced as to which concepts performs the best in this situation. Concept 2 slightly outperformed concept 1 in testing with a mean capture percentage of just over 55% and performing best in 3 out of 4 tests.Concept 4 with heated water in the trap outperformed both concepts 1 and 2 showing a mean capture percentage of approximately 58% and 62% respectively.

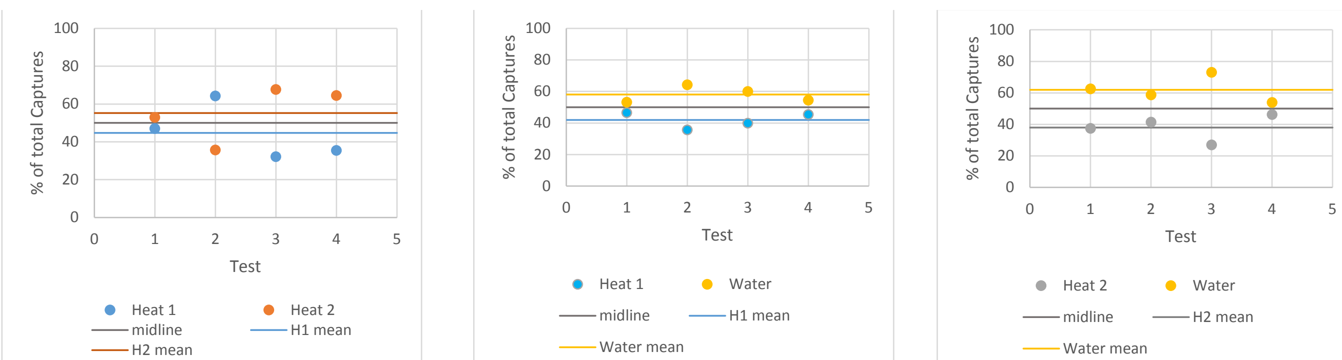


Figure 48: Scatter graphs showing the results of additional testing of concepts against one another.

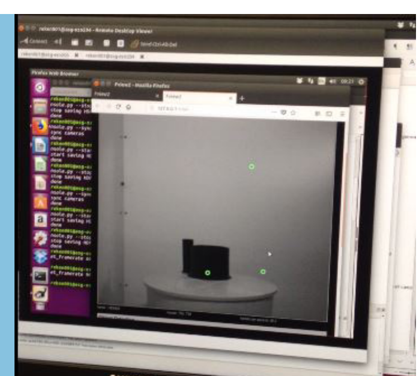
Recording, Tracking and flight path analysis

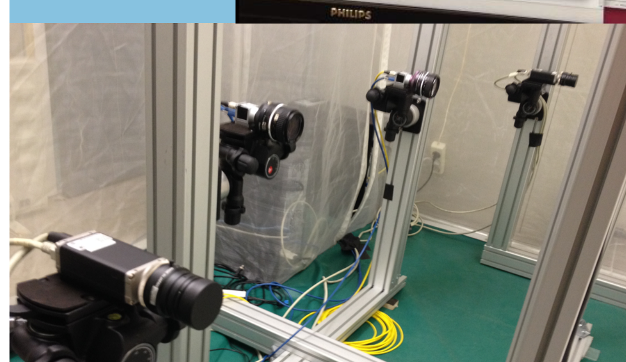
Unfortunately, the software required for 2D and 3D tracking was not working consistently and it was not possible to record the footage for analysis. However, it was still possible to retrieve outcomes based on the capture rates of the traps.

After the first week of testing, an evaluation of results was conducted. It was concluded that enough evidence had been gathered from testing concepts 1, 2 and 4 to convince the design team of a positive result. It was agreed that further testing would deliver similar results only further supporting the conclusion. The opposite can be said for concept 9 which failed to perform at all.

Further testing of these concepts against the Suna-Trap were ceased to provide time for additional tests which could provide further insights into the concepts showing elevated levels of performance.

Figure 49: (right) tracking of mosquito flight paths recorded. (below) Infrared cameras user to record activity around the trap.





Conclusion from Initial Testing

The presence of host range host cues provided by the addition of heat and moisture in the trap result in a higher capture rate. It is unclear at this stage whether this is because the additional feature make the trap more attractive to the target vectors increasing the number of flights around the trap or whether the features specifically increase the number flights into the capture zone however, the first is thought more likely. Being more attractive than the Suna-Trap results in more flights in the vicinity of the trap thus producing a higher number of captures.

From the evaluations of the hypotheses it can be concluded that the additions of heat and moisture increase the capture rate in comparison to a standard Suna-Trap. It can also be said that the alterations made to the base in concept 7 have a positive influence on the trap performance.

The addition of a heating element above the canopy showed the most notable improvement compared to the Suna in terms of capture performance. However, the addition of hot water showed to be the most preferable solution compared to the addition of only a heating element. It is thought that the additional moisture is more attractive to the target vectors increasing the number of approach flights resulting in more flights into the capture zone.

With only a low number of repetitions, the results offer some insight into which principals tested increase trap performance. Although the testing is not thorough enough to make any scientific conclusions, there is enough data to make a conclusion as to whether incorporating the feature into a new design will increase the capture rate.

Addressing the hypothesis it becomes apparent as to which concepts provide enough evidence of increased performance and should be considered in the following design.

Evaluations of Hypothesis can be found in Appendix X.

- Adding heated water out performed all concepts in duel tests
- Adding heat alone to the trap improves performance
- Concept 2 showed the most promising results in initial tests
- The Donut shaped base showed continued improvement in performance.

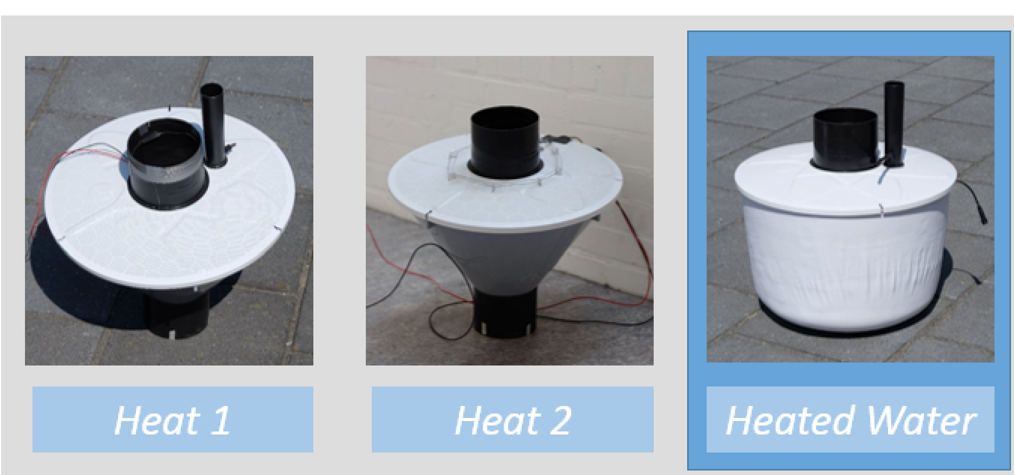


Figure 50: Conclusion of initial testing showing Hot water as the highest performing followed by Heat 1 and 2 finally the Donut Base.

4.3

THE ULTIMATE TEST
FURTHER TESTING

Having concluded upon the initial testing, the planning allowed for a further testing phase where a limited number of tests could be conducted to see how combining features from the best concepts effects performance.Tests were performed against the Suna-Trap as well as other concepts where possible. With the components available it was not possible to test all the desired combinations. For example, the addition of hot water could not be directly tested against hot water and a heating element as there was only one base part available for hot water. The test programme device allow for 3 tests of each of the following duel experiment combinations.

Hot Water and Heat 2 v Suna-Trap

Ambient Water V Suna-Trap

Hot Water V Hot Water and Donut

Hot Water v Hot Water, Donut and Heat

Hot Water + Heat 2 Vs Suna: it is expected that combining features from the most successful concepts in initial testing will result in the highest performance.

Ambient Water Vs Suna: Re-testing concept 4 with ambient water rather than hot water should provide some insight into how the trap will perform if the water is not heated. It is possible that at room temperature (approx 29^{0}C) there is enough evaporation for mosquitoes to respond to.

Hot Water Vs Hot Water + Donut: This combination aims to show whether a shallower base containing a lower volume of hot water performs as well as the original hot water concept.

Hot Water Vs Hot Water, Donut and Heat: As it was not possible to test Hot Water Vs Hot Water and Heat due to component constraints, the donut base was used for it;s ability to hold water. This test trails the highest performing concept from initial testing against a combination of all of the highest performing features.

- The combination of Hot Water and a heating element consistently produced high capture numbers in testing and outperformed the Suna-Trap as expected. Although the mean of % of total captures was not as high as seen in initial testing of individual features, the caqpture number were consistantly high suggesting the capture rate of approaches could have been improved.

	Suna V Water+Heat2			
	Suna		Water+Heat2	
Test	Captures	%	Captures	%
0				
1	13.00	30.23	30.00	69.77
2	16.00	34.04	31.00	65.96
3	13.00	39.39	20.00	60.61
4				
Mean		34.56		65.44

Figure 51: Results from further testing of Suna-Trap against Concept Heat 2

- Testing the Suna-Trap against a concept with ambient water shows that the addition of moisture doesn't increase the performance without the accompaniment of heat. The water in the trap should be at an elevated temperature from that of the surroundings in order to provide the necessary concentration gradient to attract target vectors.
- In testing, Hot Water against Hot Water with the Donut Base performed equally well. From the results it is not possible to make a clear distinction between performance of the two concepts. This suggests that a shallower base (donut) and lower volume of water does not have a negative effect the performance.
- The results show a mean % of total captures at 63% compared to hot water alone. The concept combining the hot water, heating element and donut base consistantly outperformed hot water alone, again showing high capture numbers even against Hot Water.

	H.Water V Water+Donut+H2			
	H.water		W+D+H	
Test	Captures	%	Captures	%
0				
1	16.00	40.00	24.00	60.00
2	20.00	42.55	27.00	57.45
3	13.00	27.66	34.00	72.34
4	20	42.55	27	57.45
Mean		38.19		61.81

Figure 52: Results from further testing of Hot Water against Hot Water in the Donut Base with Heating Element.

From the results it can said that the combination of Hot Water and a heating element is the best performing concept. When tested against the Suna-Trap in a duel test the new concept consistently caught more vectors than the control with high capture number being recorded. This suggests that not only is the trap more attractive but there may also be an improvement in the capture rate of approach flights.

It can be seen that 1 litre of hto water in the shallow donut base performs as well as 2 litres of hot water in a deep base (concept 4). With this in mind, the final test (combining all the features tested against hot water) can be seen as a test of Hot Water Vs Hot Water and a Heating Element. The results show the new concept outperforming Hot Water alone. This supports the claim that the combination of hot water and a heating element is the most effective for increasing capture performance.

From testing the Suna-Trap against a trap containing 2 litres of ambient water, we can see no noticable difference in performance.

This shows that it necessary to heat the water producing vapour in order to provide the necessary close range host cue. It also suggests that if hot water added cools to ambient temperature the performance of the trap is not lower than that of the Suna-Trap

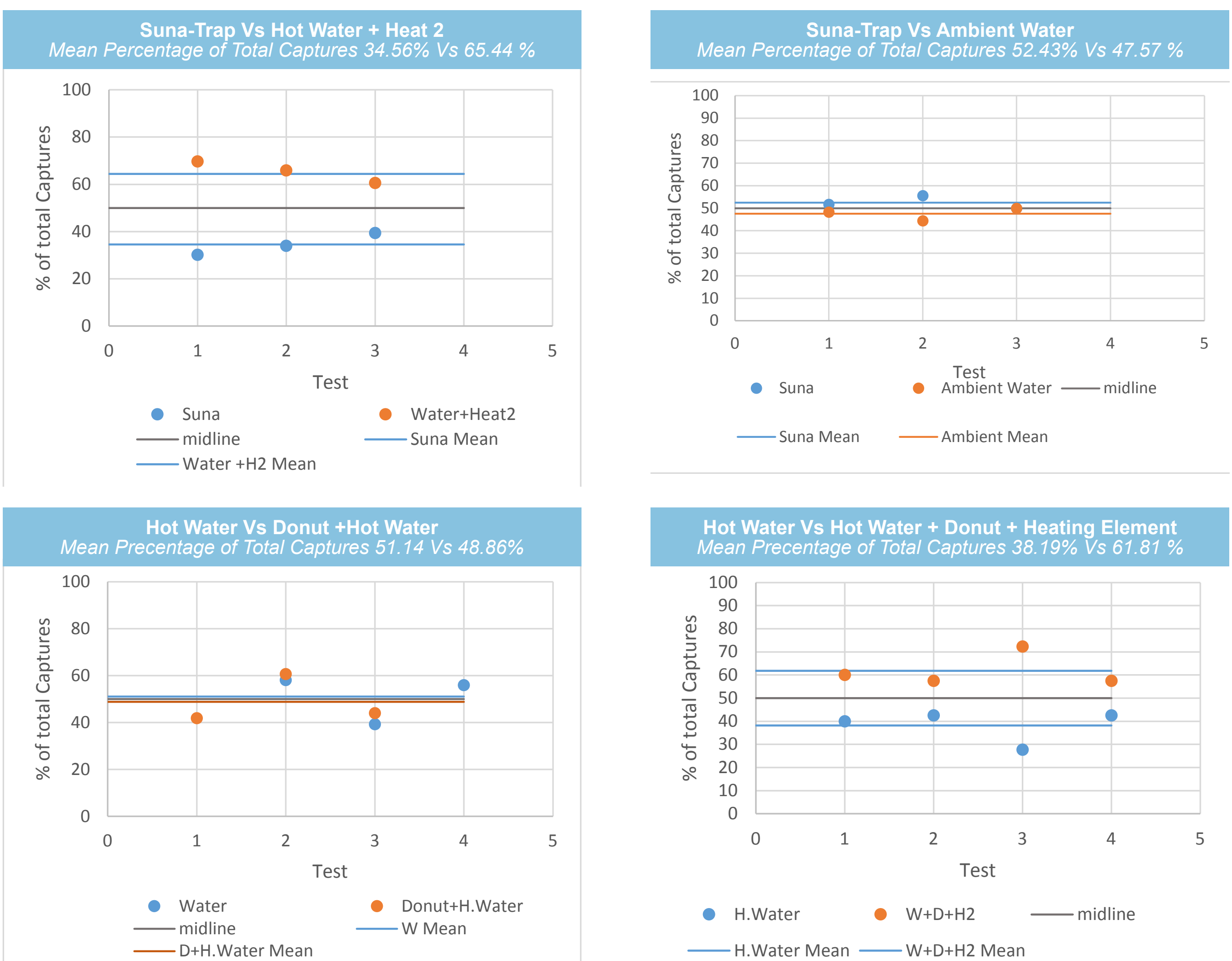


Figure 53: Scatter graphs showing results from further testing of combinations of features.

4.4

THE PROOF OF PRINCIPAL FINAL CONCLUSION

Of all the methods initially tested, providing two close range host cues to the trap with the addition of hot water has the most effect on improving performance.

From the initial testing it was concluded that the addition close range host cues to the trap improved the capture rate. A trap with the addition of hot water outperformed the Suna-trap as well as other concepts developed. It is thought that the addition of the close range host cues makes the trap more attaractive to the target vectors encouraging more approach flights leading to a high number of captures.

The addition of a heating element to the trap improves the capture performance of the Suna-Trap. A heating element situated above the canopy makes the trap more attractive whilst placing it around the rim of the inlet pipe increases capture rate.

The addition of a heating element also improved the capture performance of the trap. Placing the heating element above the canopy, warming the air expelled and providing a heat source close to the source of the odour plume showed the most improved performance. Concept 1, with the heating element placed around the rim, also showed an improvement in capture performance when tested against the Suna-Trap and it is thought that the localised heat around the inlet pipe provoke more flights into the capture zone. When tested against each other, the trap with a heating element above the canopy performed best. However, with the variance of results of individual tests it is is difficult to draw a solid conclusion as to which method of attaching a heating element is best. Without the analysis of flight recordings it is difficult to understand exactly how the addition of heat in each way effects capture performance.

Reducing the volume inside the trap and altering the airflow with a 'Donut Shaped' base has a slight improvement on the capture performance of the trap.

Concept 7 showed a consistant increased performance over the Suna-Trap catching more vectors in all tests but one. It is thought the saturation of air and odour and it's expulsion from the trap are improved making it more attractive than the control.

The gaseous volume inside the trap was further reduced when 1 litre of hot water was added in further testing. This concept performed as well as the deep base trap containing two litres of hot water. This suggests that a shallower base and reduced volume of air inside the trap improves the capture rate.

A trap with a combination of hot water to and a heat source is the most effect method of increasing capture performance of all the concepts tested.

It is thought the addition of hot water makes the trap more attractive and the electrical heating element provides a more localised heat source affecting the approach flight behaviour. However, the addition of a heating element required more power form the system and the addition of hot water results in increase energy requirement to heat the water as well as human input to fill the trap.

Figure 54: Top performing concept combing Hot Water and Heat 2 concepts.

If the hot water added to the trap cools to ambient temperature it not longer has an effect on improving the capture performance.

Adding ambient water to the trap does not seem to provide the necessary cues to mimic human presence and does not promote approach flights by the vectors. The ambient water also does not hinder the performance with the concept performing equally well as the Suna-Trap.

The combination of Hot Water in the base of the trap and an additional Heating Element around the inlet pipe would be the most effective method of improving the capture rate.

Results form initial testing showed that concept 2, positioning the heating element above the canopy, performed better than when it was situated around the rim of the inlet pipe in concept 1. It is thought that concept 2 was more attractive to mosquitoes but concept 1 lead to an increase in capture rate of approach flights. Concept two performed better as the majority of targets released approached that trap.

With this in mind, it is expected that a combination of Hot Water and a Heating Element placed around the rim of the inlet pipe could be the most effective principal for highest performance. The hot water would provide the necessary host cues to make the trap more attractive and cause increased approach flights towards the trap. With more vectors within close range of the trap, the heating element, producing a localised area of warmth around the rim of the inlet pipe, would promote more of these approach flights into the capture zone. Hence, resulting in the greatest increase in performance.

