Urban Back-up Systems

Defining a new product range for on-grid users in Cambodia

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Bachelor Thesis Industrial Design Engineering

University of Twente

Kamworks Ltd.

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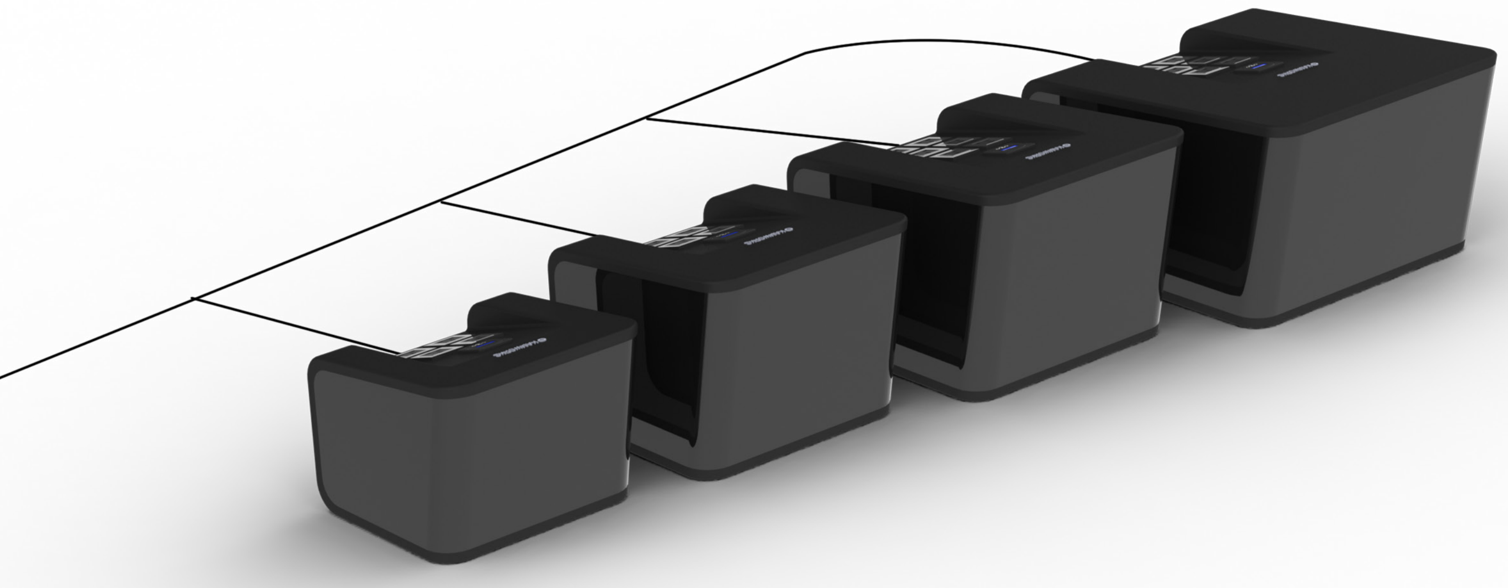

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Preface

This report presents results of a research and design project commissioned by Kamworks Ltd, a Cambodian enterprise based in Phnom Penh. The project is the final assignment of the bachelor major Industrial Design Engineering at the University of Twente, the Netherlands.
The motive for the assignment for Kamworks is that they want to explore developing a product for a new market. The University of Twente is eager to collaborate with companies such as Kamworks to offer students an opportunity to get some corporate hands-on experience. For me, Alexandra van der Meer, this was an interesting opportunity to get design experience in a foreign country.

Thank you to all that contributed to making this project a success: Firstly to Juan Jauregui Becker and Brecht van der Laan for their guidance and critical feedback. Input from Kamworks staff Jeroen Verschelling, Jim Gramberg, Arjen Luxwolda and Mengse Chie was also much appreciated. Lastly, thank you to all respondents I was able to interview and the UT staff that organised a SPARK meeting for reflecting on my project.

Image 1 A view of downtown Phnom Penh. Having some French influence, the boulevards are wide and spacious.

Image 2 (page 6-7) A streetview of downtown Phnom Penh,. The mopeds and 'tuktuks' you see are a common means of transportation in the city.

Contents

Summary

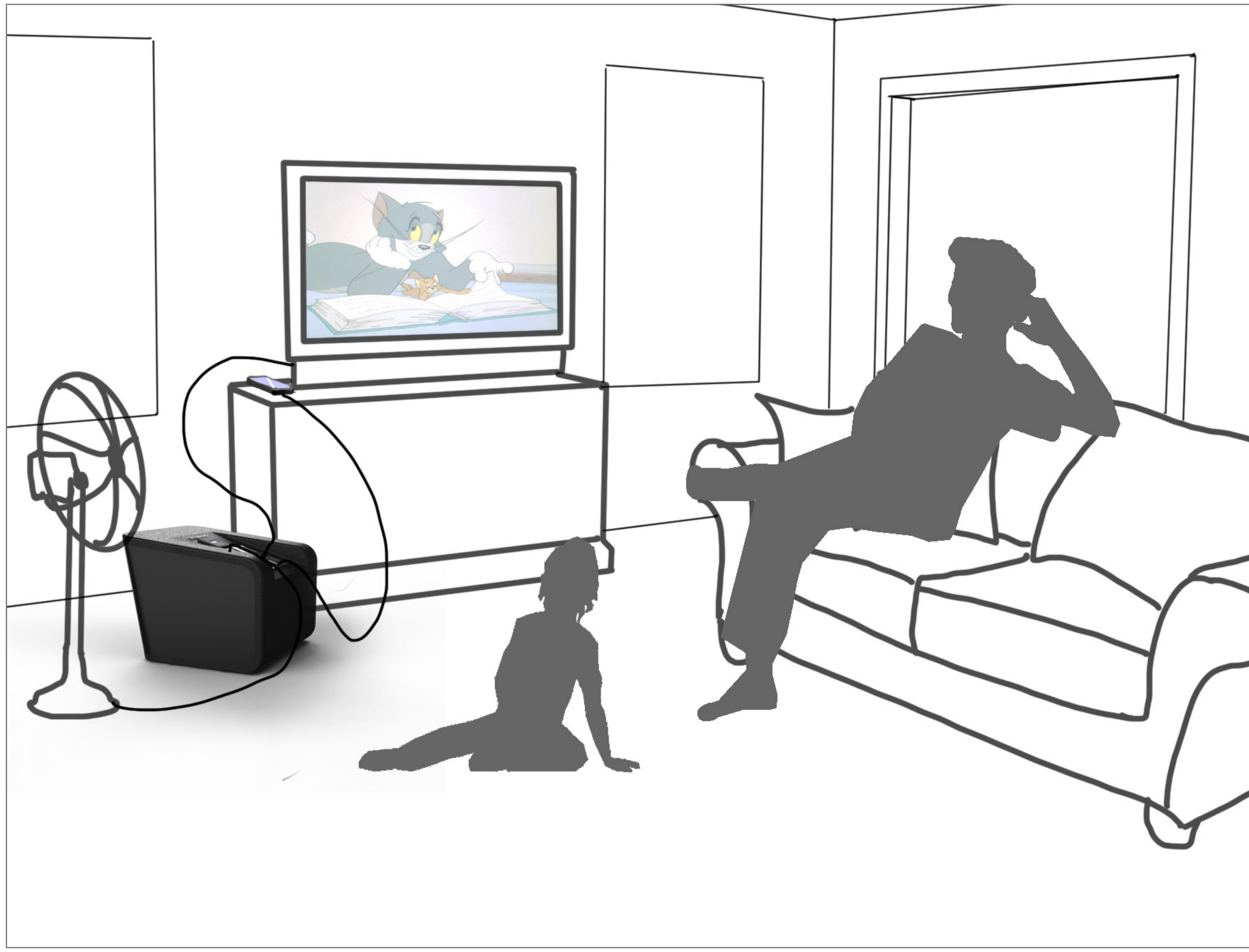
The objective of Kamworks is to launch a new on-grid or urban, plug-and-play product range for consumers in addition to their existing off-grid (rural) product range. Though currently the market for solar is mostly in off-grid areas, Kamworks suspects that in the future this will shift to include on-grid areas. Thus, they want to start introducing their brand to the urban market. To conclude whether their idea of designing a range of back-up systems would be a reasonable step and to provide a base of information about the urban market, they want this project to start with a market analysis. After this, the objective moves on to designing a first concept for the product range, focusing on feasibility. Kamworks has the resources to develop a back-up system and thinks this new product range would fit the urban market, due to frequent power cuts. They suspect the target group consists of either expats, middle class Khmer (Cambodians) with small shops or well-to-do Khmer.

A market analysis was done in a time span of ten weeks to find out about these urban target groups and whether there would be market for a back-up system. A combination of interviews, questionnaires, desk research and street observations was used to create a broad basis of information. Conclusions are:

- In terms of availability, quality and price the power situation is going to remain poor in the next 10 years.
- The best of the three target groups to focus on are the well-do-do Khmer, because among other reasons they have money to spend and are the most likely of the three groups to invest in new technology and quality products.
- Being able to show your status to others is important in Khmer culture.
- The technology that Kamworks would use for a back-up system is not suitable for powering heavy consuming devices such as air conditioners.
- Competitors for a back-up system are a generator, a UPS or ‘budget’ solutions such as candles or simply waiting for the power to come back on.
- When comparing costs, a back-up system is not a good competitor for a generator.

In consultation with Kamworks it was finally decided to design a range of 3-4 back-up systems for the well-to-do Khmer target group.

During five weeks of product design, the first steps towards creating a new product were taken. After setting up requirements (p. 40), the main focus was finding out whether the product could perform the functions stated in the requirements specified for price, physical characteristics, inputs and outputs, aesthetics and user requirements. The final concept chosen was a range of four systems that vary in power (350/1200W) and battery capacity (30/90 min). To the right a scenario and a render of the product range can be found. The product aims for a modern, wealthy style, which is important to contribute to creating status. Based on calculations and careful selection of components it can be said that it is feasible that the product can meet the requirements.
Some recommendations for next steps to take are to detail the shell design for manufacturing, to conduct a user experience test with a working model, and to think of packaging and transportation.



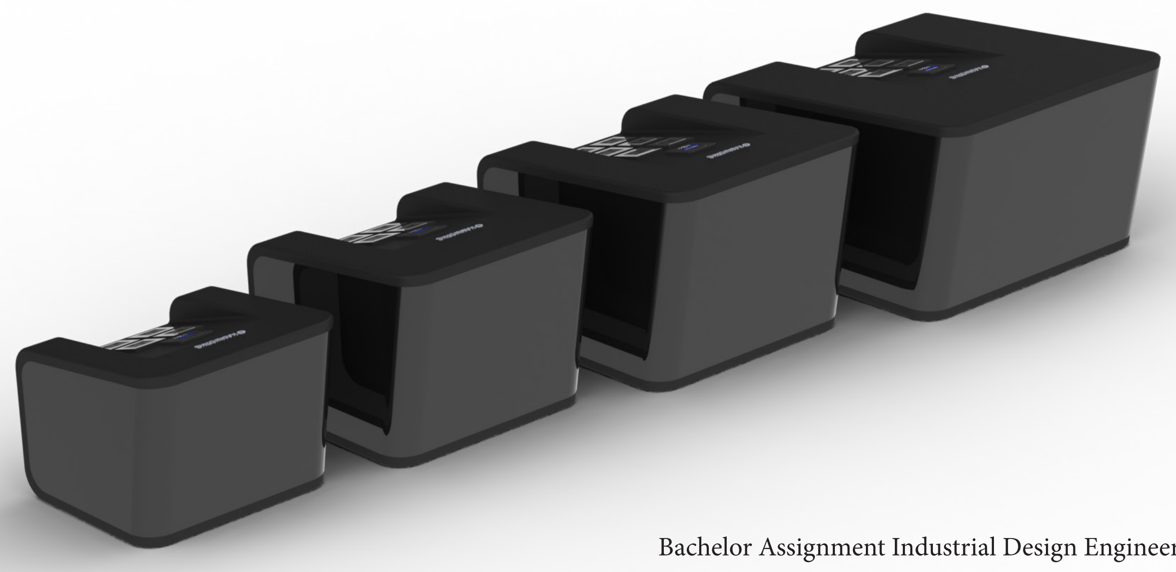
Samenvatting

Het doel van Kamworks is om een nieuwe, plug-en-play productlijn op te zetten voor de stedelijke markt, op plaatsen waar toegang is tot netstroom. Op het moment verkoopt het bedrijf vooral zonne-energie producten aan gebieden waar geen netstroom is. Echter, ze verwacht dat in de toekomst de markt voor solar zal verschuiven naar gebieden met netstroom en wil daarom alvast beginnen om haar merk op de stedelijke markt te introduceren. Het bedrijf denkt dat het een goede zet is om een reeks back-up systemen, te gebruiken wanneer de electriciteit uitvalt, op de markt te brengen. Om dit te verifiëren wil ze in dit project eerst een marktonderzoek zien. Daarna verschuift het doel naar het ontwerpen van een eerste concept voor de productreeks, waarbij de nadruk op haalbaarheid ligt. Kamworks heeft de middelen om back-up systemen te maken en denkt dat het product in de beoogde markt zou passen. Ook denkt ze dat de doelgroep bestaat uit expats, middenklasse Khmer (Cambodjanen) met kleine winkels of welgestelde Khmer.

In een tijdsbestek van tien weken is er marktonderzoek gedaan naar deze stadse doelgroepen. Hierin is ook onderzocht of er een markt zou zijn voor back-up systemen. Door een combinatie van interviews, enquêtes, desk research en straat observaties te gebruiken is er een brede informatiebasis gecreëerd. Conclusies zijn:

- De beschikbaarheid, kwaliteit en prijs van de electriciteit in Cambodja zullen de komende tien jaar nogsteeds te wensen over laten.
- Uit de drie doelgroepen kwamen de welgestelde Khmer als beste keuze, onder andere omdat ze genoeg geld te besteden hebben om een back-up systeem te kopen. Ook leken ze, vergeleken met de andere twee doelgroepen, het meest bereid tot het aanschaffen van nieuwe technologie en producten van hoge kwaliteit.
- In de Cambodjaanse cultuur is het belangrijk om je status aan anderen te kunnen laten zien.
- De technologie die Kamworks wil gebruiken voor een back-up systeem is niet geschikt voor het voeden van apparaten die veel vermogen nodig hebben, zoals air conditioners.
- Concurrenten van een back-up systeem zijn de generator, de UPS en goedkope oplossingen zoals kaarsen of wachten tot de stroom weer aan gaat.
- Wanneer alleen naar de kosten gekeken wordt blijkt dat een back-up systeem niet kan concurreren met een generator.