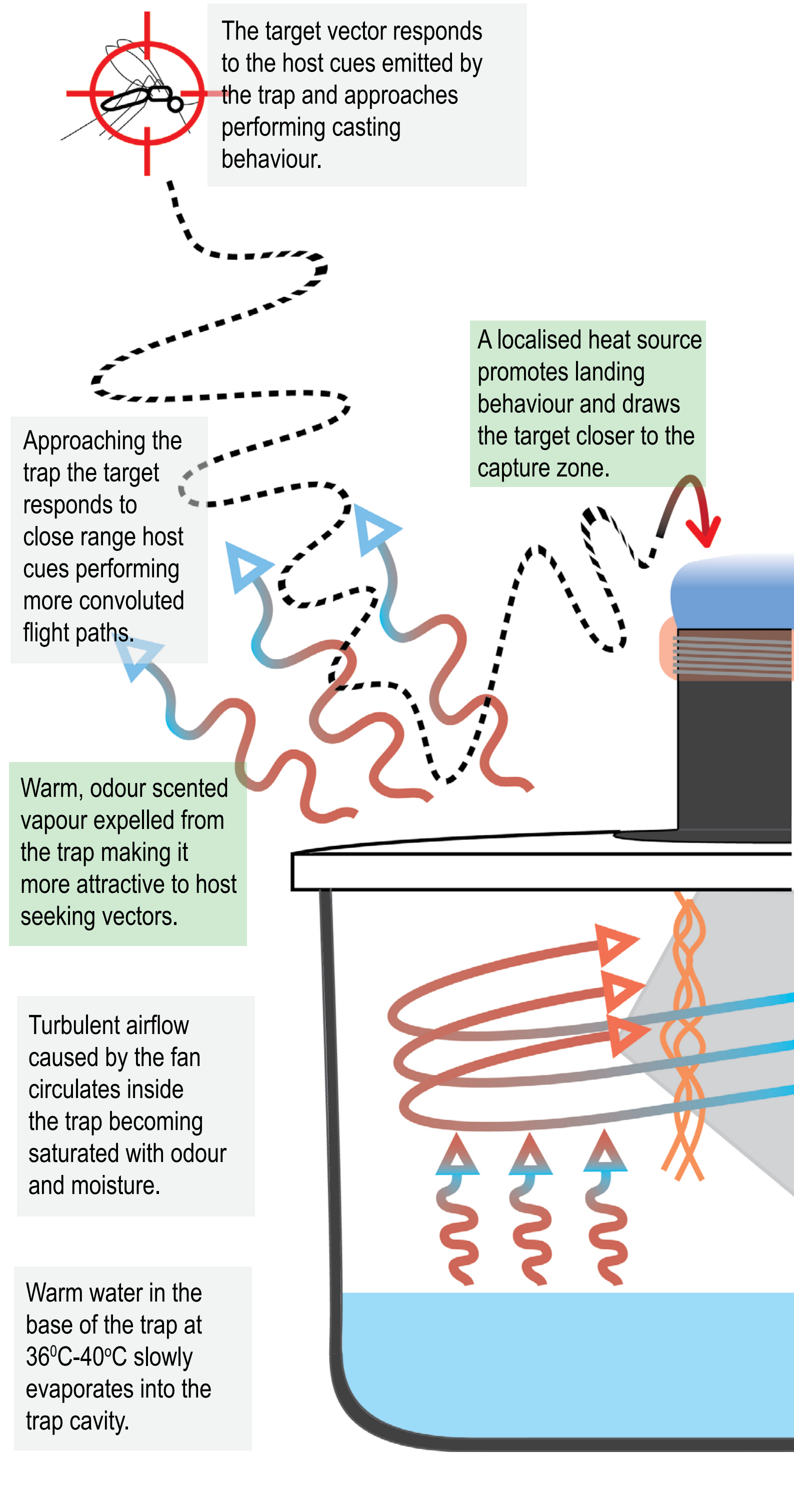


Figure 55: Visualisation of expected performance of the combination of Hot Water and a Heating Element

5.0

Chapter 5: The Challenge

Looking into the context, from a distance, this chapter investigates how mosquito traps perform in the field in terms of malaria prevention and what social, economic and environmental factors influence the design process and product solution.

Figure 56: User Checking the Suna-Trap on Rusinga Island, Kenya, during the SolarMal trial.

5.1

THE BATTLE FIELD
CONTEXT RESEARCH

In order for a mosquito trapping solution to work as an effective tool for malaria prevention, it is critical the solution is appropriate for use in context. It is important to investigate and understand the environment in which the trap is situated, the users interacting with the product and the factors and challenges faced. Context factors investigated which can then be taken into consideration during the design process leading to a more appropriate concept.

Who? Where? and Why?

Sub-Saharan Africa has posed a number of overwhelming geographical, social and economic challenges to malaria prevention over the last 60 years due to a very diverse range of environments, people and cultures as well as political boarders. The research undertaken for this project focusses on the East cost of central Africa, more specifically Kenya and Tanzania, as a number of previous studies conducted in this region provide literary resources of which can be investigated.

Although, as previously discussed, traps are commonly used by research teams for collecting samples of the mosquito populations this project addresses the use of the trap as a tool for malaria prevention so must consider the factors associated with this intended use of the trap. The use of the trap as a research tool will be considered as a secondary use in the design process.

It wasn't until 2012 a trail was conducted to investigate whether the mass trapping of mosquitoes could contribute to reduction in cases of Malaria. The SolarMal trial took place on the Kenyan Island of Rusinga with the aim to investigate if the mass implementation of mosquito traps, across the whole island, had an effect on the number of cases of malaria over 3 years (Hiscox, 2016).

The project spanned over three years from 2012-2015. Traps were implemented to bolster the nationwide strategy of malaria prevention through combined methods of vector control using long lasting insecticide treated bed nets (LLINs) and early treatment of malaria cases. The project encompassed the entire island involving all of the households on the situated on the island at the time. Systems installed remained with the household after the trial was completed.(Hiscox. 2016)

The study, as well as supporting studies conducted after the initial trial provide valuable information regarding the performance and use of the trap in a context scenario.

RESEARCH QUESTIONS

A number of areas, focusing on the context, user interaction and user product experience, must be analysed in order to answer the following research questions outlined.

1. *What was the effect of mass trapping on cases of malaria and mosquito population on Rusinga Island.*
2. *What level of community participation was required throughout the study and was this achieved?*
3. *How are the SMoTs distributed and installed in homes across the the island and what were the main challenges faced during the roll out?*
4. *How much user input is required from the homeowners and were participants able to use the trap and system?*
5. *What are the maintenance and upkeep requirements to sustain the function and performance of the trap. What were the main causes of faults and how were they fixed?*
6. *How did the product service system operate and what measures were taken to ensure it's sustainability?*
7. *Were the Islanders able to maintain the trap and product service system after the SolarMal team left Rusinga?*
8. *What are the system and maintenance costs associated with the SMoTs over the period of the trial?*

5.2

THE TRIAL:
SOLARMAL EXPERIMENT

Led by researchers from Wageningen University and Research collaborating with the Kenyan International Centre of Insect Physiology and Ecology (ICIPE) and the Swiss Tropical and Public Health Institute (Swiss TPH), The SolarMal Project was the first field trial using mosquito traps alongside long lasting insecticide treated bed nets (LLINs) as a form of Malaria prevention.

Households across the island were split into 81 clusters of 50-51 houses and traps were rolled out cluster by cluster over a two year period from 2012-2015. Each of the 4358 households were provided with a solar powered mosquito trap system (SMoT) (Holman, 2016) developed alongside Siempre Verde (Netherlands). Requiring electricity to operate, the Suna trap was provided with a 20W solar panel, a 12V/12Ah battery and a solar charge controller. The controller manages the charging of the battery and timer for the trap so that it only operates (using valuable power) from dusk until dawn when vectors are actively host seeking.

Traps were installed, monitored and maintained by a product service system managed by the SolarMal research team alongside local volunteers.

The primary objective of the SolarMal project was to determine the effects of mass trapping on clinical malaria. Secondary objectives aimed to discover the entomological and social effects of mass trapping of mosquitoes on the island; whether the introduction of mass trapping had an effect on mosquito population and species composition and how the social, behavioural and organisational context factors influence the effectiveness and sustained use of traps (Hiscox et al., 2016). The results of the secondary objective, especially the context factors effecting sustainable use are most interesting to investigate, understand and consider during the design process.

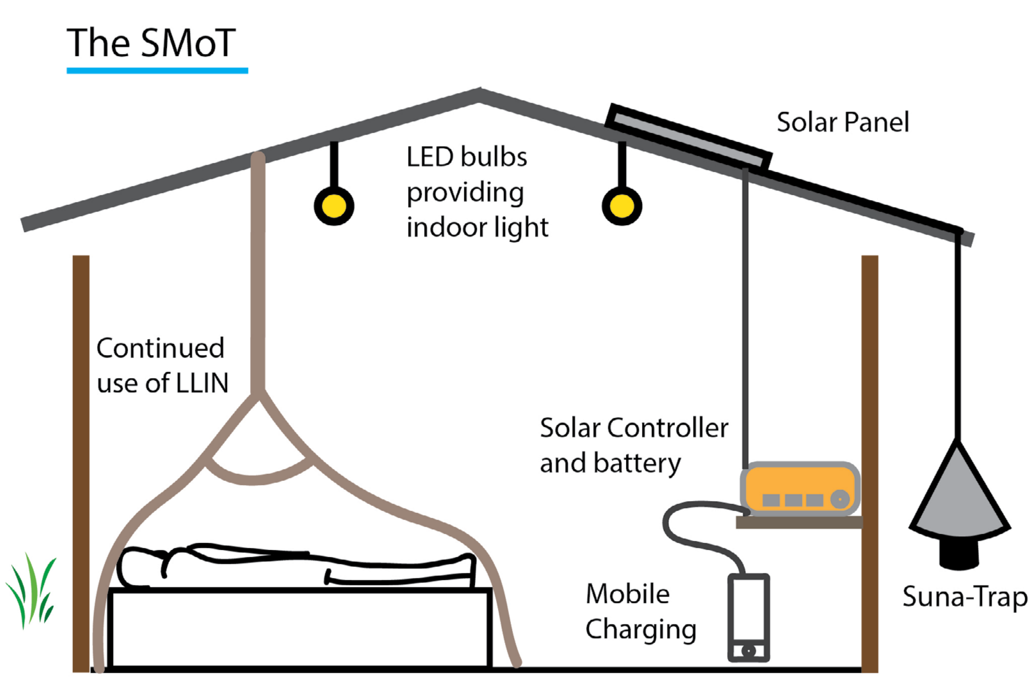


Figure 57: Illustration of the Solar powered Mosquito Trapping System as used in the SolarMal trial.

Results

Primary Objective:

Results from the clinical study show that the implementation of mosquito traps across the island lead to a 30 % reduction in cases of malaria after the three years. Fewer cases of malaria were recorded in households with a trap compared to those waiting for a trap to be installed (Homan et al. 2016).

Secondary Objectives:

Trapping host seeking mosquitoes interrupts the reproductive cycle of the vector leading to a population reduction. The effects of mass trapping across Rusinga resulted in 70% reduction in the Anopheles population (Homan et al. 2016).

With the support of the SolarMal team a sustainable product service system was maintained throughout the trial and the local perception of the SMoT system was positive. Both qualitative and quantitative data was gathered in social studies over the three years through focus group discussions, questionnaires, observations and interviews. The lights implemented with the system provided noticeable immediate benefit to the users as well as saving them money on Kerosene for lamps. However, the social studies highlighted a number of challenges faced during and after the trial.

Analysis of the social studies conducted will highlight factors and challenges faced implementing and sustaining the use of traps in the field. The research hopes provide a better understanding of the context and user in which the trap is to be designed for.

Figure 58: Infographic of the Context of the SolarMal Trial (source Wageningen University and Research)

5.3

CALL FOR A CAB: COMMUNITY ADVISORY BOARD

Installation of the systems lasted from June 2013 through to May 2015 and ran alongside a social initiative aimed at harnessing and enhancing community knowledge and support throughout the trial.

Community Advisory Boards (CAB's) were initiated around the island to aid the roll out of traps and monitoring of participants and traps throughout the experiment. The CAB consisted of 16 representatives including government administration. healthcare workers, church officials as well as to lay community members. and enabled communication between the community and research team. The research team, with advice and insights from the CAB, were able to build a product service system for the installation, maintenance and repairs to the trapping system over the course of the project.

The relationship between the board and the research team was critical when addressing challenges such as;

- rolling out and installing traps,
- creating a system to supply all the 400+ houses with yeast and molases every day
- provision of replacement odours for the traps.

Community members were given the appropriate training to maintain a sustainable system with the idea that the service would continue to run and support continued trapping of malarial vectors after the project had ended and the research team had left the island.

The study highlights the benefits of mass trapping, when used in combination with LLIN's and increased community knowledge and awareness, to the reduction of malaria. The implementation of odour baited mosquito traps resulted in a 70% decline in the population of the most significant mosquito on Rusinga and lead to a 30% decrease in malaria cases between homes fitted with a trap compared to those without (Homan et al. 2016). Situated next to the outside of the house, ideally 30cm from the ground, the traps showed to reduce mosquito home entry by 32.2% during the trial (Hiscox, Otieno et al. 2014) which reduces night biting and nuisance within the home.

Figure 59: Community Advisory Board set up during the SolarMal trial on Rusinga Island.

5.4

LAYING THE TRAP: INSTALLATION

For the purpose of the SolarMal research project, SMoTs featuring Suna-Traps were rolled out to 4358 households across Rusinga Island the SolarMal team and local technicians installed the SMoTs across 81 clusters of 50 or 51 houses over a 2 year period. Each week traps were implemented across a different cluster. (Hiscox, Homan et al. 2016).

Hiscox reports in an interview that many of the home owners lived in remote rural locations and Suna-Trap parts including bulky cones and canopies needed to be loaded into a Toyota Hilux truck and distributed, across country, throughout the day. some of the homes were in more remote rural locations and systems had to be carries to homes for installation (figure x). She also highlights that although the traps seem quite simple there are still a number of parts to assemble on location (Interview with A. Hiscox Appendix 4).The installation requires trained technicians to fit the solar panel, battery, controller and trap.

During the installation of the traps and throughout the course of the study listening surveys, questionnaires and focus group discussions helped to gather information the community and build links with locals during the installation of the SMoTs. Community members were informed to contact a project community liaison officer and the SolarMal technicians by phone to report any faults in the system. (Hiscox, Holman et al. 2016).

Figure 60: Technicians and volunteers transporting system parts and installing SMOTs

5.5

KEEPING UP APPEARANCES: USABILITY IN THE FIELD

Human input is required to keep the trap in good working order. The trap must emptied of captures, cleaned and kept clear of obstructions to work effectively. It is important to understand the user input requirements and the successes and failures during field trials in order to design a trap in which homeowners are able to operate and maintain in working order. The key user interactions with the product are during upkeep - cleaning and emptying the trap and maintenance of breakdowns to keep the system working. In order to encourage sustained user interest the design should deliver a positive interaction which does not perceived as a burden.

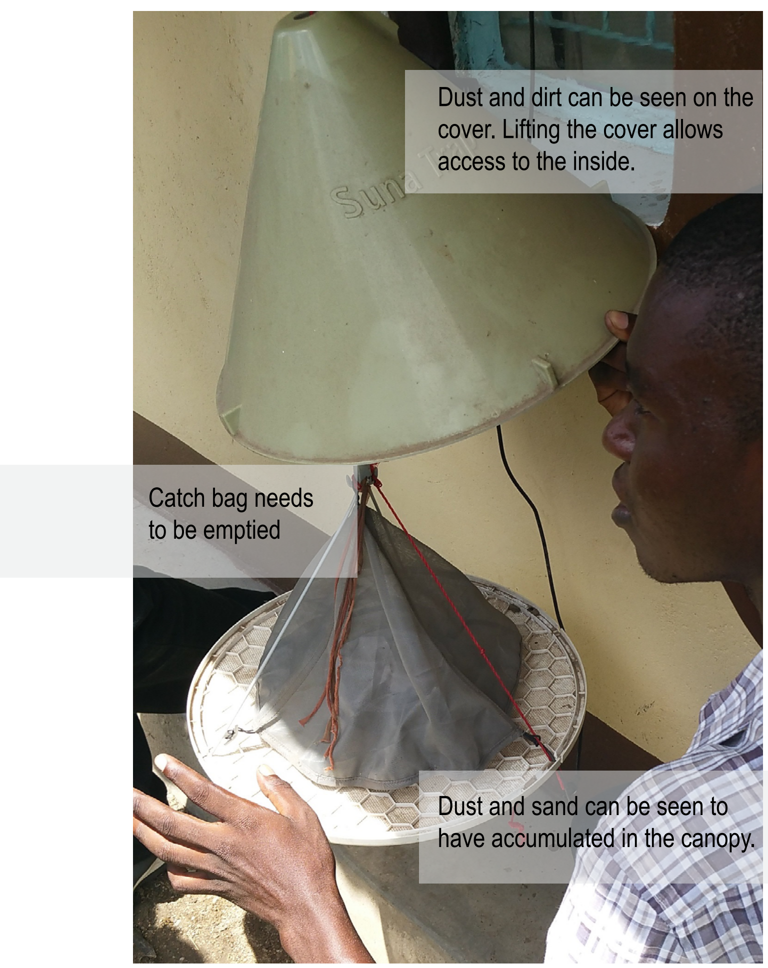


Figure 61: User checking the Suna-Trap on the Kenyan Island of Rusinga.

Cleaning and Upkeep

During the SolarMal project, homeowners participating were advised to empty the trap at least once a week, performing any additional upkeep related tasks such as cleaning the trap or clearing blockages. Local participants saw the traps as a preventative health care method and generally took care of the system throughout the study as advised.

In an interview, Hiscox explains how the traps should be cleaned weekly to remove sand (especially in the dry season) and any debris which may obstruct the trap. Spiders also manage to get into the trap and in some cases built webs in or around the trap. Inspections conducted during the study on Rusinga showed that homeowners were able to take care of the upkeep of the traps as suggested. 33% of the 100 traps inspected were clean, in good condition, had been emptied and were protected (by a fence). Another 55% of the traps were in fair condition and only 12% were in poor condition - the traps were working but were dusty/unclean, had not been emptied or weren't protected from livestock (Ketelaars et al,. 2015) Traps in this condition suggest the homeowners were more neglective of the traps and were not keeping with the advice produced for upkeep.

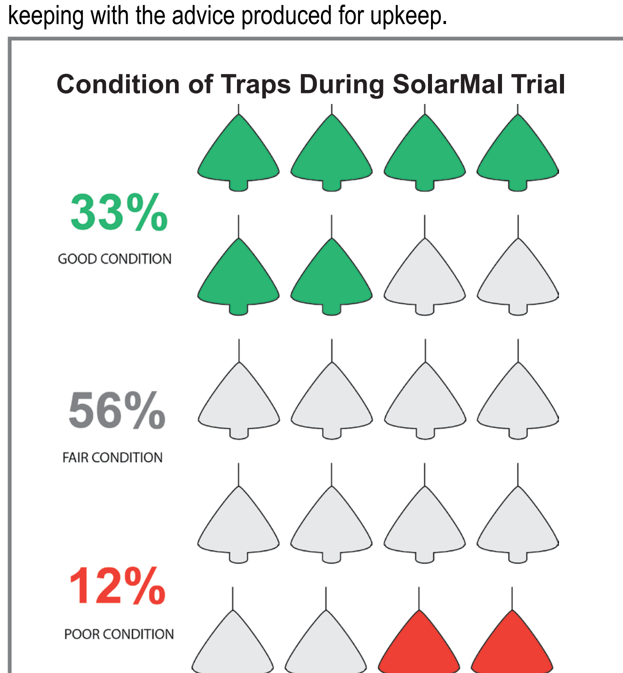
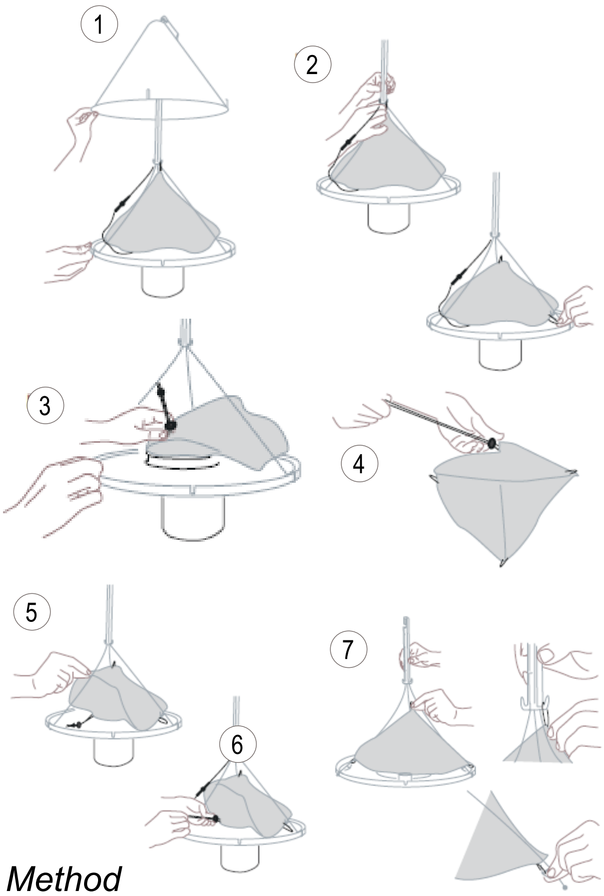


Figure 62: Infographic illustrating the condition of traps during the SolarMal Trial

Emptying the Catch Bag



Method

1. Lift lid of the trap and secure to suspension cable.
2. Unhook the bottom of the bag followed by the side fixings.
3. Loosen the drawstring and slide bag off the fan.
4. Pull drawstring to contain catch.
5. After Emptying, refit the bag over the fan.
6. Pull the drawstring so the bag is tightly fitted.
7. Reattach bag to the suspension chords and replace lid.

Figure 63: How to remove the catch bag (source BioGents.com)

The main user interaction with the product is experienced when emptying the catch bag and cleaning the trap. It is recommended to carry out these tasks once a week.

The catch bag is orientated with the opening at the bottom, attached to the back of the fan. It is attached to the trap suspension chords to hold its form. To empty the bag it must be removed and replaced which takes a number of steps, shown in figure 63.

The catch bag is fixed at a number of points which require a degree of dexterity to fix and remove. First hand experience, during the testing process outlined in chapter 4, highlighted the difficulties faced when emptying the catch-bag. During lab testing captives were generally alive in the bag when it is being removed from the trap. Loosening the bag, removing it from the fan and tightening the drawstring whilst avoiding any mosquito escapes proved to be a difficult. Refitting the bag was also time consuming ensuring the bad was properly fitted - tightly fitted to the back of the fan and not twisted.

Household surveys conducted in 2016, 1 year after the SolarMal trial, investigated how often homeowners thought the trap should be emptied and maintained. Results are shown in the table below. The 84 participants gave answers varying from every day to every two months with the majority of participants answering 'every week'. (Tubben, 2017)

Answers	Frequency
Every day	1
After two days	1
Three times a week	1
Every three days	2
After four of five days	2
Every week	29
Every one or two weeks	1
Every two weeks	9
Currently every three weeks	1
Once or twice a month	1
Every two months	2
It is not working, so I never clean it	1
Never, the trap is gone	2
During the project weekly, now I don't know	1

Figure 64: Table showing the reported frequency in which participants thought the trap should be cleaned and emptied. (by Tubben 2017)

5.6

HUNNY, I BROKE THE TRAP: MAINTENANCE

The involvement of the SolarMal team was crucial to the sustained running of the systems throughout the three year trial, building a network of contact and distribution points for information and spare parts.

During the Trial

The project team often checked randomly selected systems throughout the clusters to monitor catches and ensure systems were operating. During the SolarMal trial 20 local technicians, each assigned to a different area of the island, were trained to repair and maintain the systems. Spare parts were made available form Hajo Electrical store in th town of Mbita and is was recommended technicians and homeowners went there if needed. A phone number for the local technician was written on the system box so homeowners could report breakdowns (Tubben 2016). 314 breakdowns were reported by homeowners from the beginning of the experiment up until 2014. Most of the reports concerned faulty USB ports (25.7%) and the system turning off before sunrise (21.4%) (Hiscox, 2014).

From the investigations of studies conducted during the SolarMal trial it seems the product service system implemented, bolstered with help from the research team, were able to sustain the network of working systems. However, in the first two years after the start of the installation process it is expected there would be fewer malfunctions.

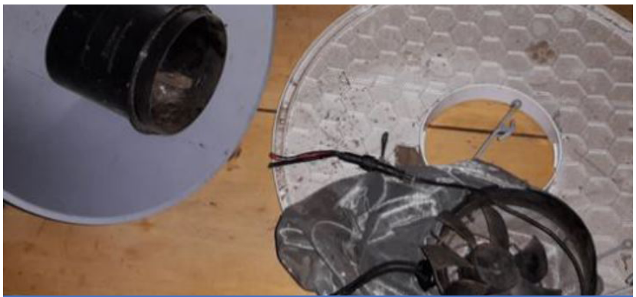
After the Trail

A study by N.Tebben in 2016 investigated whether owners were able to maintain the system without the support to the research team. The functionality of the SMoTs was analysed after 9-11 months of use following the end of the SolarMal trial. The main reasons for maintenance and the costs incurred over the period of use were among factors investigated. The condition of the systems and traps were observed in the field during visits to 81 homes. During visits interviews were conducted with homeowners to better understand how they responded to breakdowns, if it was possible to repair and the costs incurred.

The report describes that of the 81 homes inspected, only 4 (4.9%) had fully maintained the system and it was functioning as it should. Of the 65 homes still with the trap, 10 traps were still functioning and a further 7 worked with minor interference resulting in a total of 17 working traps (26.2%).

The presence of working light bulbs was also monitored and it was found that 62 out of 81 of the homes had working lights, 75% percent compared to 26.2% of working traps (Tebben. 2017).

Of the 54 participants interviewed in 2016 34 admitted at least part of the system had broken down since it was installed. The most frequently mentioned problem was the malfunctioning of the light. During interviews with 54 participants, Tubben writes that 34 respondents reported that at least part of the SMoT broke down. The table below shows that at least 6 (17.6%) of the reported breakdowns were directly related to the trap. Of the 54 interviews, only 13 participants managed to resolve the issue, either with the help of a technician or by themselves. Of those who failed to maintain the traps, reasons for not doing so included a lack of trust that neighbours were also taking care of the trap, users were unsure of who to contact for maintenance or where the spare parts shop was.



Problems	Frequency (n)
the bulb(s) broke down	21
the battery died	8
the trap is not working	5
the system doesn't last the entire night	4
the switch broke down	2
the cover of the Suna trap broke	1
the charger doesn't function well	1
the trap is stolen	1
the wires are broken	1
the battery is stolen	1

Figure 65: Picture showing example of trap found disregarded and table showing the frequency of reported breakdowns

Repairing the System

Of the 20 trained maintenance technicians spread across the island, some were still operating a service in 2016 and 15 were interviewed by N. Tubben with many reporting then had been receiving calls regarding breakdowns. One of these interviewees had maintained a record of call out's dating from January to September 2016. In this period the technician repaired 42 reported breakdowns which included calls regarding broken lights (#31), battery low, off or stolen (#10) and the trap not working (#5).

In the cases where breakdowns are reported after the SolarMal trial, respondent technicians would often make small fixes for free,for more substantial repairs requiring replacement parts a fee was arrange and to be paid by the homeowner (Tebben 2017).

Costs of repairs investigated during the study ranged from 0-7500 Kenyan Shillings (KSh) with replacement batteries being most costly. The batteries originally installed by the SolarMal team were imported from China and cost between € 22.90 to €27.45 whereas the batteries available from the shop in Mbita were inflated costing €64 to €73 (7000KSh to 8000KSh). Spare parts for the traps were not available after the research team had departed.

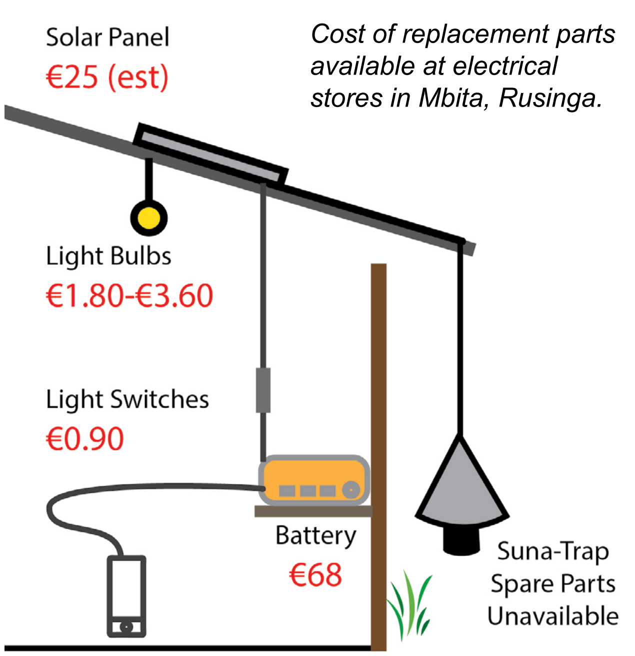


Figure 66: Illustration of costs of replacement components available at the electrical stores on Mbita (in 2016)

Having found a number of systems not working, N.Tubben proceeds to investigate why SMoT owners had not maintained the system. The report concludes that the lack of sense of ownership, 43 participants of a focus group discussion maintained that an *icipe* or former SolarMal employee, 'the whites who brought the system', should be responsible for maintenance (Tubben. 2017).

MAINTENANCE ISSUES

- *Lack of sense of ownership lead to users not feeling responsible reporting or fixing breakdowns.*
- *Light bulbs and switches were the most frequently reported faults. Perhaps as the lights are most important feature.*
- *SMoT owners didn't know how to contact a technician for maintenance.*
- *Owners didn't know about the spare parts shop or who to ask about where to find it.*
- *Although some easy fixes could be performed users lacked the knowledge of how to maintain the system.*
- *Cost of repairs up to €73 do to local prices of electrical components.*

5.7

SEEING IS BELIEVING
USER PERCEPTION

During social studies carried out during the SolarMal experiment, the user perception of the system was investigated. During focus group discussions, participants were asked; what they found to be the most important service provided by the system, whether they are convinced the trap is a beneficial tool for prevention of malaria and if they are willing to pay for maintenance.

Perception of trap

SMoT owners who valued the importance of the trap was attributed to a reduction in mosquitoes in the home and bites experienced (Ketelaars et al,. 2015). During focus group discussions the consensus was drawn that is was predominantly women who concerned themselves with the system and were mostly responsible for the maintenance.

The majority of participants (at least 3/4) recognised the trap as a tool for malaria prevention and experienced less biting and less malaria since the trap was installed (Ketelaars et al,. 2015). Due to the benefits provided by the system, participants showed a willingness to maintain the system and pay for/contribute to pay for its upkeep.

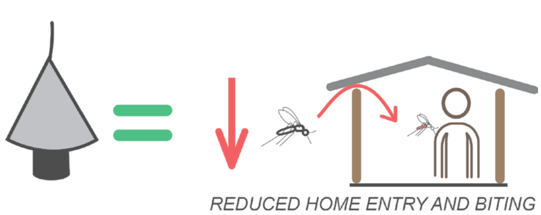


Figure 68: Traps perceived to reduce vector home entry.

Most Important Features

Of the 100 respondents to the focus group discussion, 81% said the light was the most important feature of the system. the two main reasons given for the prioritisation of the light was that it saved money on kerosene, which was used in lamps, and the ability to perform tasks in the home after dark. 76% of responses mentioned the trap among the most important features with17% of participants mentioned the trap as the most important and 23% mentioned it second. (Ketelaars et al,. 2015)

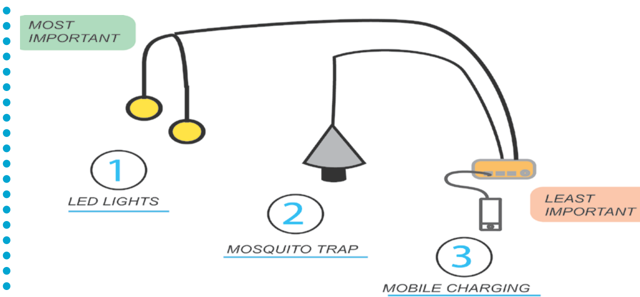


Figure 67: Features prioritised by users

Willingness to Pay

A survey was conducted as to participant willingness to pay for maintenance to the system and almost all were willing to pay at least 200Ksh (€1.73) per month. On average, people were willing to pay 424KSh (€3.67) with a maximum response of 1500KSh (€13) per month [Based on current conversion rate]. The research concludes that homeowners would most likely be prepared to pay more than they admitted with and estimates users would be willing to pay 800KSh (€6.94 per month). (Ketelaars et al,. 2015).

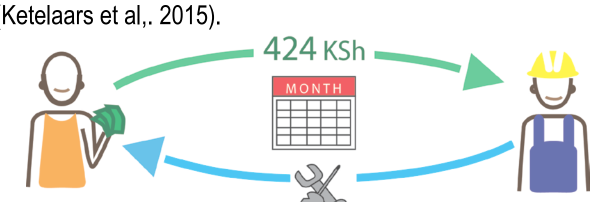


Figure 69: Users reported to be willing to pay an average of 434Ksh per month for mainetenance.

5.8

THE DEFENCE BILL
COSTS AND SAVINGS

The SMoTs were installed across the island at the cost of the SolarMal Project. The reported cost of each system was reported in 2015 to be with the breakdown of component costs shown in the table below.

Component	Unit Cost (€)	Qty	Total (€)
Battery	29.00	1	29.00
Solar Panel	22.50	1	22.50
Controller	11.60	1	11.60
LED's	3.45	2	6.90
Box	6.98	1	6.98
Cable	0.25	12	3.00
Fittings	1.23	2	2.46
Angle line	1.56	1	1.56
USB Charger	0.83	1	0.83
Set of nuts and bolt:	0.70	1	0.70
Switches	0.39	2	0.78
Clips	0.05	10	0.50
USB sockets	0.25	1	0.25
Lugs / Shoes	0.05	4	0.20
Tape	0.10	1	0.10
Glue	0.03	1	0.03
Tools and extras	0.50	1	0.50
Suna-Trap	70.00	1	70.00
	System Cost		**157.89**

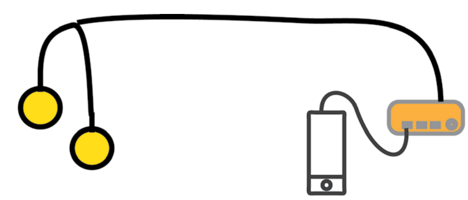
Figure 70: Cost of SMOT in 2015

Although affordable to research projects it is expected that the poorer demographic would not be able to afford to buy the system outright. Investigations by S.Ketelaars suggests that 44% of the inhabitants of Rusinga are unable to save any money. This poses a potential problem to coverage of maintained traps.

It is assumed that component prices will have reduced in recent years resulting in a lower system and maintenance costs. Mobile banking in Africa has become more prevalent and gives even low income households the ability to save, as well as transfer small amounts of money by text. The system was launched by Vodafone's Safaricom in 2007 and 2017 had 30 million users in 10 countries (Monks. 2017).

The study by N.Tebben investigated how much money homeowners were able to save after the installation of the SMoT. Results show that 38 out of 54 interviewees said they saved money on kerosene and phone charging since receiving the system.

SAVINGS FROM SYSTEM (2016)



SAVING ON KEROSENE

210KSh €1.90 to **350KSh €3.20**

MOBILE CHARGING

20KSh €0.27 to **500KSh €4.60**

TOTAL OF €2.17 - €7.80 SAVED PER WEEK

€8.68 - €31.20 SAVED PER MONTH

Figure 71: Reported monthly saving from users during SolarMal rial

In 2015 Ketelaars estimated the cost of maintenance of the trap to be €65 per year based on the lifetime of the components(see appendix x). This gives a monthly cost of €5.40 (approx 600Ksh). It can be said that, based on this information this information the system provides an opportunity to save more money than is required to maintain the system. This cost also falls between the reported amount people were willing to pay (424KSh) and how much people were expected to be willing to pay (800KSh) (Ketelaars et al,. 2015).

Tebben reports that M-Pesca is a very popular banking option across Rusinga and and is a favoured method of saving and making purchases. With the ability to set up daily/weekly/monthly payment plans it is suggested this could be a preferred method for payment of system costs.

5.9

TO TRAP, OR NOT TO TRAP... THE CONCLUSION

During the research it was only possible to scratch the surface when trying to uncover the potential factors and challenges presented by the context in which the trap's are intended to operate. However, it was possible to gain some insight from the studies conducted throughout and after the SolarMal trail. These factors and challenges can be considered during the design process influencing the design decisions and contributing to the generation of a final solution.

Odour baited mosquito traps can be used to reduce mosquito home entry and biting. Used alongside (insecticide treated) bed nets traps have shown the potential to be used a preventative healthcare tool.

The use of a mosquito trap alongside a bed net has the added benefit of reduced home entry which is particularly beneficial to the user after sun down when mosquitoes and their targets are both active. As it is not expected that the introduction of a mosquito trap will completely prevent home entry it is important that they are implemented alongside the continued use on LLINs. Used alongside an LLIN, the trap contributes to the prevention of mosquito populations developing resilience to teh insecticide by capturing mosquitoes which are not killed by the LLIN.

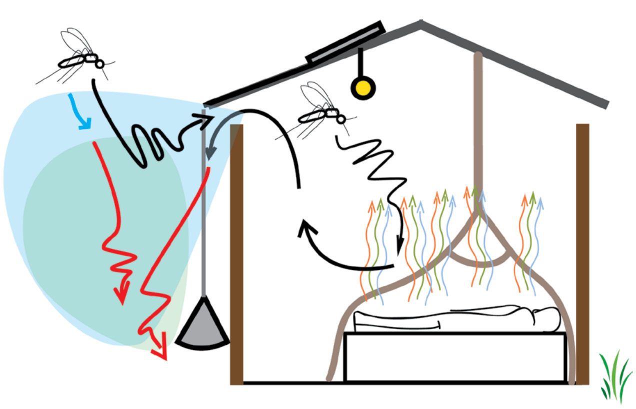


Figure 72: Expected Trap function in context

Users perceived the trap as a beneficial preventative healthcare tool reporting a reduction of mosquitoes in the home and fewer bites over a 3 month period.

It is important for users to experience the benefits of the trap in order to invest their money, time and attention to the product. Experiencing reduced annoyance from vectors in the home and fewer bites are necessary to promote demand for the system. Improving the performance could provide a more immediate and more noticeable benefit.

Although users value the trap as a preventative healthcare tool, the majority value the light as the greatest benefit from the system.