In overleg met Kamworks is uiteindelijk besloten om een reeks van 3-4 back-up systemen te ontwerpen voor de welgestelde Khmer doelgroep. In de ontwerpfase zijn gedurende vijf weken de eerste stappen richting een nieuw product gemaakt. Eerst is een programma van eisen (p. 40) opgesteld. Daarna is de nadruk op haalbaarheid gelegd: Uitzoeken of het product aan de eisen van prijs, fysieke karakteristieken, inputs en outputs, esthetiek en behoeften van gebruikers zou kunnen voldoen. Het uiteindelijke concept bestaat uit een reeks van vier systemen die varieren in vermogen (350/1200W) en batterij capaciteit (30/90min). Hiernaast is een render van de reeks te zien en een scenario van het product in gebruik. Het product streeft naar een moderne, rijke stijl, om zo in te spelen op het belang van status in de Cambodjaanse cultuur. Op basis van berekeningen en het zorgvuldig selecteren van componenten kan worden gesteld dat het product aan het programma van eisen kan voldoen.
Aanbevelingen voor de toekomst zijn om de behuizing verder te detailleren voor productie, om een gebruikstest uit te voeren met een werkend model en om aan verpakking en transport te denken.



1 Introduction

1.1 Introduction Bachelor Assignment

This report is the result of a Bachelor thesis that was realised by a collaberation of the University of Twente with the solar energy company Kamworks Ltd. The project took place from May - August 2012 in Phnom Penh, Cambodia.

1.1.1 Kamworks

Kamworks is a small Cambodian solar energy company, established in 2006. Their mission is to provide sustainable energy solutions for off-grid and on-grid communities. Part of this mission is also to raise awareness and expertise about solar energy to the local community. The core operations of Kamworks are sales, product development and installation, service and maintenance of existing products. Kamworks offers products in three categories: consumer products, energy audits (consulting) and custom professional solar systems (see sidebar and image 3). Products are sold to high-end markets such as schools, hospitals or hotel resorts, and low-end, consumer markets.

1.1.2 Industrial Design Engineering, University of Twente

The bachelor assignment for the Industrial Design Engineering bachelor is the final project in which students individually prove, test and develop their ability as Industrial Design Engineers. The project is required to be broad, have an appropriate level of complexity and result in either a tangible design proposal or specific research conclusions. The official time frame for the assignment is three months. However, the time frame of this project is four months.

1.1.3 Project Objective

The objective of this project is to define a concept for a new urban product range for Kamworks, based on market analysis. In Cambodia, solar energy is currently seen mainly as a solution for off-grid areas (Kamworks, 2012). However, Kamworks suspects that in the future, the solar trend will shift to on-grid areas like it has in Europe. The company wants to be ready for this by already introducing its brand to the on-grid market. The final objective of Kamworks is to position Kamworks as a brand that offers quality (solar) energy solutions.

KAMWORKS

Professional

Home

Consulting

Image 3 A rural family using the Moonlight, a signature solar lantern product designed and sold by Kamworks,

With the Cambodian economy booming, especially in main cities such as Phnom Penh, Kamworks sees an opportunity to enter the urban consumer market. Kamworks wants to launch an on-grid, urban product range for consumers in addition to their existing off-grid, rural product range. A good market response is suspected by designing a range of back-up systems that solve the some problems that unreliable electricity in urban areas cause, especially power cuts.
The product should be plug-and-play. Preferably, components manufactured by existing Kamworks suppliers are used to create synergy. In this project a market analysis was done to research this new urban market. Results from this analysis were used to contribute to the first steps of new product design.

1.1.4 Report Structure

Due to the fact that this project took place in a foreign country that is very different from the Netherlands, some background information about Cambodia will be provided in the next section. In Chapter 2 – Market Analysis the goal, methods and results of the market analysis will be provided. Main results include a power, user, technical, and competitor analysis. In Chapter 3 – Product Design the goal, requirements, concepts and final design proposal will be described. This final design proposal should be seen as a basis for further detailing and manufacturing of the product, not as a finished product design. Finally, in Chapter 4, conclusions and recommendations are provided. Any further background information that might be useful can be found in the appendices.
Please note that pictures of Phnom Penh have also been added where possible to provide the reader with a better image of this hot, humid and vibrant city.

1.2 Background Cambodia

To understand this design report, it is essential to know something about Cambodia in general. This section gives some general information about history, demographics, geography, economics, infrastructure and the political situation in Cambodia, mainly based on the CIA World Factbook report on Cambodia. Specific details of importance to product design will be added later. This section is meant to sketch a reference as a starting point for further reading. Please also view the images in the sidebars and main text.

1.2.1 Historical Background

Most Cambodians consider themselves to be descendants of the Angkor Empire that once was, referring to themselves and their country as Khmer and the Khmer Kingdom. This empire reached its golden age between the 10th and the 13th century, extending over much of Southeast Asia and declined in a long period of time weakened by attacks from Siam and the Cham (present-day Thailand and Vietnam).

In 1863 the Kingdom was placed under French protection by the king, becoming a part of French Indochina in 1887. This lasted up till 1953, after the Japanese occupation in World War II, when Cambodia gained full independence from France.

In April 1975 Communist Khmer Rouge, led by Pol Pot (sidebar, p. 15) captured the city of Phnom Penh by force and evacuated all cities and towns, setting out to turn Cambodia into a Maoist peasant agrarian country, with China as advisor. Currency was abolished and people were forced to do labor. The wealthy and educated were systematically imprisoned or killed. At least 1.5 million Cambodians died in a time frame of three years due to execution, forced hardships or starvation (see sidebar, p. 15).

The Khmer Rouge was driven from the cities in 1979 by a Vietnamese invasion, after which 10 years of Vietnamese occupation began and with it thirteen years of civil war. In 1993 UN-sponsored elections brought a certain level of peace and stabilization to the country. In 1999 the last of the Khmer Rouge surrendered and since 2003 the elections have been relatively peaceful (SEARDF, 2007; CIA, 2007-2011).

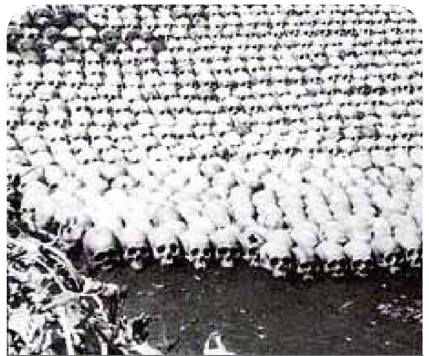
Cambodian flag

Khmer Rouge flag

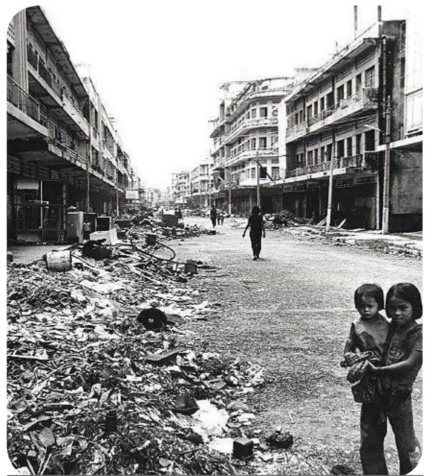
Countryside near Kratie

Phnom Penh skyline

Pol Pot, leader of Khmer Rouge



Mass graves, Choeung Ek



Phnom Penh, just after Vietnamese capture, 1979

Image 4 Map of Cambodia, relief

1.2.2 Geography

With 181,035 km^2 of land, Cambodia is about four and a half times the size of the Netherlands. The terrain consists mostly of low, flat plains and mountains in the southwest and north (see image 4). Waterways such as the huge Tonle Sap lake and the Mekong River influenced Cambodian ways of life. Natural resources are oil and gas, timber, gemstones, iron ore, manganese, phosphates and hydropower potential.

Cambodia knows a humid, hot, tropical climate defined by the monsoon winds which bring a rainy season from June to November and a dry season from December to May. There is little seasonal temperature variation. The lowest average is 21°C in January; the highest average 35°C in April (ClimateTemp.info, 2008-2012).

1.2.3 People and Society

Cambodia has a population of about 15 million people (July 2012 est.), of which 90% are Khmer, 5% Vietnamese, 1% Chinese and 4% other nationalities. About 20 percent of the population was living in urban areas in 2010. The average age is 23 years, with a birthrate three times the amount of the death rate (25 vs. 8 per 1000 population, 2011 est.) (see sidebar). Life expectancy at birth is 60 for males and 65 for females (2011). The official language is Khmer, other languages being Chinese, French and English. Of males over 15 years old, 85% could read and write in 2004; for females this is 64%. Most of the country (96.4%) is Buddhist, the official religion (1998 census) (CIA, 2007-2011). A picture of Buddhist monks can be viewed in the sidebar.

1.2.4 Government

Cambodia knows a multiparty democracy under a constitutional monarchy, of which the constitution was promulgated on the 21st of September 1993. The main party is the Cambodian People's Party (CPP). Prime Minister has been Hun Sen since January 1985, the current monarch is King Norodom Sihamoni (CIA, 2007-2011).

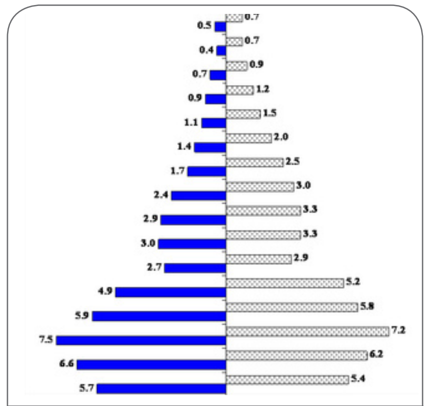
1.2.5 Economy

The Cambodian GDP is $32.95 billion (2011 est.) with a growth rate of a 6.7% (2011 est.). With a GDP per capita of $2,300, this makes it amongst the poorest countries in the world. For comparison: The Netherlands has a GPD of 42,300 per capita. The official poverty thresholds per day vary too though: $ 37.50 in the Netherlands vs. $0.61 in Cambodia (UN, 2007; CIA, 2007-2011; CBS, 2011).

Cambodia's economy has been growing for the past fifteen years. For example, poverty has been reduced from 47% in 1993 to 30% in 2007. Primary school enrollment, clean water sources and life expectancy have also improved in that period of time. However, inequality levels have also risen, according to the UNDP Cambodia. As an indication: the highest 20% of the populations held 46% of the income share in 2008 (UN, 2007; TheWorldBank, 2011).

Cambodia produces and exports agriculture products such as rice, rubber, corn, vegetables, cashews, cassava and silk (see sidebar). Main industries are tourism, garments, construction, rice milling, fishing, wood and wood products, rubber, cement, gem mining and textiles.

Buddhist monks



Age distribution, CIPS 2004

Cashews

Rice production, Kampong Speu

Mopeds are very common

Illegal logging is a problem

A traditional wedding

Image 5 Chinese power in Cambodia?

Political cartoon by Sacrava

(Sacravatoons no 2240)

1.2.6 Transportation

Transportation infrastructure in Cambodia consists of airports, roads and waterways. There are no working railways. Of all 40,000 km of road, only 7.5% was paved in 2007. Like many other aspects, infrastructure is improving with more roads being built and paved (CIA, 2007-2011). Often people use motorcycles or mopeds, instead of cars or trucks (see sidebar).

1.2.7 Transnational Issues

With its direct neighbors, Cambodia has some transnational issues, according to the CIA World Factbook. These include concerns about upstream Mekong dam constructions in Laos and border disputes with Thailand and Vietnam. Also, Cambodia has some production of methamphetamine and is vulnerable to money laundering due to its cash-based economy and porous borders. Lastly, China has a large influence in Cambodia, financing many building projects, loaning money to the Cambodian government and owning businesses and real estate (see image 5). The influence of China in Cambodia has led to some discussions within ASEAN (Sokheng, 2 April 2012).

2 Market Analysis

This chapter describes the approach used and the results generated from a market analysis conducted in a time frame of ten weeks in Phnom Penh. First, the problem, goal, hypotheses and methods are described. Secondly, research results are presented. Lastly, a conclusion for the designer is derived from these results.

2.1 Problem

The objective is to define a profitable new product range for urban consumers in Cambodia. Kamworks expects that offering a range of back-up systems would be a successful move, due to the facts that black-outs are still common in Phnom Penh and that diesel prices (for powering generators) are going up. Kamworks has defined three potential target groups: Expat families, middle class Khmers and well-to-do Khmers. However, since the company has always focused on rural markets in the past, it does not have enough information about this new market to continue with product design.

2.2 Analysis Goal

Kamworks needs enough information about the market to make design decisions. A target group must be chosen based on founded arguments. Also the question must be asked whether there really is a market for the back-up range they propose. Factors that influence this question are the future power situation, competition and feasibility. The main goal is to find out: **To which extent is there an opportunity within one of the target groups for an urban back-up system?**

This main question is split into four sub questions:

1. What future power situation in Cambodia is to be expected in the next 1-10 years in terms of availability, quality and price?
2. Which of the three target groups should Kamworks focus on, based on a profile of their housing, power cut experience, electricity needs and mindset towards buying a new product?
3. What are technical specifications and possibilities of a back-up system?
4. What competition could Kamworks encounter?

Image 6 Business at the Russian Market (Phsar Toul Tom Poung), Phnom Penh 2009.

2.3 Hypothesis

Kamworks expects that:

1. There will be a market for back-up systems.
2. The target group will be either middleclass Khmer that own a small home business, expats families or wealthy, educated ('well-to-do') Khmer.
3. Diesel prices will continue going up.

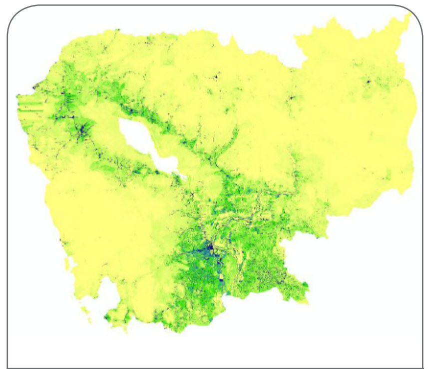
These first two hypotheses will be tested in this market analysis. The third will be assumed to be true, as rising prices for fossil fuels are an international trend.