Participants in the SolarMal trial experienced less biting from mosquitoes at night and felt there were fewer cases of malaria experienced since the traps were installed. However, the LED lights were seen to have the most benefit to the user providing the required illumination to complete tasks after dark adn saving money on kerosene used in traditional lamps. It was even reported this allowed children more time to do their homework in better lighting conditions. This can further improve quality of life and social economic development of the population.

Community participation is necessary for the effective implementation and sustained use of a mass trapping network.

The SolarMal studies showed the importance of community co-operation to implement and sustain the networks of traps. The CAB played a key role in communications between the homeowners of Rusinga Island and the SolarMal team. The importance of community feedback was especially highlighted when facing problems such as the supply of yeast/molasses mixture and replacement odour across the Island.

The logistics of mass implementation of systems across an area provides multiple challenges. Bulky parts makes distribution and transportation to Rural locations difficult and technicians are required to install the systems.

Bulky and un-stackable parts, especially the cone of the Suna-trap, made transport difficult as only a certain number could be loaded into the truck. Access to more remote locations was only possible by foot making distribution of bulky systems more difficult. Tools required for installation also needed to be transported and technicians were required to install system.

The trap requires CO2 which can be provided by fermentation of yeast and molasses. This requires daily sustenance of the mixture.

CO2 is a key chemical used universally to attract mosquitoes and combined with unique, human mimicking synthetic odour is very attractive and increases capture rates of mosquitoes. This presents a significant problem to the use of trap in the context. A mixture of yeast and molasses is a low cost method of producing CO2 however the mixture needs to be checked and sustained daily to produce the best results. Current research is investigating the effects of synthetic compounds which mimic CO2 and can be applied within the trap in a similar way to the

Cleaning and emptying the trap once a week is an appropriate schedule users agree to and are able to keep up with. However, additional user input requirements, such as adding hot water, could be detrimental to the usability.

88% of users reported that they checked, cleaned and emptied the trap once a week and agreed this was an appropriate schedule. If the trap is not cleaned this regularly working condition can be maintained for some time but the product becomes more susceptible to breakdowns. Additional features added to the trap which require more frequent upkeep would be negative to the usability asking to much of the user.

The odour bait is essential to the system and should be replaced every 3(to 6) months. The user should have access to a supply of replacement odour strips and be able to replace it with a new one.

Essential for attracting mosquitoes to the trap (and away from the users) but has a relatively short lifespan loosing its potency after three months. Specific synthetic odours are more effective however a strip of worn sock can also be used. The odour must be positioned in the airflow within the trap to best saturate the air. If water is added to the trap, the odour strips should be kept dry to maintain the lifetime.

In most cases, a maintenance technician and/or spare parts are needed to fix breakdowns in the system and trap itself. After the trial, users were unaware of the product service system still available and struggled to maintain the system and trap without the support.

Most of the reported breakdown were connections in the system including USB for phone charging, the light switches and bulbs not working. Improving the quality of the connections should reduce the need for maintenance and space parts. As well as becoming more available, the cost of replacement LED bulbs is thought to have reduced since 2016 and continue to do so.

Although many users have shown a willingness to pay, maintenance can be expensive. Depending on the issue, replacement parts such (as the battery) can be too expensive for the consumer.

In order to sustain the function over a number of years, maintenance is crucial and the upkeep costs add up. It is unknown how much individuals would be required to save per month for upkeep but but estimates in 2016 suggest a yearly cost of 65. A weekly saving of of 5.50 per month may be unachievable for many users. Although the continuous expansion of mobile SMS banking apps provides users with means of saving and paying for system costs, other expenditures such as food and school fees are prioritised.

6.0

Chapter 6: The Solution

M-TEGO

REDUCING VECTOR HOME ENTRY

The trap should be hung outside a home in rural Africa. The CO_2, Synthetic human odour and close range host cues attract the vectors towards the trap rather than the eaves of the home. With a reduction in home entry and biting, malaria transmission can be reduced.

A TOOL FOR MALARIA PREVENTION

Used alongside insecticide treated bed nets, mosquito traps have shown potential to contribute towards the reduction of vector populations and transmission of malaria.

A RESEARCH TOOL

Designed for use in Africa, this trap provides a tool for sampling vector populations in Africa. Light weight, Foldable for transport and robust it is the most suitable product for use in rural Africa.

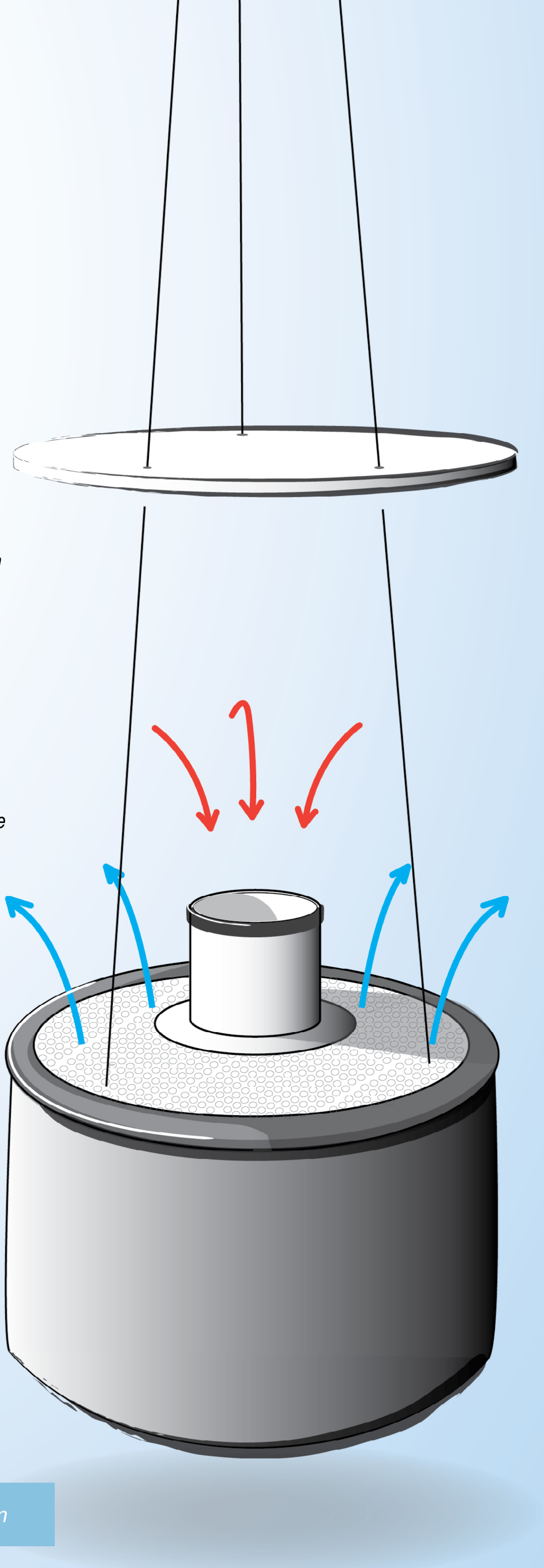


Figure 73: M-TEGO - visualisation of final design

6.1

THE GOOD, THE BAD AND THE UGLY
SWOT ANALYSIS

In chapter 4 it was concluded that the addition of close range host cues was the most effective method of improving the capture performance of odour baited mosquito traps. It is thought the combination of hot water in the base of the trap and a heating element around the rim would be the most effective method of delivering improved high capture numbers. This is a new method not currently being used in the market and delivers better results in the lab when compared with the benchmark Suna-Trap.

In order for the new design to be an effective and successful tool for the prevention of Malaria transmission, its working condition must be maintained. From the research outlined in Chapter 6, key factors were drawn from the findings and conclusions. These were then analysed and concluded highlighting the factors to be most influential to success of the product in context.

The factors from both technical and context investigations throughout the project were listed (Appendix X) and consider during a SWOT (strengths, weaknesses, opportunities and weaknesses) analysis of 'The implementation of odour baited suction mosquito traps as a tool for prevention of malaria in Africa'. The aim of the SWOT analysis is to highlight the key issues in order to define appropriate design goal for the final design phase of the project. The confrontation matrix (also Appendix X) aids the evaluation of factors highlighting the most relevant positive and negative issues in the system. Analysis of these issues, taking into account all factors aids the development of a central problem definition.

Having defined the central problem definition, design goals can be generated to direct the design process towards a successful solution.

SWOT Analysis: The implementation of odour baited suction mosquito traps as a tool for prevention of malaria in Africa

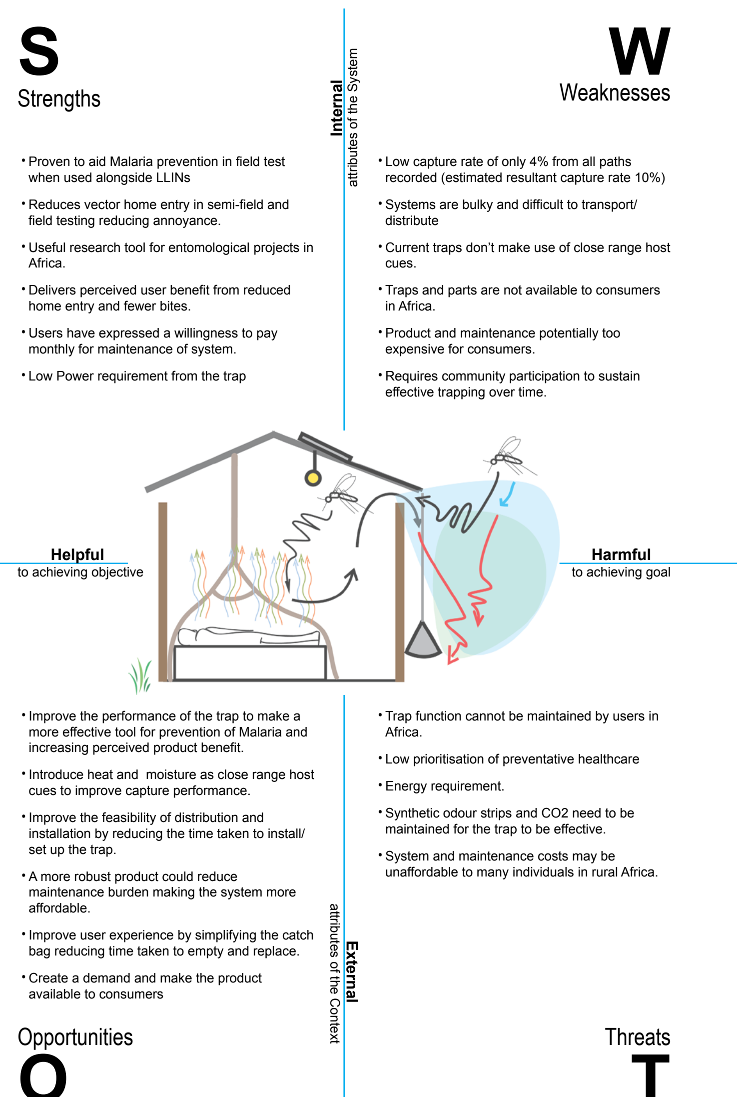


Figure 74: First stage of SWOT Analysis summarising strengths, weaknesses, threats and opportunities.

6.2

TARGET IDENTIFIED DESIGN GOALS

Central Problem Definition

The SWOT analysis supported the definition of a central problem based on the insights gained from the previous research and design phases.

With community participation and the support of an affordable and sustainable product service system, the use of odour baited mosquito traps alongside LLINs have potential to contribute to the eradication across Africa. In order to be more effective as a tool for prevention of transmission and control of vector populations, the performance of the trap must be improved. Although many insights have been gathered which can be considered during the design phase, it is not possible to design a market ready product without semi-field and field testing with users in context.

It is necessary to first design a Minimal Viable Product which can be used in lab and field tests before further developing the product. Studies during the SolarMal trial showed the users experienced benefits from the trap over a three month period suggesting this is a minimum time required for the trap to have an effect. This is also the time period required for further lab testing. For Lab testing only a single working prototype is required, preferably with spare parts for ease of use during experiments. However for field research up to 150 traps could be required. Considering these factors whilst addressing the Central Design problems resulted in the generation of the following Design Vision:

Design Vision

To design an odour baited mosquito trap, with the addition of close range host cues, suitable for lab and field testing leading towards the further development of a market ready product.

Design Goals

The sub-design goals (Appendix X) have been developed into key design goals to consider and communicate throughout concept generation. Features and design decision should address these main design goals which will be used to evaluate the final solution.

Increase the capture rate of the trap in order to be more effective against transmission of Malaria.

Should be suitable for testing in the field with a lifespan of up to 3 months.

Implement water into the trap in a way that is feasible for users to maintain optimal working condition.

Incorporate the capacity maintain a source of hot water approx 1ltr @ 40ºC and maintain throughout peak biting times.

Implement a heating element to the trap to provide a localised heat source drawing vectors into the capture zone.

Do not exceed the capabilities of the current system based around a 20W solar panel (0.2kWh/day). Only use 50% of potential energy to incorporate safety factor (0.1kWh/day).

Reduce the bulkiness of the trap making it more suitable for transport and distribution in rural Africa.

Create a robust system to avoid damage during distribution and use and reduce maintenance requirements.

Address the usability issues highlighted improve the user interaction with the product when carrying out weekly upkeep tasks.

Within the design, allow for the replacement of component in the event of failures.

Design should be suitable for production of batches of 1-150 traps.

6.3

WHICH WAY TO GO? DESIGN APPROACH

Using product concept highlighted as the highest performing as a starting point, the design approach attempts implement heat and moisture into the a trap in a way which is suitable for field testing and further development.

A number of ideas were continuously generated and discussed throughout the project. During an ideation phased these ideas were further explored and developed generating a range of product solutions.

Solutions generated in the ideation phase are analysed and evaluated promoting convergent design thinking and decision making and resulting a first generation concept solution.

To evaluate the initial concept, 2 focus group discussions were held to evaluate and contest the design decisions made as well presents alternative solutions to be considered. The discussions provide the feedback required to confidently make design decisions during the final concept development phase.

Although final testing is outside of the scope of this project. A working prototype of the final concept should be developed for final and further testing. The prototype should be suitable for 3 months of testing under lab conditions, as described in Chapter 4 and represent all the main features to test usability and user interaction with the new design.

The construction of a prototype also provides insight into the manufacture and assembly of the intended product which can be incorporated , improving 'the design for manufacture' and 'design for assembly'.

6.4

POSSIBLE ROUTES IDEATION PROCESS

Considering the design Vision and Goals, functions of a successful design solution were addressed individually. Using a morphological chart to structure the ideation process, ideas were developed as potential solutions to each function (plotted left to right in figure X). Having developed a number of potential solutions for each function - possible combinations can be generated by selecting a a solution from each row and analysing the result.

The combinations of design solutions were analysed against the design goals to conclude which solution would be thought most appropriate and move forward with development.

Due to the knowledge gained from the detailed research, initial design and testing - design decisions leading towards a final concept could be made quickly In some cases it was found that multiple solutions from the same row could be implemented alongside one another providing mo

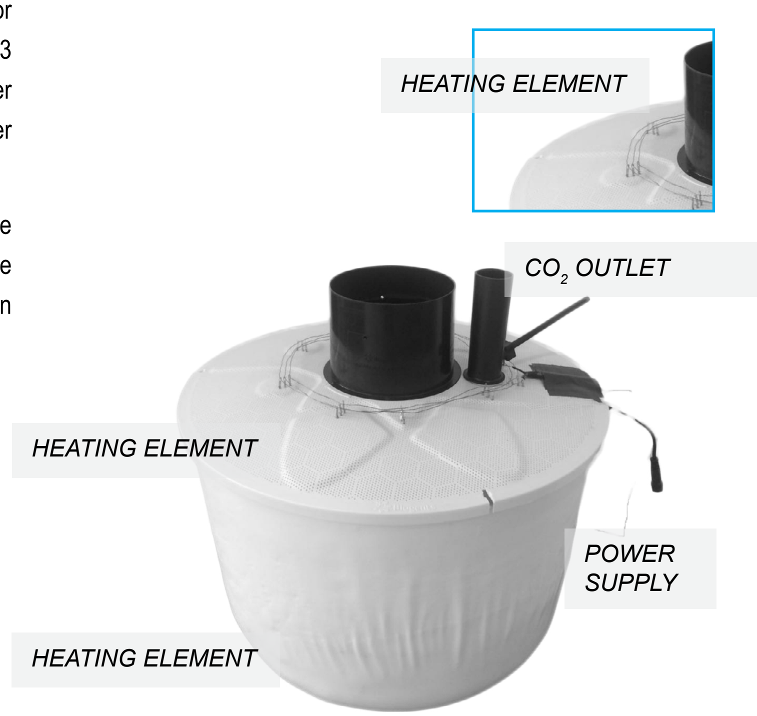


Figure 75: Heat 2 and Hot water concepts combine.

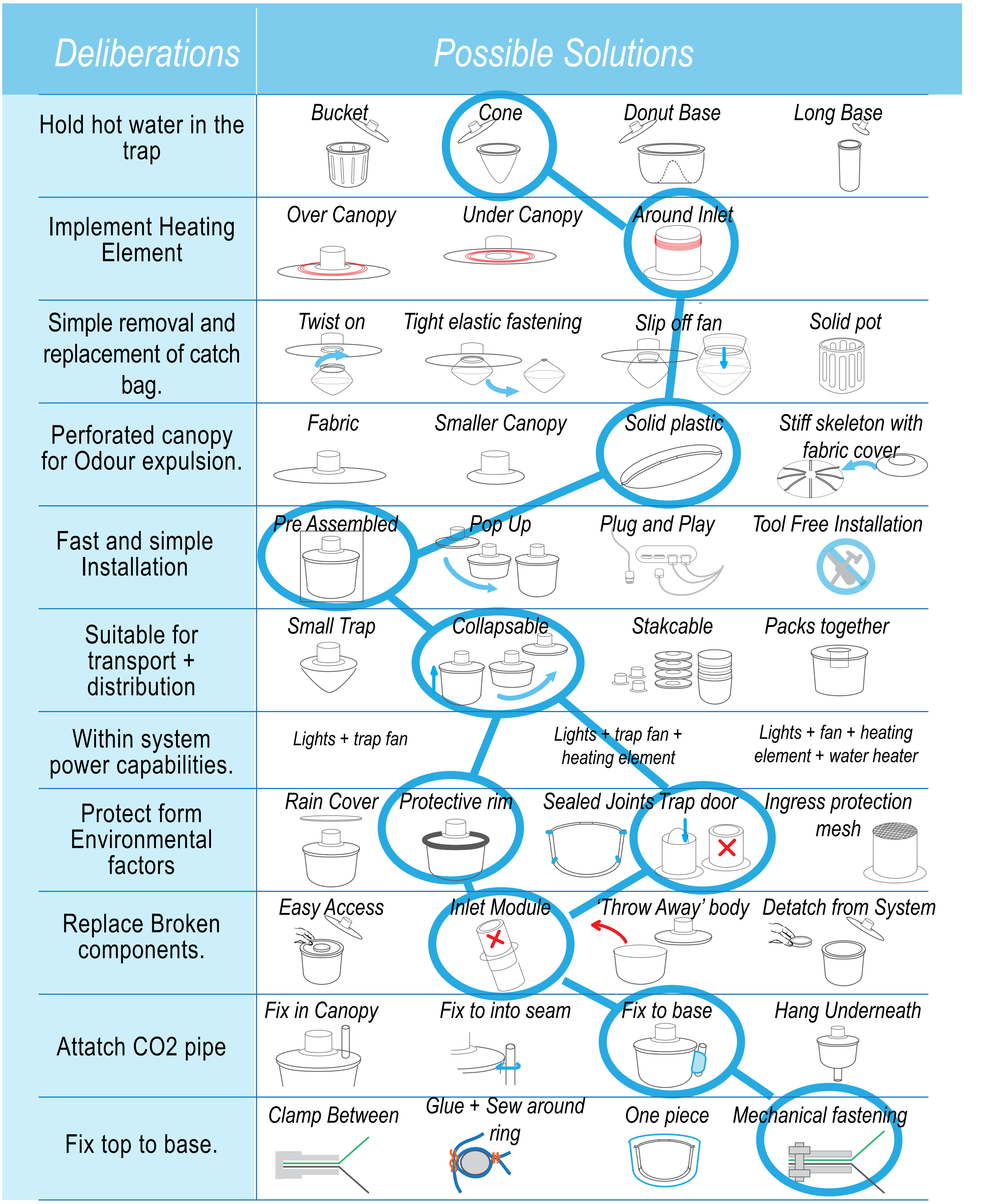


Figure 76: Morphological chart of ideas geerated.

6.5

GENESIS

1ST GENERATION CONCEPT

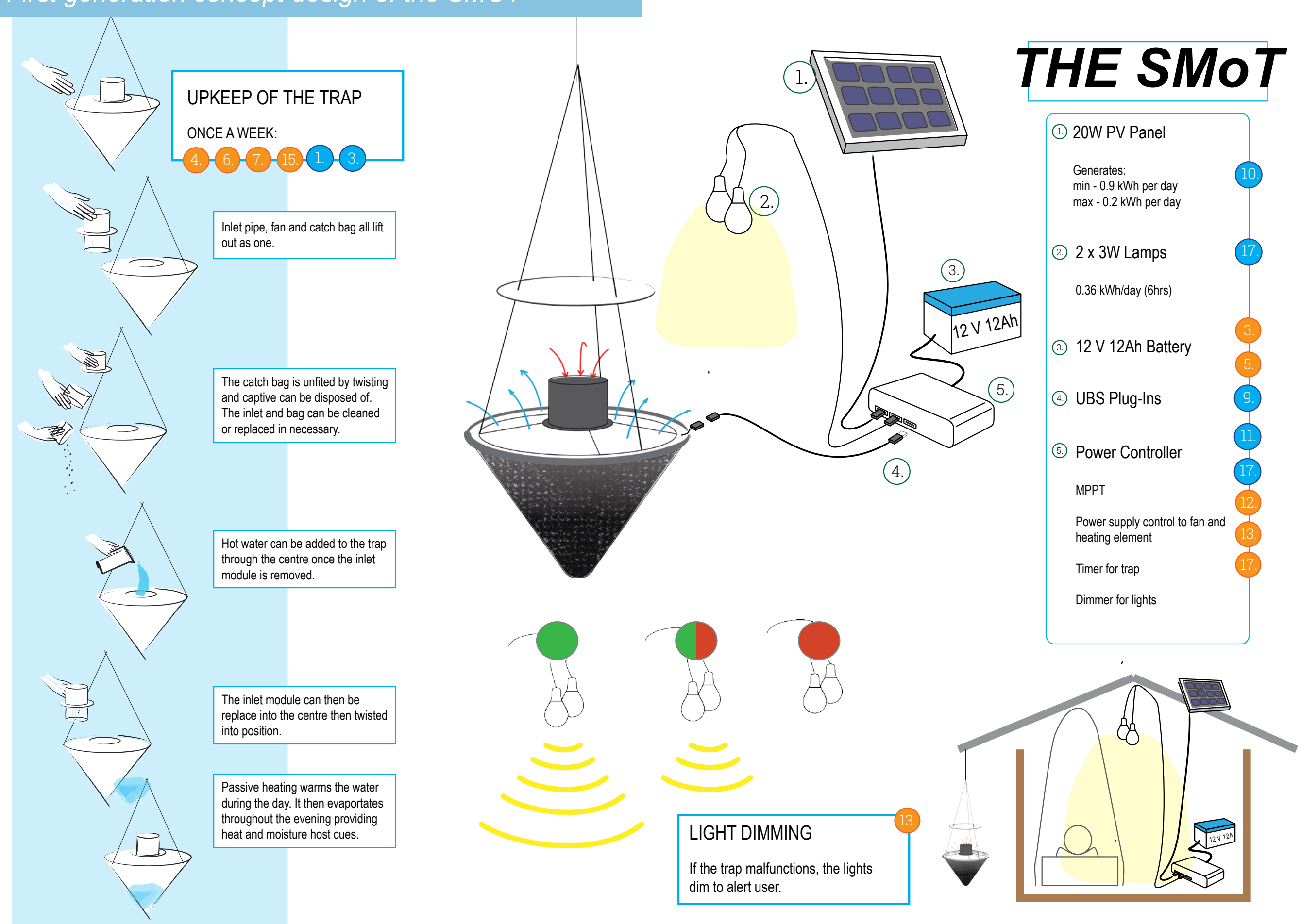
From the combination of feature solutions highlighted in the morphological chart it was possible to develop a first generation concept. The concept solution considers all of the design goals generated, with a prioritisation of those outlined earlier in the chapter. Features within the concept can be linked to the design goals driving the decision. Reflection of the goals aids the effective evaluation of the solution. The numbered annotations link the feature solution to the design goal addressed.

KEY FEATURES

THE SYSTEM - The system supporting the use oft he trap remains relatively unchanged as this is not the ficus of the this project. The 0.2KWh of power available from the system is based on the average 6.9 sunlight hours per day experienced in Kenya (Appendix X). It is recommended that products from successful solar home systems are used as they are design for use within the intended context. It is expected these more suitable components will be more robust, simple for users and reduce maintenance requirements compared to the systems used in the SolarMal trial.

COLLAPSIBLE BASE - The conical base can be filled with up to 3 litres of (hot) water providing heat and moisture host cues. The base is is to be made from Tarpaulin material, a light weight reinforced polyethylene sheet commonly used in construction. Reinforced with a (cotton) matrix, the material is tough, robust, waterproof and lightweight (for material details see appendix X). The thin plastic sheet is very flexible and can collapsed into the

Figure 77: First generation concept design of the SMOT



canopy when empty. In its 'packed' state the base fits entirely inside the canopy massively reducing the size of the product. This reduces the 'bulkiness' of the products improving feasibility of transport and distribution.

INLET MODULE - The inlet module sub-assembly consists of three main components, the fan, the inlet tube and the catch pot. The single module is simple to remove allowing the user to carry out the necessary weekly check, empty and clean the trap. When the replaced, contact points on module are connected to contacts in the trap proving power to the fan and heating element. This ensures the fan and element cannot be turned on when in the hands of the user. The three main components fit together with bayonet fixings. The looser of the two, which can be simply removed by the user, is the catch pot.

C***ATCH POT -*** Twisting the pot allows the user to remove the catch with little effort and the solid stricture allows the user to tip out the contexts. The solid frame hold the shape of the inner catch bag eliminating the need to fix the bag to multiple points of the trap reducing the time and therefore burden of weekly upkeep.

HEATING ELEMENT - The additional electric heating element provides a localised area of warmth (min 2ºC above ambient) around the inlet pipe mimicking human presence. The aim of drawing approaching vector flights into the capture zone. When fitted into the trap, power is provided to the element through the night.

PROTECTIVE RIM - The rubber-like rim around the perimeter of the trap protects the joint between the canopy and base providing additional support. It also serves to protect the trap from knocks and livestock when suspended outside the home.

RAIN COVER - Which in the 'packed' configuration the rain-cover fits underneath the canopy holding the empty base inside. During installation the rain cover is removed from underneath the trap and fitted into the rigging preventing ingress from rain.

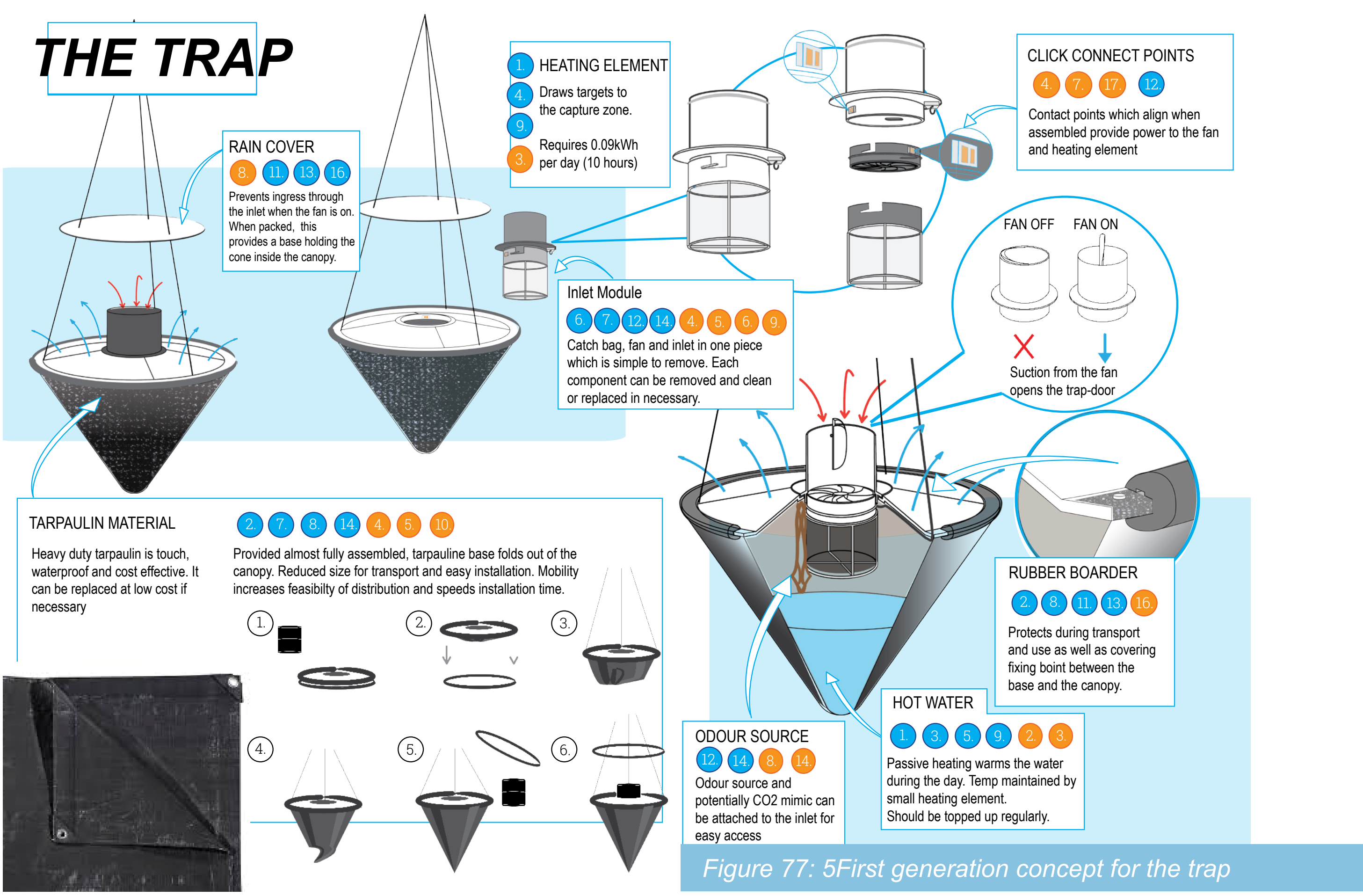


Figure 77: 5First generation concept for the trap

6.6

THE VALIDATION
FOCUS GROUP DISCUSSIONS

Before further development, a concept evaluation is necessary to deliberate the design decisions and resultant feature solutions generated. It was not possible within the scope of the project to conduct final product lab testing so focus group discussions were organised to evaluate the concept.

The first of three discussions was attended by Dr. ir. Muijres and Antoine Cribellier of the experimental zoology department of Wageningen University. During this discussion the general solution was discussed as well as specific features and design decisions. The second Discussion was held at the Technical University of Delft, Department of Industrial Design and made up of students from the three design master disciplines . The aim of this discussion was to address issues within the current design which still required attention.

The final discussion focused on the manufacturing and prototyping capabilities suitable for one off and small batch production.

The analysis of information from these discussions provides additional insights and opinions which can be considered during the final design iteration.

Outcomes From
Focus Group Discussions

Outcomes from focus group discussions were summarised and evaluated against the current solution initiating an additional design iteration. More details of the discussions can be found in Appendix X.

Many key points were raised during he discussions which were thought to be influential to the definition of the final design.

- ***What are the benefits of the Cone shaped base?***

  The decision to use a cone shaped base was made based upon the expectation that when filled with water it would help to stabilise the product in context. It was also thought the cone would be easier to fold into the trap de to less material used.

  It was suggested that returning to a bucket shape would increase the surface area between the base and water inside aiding passive heating in context. Collapsible beach buckets were mentioned as a comparative product with a stiff ringed base able to collapse up to the rim of the bucket. It was also highlighted that the cone shape would result in the base being in the shadow of the canopy during periods of the day when the sun is highest and passive heating is most effective.

- ***Does the use of the rain cover effect/interfere with the performance of the trap?***

  F. Muijres and A.Cribellier questioned the influence of the rain cover as previous concepts with canopies did not show ed mixed results in testing.

- ***Without an additional submerged heating element, how is hot water temperature reached and maintained throughout the night?***

  It is thought that passive heating of water in the trap is a convincing method of providing hot water. Solar energy heats the black base material and water contained within throughout t the day. However the idea to add an additional heating element was discussed. Submerged in the water it would be activated during key times if the water temperature is too low.

- ***Is a single piece canopy most feasible for prototyping and small batch production?***

  During the second discussion, with design student of TU/Delft, the canopy was raised a key challenge to prototyping and small batch production. Due to the perforation requirement, it may not be possible to prototype with the facilities available. Instead a skeleton frame could be produced and covered with a porous material such a elasticated fabric.

6.7

THE CUT

FINAL DECISIONS

Replacement of conical base with a 'bucket' shape with a circular rim and base.
Additional heating element to maintain temperature of hot water during key time is not necessary.

Additional submersion heater not required within the trap as passive heating is expected to provide the necessary conditions for evaporation throughout the night.

It was concluded the difference in specific and latent heat capacities of water and temperature differences experienced during night and day suggests the water will take longer to cool down at night than it took to warm up during the day. A temperature gradient between the warm water and surrounding air would be maintained throughout the night.

The height of the rain-cover should be subject to results of further testing.

It is not possible to conclude on the effect of the rain-cover however it is an important feature justifying the requirement for further testing. The optimal height in which the canopy should be fixed so as to protect from ingress but also not hinder performance should be defined through lab testing.

Single piece canopy is expected to be most appropriate for manufacture, assembly and performance in context.

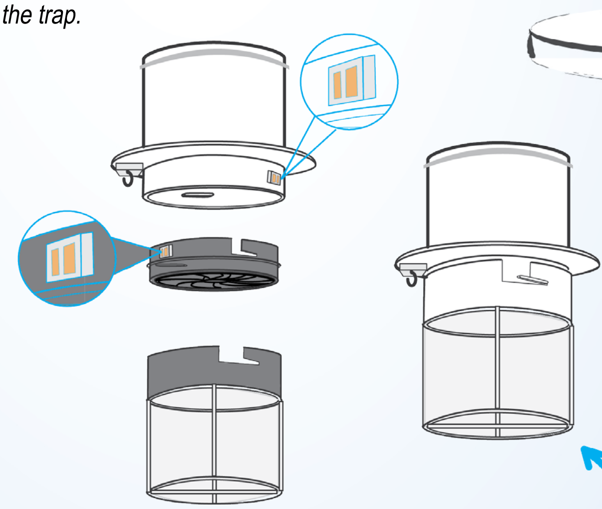
Reducing the number of parts and using one robust component results in a more robust solution thus reducing potential maintenance needs. During initial prototyping both methods will be trailed although it is expected that the assembly requirements of a skeleton frame with fabric cover would be time consuming and not easy to repeat.

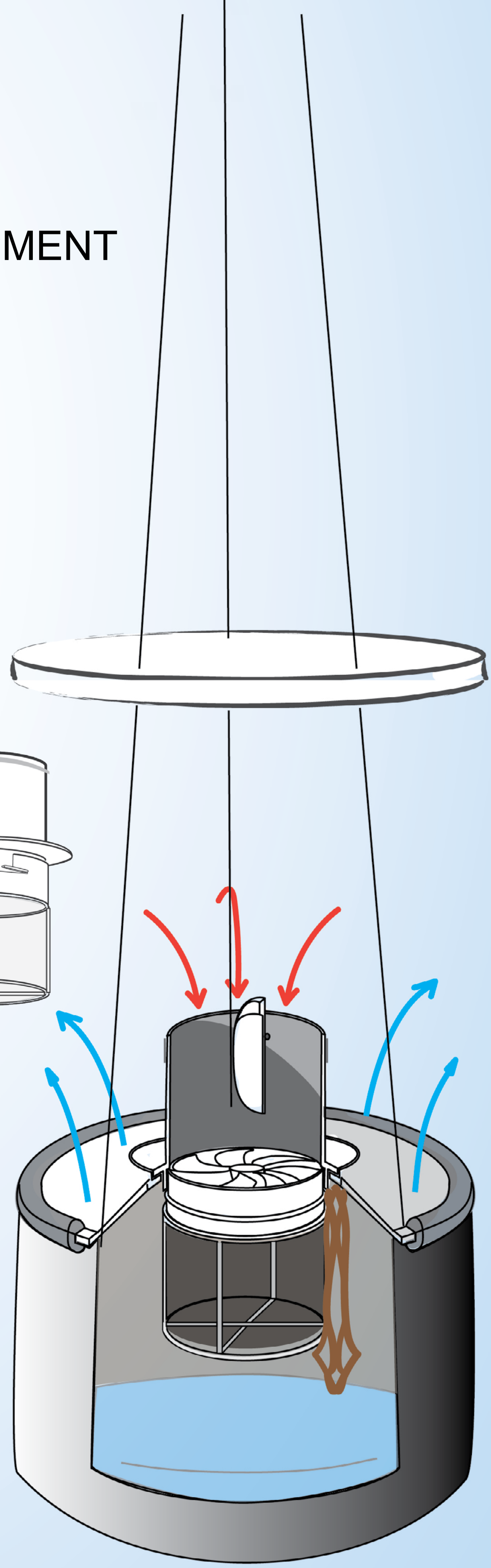
6.8

READY FOR DEVELOPMENT
THE FINAL CONCEPT

INLET MODULE

Removable inlet module reduces time taken to empty and clean the trap. The catch pot is removed with a gentle twist allowing for the safe removal of captured vectors. Copper contact connectors between the traps allow for the provision of power to the fan and heating element when fitted into the trap.





Plume of host cues

A plume of CO_2. Synthetic human odour, and vapour is emitted from the trap through the perforated plastic canopy attracting larger number of mosquitoes than other products.