2.4 Method

To test the hypotheses and to be able to achieve the analysis goal, several different methods will be used:

- Expert interviews
- Questionnaire amongst the proposed target groups
- Desk research
- Street observations

There are several reasons why such a mix of methods has been chosen. Firstly, using different methods is a good way to verify results, especially since no professionally composed research pool could be provided for the questionnaire. By comparing information from different methods, it is more likely to catch biases or false information. Secondly, Kamworks thought using these different methods would be a good way to efficiently gather information. Lastly, as a designer in a foreign country, it is important to have a broad foundation of information in case the need arises to make assumptions in the rest of the design process. The culture differences between Cambodia and the Netherlands cause logical assumptions to be more difficult to make than they would be in the Netherlands. Thus in this analysis more information was needed than perhaps would be needed when asking the same questions about a Dutch market.



Population Density, 2010

2.5 Power Situation

Since Cambodia is a developing country, the availability of electricity is not a given thing (see image 7). There is no national grid: power is either imported (see sidebar, p. 23) or produced locally by approximately 300 different license holders (311 in 2010 (Electricity Authority of Cambodia, 2011)) who produce and sell energy to their own area. More than half of the country is not connected to a grid electricity supply. Those who are, often have to deal with black-outs, the severity of this depending on their living area. Also, the quality of electricity is poor due to low maintenance and lack of control. The prices for power are high, ranging from 0.15 USD to 4 USD per kWh (Electricity Authority of Cambodia, 2011; Energypedia, 2012). Cambodia is hungry for power: The growth rate of the demand was 22.3% on average between 2003 and 2008, the supply lagging behind with a rate of 21.5% (Energypedia, 2012). According to all experts that were interviewed, the demand will continue to grow. However, the main question is: What future power situation in Cambodia is to be expected in the next 1-15 years, in terms of availability, quality and price? Making a well-founded estimate about this is crucial for designing a back-up system, as the necessity for a back-up disappears when power is available around the clock.

In the following paragraph, an estimate of the future power situation is described, based on an outline of the current power situation and developments derived from expert interviews and desk research, which can be found in **Appendix A and B**.

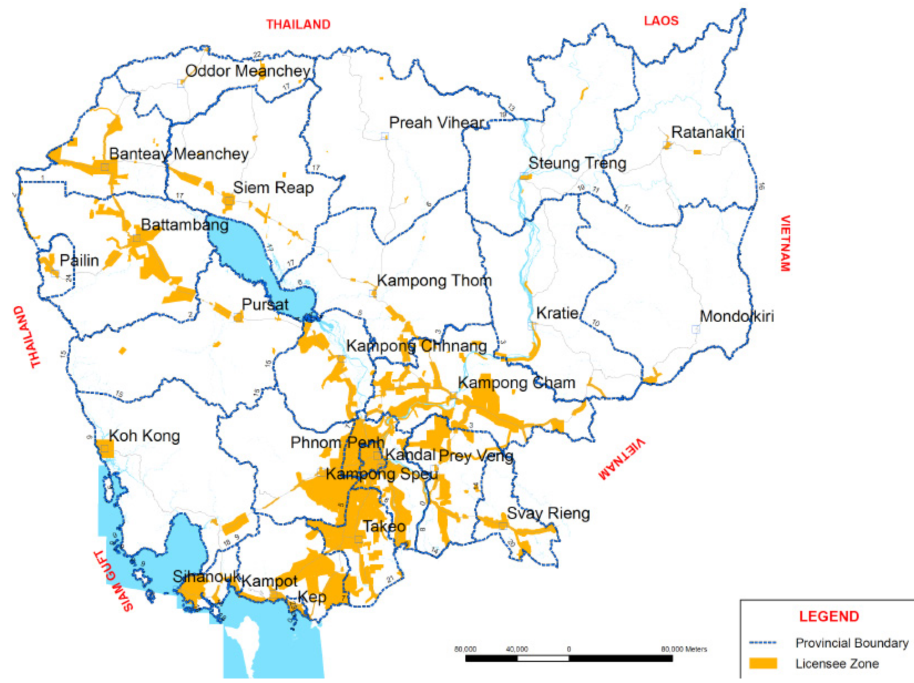


Image 7 General Situation of Electricity Supply in the Kingdom of Cambodia, 2010 (Ministry of Industry, Mines and Energy, 2009). The spread of electricity, marked in orange on the map, shows correspondence to the population density, as can be seen above, in the sidebar.

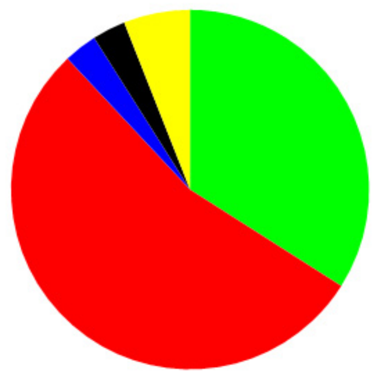
Expert opinions differ about the future power situation in Cambodia. Four experts are certain that availability of power will continue to be a problem for at least the next ten years. Mr. Gaglardi and Mr. Van Manvelt however were positive of the Cambodian government being able to build sufficient supply within 5 years. Weighing all of their opinions together with articles found during desk research, it is a well-founded estimate that power availability will continue to be a problem in the next ten years. There are several main factors that influence this, according to Mr. van de Hulst:

- The growth of the energy demand
- The growth of the supply, depending on new plants and power import
- The expansion and quality of the grid

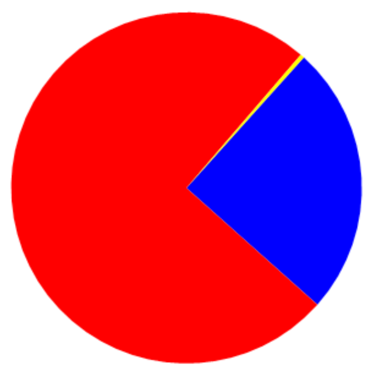
2.5.1 Availability

Availability of electricity will continue to be a problem. The demand will be ahead of the supply until the market is more saturated. As more than half of the country does not yet have electricity access, the demand will grow as more areas get connected. According to the government's estimate, the demand will quadruple over the next ten years. If the growing rate of 22% would continue, the demand would even be seven times as high as it is now. Demand increases instantly; power supply does not, as it takes about five years to build a new plant (Hulst, v.d., 2012).

Image 8 A diesel generator charging car batteries in Kampong Cham area.



Cambodian power sources, 2010



Cambodian power import, 2010

"Part of the interest for Thailand to put money into this, is to buy the energy back. I think it's an interesting agreement because it seems like Thailand could invest in a powerplant here and sell the power to Cambodia for a higher price than they would be able to in Thailand. At the same time it's cheaper to build a powerplant like that here; especially in Koh Kong, which is out in the middle of nowhere. And this is a very big coal fire plant; I'm not sure how they would be able to build that in Thailand, given the environmental regulations that they have. So building it this way is a way for Thailand to get around the regulations."

Don Weinland on the Koh Kong coal plant, 2012

A large portion of energy produced by new power plants built by foreign companies from China and Thailand will go to the countries of their investors (see quote, sidebar). Many of the new plants will be hydro powered, a power source dependent on rainfall and water (see sidebar p. 22). Thus, during dry season, especially in the hottest months (March-May), a continued increase in power cuts is to be expected.

As power supply is already better in downtown areas than in more suburban or rural areas, it is likely this trend will continue. The power availability thus will not be spread out equally geographically speaking. Therefore, designing an urban product range, one must consider the fact that there are and will continue to be some urban areas where power availability is high, if not around the clock in the future. (See image 8 for a picture of how some off-grid villages get their source of electricity using car batteries.)

2.5.2 Price

Electricity will remain expensive, as there is no direct cause for the price to drop: Firstly, the supply will remain scarce in Cambodia and become scarcer globally. Secondly, it is interesting for exporters of energy to sell at a high price in Cambodia, because tariffs are already high. Thirdly, some of the tariffs of electricity from new plants are being set already (Weinland, 2012), keeping the price artificially high. At the same time, the price for solar panels is dropping (Gramberg, v.d. Hulst, 2012), which could provide interesting prospects for on-grid solar energy in the future.

2.5.3 Quality

Investments will be necessary to improve the quality of the net. It is probable that improvement of quality comes second to expanding the net and supply in the current development. Cambodia faces a huge challenge on that account. The quality, maintenance and control of power will improve, but perhaps more slowly than the expansion and supply.

2.6 User Analysis

Kamworks wants to research three potential target groups: middle class Khmer families that own a small home business, expat families and well-to-do Khmer families. In the following section a profile will be sketched of these target groups, based on a questionnaire held amongst these groups and expert interviews (**Appendix A, C**). The focus lies on their living situation, experience of power cuts, electricity needs and probable mindset towards buying a back-up system. The specific goal is to find out which of these target groups would be the most suitable to focus on when designing, marketing and selling a Kamworks back-up product. Besides that, it is also a goal to find out which target group would be the best potential group to sell on-grid solar Kamworks products to in the future (see 1.1.3).

2.6.1 Middle Class Khmer

Middle class Khmer can be found all over Phnom Penh, ranging from downtown to the suburbs. According to the questionnaire and street observations, most have their own house with a home business (see sidebar). They live behind or above their business with their whole family. Many people in the family help out with the business. The average size of the households measured is five people, with four adults and one child. Compared to the demographic counts in 2008 (ECLAC/CELADE 2010-2012), household sizes measured correspond to the actual counts. All respondents intended to reside in Cambodia permanently.

The amount and duration of power cuts that respondents were exposed to varied (see sidebar, p. 26). On average the black-outs of this target group lasted one to two hours. During the cooler season (October-January) the average frequency was less than once a month, during the hot and dry season (February-May) the average was one to three times a week and during rainy season one to three times a month.

Most respondents (80%) experienced power cuts as inconvenient. The other 20% was not really bothered by power cuts but did not think them convenient either. Further into the suburbs, where black-outs are more common and last longer, some people owned small Chinese generators. Overall they were satisfied with their generator but commented that it was either noisy, broke some lights, could not run all of the devices, and used a lot of fuel.

The electrical devices people found most important during a black-out can


Local beauty salon


Cook at a local restaurant


Local internet café

Middle class Khmer
1 Cell phone charger
2 Refridgerator
3 Light
4 Freezer
5 Rice cooker
6 Fan
7 Air Conditioner
8 Computer (Desktop)
9 Laptop

Expats
1 Refridgerator
2 Freezer
3 Fan
4 Light
5 Computer (Desktop)
6 Laptop

Well-to-do Khmer
1 Fan
2 Light
3 Air conditioner
4 Internet router**
5 Laptop
6 TV

Most important electrical devices*

* All devices noted scored higher than 2 in a range of 1-3, where 1 was not important during a black-out and 3 was very important during a black-out.

** The internet router was added to the questionnaire later, thus for comparison it is impossible to say to which degree middle class Khmer and expats found an internet router important.

be found in the sidebar. These respondents almost always said that if they owned a device, it was at least medium important. This could mean that middle class Khmer are more attached to using their electrical devices than the other two target groups, or it could be due to a bias. For example, they might not have understood or found it difficult to empathize with the situation of a power cut.

Electricity needs vary according to the type of shop they run; for example a print shop needs a lot of electricity for four printers and two photocopying machines, while a shop that sells snacks and drinks may just need lights, fans and perhaps a refrigerator.

The mindset of these respondents, based on observations and expert interviews, is to spend money when it is available and not think too much of future investments. Thus, pay-back time should be short. Some said they wanted a generator but thought it was too expensive. According to Mr. Gaglardi, when Khmer earn enough money, one of the first things purchased would probably be a car, moped or smart phone, to show their status has improved (see sidebar, p. 27 for an anekdote). He states too that sustainable energy is not yet something they would consider when buying products, as they want to enjoy all the luxury they can afford.

2.6.2 Expat Families

Expat respondents mostly lived in or close to downtown Phnom Penh, in a rental house or apartment. The average household size was four people with two adults and two children. As the questionaire was held at an international school swimming match, one can state that their children went to an English international school. Though time spent in Cambodia varied from 1-10 years, 50% of expats intended to stay in Cambodia for 0-2 more years. Another 25% expected to stay for 3-4 more years. Since expats were interviewed at an international school swimming competition, this could provide a bias. For example, different cultures can vary in their sports enthusiasm and not all international schools were included in the competition, though the largest were present: NISC, ISPP, iCAN and Logos. On average power cuts lasted less than 15 minutes (see sidebar, p. 26). During cool season black-outs occurred less than once a month on average; during rainy and hot and dry season this was 1-3 times per month. This corresponds with the statement of experts that in downtown areas power cuts are less frequent and shorter. Most respondents experienced power cuts as inconvenient (70%). However, 20% didn't care because their house or apartment had a generator (usually an investment of the landlord). The rest did not have a generator but did not care either. The people who had access to generators had large ones (20kVA for example) that could run all of their AC's. Their satisfaction with their generators was high to very high.

In general, expats owned more devices than middle class Khmer but seemed to be more selective of the devices that they found medium or very important during a power cut. They ticked many devices as 'not important', even though they did own them. On the previous page the electrical devices that expats found most important can be found in the sidebar.

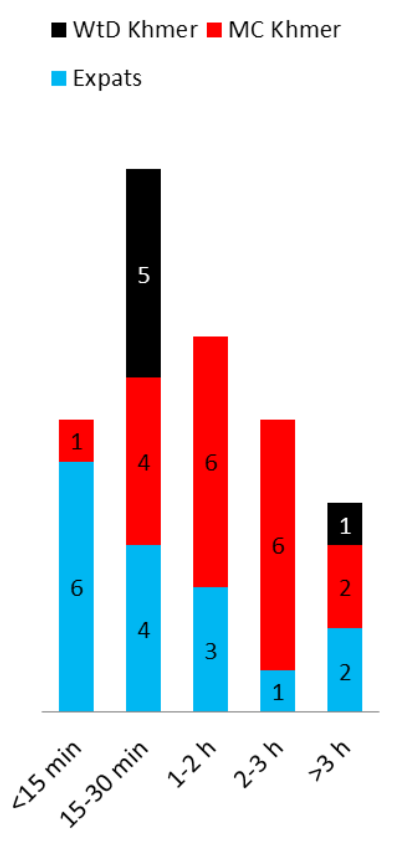
The fact that many devices were owned by a larger percentage of expats suggests that expats have more money to spend than middle class Khmer on electric devices and electricity. This assumption is strengthened by the fact that tuition for the participating schools ranges from $2,000 to $16,000 per year, according to these schools' websites. The rental houses and apartments that expats live in also tend to be of a high price, based on advertisements placed on an expat Yahoo group (Cambodia Parent Network, 2012). According to Gaglardi, there is also a difference in investment habits between Western people and Cambodias: Cambodians will invest in showing their status or money by buying an expensive car or furniture made of expensive wood, whereas Western people will invest in quality of life and do not show their status in the same manner.

All experts agreed that in general, expats are educated about sustainable energy and more willing to invest in it than Cambodians. However, due to the fact that they are here on a short-term basis and live in rental houses, they are careful with large investments. When they leave they usually try to sell most of their belongings (Cambodia Parent Network, 2012).

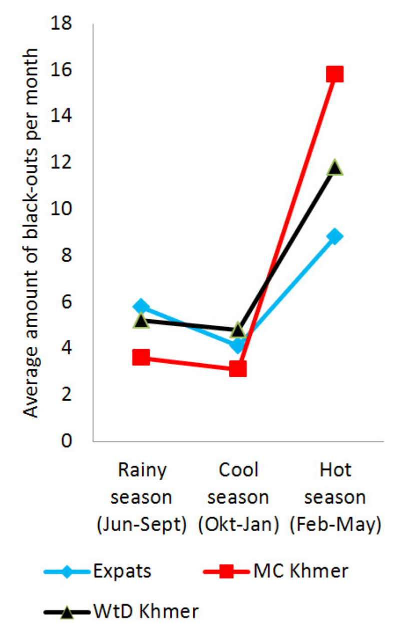
2.6.3 Well-to-do Khmer

Of the well-to-do Khmer only six men were questioned due to difficulty finding respondents. The results were verified by comparing them to observations and expert interviews.

Respondents lived mostly in downtown Phnom Penh in their own house. Some had a second house in the suburbs or province, or planned to build one there. The average size of their household was 6 people with 4 adults and 2 children. All respondents intended to live in Cambodia permanently, though one said it would depend on the living conditions here. Half of the respondents had studied abroad; in Russia and Korea. For younger wealthy



Duration of black-outs



Frequency of black-outs

A Big Rig (Lexus) SUV is a Phnom Penh status symbol. Out on the streets you will see an unusual amount of them.

From a Western viewpoint, these car owners must all be rich, have a nice house or apartment and a wealthy lifestyle. Which is true for some but it is not a given. For example, a local student told a story of her neighbor who owns a one room apartment on the ground floor, parks his Lexus there every night and sqeezes into his tiny bed beside it. Gaglardi also explained that some people will own a Lexus but eat on the street corner for $0.50 a meal. If a Khmer man's business is falling, the last thing he will sell is his car to keep from losing face.

The Lexus story

Khmer it is also common to study in the USA, Australia or France, according to experts.

On average the black-outs of this target group lasted 15-30 minutes (see sidebar p. 26), with the exception of one man who lived in the suburbs who experienced black-outs of more than three hours. The man who was planning to move to a house in the suburbs also worried about more power cuts there. This corresponds with the assumption that in downtown areas power cuts are shorter and less frequent. During cool season the average frequency was less than once a month, during rainy season the average was 1-3 times per month and during hot season 1-3 times a week, as with the middleclass Khmer that were interviewed.

Most of the respondents (5 out of 6) found black-outs inconvenient. One person did not care about black-outs because they occurred for less than 15 minutes, less than once a month. Only one of the respondents owned a generator, with which he was not satisfied. Most thought generators were too noisy, bad for the environment and for health, or too expensive. Two said they did not need a solution to power cuts.

Keeping cool and being able to continue work were the most important issues to the well-to-do Khmer, judging by the appliances they found most important and additional statements made. One man said that his security camera was extremely important to him. His house had been robbed in the past and he was worried about the safety of his family during a power cut. On the previous page the electrical devices that these respondents found most important can be found in the sidebar.

According to all forms of research used, well-to-do Khmer are quite wealthy, some even extremely rich. All respondents owned a nice car, smart phone and had a good job. On the streets of Phnom Penh many expensive cars can also be seen every day. One respondent had six air conditioners to cool his house and did not own a fan. They were more aware than the other Khmer target group of the prospects of sustainable energy for their own health and for the environment. Most thought of solar as an energy solution for rural areas, which corresponds to the statement Kamworks makes about this (see 1.1.3). Like many wealthy Cambodians they seemed to have the 'status' mindset to show their wealth, however also adapted some of what Mr. Gaglardi refered to as Western lifestyle to invest in quality of life.

2.7 Technical Analysis

Before starting product design, it is important to find out what the possibilities and approximate specifications of the proposed type of back-up system are. That way, something can be said about price and functional possibilities.

2.7.1 Components

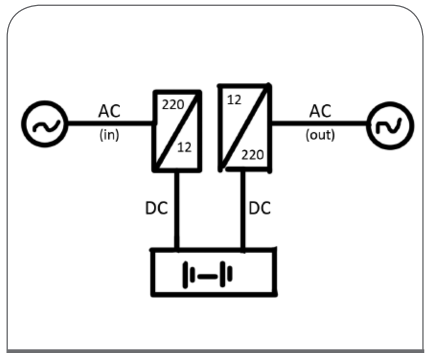
To build a basic back-up system, the following components are needed: an inverter, charger and batteries. To be able to charge with a solar panel, a charge controller or grid inverter must be added. To be able to switch on automatically, an automatic transfer switch (ATS) is needed. It is possible to get a charger-inverter with ATS in one component (for example the Victron Energy MultiPlus). Please view the sidebar to see a basic back-up circuit. Kamworks prefers using products of their existing suppliers, specifically Victron Energy for inverters and chargers, and Ritar for batteries. The type of battery that must be used is a deep cycle absorbed glass mat (AGM) lead-acid battery (Luxwolda, 2012).

2.7.2 Power Range

This technology for a back-up system decribed above is most suitable for smaller power ranges such as 200 to 1500W. For example, powering a 2000W air conditioner (AC) on batteries for more than an hour is not something Kamworks aspires to do with this product, as it would require quite an expensive inverter and an extreme amount of (heavy) batteries. An estimate of power needs of small shops such as restaurants, print shops and hair salons quickly proved that this market was not suitable for the proposed back-up system, as their power needs were too high (**Appendix D, F**). For simple household purposes such as lights, fans, tv and computers however, the back-up is an option. In the sidebar please find an estimate of the costs for a small, medium and large system that provides three hours of back-up power, More details can be found in **Appendix D and F**.

2.7.3 Household Electrics

As stated before, the back-up technology is more suitable for smaller power ranges. So what happens when a household has many appliances such as AC's, refrigerators and televisions running when a power cut occurs? For the consumer it would be most convenient if the devices they need, switch on automatically without needing to turn on the back-up. This is possible, but to prevent the back-up from overloading, a special black-out 'group' would need to be wired, so that the system could be connected only to this group. However, according to experts (V.d. Hulst, 2012) this is a very difficult solution in Cambodia, as most houses have a chaotic electric wiring structure. Going for this option would mean one needed to rewire the entire house; something that does not line up with the objective of Kamworks to design a plug-and-play product. Thus, within the demands of Kamworks, the product cannot be connected to the house so that it switches on automatically.



Basic back-up circuit

S (350W)	$500
M (800W)	$1050
M** (800W)	$1350
L** (1200W)	$2150

Estimate of system costs*

* To see the calculation this estimate is based on go to **Appendix F**.

** These models use the more expensive 'MultiPlus', which is a programmable charger-inverter.

Image 9 Electric wiring of the grid and in households can be very chaotic.

2.8 Competitors Analysis

Before introducing a new product one must look at the competition. In the following section both the competing companies of Kamworks and competing products for a back-up system are described.

2.8.1 Competing Companies

In Cambodia, four direct competitors of Kamworks are Khmer Solar, KC-Solar, Solar Energy Cambodia (SEC) and Comin Khmer, a part of Comin Asia (Energy.sourceguides.com, 2012; Seada, 2012). All of these companies offer custom made solar energy solutions, as well as small plug-and-play home energy systems. For Kamworks, KC-Solar, Khmer Solar and SEC this is one of their core businesses, for Comin Khmer this is a small branch of one of their market sectors, as they are a much larger company also operating in Thailand and Vietnam (Khmer Solar, 2012; SEC, 2012; Comin Asia 2012).

Around 2005-2008 it appears there was a trend to get into the solar energy business for off-grid communities, as three of the five companies named were then founded. Kamworks is the only company that was not founded by a (part) Cambodian. This could be a disadvantage in marketing as the leading staff did not grow up in Cambodian culture. Kamworks also differs from for Khmer Solar, SEC and KC-Solar in the sense that they only advertise on delivering full systems, whereas the others also advertise on parts such as batteries and inverters.

Among Kamworks' direct competitors there appears to be little competition for an urban back-up system. Only Comin Khmer is in this business at the moment, and they aim for the professional market instead of the individual consumer market. However, the components that other competitors sell could be used to make a back-up system.

2.8.2 Competing Products

Competing products are low-budget solutions, the generator, UPS systems and solar back-up systems. See **Appendix E** for a comparison table.

Low-budget Solutions (see sidebar)

Many rural Khmer people are used to not having power. Also, power outages are common in (sub)urban areas. Some are quite easy going about it: "When the power is out in the restaurant we just have to relax for a moment until the power is back on," says a waiter at restaurant Baitong, Phnom Penh.

Rural villages utilise energy sources such as oil lamps, candles, charcoal, wood and (car) batteries charged by a generator (Dano, Bona 2005; Davanall 2012). During black-outs these solutions can be used by urban people as well. In case the sun has already set during a power outage, an originally rural habit is to go to sleep.

Generator

Currently the product that is the most used during power cuts is the generator (see sidebar); an electricity generator that runs on diesel or petrol, varying from small types (1.5 to 30 kW) for households to larger industrial generators (up to 2000 kW) (Wikipedia, 2012).

The user experience differs per device. Often the motor has to be started when it is needed. However some generators can start automatically if a system for this is added. It can be connected to the electric network; so if

Low budget - Candlelight

Low budget - Fan

Low budget - Sleep

Diesel generator, 3.8 kVA

APC Home UPS, 1 kVA

Solar Backup Generator (USA)

the power output of the generator is sufficient, all connected devices will be able to run on the generator once it has been turned on. To connect a generator some electrical expertise is required. In practice this is often improvised and old or low-quality generators are used (Dana, Bona 2005; Kamworks 2012). Downsides of a generator are the noise production, emissions and the price it costs per kWh in comparison to grid connection due to the price of diesel or gas. Also, if a generator has a low quality output it could break sensitive devices that are connected to it.

A three hour back-up system, using the European quality parts that Kamworks requires for all their products, is much more expensive than a generator that can deliver the same amount of power. More information about this comparison can be found in **Appendix F**.

UPS Systems

The backup system Kamworks has in mind uses the same technology as a UPS (Uninterruptable Power Supply) (Rasmussen, 2011). UPS devices are already common in Cambodia to protect computers or networks from falling out and losing data when the power goes down. From street observations and store visits it seems that, for consumers, using a UPS for other purposes than computer devices is not common. A salesman at an electronics store even falsely stated that the UPS would not work with anything other than a computer.

A global company, APC (American Power Conversion Corporation) does sell UPS Home systems for countries with unreliable power grids in Bangladesh, Bhutan, India, Nepal and Sri Lanka. In India the price for the 1000VA model is between $500 and $750, depending on the type of battery and shell it comes with (AG Systems India, 2012) (see sidebar).

Existing Solar Back-up Systems

There are solar back-up systems available in the United States and the United Kingdom, offered for example by Urban Solar (UK) or Solutions from Science (USA), as seen in the sidebar. The back-up system offered by Urban Solar is very similar to the solar home systems that Kamworks offers. They are marketed as a solution to lower energy bills, use solar at night and to provide back-up (Urban Solar, 2012). Solutions from Science also offers a system that can be charged either by solar or the AC wall outlet (mysolarbackup.com, 2012).

2.9 Conclusions for the Designer

Energy Situation

Kamworks suspected that there would be a market for a back-up system. Based on results this can be confirmed, as there will continue to be problems in power availability over the next ten years. A critical note however is that many Khmer are used to power cuts and, even though they might find them inconvenient, might not feel a strong need to find a solution. It should be kept in mind as well that in downtown Phnom Penh areas power availability is already less of a problem than in the suburbs.

Target Group

Kamworks suspected that either middleclass Khmer, expat families or well-to-do Khmer would be a good potential target group. After discussing results it was decided to focus on the latter for the following reasons. Although expat families seem like a good market due to their mindset of investing in life quality and susceptibility towards sustainable energy, it was decided not to go for this target group. Expats do not want to make large investments due to their temporary living situation in Cambodia. Middle class Khmer probably will not have the money to invest in a back-up solution. This is based on the fact that many wanted a generator but found it too expensive. Another argument is that they do not have a long-term investment mindset.
Well-do-do Khmer are well educated and have money to invest in the quality and appearance of their lifestyle. Both their education and their aspiration to show that they are modern make them more open to sustainable energy solutions, making them the most interesting future target group for Kamworks to spread their brand name and reputation. Lastly, the energy needs of this group mainly involved keeping cool and being able to continue to work. Though the back-up system will not be able to power their air conditioners, it could power things like a fan, light, laptop and internet router. On the following page a collage of the target group can be found.

Image 10 (page 34-35) Moodboard of the chosen target group

Technical Possibilities

Based on the technical analysis it can be said that for powering large devices over 1000W the back-up technology is not suitable unless huge battery banks are built. Also, connecting the system to the house so that it will switch on automatically is not an option if Kamworks wishes the product to remain plug-and-play, because this would require a professional rewiring the house to install the product.
Taking this into account, Kamworks still finds it very important that the product is plug-and-play. They do not want to use their resources, such as staff and money, for time consuming installation, service and maintenance of the product.

Competing Products

Competing companies such as Khmer Solar, KC-Solar, Solar Energy Cambodia (SEC) and Comin Khmer are not offering a plug-and-play back-up system at the moment. Some do sell the individual parts that are needed to build a back-up system. The most important competing products in Cambodia are the generator and the UPS. In price the back-up system cannot compete with a generator, so it must focus on other selling points.

Course of Action

It was decided to continue designing a plug-and-play product for the well-to-do Khmer target group, focussing on back-up systems. There seems to be a market for back-up systems and producing such a system is possible within the available resources of Kamworks.

Well-to-do Khmer

- Educated
- Have a good job
- Nice cars and houses
- Status is important
- Family values
- Enjoying life

3 Product Design

In this chapter the project moves from analysis to design, a phase which took place in a time frame of five weeks. First the design problem and goal will be explained. Secondly, requirements, concept designs and the final concept are presented.