Odour Baited

Synthetic odour is fitted to the underside of the rim of the inlet pipe. It can then be accessed by the users when the module is removed so they can replace the bait every three months.

Water filled base

Up to 3 litres of water should be added to the trap. This is able to heat up during the day due to passive heating from solar radiation. Cooling down slowly during the night, a temperature gradient is maintained throughout vector host seeking periods.

Figure 78: The final concept oslution for the M-TEGO

6.9

LEARNING CURVE

THE PROTOTYPE

A number of approaches were trial in the design and development of the final prototype. The goal being to produce a one off working prototype suitable work lab testing to prove the design principals within the new trap.

The production of a working prototype also allows to the evaluation of potential manufacturing techniques and assembly procedures. Individual feature designs within the concept can also be tested, such as the twist contact connection points between the trap, fan and inlet pipe providing power to the system.

As well as tarpaulin, a PVC sheet material was tested for the base is the properties also fit the need of the [product and it was thought to be more robust. However, testing showed the material was not flexible enough to pack inside the canopy correctly.

Figure 79: Prototyping contact points

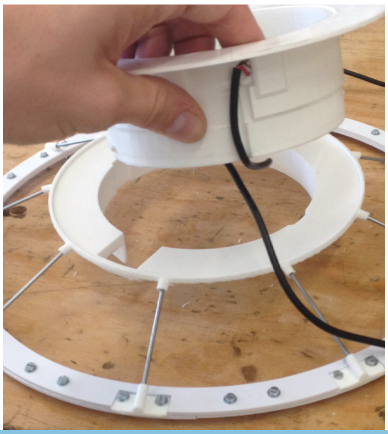


Figure 80:Assembling prototype

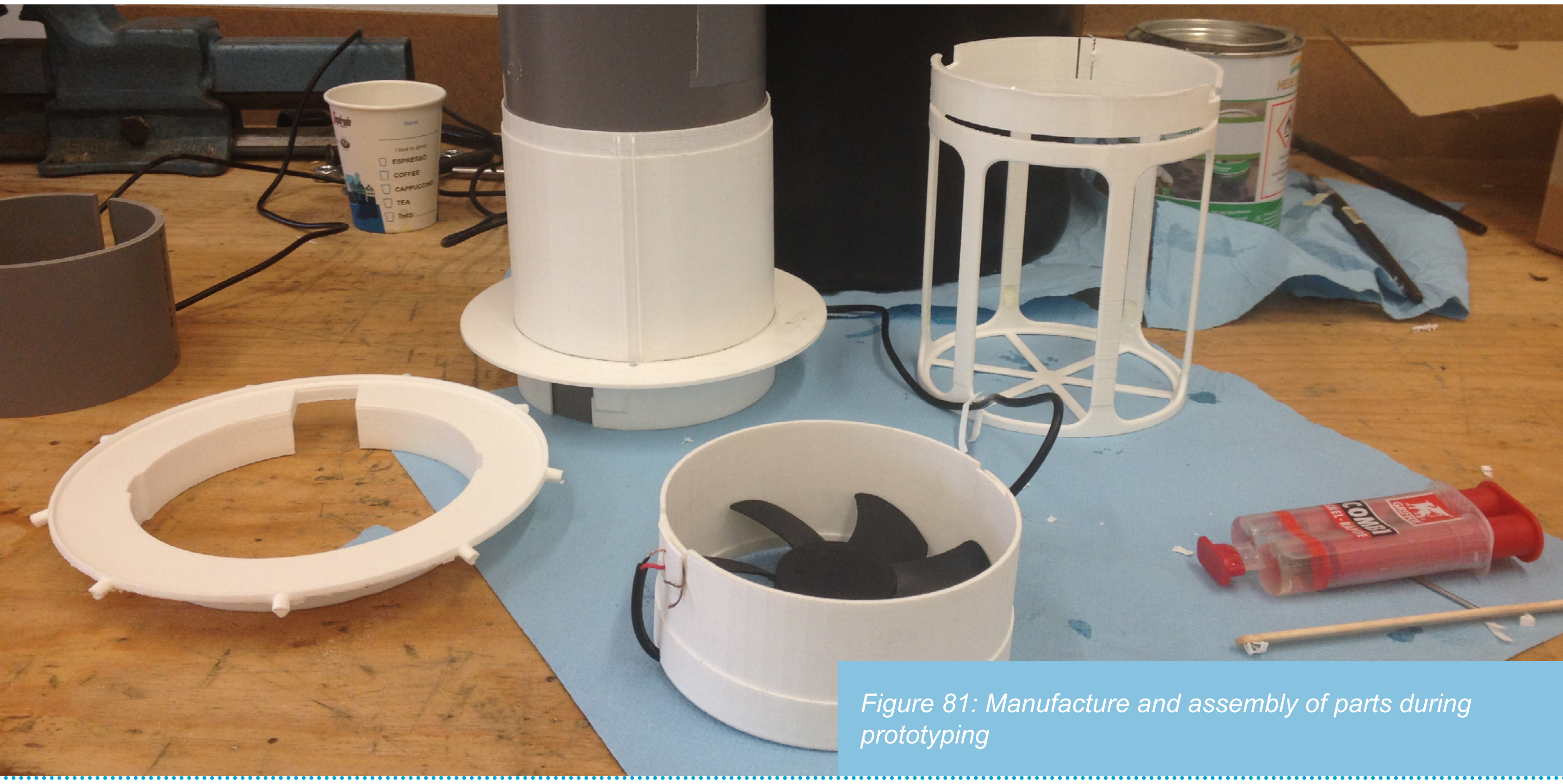


Figure 81: Manufacture and assembly of parts during prototyping

6.10

THE ULTIMATE SOLUTION
THE FINAL DESIGN

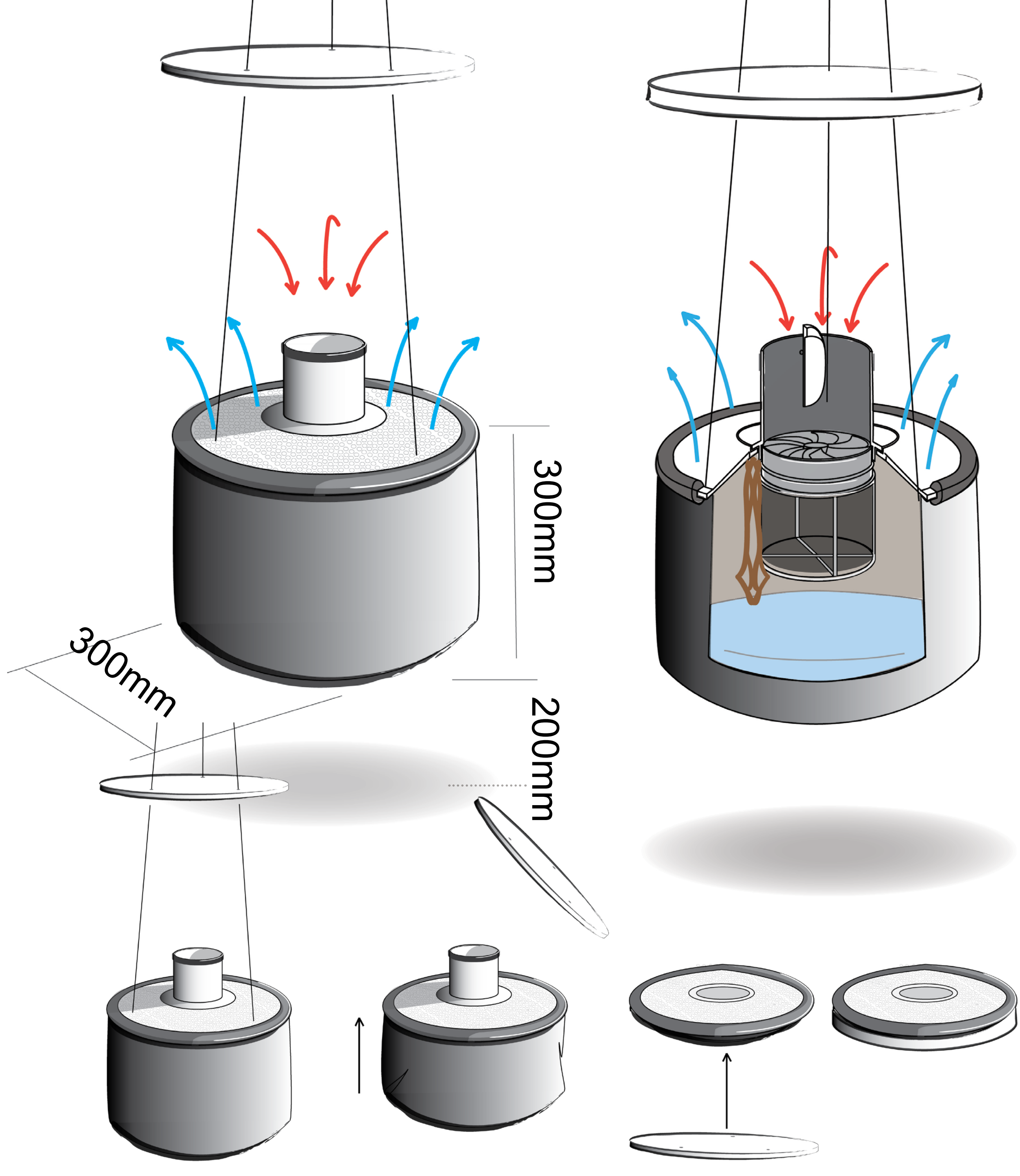


Figure 82: Illustration of overview of final design

6.11

EVALUATION

This innovative odour baited mosquito trap design uses warm water and an electric heating element to increase the capture performance of the trap.

The expected increase in approach flights do to the warm water is attributed to the addition of two close range cues promoting a response in vector host seeking behaviour. The heating element fitted around the rim of the inlet pipe aim to provide a localised heat source encouraging a higher number of vector approach flights into the capture zone thus increasing the capture performance.

The lifetime of the design is expected to exceed three months in the lab and field. In the eventuality of breakdowns, simple, low cost parts can be replaced without the need for additional tools.

The reinforced polyethylene material is waterproof, puncture resistant and can be replace at very low cost if necessary. The lifetime of all other components are estimated to greatly exceed three months. The connection between the base and canopy is the load bearing area and most vulnerable especially if overfilled. The base , upper ring, and canopy are held together with plastic rivets which can be applied by hand and cut off with a knife if needed to be disassembled.

Passive heating from solar radiation heat the water in the trap during the day. The water continues to evaporate during the evening during peak biting time.

1-3 litres of water contained within the black polyethylene base passively heats during the day from solar radiation. A temperature gradient is maintained throughout (the majority of) the night between the water in the trap and ambient temperature outside providing the most attractive plume of CO2, odour, heat and moisture.

A heating element is embedded around the rim of the inlet pipe providing a localised area of elevated heat (approx 1-2°C) drawing approaching mosquitoes into the capture zone.

The requirement to run for 10 hours from 8pm until 6 am is 0.096KWh and alongside the 0.33KWhs required to run the fan is less than 0.5WKhrs. This is less than 50% of the average solar power expected to be generated by a 20W solar panel installed on a household in Kenya.

When unfilled, the inlet module can be removed and allowing the thin and flexible base of the trap collapses into the canopy for more feasible transport and distribution in Rural Africa.

The rain shield can then be clipped to the rim of the canopy from underneath holding the base in place leaving a streamlined and stackable product for transport and distribution. This also allows for the user to easily transport the trap themselves creating an opportunity for them to take the trap for repairs rather than making a call out.

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The rain shield can then be clipped to the rim of the canopy from underneath holding the base in place leaving a streamlined and stackable product for transport and distribution. This also allows for the user to easily transport the trap themselves creating an opportunity for them to take the trap for repairs rather than making a call out.

The inlet module requires a gently twist before lifting out of the trap. This allows for the main components to be quickly removed from the trap with minimal effort.

During (weekly) upkeep, the time taken removing the catch bag as seen with the Suna-Trap improving user experience. This also provides easy access to the fan for cleaning and eventually, maintenance or replacement. The copper contacts on the parts, which connect when assembled provide power to the product without the dangling wires which often result in frequent breakdowns

7.0
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5.0
REPORT APPENDICES:

IPD GRADUATION PROJECT

DESIGN OF AN **ODOUR BAITED MOSQUITO TRAP FOR MALARIA PREVENTION** IN AFRICA

HENRY FAIRBAIRN 4578716

APPENDIX 1
PROJECT BRIEF

2438

DESIGN FOR our future

TU Delft

IDE Master Graduation

Project team, Procedural checks and personal Project brief

This document contains the agreements made between student and supervisory team about the student's IDE Master Graduation Project. This document can also include the involvement of an external organisation, however, it does not cover any legal employment relationship that the student and the client (might) agree upon. Next to that, this document facilitates the required procedural checks. In this document:

- The student defines the team, what he/she is going to do/deliver and how that will come about.
- SSC E&SA (Shared Service Center, Education & Student Affairs) reports on the student's registration and study progress.
- IDE's Board of Examiners confirms if the student is allowed to start the Graduation Project.

USE ADOBE ACROBAT READER TO OPEN, EDIT AND SAVE THIS DOCUMENT
Download again and reopen in case you tried other software, such as Preview (Mac) or a webbrowser.

STUDENT DATA & MASTER PROGRAMME

Save this form according the format "IDE Master Graduation Project Brief_familyname_firstname_studentnumber_dd-mm-yyyy". Complete all blue parts of the form and include the approved Project Brief in your Graduation Report as Appendix 1 !

family name: FAIRBAIRN
initials: HJR given name: HENRY
student number: 4578716
street & no.: GISTSTRAAT 12
zipcode & city: 2611 PT DELFT
country: NETHERLANDS
phone: +44 7542856186
email: FAIRBAIRNH@LIVE.COM

Your master programme (only select the options that apply to you):
IDE master(s): (★) IPD ( ) Dfl ( ) SPD
2nd non-IDE master:
individual programme: - - (give date of approval)
honours programme: ( ) Honours Programme Master
specialisation / annotation: ( ) Medisign
(★) Tech. in Sustainable Design
( ) Entrepeneurship

SUPERVISORY TEAM **

Fill in the required data for the supervisory team members. Please check the instructions on the right !

** chair: Jan-Carel DIEHL dept. / section: DE / DfS
** mentor: Henk Kuipers dept. / section: ID / AED
2nd mentor: Florian Muijres
organisation: Wageningen University and Research (WUR)
city: Wageningen country: Netherlands

comments (optional)

Chair should request the IDE Board of Examiners for approval of a non-IDE mentor, including a motivation letter and c.v..

Second mentor only applies in case the assignment is hosted by an external organisation.

Ensure a heterogeneous team. In case you wish to include two team members from the same section, please explain why.

IDE TU Delft - E&SA Department /// Graduation project brief & study overview /// 2018-01 v30 Page 1 of 7

TU Delft

APPROVAL PROJECT BRIEF

To be filled in by the chair of the supervisory team.

chair Jan-Carel DIEHL date 08 - 03 - 2018 signature [signature]

CHECK STUDY PROGRESS

To be filled in by the SSC E&SA (Shared Service Center, Education & Student Affairs), after approval of the project brief by the Chair. The study progress will be checked for a 2nd time just before the green light meeting.

Master electives no. of EC accumulated in total: 31 EC

Of which, taking the conditional requirements into account, can be part of the exam programme 31 EC

List of electives obtained before the third semester without approval of the BoE

[X] YES all 1st year master courses passed

[ ] NO missing 1st year master courses are:

name A. Blom date 21 - 03 - 2018 signature [signature]

FORMAL APPROVAL GRADUATION PROJECT

To be filled in by the Board of Examiners of IDE TU Delft. Please check the supervisory team and study the parts of the brief marked **. Next, please assess, (dis)approve and sign this Project Brief, by using the criteria below.

- Does the project fit within the (MSc)-programme of the student (taking into account, if described, the activities done next to the obligatory MSc specific courses)?
- Is the level of the project challenging enough for a MSc IDE graduating student?
- Is the project expected to be doable within 100 working days/20 weeks ?
- Does the composition of the supervisory team comply with the regulations and fit the assignment ?

Content: [V] APPROVED [ ] NOT APPROVED

Procedure: [V] APPROVED [ ] NOT APPROVED

comments

name A Huwae date 3 - 4 - 2018 signature [signature]

Initials & Name HJR FAIRBAIRN Student number 4578716

Title of Project Design of an odor baited, solar powered mosquito trap

APPENDIX 2
Product Benchmarking: trap evaluation

BG SENTINEL

Pros

- The spring loaded base makes the trap collapsible.
- The wide circular canopy provides a large surface area, like that of a person, where odour is emitted.
- Odour bait mimicking human scent can be added.
- CO2 can be provided alongside the trap.
- Widely used by researchers.

Standing orientation has shown to be more attractive in the (similar) Suna-Trap.

Cons

- Not suitable for use over long periods.
- Lightweight base situated on the ground is nit suited to rough terrain, strong winds or f(flash) flooding.
- Capture rate unknown but assumed to be similar to a Suna-Trap in standing orientation (<10%).

BG SUNA

Pros

- Design decisions made based on intended use in Africa. Though plastic cone protects the catch and working parts from weather (rain and sand ingress)
- The wide circular canopy provides a large surface area, like that of a person, where odour is emitted.
- Proven to reduce malaria in the field (with collaboration of locals and researchers)

Cons

- Large and bulky parts are detrimental to transport and logistics. Catch bag has many fixing points and can be difficult to fit and remove (especially when full).
- Injection moulded parts (tooling) can be expensive.

MMX

Pros

- Design incorporates CO2 and odour attractants
- Fairly robust and protected from weather conditions including rain and sand.

Cons

- Large and bulky parts are detrimental to transport and logistics.
- Reports explain that the trap is difficult to empty and clean.
- Large plastic body is subject to damage, it is brittle and will smash if dropped.
- Production of this trap has been discontinued.

CDC LIGHT TRAP

Pros

- Small and lightweight making it easy to transport.
- The trap is easy to set up and pack away
- Canopy protects the trap from rain to a degree.
- Widely used by researchers for many years.
- Cheap to produce.

Cons

- Not robust and may not deal well with more extreme weather.
- Small fan and therefore capture area.Design doesnt especially facilitate the addition of CO2 or synthetic odours.
- Working parts are unprotected and subject to danage..

MM PATRIOT

Pros

- Relatively robust.
- Incorporates CO2 and lures.
- Easy to use in terms of cleaning and emptying the catch pot.
- Can be left for long periods of time.

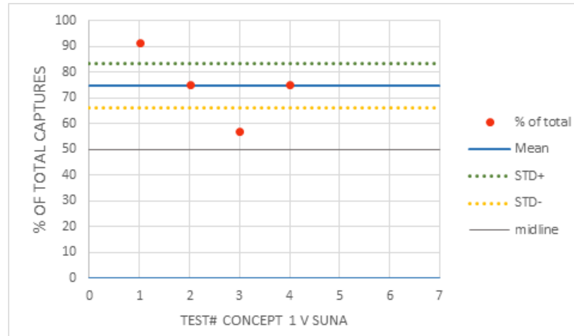
Cons

- Expensive at $330 per unit (not incl. propane tank).
- Requires propane to produce CO2.
- Heavy and difficult to transport in the field.
- Difficult to set up in the field due to large heavy parts.