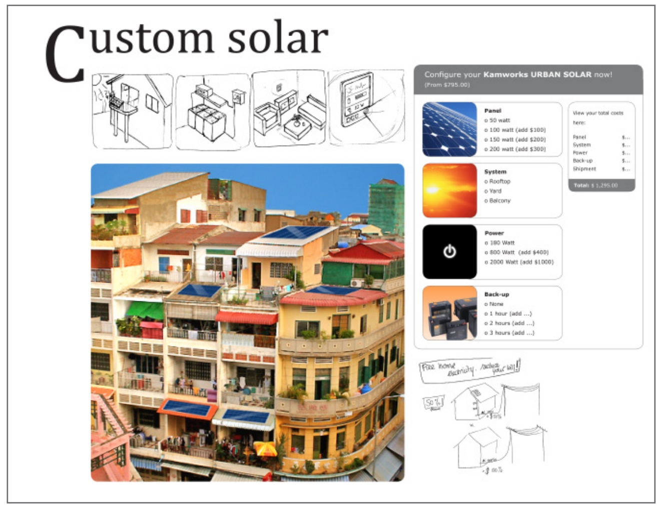
3.1 Design Problem

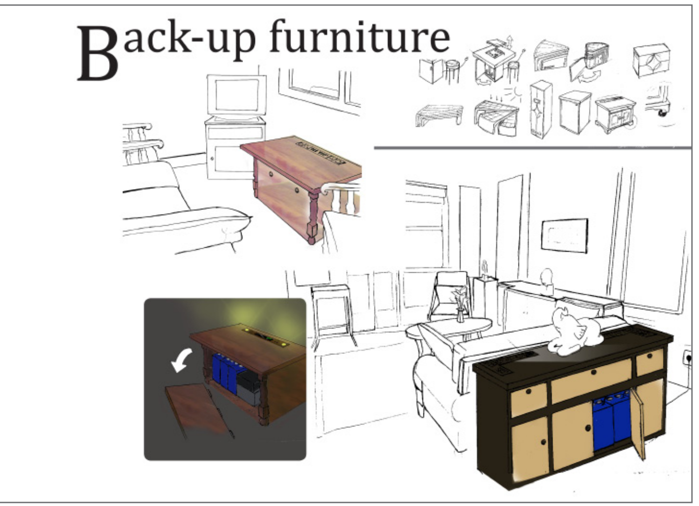
Kamworks wants to launch an on-grid or urban product range for consumers in addition to their existing off-grid, rural product range. Based on market analysis, it has been decided to design a plug-and-play range of back-up systems. The range will include three to four models, the smallest of which will supply the least amount of power and the largest the largest amount of power. The target group consists of upper class, educated Khmer people who live in urban areas (see moodboard, p. 34-35). Sourcing of components has to be similar to existing sources to create synergy. The final objective of Kamworks is to take a first step into the urban market, to position Kamworks as a brand that offers quality (solar) energy solutions for off-grid *and* on-grid areas (see 1.1.3).

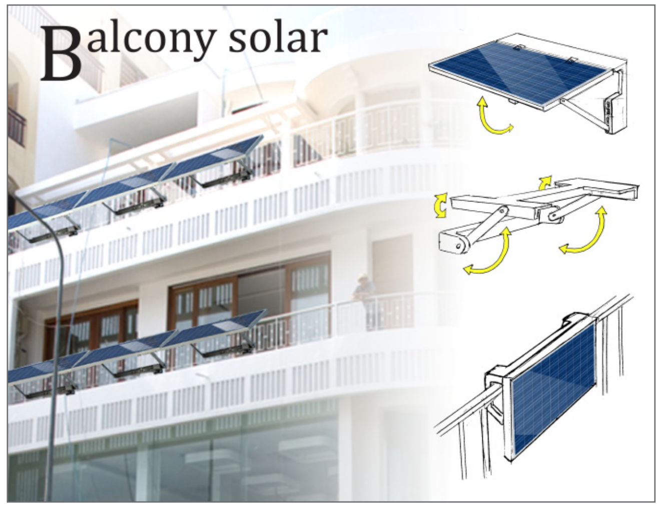
3.2 Design Goal

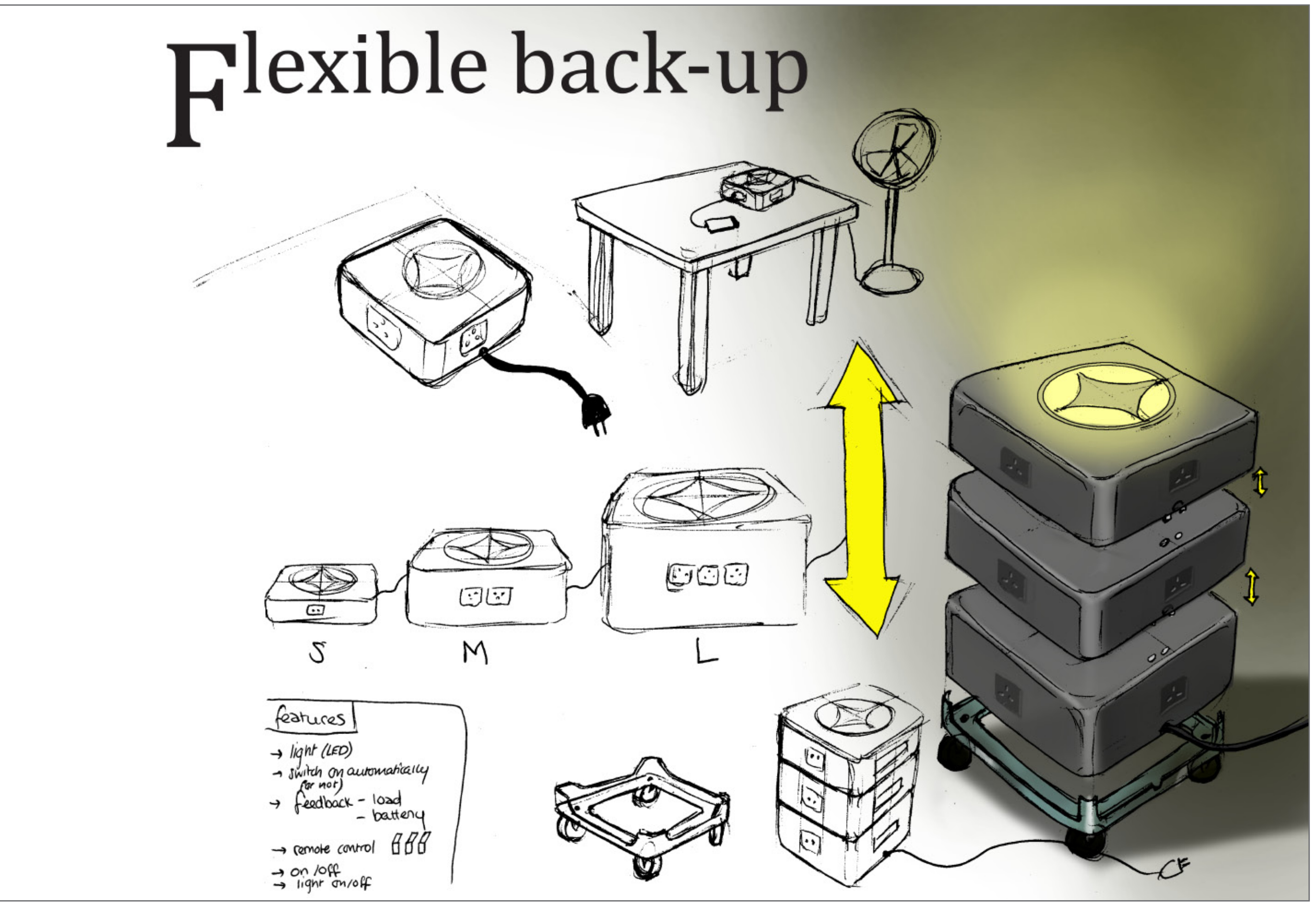
The design goal is to create a concept design of the product range. In this concept design, the focus lies on whether it is feasible to achieve the desired functionalities of the product within the requirements. This includes:

- Setting up detailed requirements
- Knowing the basic components that are needed, including their possibilities and constraints
- Exploring different ways of realizing the product functionality
- Designing basic circuit structure
- Designing the main aesthetic appearance or style of the product exterior
- Making recommendations for going into the next phase of detailing the design.









Images 11-15 Some other product ideas that were designed before moving on to the final concept design. For more details and full sized images of the product ideas, please go to **Appendix G**.

3.3 Other Product Directions?

At this phase in the project, some critical reflection on the decided course of action took place. Since the final goal is to enter the urban market to sell on-grid solar in the future, not specifically to sell back-up systems, other product ideas could also be explored. For the purpose of looking at the design problem from a broader perspective, some time was spent creating more product ideas, thumbnails of which can be seen on the left hand page. In the following paragraph a short description of the ideas will be given as well as argumentation why it was chosen to continue with a basic back-up system instead of another one of these design ideas. Larger images of these designs can be found in **Appendix G**, along with argumentation why they were not chosen as a product direction.

The back-up furniture was designed as an unobtrusive back-up system that users can easily adopt in their range of household furniture. Kamworks did not choose this design because the product did not fit with their company profile and it was thought to be a risk to combine the two functionalities of furniture and back-up. The portable charger was designed as a cool urban gadget. However, a good gadget takes a lot of development time and many have to be sold to generate a significant amount of profit. The balcony solar was designed to make solar energy more available to urban users who live in apartments. Kamworks liked this idea, but decided to leave it as an idea for the future. Custom solar was designed as a way of mass customization for solar energy products; users can select the amount of panels, back-up time (optional), mounting system and power they want. This idea was very popular, but thought to be too far in the future for the current Cambodian market. The last design, shown larger in the overview, was the most popular; the flexible back-up system where users can 'add up' back-up time and power by connecting small back-up systems together, making the system more portable.
Having explored other options for urban products, Kamworks still wanted to continue developing a basic back-up system because it was the option that suited both the urban market and their own possibilities for developing a product. It was decided to further explore the flexible back-up design, along with other options for configuring a basic back-up system.

3.4 Requirements

Based on the market analysis, the following requirements (p. 41) have been set up. To illustrate why some requirements were set, an elaboration on the requirements is added below.

Image 16 (page 40-41) Moodboard of the required aesthetic style of the product,

The cost target was based on a maximum retail price of 1000 USD, specified by Jeroen Verschelling and corrected by the 30% margin that Kamworks applies on all products. The geometry requirement was based on keeping the product reasonably managable in size. If the product expands in height it is easier to transport than if it grows in base size. However, the base size has to be reasonably large since most components can not be stacked due to rising of heat. The maximum weight was based on an estimate of the weight of the batteries that will be needed.
The style to be aimed for is based on the style of popular, modern status products (see moodboard, p. 42). The minimum power was derived from the fact that the smallest model should be able to power a laptop, a router, a CFL light and a small standing or table fan, and the largest for example, 2-5 lights, three fans, a 40" plasma TV (500W), a laptop and an internet router.
The minimum battery life is based on the questionnaire results: The peak of black-outs was at 15-30 minutes for the chosen target group. However, in the overall results the peak was at 1-2 hours. Thus, going for a battery life of 1-2 hours makes the product useful for a larger group. On the other side, unnecessary batteries bring unnecessary weight with them. The requirements was set at 30 minutes to leave the option open for creating a 'light' model and a heavier model for longer power cuts.
The required use of Victron Energy inverters is based on the fact that Kamworks wants to offer quality, stable electric output products, which is guaranteed with Victron products. Kamworks also demands a lifespan of 5 years and a solar add-on possibility for the larger models. The product must be quiet, as many respondents said that noise was a negative aspect of a generator. Since trying to stimulate local employment is in line with Kamworks' company culture, it is a wish to manufacture the product in Cambodia. Another wish is to use only components produced by existing suppliers to create synergy. Kamworks expects that transport will be mainly from their Sre Ampil office to Phnom Penh. Transport by moped is common in Cambodia. For larger models, this could mean parts have to be transported separately.

Purpose

The purpose is to design a plug-and-play range of back-up systems. The range will include 3-4 models, the smallest of which will supply the least amount of power and the largest the largest amount of power. The target group consists of upper class, educated Khmer people who live in urban areas (see moodboard, p. 42).

Cost Target

- The maximum cost price of the packaged smallest model is 700 USD.
- The maximum retail price of the packaged largest model is 2,100 USD.
- The total batch size for the product range is 250.

Geometry

- The maximum floor area for all models in the range is 600 mm x 700 mm.
- The maximum height of the smallest model is 350 mm
- The maximum height of the largest model is 550 mm.

Physical Characteristics

- The maximum weight of the smallest model is 40 kg.
- The maximum weight of the largest model is 100 kg.
- WISH: The larger models that are too heavy to carry can be made portable for the user.

Aesthetics

- The style to be aimed for is modern. (see moodboard, p. 40)

Performance Characteristics

- The minimum power for the smallest model is 180 W.
- The minimum power for the largest model is 1200 W.
- The minimum battery life for each model, if the model is supplying full power capacity, is 30 minutes.
- The minimum lifespan that the product should function is 5 years.
- A Victron inverter must be used for all models due to the pure sine wave output that it generates and its ability to stabilize a fluctuating AC power input.

Inputs

- AC power
- For the largest two models of the product range, solar input should be possible.

Outputs

- AC power
- Little noise: less than 40 dB ('quiet office')
- Communication about battery life to the user
- Communication about power load to the user

Manufacturing Considerations

- WISH: Preferably, components are sourced at the same manufacturers that Kamworks currently relies on to source their components.
- WISH: Manufacturing should be done locally as much as possible.

Packaging Considerations

- During transport by moped at any time of the year from the Kamworks stockroom in Sre Ampil village, Kandal province, to Phnom Penh city a maximum of 1% of the transported products or product parts are damaged.

Environmental Requirements

- Be suitable for indoor use in Cambodia.
- Operate at high humidity (70-85%)
- Operate at high temperatures (28-35°C)

User Requirements

- The product must work as soon as it is connected, without needing further manual installation ('plug-and-play')
- The user should be able to to charge the back-up and connect devices to it, without needing the user manual.
- The user should be able to unpack and make the device ready for first use in 10 minutes.
- The product must be safe in an environment with inexpert users and children.
- The exterior of the product that users could touch is isolated from any electric current.
- The user manual of the product clearly states which interactions with the product could potentially cause danger to the health of the user.
- The product must have short circuit protection.

Maintenance

- The product needs maintenance less than one time per year.
- WISH: The product does not need any maintenance the first five years.
- WISH: Kamworks has the ability to check the status of the larger products remotely, meaning without someone from Kamworks being physically present with the product.

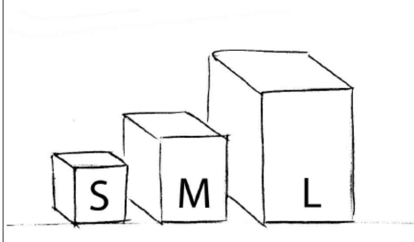
Modern

Table 1 Summary of estimates of specifications for the different concepts

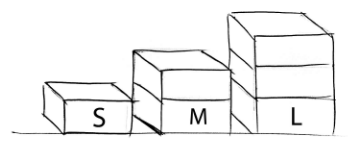
Model	Power (W)	MultiPlus?	Back-up time (h)	Costs* (USD)	Weight (kg)	Volume (L)	Dimensions** (HxWxL) (mm)
Standard							
XS	180	No	1.5	180	14.2	8	
S	350	No	1.4	230	25.4	14	245x424x260
M	800	No	1.7	540	65.5	29	375x684x229
M	800	Yes	1.7	700	64.0	31	375x516x488
L	1200	Yes	1.5	930	82.0	39	375x550x567
XL	1600	Yes	1.6	1020	112.5	60	
Flexible							
1x S	350	No	0.8	200	15	8	245x320x237
2x S	350	No	1.6	400	30	16	245x320x237 (2x)
3x S	350	No	2.4	600	45	24	245x320x237 (3x)
1x L	800	Yes	0.5	580	23.5	14	375x376x214
2x L	1600	Yes	0.5	1160	47	28	375x376x214 (2x)
2x L	800	Yes	1	1160	47	28	375x376x214 (2x)
Battery Standard / Battery Flexible							
XS	180	No	1.5	180	14.2	10.2	
S	350	No	0.8	200	15.0	10.2	245x320x237
S+	350	No	1.5	230	25.3	20.5	235x424x260
M	800	No	0.5	380	21.3	13.5	
M+	800	No	1.7	540	65.5	54.0	
M	800	Yes	0.5	580	23.5	13.5	375x376x214
M+	800	Yes	1.7	700	64.0	54.0	375x684x229
L	1200	Yes	0.5	770	31.5	21.5	375x379x260
L+	1200	Yes	1.5	930	83.0	72.0	375x516x488
XL	1600	Yes	0.5	800	39.0	29.0	375x516x306
XL+	1600	Yes	1.6	1020	112.5	102.5	375x550x567

*These costs include 7% import tax. They do not include the 30% margin.

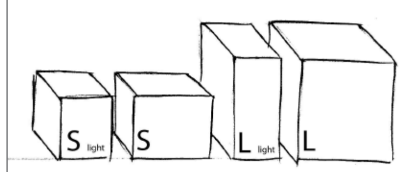
**Only dimensions for models that were likely to be taken up in the range if that concept were chosen have been figured.



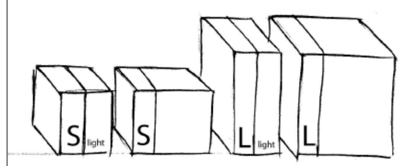
Standard: fixed power and battery time



Flexible: Possibility to add power and battery life



Battery Standard: Fixed power and battery time



Battery Flexible: Possibility to add battery life

3.5 Concepts

To be able to say something about the consequences of the design for price, development and functionality, Kamworks requested to see several concepts in which these aspects are analyzed. The focus lay on technical possibilities and price. Aesthetic design was not important in this phase. Four concepts were generated and their feasibility was analyzed. Also they were compared to see which one would most closely fit the requirements. The concepts are Standard, Flexible, Battery Flexibly and Battery Standard (see sidebar for basic visualisation).

3.5.1 Concept Description (see sidebar)

Standard – As the name suggests, the 'Standard' concept is the simplest concept. The models all have the same battery life while varying in power. There is little flexibility in settings and there are no parts that can be removed or added by the user. The back-up time is set at 1.5 hours, based on the duration of black-outs found in the market analysis questionnaire. This should make the system usable for a large group of people.

Flexible – The 'Flexible' concept has more flexibility than the Standard; there are only one or two sizes of the model. However, each model can be added to another model equal to it, doubling the power or the battery life. The user can choose whether to put them together or separate them for smaller use. Also, when upsizing the back-up system, it is not necessary for the user to buy a whole new system, but it is possible to expand the existing system.

Battery Standard – Looking at the market analysis results, one sees that there is a group of people who have black-outs that last 15-30 minutes. For these people it might be a nuisance to have an unnecessary amount of heavy, expensive back-up batteries, as all they really need is more power for a short amount of time. On the other hand there are consumers who do need more than an hour of back-up. This concept varies in power (2 sizes) and in back-up time (30 min or 90 min) to fit these need differences.

Battery Flexible – This concept is similar to the Battery Standard concept, except that it offers the possibility of removable battery units (30 min or 90 min), making it more flexible. This way, if consumers move house, want more back-up time, or if the battery quality diminishes, they do not need to buy the entire system again but can purchase a new battery unit.

3.5.2 Method

The concepts were generated based on different ways to set up the product line in terms of power and battery life variation. About all of these concepts, the following questions were answered:

1. Which components are needed?
2. What is an estimate of the costs in relation to the power and back-up time that the product can deliver?
3. What is an estimate of the total weight?
4. How can the components, roughly, be assembled together?
5. What are basic dimensions of the product?
6. What is a basic drawing of the circuit needed for the product?

For the Flexible and Battery Flexible concepts the following additional questions were asked:

7. Is it possible to 'add' up the power and/or battery life when connecting two systems?
8. Is communication needed between the connected systems? If so, hat kind of information is needed?
9. Is it feasible to 'add' systems together by an easy system for the user? (So that the user does not need to wire anything or think about electronics)

The results can be found in the table on page 44 and are summarized in the following discussion.

3.5.3 Concept Discussion

The benefit of the Standard and Battery concepts is that they are very plug-and-play. They are not expandable, however, like both flexible concepts. The flexible concepts' settings have to be changed when expanding them, making them in return less plug-and-play. When more batteries or another MultiPlus are added into circuit, components need to communicate with each other to change to the correct settings. Additional hard- and software is needed to turn this into an easy operable system for the user. As can be seen in table 1 (p. 44) the Flexible concept also leads to heavier and more expensive products than if they were made in the 'standard' way. Since batteries are easily damaged when charged wrongly, another benefit of not making the system flexible is that there is a high certainty of quality preservation, due to the fact that there is only one setting which is programmed by Kamworks. Though the Standard offers a larger range of power sizes, it does not offer the more lightweight option of a shorter back-up time like the Battery concepts.

3.5.4 Concept Choice

In a review with Brecht van der Laan, Kamworks supervisor, a concept choice was made. Though excited about the flexible concepts, Brecht did not like needing to add more software and hardware to the product, making it unnecessarily complicated. Adding to this the other cons named in 3.5.3 and measuring the flexible concepts to the requirements, these choices were eliminated.

Choosing between the Battery Standard and the Standard concept was mainly the choice of either having more variation in power or giving the user the option of a more lightweight solution. According to the market analysis, well-to-do people often live in areas closer to downtown where power cuts are shorter. Considering the high price, size and especially weight of excess batteries, it was agreed that choosing for the Battery Standard concept would provide a more fitting solution for the target group.

3.6 Final Design

The Kamworks Urban Back-up is a battery powered device that will provide power when the mains fail. The device uses grid electricity to charge and has several AC outputs for plugging in devices. It is available in four sizes: S30, S90, L30 and L90. The S models can deliver 300W at 25°C (250 at 40°C) for either 30 or 90 minutes. The L models can deliver 1000W at 25°C (900 at 40°C) and have the possibility to charge using a solar panel. A no-break function is possible using the L models. This means a device can run on the grid via the back-up system, and when the power drops the system automatically switches to battery power, creating a current that does not 'break'. An exploded view of the product can be seen to the right, along with a render of the entire product range.

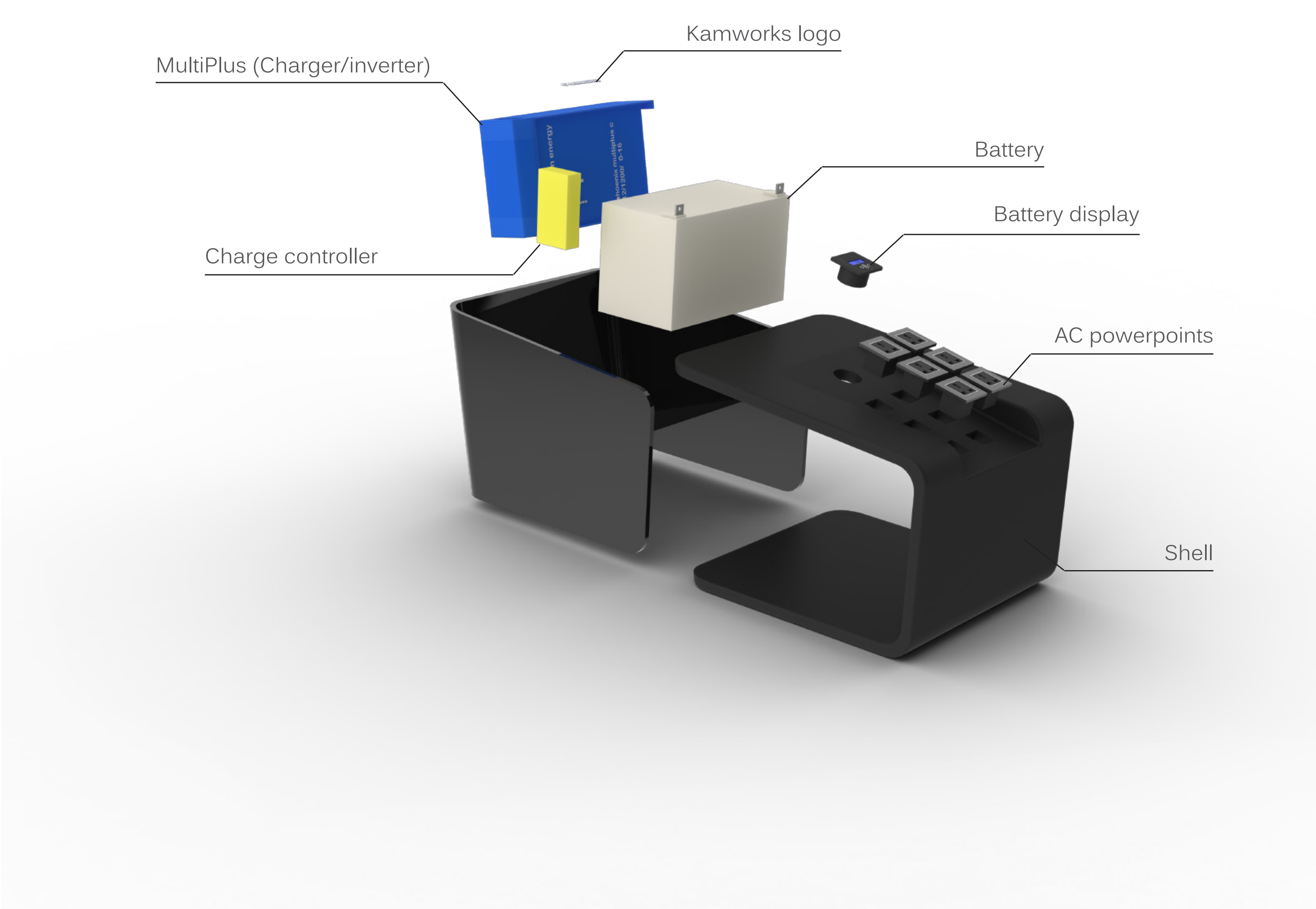
3.7.1 Style and User Interface

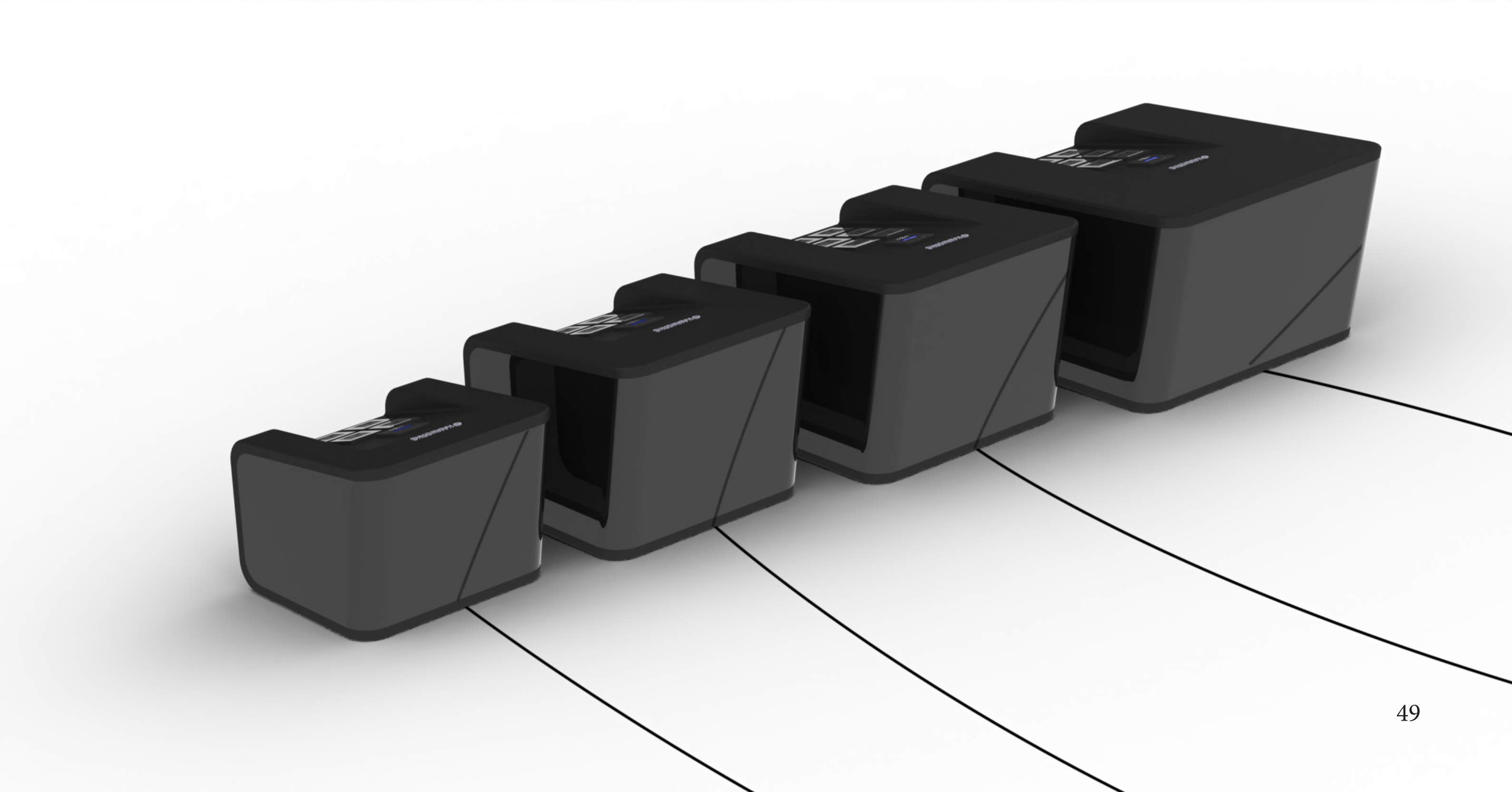
The style of the moodboard has been used as inspiration for the design of the product exterior. Materials are not yet specified because they depend on the more detailed shell design that still needs to be made. However, whether plastic or metal; a combination of matte and gloss should be used with chrome accents. Black or metallic grey would be good colours.
Either four or six outlets are provided, depending on size S or L. Each model also has one wire for connecting to an AC input for charging. A battery monitor measures the battery voltage and can display what percentage of the battery is full or how much battery time there is to go at the current discharge rate.