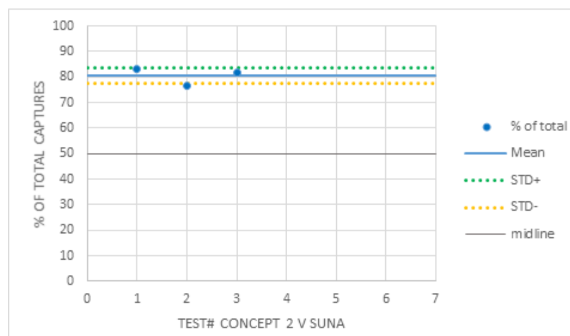
APPENDIX 3
INITIAL CONCEPT TEST RESULTS.

Duel Test Against Control

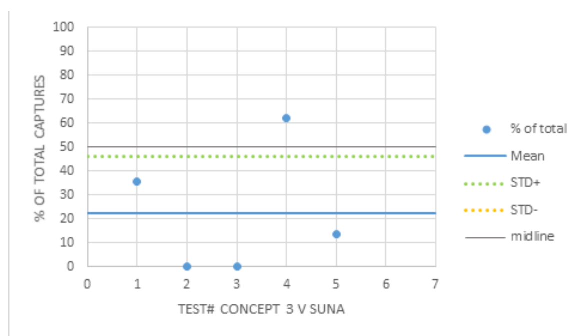
	Concept 1	***Heat 1***		
		Captures		
	Test #	Suna	Concept	% of total
	Test 1	2	22	91.67
	Test 3	3	9	75.00
	Test 4	9	12	57.14
	Test 5	4	12	75.00
	mean			74.70
	standard dev.			8.42



	Concept 2	***Heat 2***		
		Captures		
	Test #	Suna	Concept	% of total
	Test 1	4	20	83.33
	Test 2	8	26	76.47
	Test 3	2	9	81.82
	mean			80.54
	standard dev.			2.94

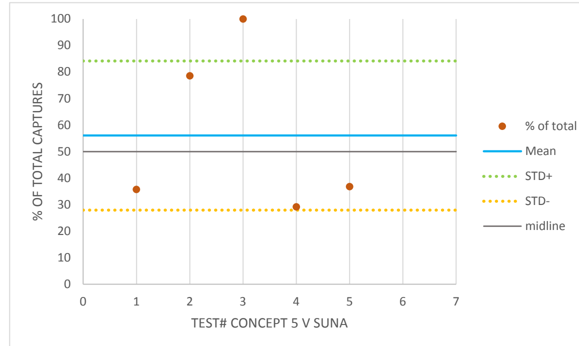


	Concept 3	***Plug***		
		Captures		
	Test #	Suna	Concept	% of total
	Test 1	9	5	35.7143
	Test 2	8	0	0
	Test 3	16	0	0
	Test 4	8	13	61.9048
	Test 5	13	2	13.3333
	mean			22.19
	standard dev.			23.763

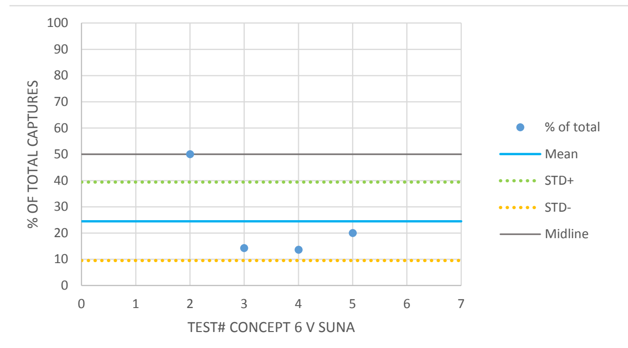


	Concept 4	***Water***		
		Captures		
	Test #	Suna	Concept	% of tc
	Test 1	8	16	66
	Test 2	5	22	81
	Test 3	9	12	57
	mean			68
	standard dev.			10

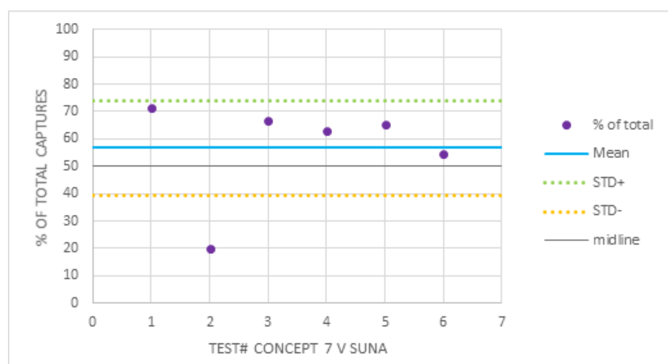
Concept 5 Canopy			
	Captures		
Test #	Suna	Concept	% of total
Test 1	9	5	35.71
Test 2	3	11	78.57
Test 3	0	5	100.00
Test 4	17	7	29.17
Test 5	12	7	36.84
Test 6			
mean			56.06
standard dev.			28.09



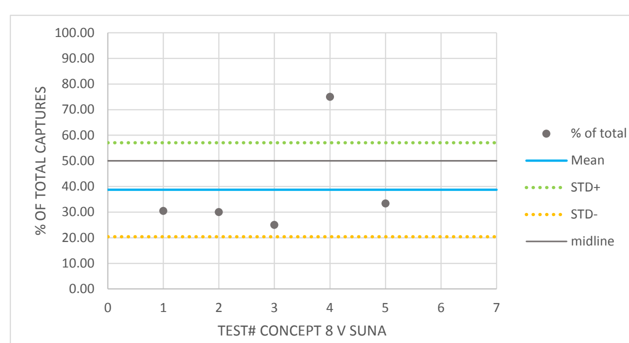
Concept 6 Overhang			
	Captures		
Test #	Suna	Concept	% of total
Test 1	0	0	
Test 2	5	5	50.00
Test 3	6	1	14.29
Test 4	19	3	13.64
Test 5	16	4	20.00
Tets 6			
mean			24.48
standard dev.			14.94



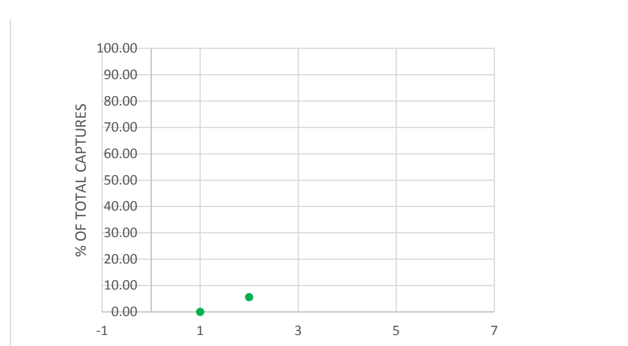
Concept 7 - Donut			
	Captures		
Test #	Suna	Concept	% of total
Test 1	6	15	71.43
Test 2	8	2	20.00
Test 3	2	4	66.67
Test 4	10	17	62.96
Test 5	8	15	65.22
Tets 6	15	18	54.55
mean			56.80
standard dev.			17.22



Concept 8 Lower Capture Zone			
	Captures		
Test #	Suna	Concept	% of total
Test 1	16	7	30.43
Test 2	7	3	30.00
Test 3	6	2	25.00
Test 4	1	3	75.00
Test 5	16	8	33.33
Tets 6			
mean			38.75
standard dev.			18.32

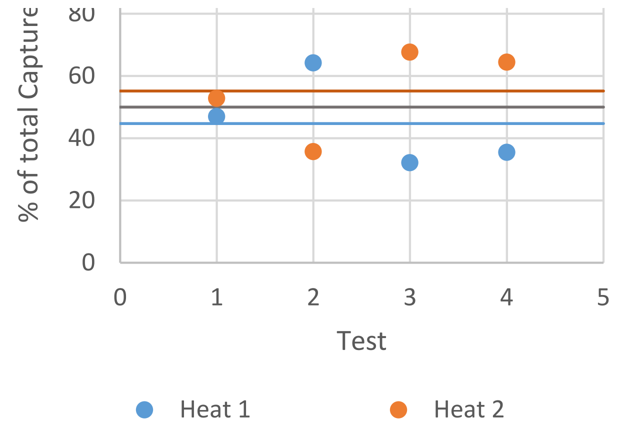


Concept 9 Reversed			
	Captures		
Test #	Suna	Concept	% of total
Test 1	5	0	0.00
Test 2	17	1	5.56
Test 3			
Test 4			
Test 5			
Tets 6			
mean			2.78
standard dev.			2.78

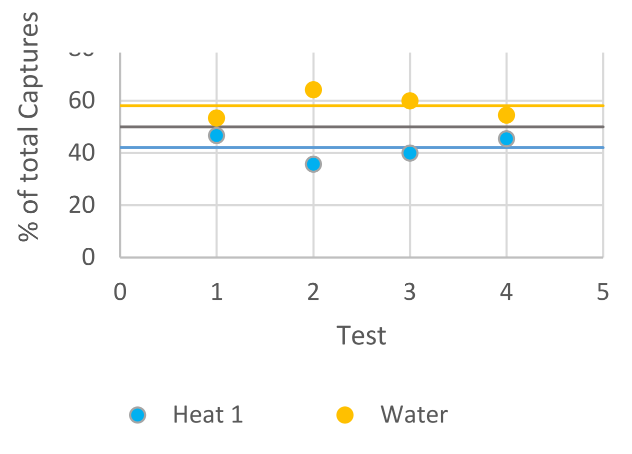


Duel Test of Heat 1, Heat 2 and Hot Water

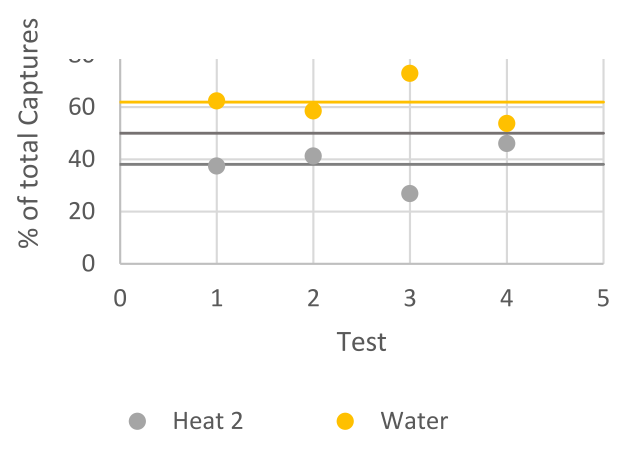
	Heat 1		Heat 2	
Test	Captures	%	Captures	%
0				
1	8.00	47.06	9.00	52.94
2	9.00	64.29	5.00	35.71
3	10.00	32.26	21.00	67.74
4	11	35.48	20	64.52
Mean		44.77		55.23



	Heat 1		Water	
Test	Captures	%	Captures	%
0				
1	7.00	46.67	8.00	53.33
2	5.00	35.71	9.00	64.29
3	14.00	40.00	21	60.00
4	20.00	45.45	24	54.55
Mean		41.96		58.04

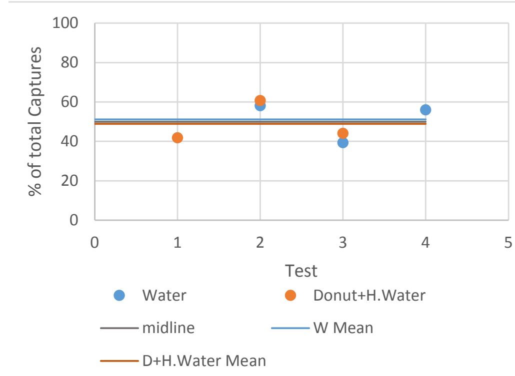


	Heat 2		Water	
Test	Captures	%	Captures	%
0				
1	9.00	37.50	15.00	62.50
2	12.00	41.38	17.00	58.62
3	10	27.03	27	72.97
4	12	46.15	14	53.85
Mean		38.02		61.98

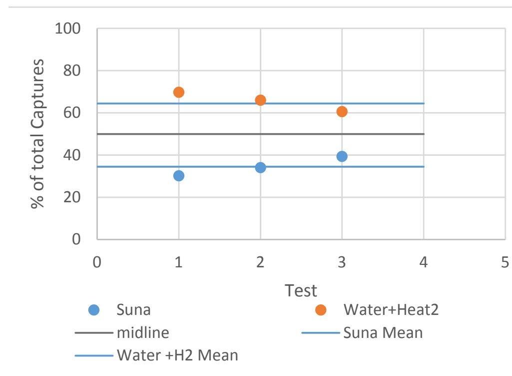


Combining Features

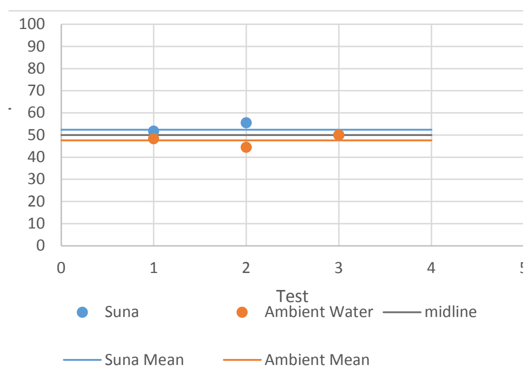
		Water V Water + Donut		
	Hot Water		Donut + H.Water	
Test	Captures	%	Captures	%
0				
1	25.00	58.14	18.00	41.86
2	11.00	39.29	17.00	60.71
3	14.00	56.00	11.00	44.00
4				
Mean		51.14		48.86



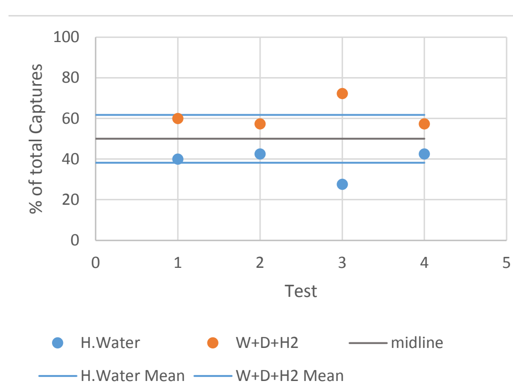
		Suna V Water+Heat2		
	Suna		Water+Heat2	
Test	Captures	%	Captures	%
0				
1	13.00	30.23	30.00	69.77
2	16.00	34.04	31.00	65.96
3	13.00	39.39	20.00	60.61
4				
Mean		34.56		65.44



		Suna V Ambient Water		
	Suna		Ambient Water	
Test	Captures	%	Captures	%
0				
1	15.00	51.72	14.00	48.28
2	20.00	55.56	16.00	44.44
3	20.00	50.00	20.00	50.00
4				
Mean		52.43		47.57



		H.Water V Water+Donut+H2		
	H.water		W+D+H	
Test	Captures	%	Captures	%
0				
1	16.00	40.00	24.00	60.00
2	20.00	42.55	27.00	57.45
3	13.00	27.66	34.00	72.34
4	20	42.55	27	57.45
Mean		38.19		61.81



APPENDIX 4
Hypothesis Evaluation

Hypothesis 1 – Concept one shows that adding heat to the outside of the inlet pipe, just below the rim, produces a higher capture performance than without. This suggests that the heating element produces a close range host cue which provokes close range flights into the capture zone.

Hypothesis 2 – Concept 2 showed the highest average increase in capture rate catching 80% of the total catches across the tests. With a small standard deviation in the results, it can be concluded that adding heat in this way increases performance. Exactly why the capture rate is increased is unknown as flight paths were not recorded but it can be assumed that the warm air re-circulating through the trap draws the targets towards the capture zone.

Hypothesis 3 – Although the concept did provide a wider capture zone with high suction velocity, this variation had a negative influence on performance. It is thought that the wider influence of the strong suction zone resulted in more of the odorous air from the trap being re-circulated and not expelled, reducing the attraction of the trap.

Hypothesis 4 – Concept 4 showed a convincing increase in capture rate and suggests that the combination of host and moisture providing close range host cues makes the trap more attractive to the target vectors. It is probable that the trap causes and increase in approach flights resulting in more captures rather than an increase in the percentage of approaches resulting in capture. It is also probable that the addition of these close range host cues results in closer approach flights which could lead to an increased number of flights resulting in capture.

Hypothesis 5 – It is not possible to make a conclusion to this hypothesis based on the results obtained. Further repetition would be needed and the 3D paths analysed to see how the canopy affects the product performance. Although two tests showed a large increase in performance, the concept was outperformed in the majority of the test. It is assumed that over a number of repetitions it would be found that the performance is approximately equal to that of the Suna-Trap.

Hypothesis 6 – It is not possible to conclude this hypothesis is a true statement. It is believed that the concept has potential and readdressing the prototype could produce more conclusive results. The reduction in performance could have been due to the foam material used for the canopy. Without recordings of the flight paths it is difficult to say if the hypothesis can be truly addressed. However, for all intent and purpose it can be assumed for now that this alteration results in lower capture performance.

Hypothesis 7 – From the results recorded it can be assumed that the intervention in shape of the base did slightly improve the capture rate. It is probably that the odour saturation of the air was increased and the trap became more attractive to the targets. With further testing and accurate simulations it should be possible to optimise this concept to further increase the capture rate.

Hypothesis 8 – It is not possible to conclude on this hypothesis. The trap performed poorly against the Suna-Trap. The canopy used in this concept featured a pattern of larger holes than that of the Suna-Trap and it was later found that this is detrimental to performance. It is therefore not possible to conclude on whether the absence of an inlet pipe inhibits performance or not.

Hypothesis 9 – Based on the initial failures in testing and the uncertainty of the effectiveness of the prototype in can be assumed that this concept does not prove this hypothesis to be true.

APPENDIX 5
Interviews

Dr A. Hiscox

:andra Hiscox

Constructed Skype Interview (informal)

mary of Discussion

›duction of Intent

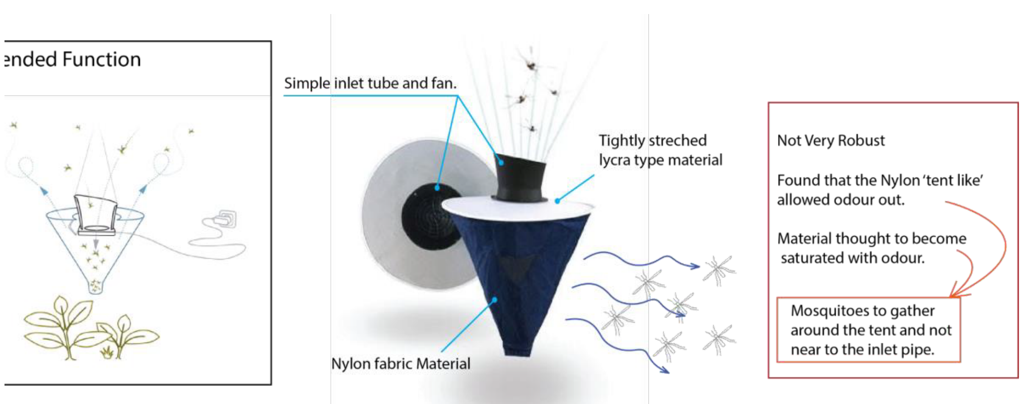
ıy thesis project I am developing a new Odour baited SMoT with an improved capture rate which could be suitable for ı Africa. The project is split into two sections: the first focusing on technological aspects which could be implemented to ɜ a trap with a higher capture rate than the benchmark Suna-trap, and the second is to investigate the context factors lesign a trap which is suitable and available (to BoP consumers) in Africa.

gn Decisions

nterested to understand the design intent behind the development of the Suna-trap and the decisions which lead to the ı of the final product.

did you approach the design of the Suna-Trap?