3.7.2 Main components

The main components used are a charger, inverter, one or several AGM deep cycle lead-acid batteries, a battery monitor and universal power sockets. In the large models, the charger and inverter are replaced with one MultiPlus, a programmable charger-inverter. Also, a charge controller is added for providing the option of solar charging (see exploded view to the right). Please refer to **Appendix I** for further specification of which components are used per model.
On the following pages a more detailled description of components and their functions is given. On page 52 the circuit connection of components is shown for the L models.

Image 17, 18 Some images of the final concept. The exploded view shown to the right is of the L30 model.





Inverter

(Victron Energy, Phoenix Inverter 350W)

An inverter converts DC power to AC power. The amount of power this inverter can deliver depends on the ambient temperature: 300W at 25°C and 250W at 40°C. It has short circuit protection and operates at a maximum humidity of 95%. It can be mounted vertically or horizontally.

Charger

(Victron Energy, Blue Power Battery Charger IP 20 12/7 or 12/10)

A charger converts AC power to DC power to charge batteries. The chargers used are capable of four stage adaptive charging to optimize battery lifespan. It has protection against battery reverse polarity, output short circuit and over temperature. The maximum charge current is programmable. It operates at a maximum humidity of 95%. It can be mounted vertically or horizontally.

Charger-inverter

(Victron Energy, MultiPlus Compact 12/1200/50-16 230V)

A MultiPlus is both a charger and an inverter. Besides that it has more functions to make it an intelligent power manager, such as a possibility for parallel operation and being able to set a maximum shore current for when it is used with a solar panel. Most of these functions are programmable to fit exact needs by connecting to a computer that has the correct software. The MultiPlus can be wall mounted vertically or horizontally. Enough space (10 cm) must be left around it to allow ventilation, according to its manual.

Deep Cycle AGM Lead-Acid Batteries

(Ritar, RA-12/33 or RA-12/100)

According to Kamworks and desk research these are the type of batteries that should be used as high discharges are expected. Depth of discharge (DOD) is still of direct influence on battery lifespan* though. For example, a battery that can run 1000 cycles at 50% DOD can only run about 500 cycles at 100% DOD (Electropedia, 2009). By restricting the DOD, lifespan* can be improved dramatically. According to Arjen Luxwolda (Kamworks Technical Director), a 70% DOD is a good rate with the Ritar batteries they use.
AGM type deep cycle batteries have several advantages over gelled or flooded types. The batteries are ‘dry’ and sealed, which makes them safer to use and transport, as no acid can leak. No water refills are necessary like with flooded batteries. Though gel batteries are also sealed, AGM batteries are more resistant against overcharge and warm weather.
Despite this, AGM cannot tolerate an over voltage either. It would cause temperature rise, leading to unwanted chemical reactions and gassing.

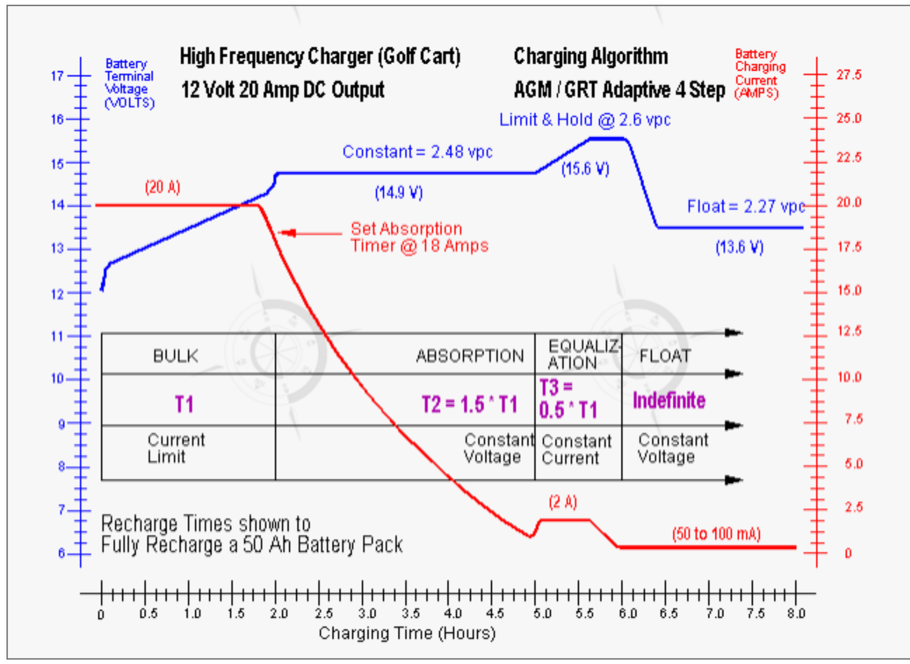
Inverter

Charger

MultiPlus Compact

Ritar RA 12-100 battery

Image 19 A graph of the AGM optimal charge cycle for a 50 Ah, 12 V battery pack (Marine-Electronics.net). The Victron chargers go through all stages seen in the graph except for the equalization stage.



Battery Monitor

Charge controller

At a certain pressure the battery’s valves open to equalize the pressure increase. However with the escaping gasses, substances that are supposed to remain sealed inside, escape the battery. Thus capacity drops, decreasing lifespan*. According to Arjen, they are best charged at a maximum current that is 10% of their capacity (Ah). To be precise, to charge an AGM battery optimally, four different phases are needed (image 19). The batteries cannot be stacked due to geometry and heat generation.

Battery Monitor

(Victron Energy, BMV 600S)

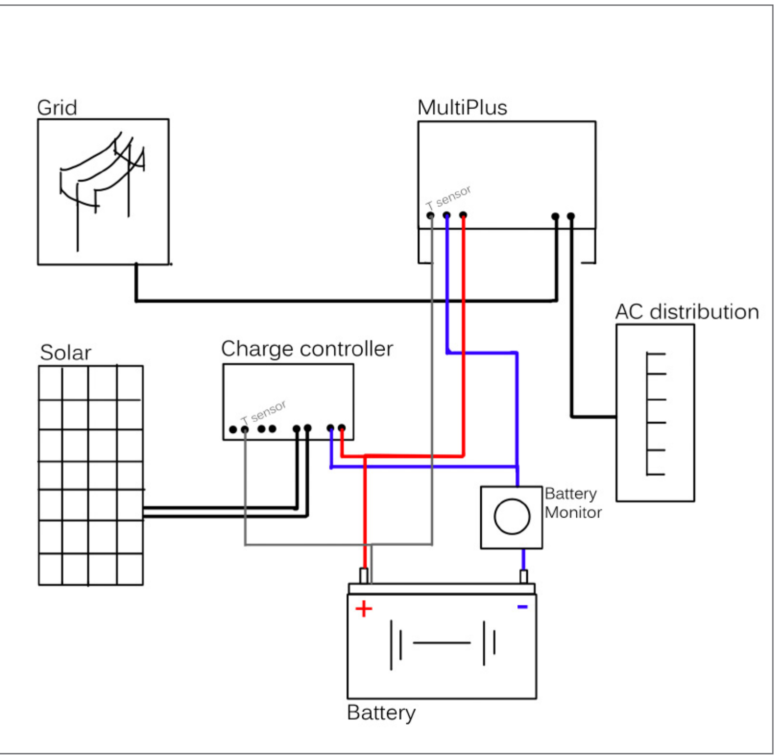
The BMV 600S is a precision battery monitor that can display the battery voltage (V), battery charge/discharge current (A), Ampère-hours consumed (Ah), state of charge (%), and time to go at the current rate of discharge. It also has a visible and audible alarm for when the battery is discharged or overcharged. Lastly it has a programmable generator start relay.

Charge Controller

(Victron Energy, BlueSolar 12/24-PWM, 10A or 20A)

A charge controller is needed when the batteries are to be charged by a solar panel. The charge controller converts the power from the panel so that it is suitable to charge the battery. Like the other chargers, it has adaptive four stage charging, short circuit protection and a programmable maximum charge current. It should be mounted vertically.

*Battery lifespan can be defined as the number of complete charge - discharge cycles a battery can perform before its nominal capacity falls below x% of its initial rated capacity. A common value used for x is 80% (Electropaedia, 2009).



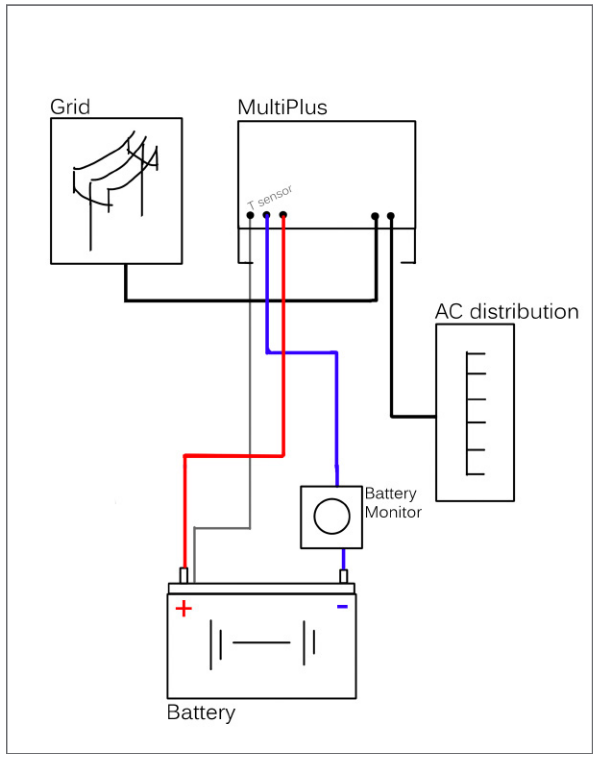


Image 20, 21 Circuits for the L models. To the left a solar panel is connected in addition to the grid. The circuit for the S models are similar, except that they do not have an option for solar input and use a seperate charger and inverter.

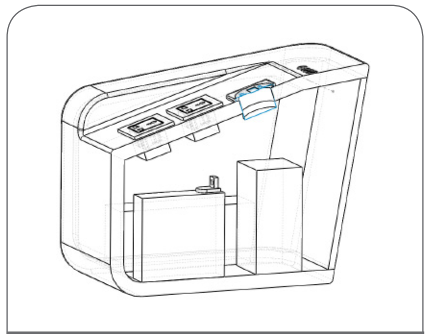
Table 2 Specifications of the different models in the product range

Size	Power (W)	MultiPlus?	Battery size* (Ah)	Back-up time* (h)	Charge time** (h)	Costs*** (USD)	Weight (kg)	Battery Weight (kg)	Dimensions (HxWxL) (mm)
S30	350	no	33	0.8	7	300	15	10.2	324x400x404
S90	350	no	100	2.4	7	375	34	29.0	374x440x452
L30	1200	yes	100	0.7	7	920	39	29.0	399x480x549
L90	1200	yes	300	2.1	7	1125	92	81.6	399x600x663

*For battery size as many of the same size as possible are used, even though this means a slight overcapacity in back-up time for some models. The RA100 is already used by Kamworks for other systems, which is easy for keeping stock.

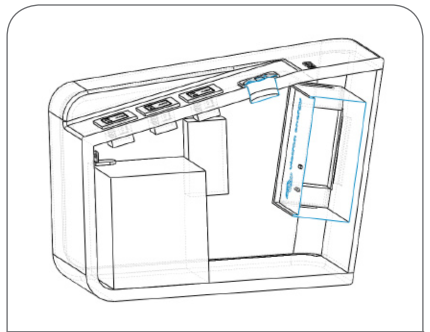
**This is the charge time at the maximum discharge of 70%. The batteries can only be charged with a maximum current of 10% of their capacity to prevent damage.

*** These costs include 7% import tax. They do not include the 30% margin. They are based on the price for the batteries, charger, inverter, charge controller (if used), and battery monitor. They do not include shell and manufacturing costs.

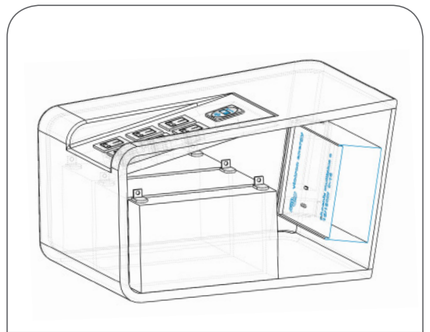


S30: seperate charger and inverter

S90: seperate charger and inverter



L30: MultiPlus and charge controller



L90: MultiPlus and charge controller

3.7.3 Product Lifespan

According to the requirements, the product must have a five year, low maintenance, lifespan. The weakest link in this product's lifespan is the battery (Luxwolda, 2012). To maintain lifespan, the batteries are charged by an adaptive process that all chargers used are capable of. This process has four stages (bulk, absorption, float and storage) to optimize the charging process. Also, they use a temperature sensor to lower the charge rate when the batteries are in danger of overheating. Another precaution taken to control lifespan is to program the system to shut down in case the depth of discharge reaches 70%.

The amount of Ampère hours that the battery in each model can deliver are calculated (**Appendix J**) so that when the batteries have reached 80% of their original capacity after 7000 cycles (30°C, 50% depth of discharge), the promised 30 or 90 minutes can still be provided.

As temperature has a direct effect on the amount of chemical reaction taking place in the battery and thus lifespan, spacing and cooling of components is also important. Space has been left between all components, including the recommended 10 cm around the MultiPlus. However, air circulation also affects cooling of components. The inverters and chargers all have fans. Detailing needs to be done on where air vents should be placed and whether the components are spaced appropriately.