- The SolarMal project intended to use the Mosquito-Magnet MMX trap however the product was discontinued and no longer produced by mosquito magnet. The need for a replacement trap was required within 12 months.
- We approached Biogents for a replacement trap which could perform as well as the MMX trap in the expected Environment on Rusinga.
- One product, the Mosquitito, seemed it might be suitable however further investigation showed some potential issues which could be improved with further development.



initial evaluation concluded the Mosquitito:

- Was not robust enough for field work in Africa as the traps were going to be in permanent locations rather than moved around.
- Odour was expelled through the conical catch bag which was made of a 'sort of nylon fabric' which was thought to become saturated with odour over time (however GSMS or other analytical methods were performed to determine whether/how much odour is absorbed). This resulted in elevated levels of mosquito activity around the base of the trap rather than the inlet pipe.
- It was feared that the intended orientation and elevation the trap could be subject to flooding during the periods of heavy rainfall experienced in Rusinga.]]

Why is the back of the product a cone?

- The cone was found to become saturated and emit odour causing mosquitoes to accumulate around the base rather than around the top where they can be captured.
- The nylon material was first replaced with an aluminium cone but that was found to be too heavy. It was also too expensive and there was an anticipated risk of theft due to the value of the metal.
- In the end plastic was chosen as it was thought to be robust enough to last up to three years on Rusinga. Also, the base was not water resistant so the product could be turned upside down and the cone also served at a water cover. UV resistant plastic was used to protect against degradation over the course of three years in the field.
- Changing the cone shape was not considered due time constraints and no reason to doubt that the form, taken from the Mosquitito, needed to be changed.

- The Lycra type material that served as the canopy was also replaced by plastic as it was thought to be more robust. It was also possible to use UV resistant plastics and a white/black colour contrast between the canopy and inlet tube.
- A number of hole-patterns were trialled in dual choice tests and it was found that patterns consisting of more, smaller holes was more attractive to the target mosquitoes than options with hole-patterns of larger holes.
- The length of the CO2 outlet tube was also determined from results of dual choice test where multiple lengths of tube were tested.

- After initial development the new 'suna-trap' was tested against competitor products. (Reported in paper 'Development and optimisation of the Suna-trap as a tool for mosquito monitoring and control' by A. Hiscox et al) These being the CDC light trap, BG sentinel and MMX trap.

- The traps were tested in the lab environment as well as outside a hut in semi-field experiment set up in Africa.
- The Suna-trap was found to perform as well as, if not better than the other traps as well as found to be better suited to the intended scenario.

Rusinga

The set up for the Rusinga experiment had a trap suspended outside the home. Why was the trap placed outside the home as opposed to inside and why so close to the house?

- An objective of the SolarMal project was to determine if the implementation of mosquito traps could reduce mosquito house entry and reduce populations of outdoor biting mosquitoes. A number of trials were conducted in the semi field experiment environment to determine at which height the trap was most effective. During the trial mosquito home entry was reduced.
- There is a delay between the infective mosquito bite and the malaria infection which causes the symptoms experienced – 10-14 days on average. This makes it harder for people to appreciate the traps as an immediate benefit. Mosquito bites are still seen as an annoyance and unless people can notice a reduction in mosquito bites they may fail to see benefit of the traps in the short term. In many areas of the Island the traps caught very few mosquitoes sometimes only a couple in a night.

From what I understand, the sustainability of the trapping systems throughout the project relied on the SolarMal team and local technicians who received training and were employed by the team to help maintain the systems. However, when the experiment ended and the team withdrew, the product service system that was left didn't work for a number of reasons and in many cases traps were discarded and only the lights provided remained working,

- Yes, the systems remained with the houses in which they were installed. There was a plan for a community-based organisation to lead the maintenance of systems once the research project had ended. A 'community advisory board (CAB) were established and they in turn set up a sustainability board but were unable to source the replacement parts and set up a business. Other problems surrounding a sustainable product service system included people's ability to save, willingness to save and overheads involved before parts can be purchased.

- It is easy for people to see the immediate benefits of the indoor lighting and there are many really good reasons for maintaining them. It is, and it is often the case, that the feeling of 'having' is better than the 'not having' something. In the way that it is easy to see the benefits of having lights at night or phone charging. When you remove a negative thing such as, stopping the mosquito bites, it is less attractive as that is how it should be. It is like providing affordable healthcare.... It's is appreciated but in a different way because that's how it should be: healthcare should be available.

What context related difficulties did you face when implementing traps in Rusinga?

- The traps are pretty big and bulky. Many of the SolarMal systems were provided to homeowners in more remote locations and each day we had to load the car (Toyota Hilux) up with cones, canopies, fans and nets and head out across country. Although the traps seem quite simple there is still a number of components and set ups often took a while. For the people receiving traps, it could take a little while to get to grips with the set up and the kind of fiddly bits. Although after a few uses it becomes easier.
- Essential smaller, more lightweight traps which are easier to distribute and install would have been great. It would also improve logistics on a greater scale especially with shipping costs etc.

It is a question which pops up regularly and the answer is still unclear – does the addition of attractants increase the number of mosquitoes drawn to the home?

- There is nothing to suggest it does. Studies have shown that the current synthetic odours are not more attractive than a human being but they are as attractive as a human odour placed in a trap. The odours given off from the home are far more attractive to mosquitoes than the odour in the trap. Mosquitoes can pick up on the elevated CO_2 levels combined with odours from houses or villages from long ranges. Of course it all depends on conditions such as wind etc. but mosquitoes can pick up on plumes from 75m, 150m... 200m.
- Essentially the attractiveness of the trap is competing against humans. Placing the traps too far from the home wouldn't work as mosquitoes would be more attracted to the house or village rather than the trap.
- The current, push-pull project I am working on utilises the human odour from the eaves of the home. By implementing repellents impregnated on to fabric and positioned in the eaves the mosquitoes are repelled from the home. The trap positioned outside the home lures the mosquitoes which have been repelled, as well as those mosquitoes which are yet to encounter the home.

I investigated possible scenarios of mosquito home entry and hypothesis of behaviour which leads me to wonder if it is the overlap of odour from the home with the synthetic odour from the trap which forms a concentrated area which is very attractive to the mosquitoes and it is this that causes them to enter the trap. (Shows quick sketch home entry diagram with trap set-up).

- Yes this is quite possible and is what we imagine might be the case. However the traps do not fully prevent home entry, and bed-nets should always be used. In many cases it is thought that mosquitoes caught in the traps have been unable to find a blood host and approach the trap after exiting the home.

Looking back at the Rusinga experiment, knowing what you now know? What would you do differently in a repeat experiment?

- Probably developing the traps to be easier to transport, install and maintain. Especially so they can be left on site and continue being used successfully.
- And better development of a sustainability programme to enable the systems to keep running once the research project ended.

M. Murindahi

Interview

A PhD researcher conducting a research on malaria

Semi Constructed Interview (informal)

Summary of Discussion

Introduction of Intent

For my thesis project I am developing a new Odour baited SMoT which could be suitable for use in Africa. The project is split into two sections: the first focusing on technological aspects which could be implemented to create a trap with a higher capture rate than the benchmark Suna-trap, and the second is to investigate the context factors and design a trap which is suitable and available (to BoP consumers) in rural Africa. From this interview I hope to understand more about the social environment in which the product is intended.

Involvement with malaria prevention

Can you tell me more about what you do and your experience with Malaria and Malaria prevention in your case or Research?

The research I am working on is aims to investigate whether a Citizen Science approach can work in lower income countries to help in malaria prevention.

Despites the success that has made in the past decades in malaria control in my case, malaria is brought again on the table since its increase since 2012. There are interrelated factors that have contributed to this upsurge. These include: the variability of rainfall that increase breeding sites, temperature that influence the development of the vector and the parasite, the increase of insecticide resistance, the increase of feeding and biting behaviour change of the vectors, the drop/ low coverage of preventive measures.

In order to understand this increase and to provide with malaria mosquito data that have been missing in our country, citizen science approach is foreseen as key in mosquito control and monitoring. In addition, traditional method (HLC) do not work on the required scale due to lack of resources and funding. There is inadequate technical capacity for mosquito surveillance. With the lack of professional personal available, the approach turns to citizens to transmit their observations of their homes to scientists to help to understand the current malaria increase. Agriculture is the main sources of income in Rwanda. In the recent years, the development of agriculture has led to an important transformation of the ecological landscape, creating suitable habitats for malaria vectors. Evidence shows that the introduction of intensive irrigation agriculture increases the malaria transmission. It is very important to gather data on mosquito populations and prevalence and continue to monitor as agricultural industries continue to expand. The survey was conducted aiming to gauge the perception of nuisance in 2 settings in rural areas. The results demonstrate that research can rely on population experience and knowledge in the determination of mosquito spots. Mosquito traps were well accepted because residents saw a way to reduce mosquitoes in their home.

Participation in the research empowered the participants since they could provide their homes to collect some mosquitoes hence reduce the risk malaria transmission but also to gauge the outcome with their practices in malaria control.

Level of Knowledge

1. To what extent are people aware of the dangers of malaria?

- People are well informed on malaria (the disease) however the knowledge on mosquitoes (breeding sites) is still low.

   a. What are the main reasons for lack of knowledge of malaria?

- There is no Lack of knowledge on malaria (the disease) but the knowledge on the mosquitoes (breeding sites) need to be improved especially what are the practices they can do to reduce mosquitoes or to avoid mosquito biting in their environments or homes.

2. How are people educated about the dangers of malaria?

   a. Are people aware of the various malaria prevention methods (bed net, insecticides, residual spraying and traps)

- Yes, methods currently provided or in place.

   b. Are people concerned with protecting themselves from malaria?

- People are concerned with protecting themselves but don't for a number of reasons Such as bedbug infestation as people perceive bedbug biting as a threat than mosquito bites. Bed nets are a good environment for bedbug since it become easy and direct to feed on the host during the night. Weather is another factor such as hotness, itching discomfort were among the cause for not using bed nets as found in a study conducted in the area (Ingabire et al., 2015). In the same study it was found that Men tend not to use bed net more than women do. There is not enough bed nets per house due to low coverage of bed nets. Hence lacking funds or delay in the availability of the funds can hinder the execution of activities planned for malaria control. Due to poverty, not all the people can afford a bed net because of lack of resources.

   c. How about protecting their children?

- At a household level, the head of the household prioritize children and pregnant women. However due to unavailability of bed nets (a net per 2 persons per house), then sometime children are not protected as well especially when the number of people per house increases.

3. Are people aware of the cost of malaria treatment?

Yes they are, almost the all population have access to malaria treatment through an health Insurance programme in place however there are a few who do not have the health insurance hence cost becomes a factor to not get treatment because they can't afford it without an health insurance it costs in this case.

   a. How about the cost of prevention?
   Due to the programme which is in place that provide with bed nets.

   b. Do people not recognise that prevention costs are usually much cheaper than treatment and they could save a lot of money over a year?

- It could be possible through education to show people the potential of purchasing nets themselves by instalment hence it will help to save life and prevent them from getting sick which further will cost more for the treatment.

4. How valuable are bed nets within rural communities?

- I prefer to leave a blank since this is not a conclusion from a research it is just speculation. Leave a blank= no answer

Finance

1. What are the main financial management systems available to people in Rural Rwanda (conventional banking, mobile banking, table banking or individual savings?)

   I prefer to leave a blank since this is not a conclusion from a research it is just speculation. Leave a blank= no answer

2. Do you have any knowledge on the unofficial 'table banking' approach to community saving/lending in Rwanda? (Table banking is a group funding strategy where members (usually women) of a particular group meet once every month, place their savings, loan repayments and other contributions on the table then borrow immediately either as long term or short term loans to one or a number of interested members)
   - I do not know. However, I understand the concept and can see it can be profitable to the people in their communities.

3. In table banking groups, what are people most likely to borrow money for?
   - Probably bed nets will be the last on the list. Mainly health insurance school fees, food or other costs such as providing to birth delivery expenses for example or to invest in business development.

APPENDIX 5
SWOT ANALYSIS

Internal attributes of the System

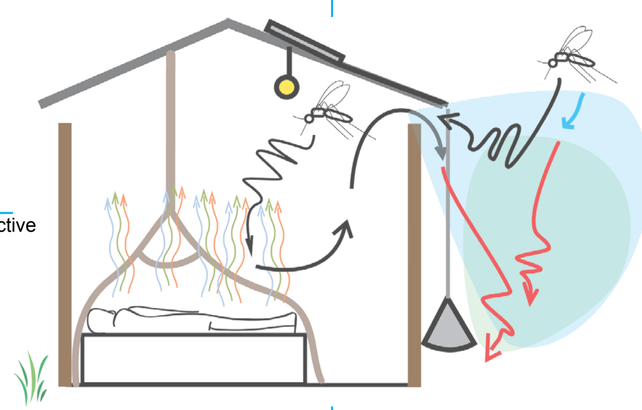
S
Strengths

- Proven to aid Malaria prevention in field test when used alongside LLINs
- Reduces vector home entry in semi-field and field testing reducing annoyance.
- Useful research tool for entomological projects in Africa.
- Delivers perceived user benefit from reduced home entry and fewer bites.
- Users have expressed a willingness to pay monthly for maintenance of system.
- Low Power requirement from the trap

W
Weaknesses

- Low capture rate of only 4% from all paths recorded (estimated resultant capture rate 10%)
- Systems are bulky and difficult to transport/ distribute
- Current traps don't make use of close range host cues.
- Traps and parts are not available to consumers in Africa.
- Product and maintenance potentially too expensive for consumers.
- Requires community participation to sustain effective trapping over time.

Helpful to achieving objective



Harmful to achieving goal

- Improve the performance of the trap to make a more effective tool for prevention of Malaria and increasing perceived product benefit.
- Introduce heat and moisture as close range host cues to improve capture performance.
- Improve the feasibility of distribution and installation by reducing the time taken to install/ set up the trap.
- A more robust product could reduce maintenance burden making the system more affordable.
- Improve user experience by simplifying the catch bag reducing time taken to empty and replace.
- Create a demand and make the product available to consumers

Opportunities
O

- Trap function cannot be maintained by users in Africa.
- Low prioritisation of preventative healthcare
- Energy requirement.
- Synthetic odour strips and CO_2 need to be maintained for the trap to be effective.
- System and maintenance costs may be unaffordable to many individuals in rural Africa.

Threats
T

External attributes of the Context

SWOT Analysis

	Opportunities					Threats				
	Improve the performance of the trap to make a more effective tool for prevention of Malaria and increasing perceived product benefit.	Introduce heat and moisture as close range host cues to improve capture performance.	Improve the feasibility of distribution and installation by reducing the time taken tc install/set up the trap.	A more robust product could reduce maintenance burden making the system more affordable.	Improve user experience by simplifying the catch bag reducing time taken to empty and replace.	Trap function cannot be maintained by users in Africa without support.	Low prioritisation of preventative healthcare	Requires electrical and human energy and additional energy requirements could be detrimental.	Synthetic odour strips and CO2 need to be maintained for the trap to be effective.	System and maintenance costs may be unaffordable to many individuals in rural Africa.
Proven to aid Malaria prevention in field test when used alongside LLINs	+	0			-	--	-		-	--
Reduces vector home entry in semi-field and field testing reducing annoyance.	+	+	+			-	+		-	-
Useful research tool for entomological projects in Africa.				+		+	+	-		-
Delivers perceived user benefit from reduced home entry and fewer bites.				+	+	-	+	-		-/+
Users have expressed a willingness to pay monthly for maintenance of system.	++						+			+
Low Power requirement from the trap		-					+	-		
Suna= Low capture rate of only 4% from all paths recorded (estimated resultant capture rate 10%)	++	++		+		-	-			
Systems are bulky and difficult to transport/distribute		-	++		+	-	-	-	-	
Current traps don't make use of close range host cues.	+	++			-	-	-		0	
Traps and parts are not available to consumers in Africa.	+			-		-	-			
Product and maintenance potentially too expensive for consumers.	--			++		--	--		-	--
Requires community participation to sustain effective trapping over time.	-			-	-	-	-		-	-

Negative Issues (Potential Problems)

- Increasing performance makes the traps more effective *versus* Users unable to maintain the system.
- The trap (system) cannot be maintained without support *versus* Use of traps alongside LLINs can reduce Malaria.
- The trap (system) cannot be maintained without support *versus* Maintenance of the trap could be too expensive for the user.
- Low prioritisation of preventative healthcare *versus* Maintenance of the trap could be to expensive to the user

Positive Issues (Potential Solutions)

- Improving performance for a more effective product *versus* Users expressed a willingness to pay
- Improving performance for a more effective product *versus* Current Traps have a low capture rate.
- Introducing heat and moisture more a more effective trap *versus* Current Traps have a low capture rate.
- Introducing heat / moisture more a more effective trap *versus* Current Traps don't have close range host cues.
- Improve distribution and installation *versus* traps are bulky and difficult to transport.
- A more robust system would require less maintenance *versus* Maintenance costs are unaffordable to users.

Key Issues

- Increasing performance makes the traps more effective *versus* Users unable to maintain the system.
- The trap (system) cannot be maintained without support *versus* Use of traps alongside LLINs can reduce Malaria.
- The trap (system) cannot be maintained without support *versus* Maintenance of the trap could be too expensive for the user.
- Low prioritisation of preventative healthcare *versus* Maintenance of the trap could be to expensive to the user

CAUSE
Low capture rates found in current products is detrimental to the potential use of odour baited mosquito traps used alongside LLINs, as tools for prevention of malaria in the field. Increasing the performance by adding a source of hot water as well as an external heating element makes the traps more effective. Although agreeing weekly upkeep was possible and showing a willingness to pay for monthly maintenance, users have shown to be unable to maintain the system without the support of a product service system. Combined with the low prioritisation of preventative healthcare and the expense associated with purchase and maintenance contributes to the low demand for the product.

EFFECT
Without improving the capture rate, as well as appropriateness in context, mass trapping of mosquitoes using SMoTs may not be effective enough to deliver the user benefit required for community wide sustenance of the system. As well as technical design challenges related to improving performance, the design most consider the use in context and address the challenges highlighted in order to be effective.

CENTRAL PROBLEM DEFINITION

With community participation and the support of an affordable and sustainable product service system, the use of odour baited mosquito traps alongside LLINs have potential to contribute to the eradication across Africa. In order to be more effective as a tool for prevention of transmission and control of vector populations, the performance of the trap must be improved. Although many insights have been gathered which can be considered during the design phase, it is not possible to design a market ready product without semi-field and field testing with users in context.