3.7.4 Stiffness and Strength

As the weight of the models is high, further attention must be put into detailing the design so that the shell can hold the weight. When designing the way to lift the model, it is very important to keep in mind that the weight distribution per model varies and might be counterintuitive to the user, especially in the L90 model (see sidebar for placing of components per model). This needs to be physically communicated to the user by placing handles in a way that the user is encouraged to lift the device in the correct way. For example, the handles could be in line with the center of gravity. Also, lifting with two or more people should be assumed, especially for the largest model. Another idea is to create a trolley system where the model can be moved on wheels.

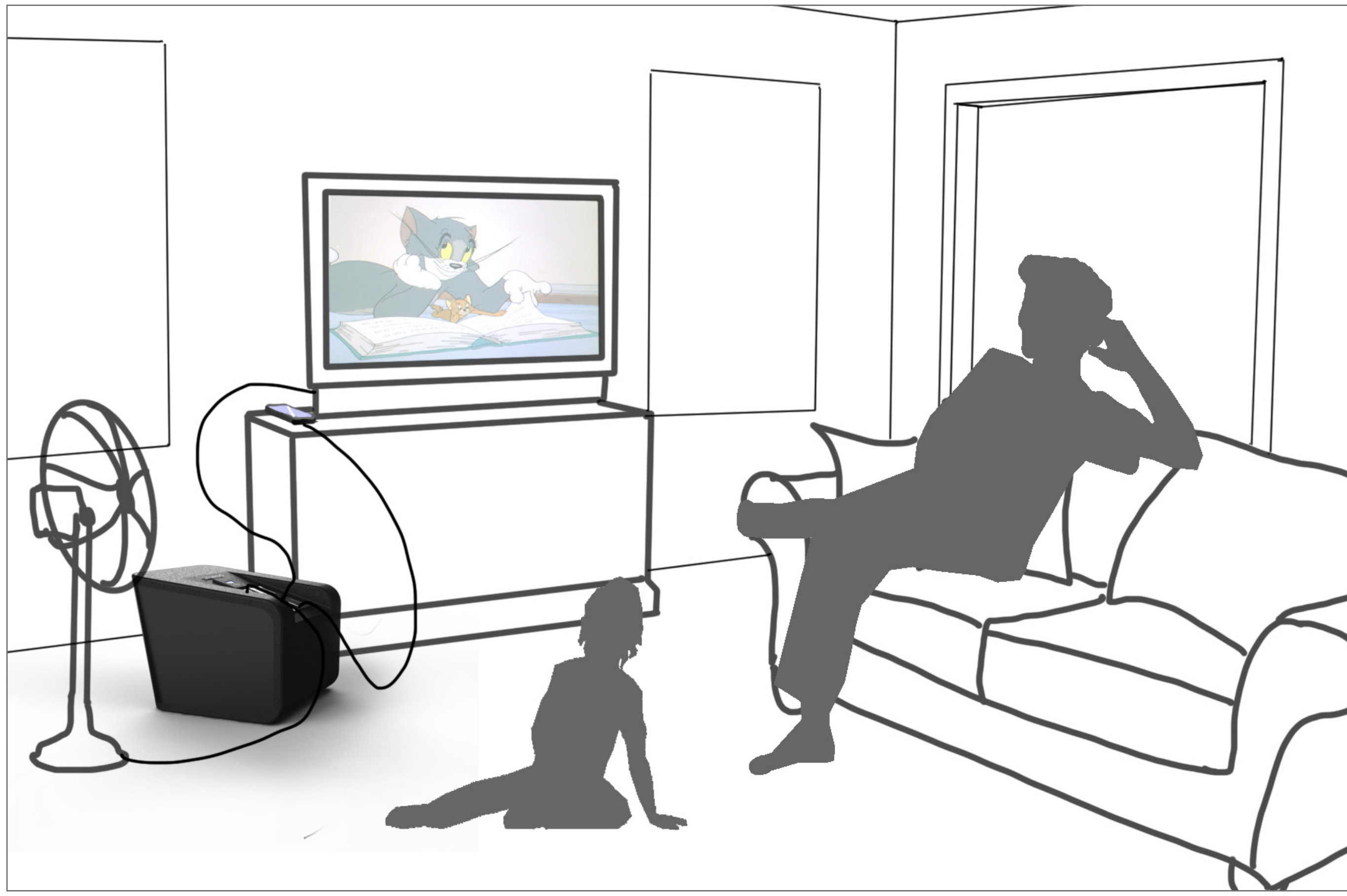
When plugging in and out the device is also be subjected to force, so this part must be strong. Lastly, the shell must be strengthened to maintain its shape in case of pushing from the side, to prevent it from shifting into a more trapezoidal shape.

3.7 Design Evaluation

The components that are needed have been well chosen to provide the required functions. They provide safety because they have short circuit protection. They provide a stable electric output due to the use of high quality components and longer lifespan due to adaptive charging and air space in between components. The product conveys the desired style, which also fits well with the style of the existing Kamworks solar home systems. A scenario of the product in use can be viewed to the right and is explained in the sidebar.

Some aspects still need to be developed further or might need to be reconsidered. The weight of the product is high. Since it needs to be put in the place where it is needed this is a critical point; how will the user transport it throughout their house? Especially of the largest model, the weight requirement of 100 kg, is challenging to meet as the shell must be very strong to support the 90 kg inside the model. For this model it is recommended to design a system to be able to transport it on wheels. The shell and mounting of components must be detailed further. The shell and its connections with the components will determine if the product is robust enough, which is very important for use and transport. Also, air ventilation should be looked into. At the moment space has been left between components, but the air flow to cool the components down must be analyzed and optimized. Lastly, though the product has been designed to be easy to use and plug-and-play, it would be good to verify whether users perceive it as such in a user test with a working model. In such a test it could be verified as well whether the product is safe enough to use around children. The height of it could make it easy for kids to play with. The reaction of children to the product must be researched and possibly extra safety precautions must be designed.

Image 22, 23 Two drawings of the product in use. In the top scenario the product is used for leasure; to be able to comfortably watch TV with friends or family in the coolness of the fan. In the second scenario the product is used for either leisure or work, as the person is using his laptop and the internet. The back-up system is connected to the grid, creating the option for a no-break functionality. If the user plugs his laptop and router into the system instead of directly into the grid, the system will automatically switch to battery power in case of a power cut. This is extremely useful when downloading from the internet, using a desktop computer and to prevent annoyance and waste of time due to losing internet connection. There are many other scenarios that can be thought of, such as a party, avoiding sleepless nights because of the heat, or even a yoga class where music is played and fans are used.



4 Conclusion

4.1 Conclusions

The objective of Kamworks is to launch a new on-grid or urban, plug-and-play product range for consumers in addition to their existing off-grid (rural) product range. To conclude whether their idea of designing a range of back-up systems would be a reasonable step and to provide a base of information about the urban market, they wanted this project to start with a market analysis. After this, the project goal moved on to designing a first concept for the product range, focusing on feasibility.

Based on the market analysis of the power situation, different target groups, technical possibilities and competitors, Kamworks was able to conclude that, considering their product development possibilities, a range of back-up systems would be a good product direction.

The concept designed is feasible for Kamworks and aims at a missing functionality in the urban market as desired. The concept is feasible because it uses components sourced similarly to other Kamworks products, creating synergy. The technology used is within the company's field of expertise. Secondly, as required, the product is plug-and-play and could reach a lifespan of five years. This meets their important terms of not needing to use their resources for a lot of installation or maintenance. Lastly, based on feasibility calculations it can be said that the required functionalities of the product can be achieved within the requirements of price, physical characteristics, inputs and outputs, aesthetics and user requirements.

Image 24 A final view of part of the Phnom Penh skyline. On the left hand side one of the building projects can be seen; the building covered in green.

4.2 Recommendations

For further development of this product there are some recommendations for future steps.

When using the market analysis it should be kept in mind that some conclusions could be false or biased, due to two things. Firstly the researcher is from Holland and could have misinterpreted Cambodian answers or lifestyle due to a barrier in language and culture. Secondly, the questionnaire was not held amongst enough respondents to make any exact statistic statements. Critical conclusions should be verified in further prototype testing.

For further product design, the shell of the concept needs to be detailed in terms of handles, possibly wheels, strength and stiffness, air ventilation and manufacturing. Air ventilation especially could have a major influence on lifespan, as the hotter the batteries get the more capacity they lose with each cycle. Adding to that, packaging design for transport is important, especially since the overall Cambodian road quality is poor.

Performing user tests with a model is recommended. A working model would be preferred due to a possible language barrier in combination with the fact that many Cambodian respondents seemed to be unfamiliar with a research situation where it is expected to empathize with an imaginary situation.

Evaluation

Having the opportunity to complete my bachelor assignment in Cambodia was amazing. Besides learning a lot from my thesis, I learned at a rapid pace from being alone in such a new situation and in a culture so different from my own. Having spent four years in South-East Asia as a child some experiences freshened up details from the past.
Collaborating with Kamworks was pleasant. Communication was smooth due to the fact that Kamworks management is mostly from the Netherlands. Also, my supervisor Brecht van der Laan was very accessible for discussions and meetings.
Despite that it was more difficult due to distance and time difference, I think keeping in contact with the University of Twente was managed well too. Via e-mails from, among others, Arie-Paul van den Beukel, it was very transparent what was expected of me. Skype meetings with supervisor Juan Jauregui Becker were clearly planned and structured. It was great that Juan could empathize well with some Cambodian culture differences, due to it having some parallels with Venezuela, his homeland.
Sometimes I had difficulty working individually, as I always enjoy the spirit of group efforts.

Despite slow internet and stomach bugs, I will miss Cambodia. All in all it was an unforgettable experience which I would recommend to any student who is up for it.

Image 25 A view of the Kamworks office and workplace in the village of Sre Ampil.

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Appendices

A Expert Interviews

Six experts were interviewed about the power situation in Cambodia, whether there would be a market for a back-up system and what requirements for such a system would be. Depending to the interviewee's expertise, more the focus of the interview was adjusted. In the following summary, please read who were interviewed and what their field of expertise was.

Name: Pete Davenall
Date & time: 3 May 2012, 10.15 am
Function: Energy Audit Consultant at Kamworks Ltd., working there since April 2012
Background: Originally from Londen, Pete has lived in Cambodia for 6 to 7 years, mostly in Phnom Penh. He is married to a Cambodian woman and looks after many Cambodian children. He started his career studying Electrical Engineering in London.
Interview: The interview was about the power situation in Cambodia, whether there is a market for a back-up system and Cambodian lifestyle and mindset in general.

Name: Jim Gramberg
Date & time: 8 May 2012, 4.00 pm
Function: Managing Director at Kamworks Ltd, since March 2012
Background: Originally from Holland, Jim has worked in retail in America, the Netherlands (12 years at Ahold), and done business in and with Asia for 15 years in foods and wine. In Asia he has lived in Korea and Thailand and has recently moved to Cambodia with his Cambodian wife and daughter. He is interested in making quality of life and economy better for poor people around the globe.
Interview: Having a lot of sales and marketing experience, the main topic was which market would be good to access in Phnom Penh for a back-up system. Jim had a distinct hunch that Khmer who owned small home businesses would be a good target group.

Name: Rogier van Mansvelt
Date & time: 10 May 2012, 1.00 pm
Function: Green Energy Consultant, freelance
Background: Rogier is also Dutch. He has worked as green energy consultant in Cambodia for 7-8 years in the fields of solar, biogas, wind and water pumps for NGO's, the World Bank and other organizations. Though permanently living in Phnom Penh, he has stayed in Laos, Thailand and other Cambodian areas during projects.
Interview: This interview focused mainly on the current power situation and whether there would be a market for a back-up system. Rogier actually built a solar back-up system himself several years ago but did not use it a lot anymore due to fewer power cuts.

Name: Don Weinland
Date & time: 24 May 2012, 10.15 am
Function: Reporter at The Phnom Penh Post, Phnom Penh.
Background: Don has been in Phnom Penh for a year. In 2003 he moved to China at age 19. He moved in between China and the States for 7-8 years, mainly studying in both places (Chinese, Journalism). Afterwards his ambition was to find a journalism job in China. Since vacancies for inexperienced reporters are hard to find there, he decided to get some experience in Phnom Penh first. He reports on business: mainly in the oil and telecom sector. He has reported on the Koh Kong coal plant as well.
Interview: Don was able to give a lot of information about the current developments in the power situation in Cambodia, especially from the angle of business and politics in this sector and the type deals that are being made. He was also able to recommend some further resources.

Name: Robert Jan van de Hulst
Date & time: 24 May 2012, 7.00 pm
Function: Automation manager at Advanced Technical Services (ATS), Phnom Penh
Background: Robert Jan has a technical background in the field of designing systems and control, from repairing TV's to designing chicken butchering machines. He has done many educations, courses and jobs in the fields of electrical engineering, mechanical engineering and hydraulic engineering. He started his career in Europe, traveling a lot in his spare time. Nowadays he is married to a Khmer woman, has two children and has worked in Cambodia for 12 years.
Interview: The focus lay on the power situation in Cambodia and technical possibilities for a back-up system. Having a lot of engineering experience, Robert Jan was able to get into many very specific details.

Name: Anthony Gaglardi
Date & time: 23 May 2012, 10.00 am
Function: Sales & Business Development Manager at Advanced Technical Supplies, Phnom Penh
Background: An American Khmer who has lived in Cambodia for 7 years. Anthony was born in Cambodia, but went to high school in the USA. He came back to Cambodia without a specific plan. He then hooked up with family and friends to do various types of business. The past 3.5 years he has been working in the electricity sector at ATS, where he is responsible for sales. He is doing his bachelor in business at the moment.
Interview: Born Cambodian but being exposed to American culture for many years, Anthony was able to put his finger on many differences between Cambodian and Western mindset and lifestyle. He was also able to say some valuable things about the Cambodian urban market, having a sales background himself.

B Power Analysis

The prediction of the future power situation is based on an analysis of the current one and developments that are taking place, both of which are presented in this section.

Current situation

In 2010, Cambodia used 2.5 billion kWh of power. In comparison to neighbours Thailand (132 billion kWh, 2008) and Vietnam (86 billion kWh, 2010) you could state that this quantity is quite insignificant.
The electricity supply in 2010 consisted of 34% imported electricity from Vietnam, Thailand and Lao, 54% diesel or heavy fuel oil, 3% hydropower, 3% coal and others. In December 2011 the 193 MW Kamchay hydro dam came online, probably kicking up the hydropower percentage.
The distribution of this supply is patchy: Many villages and cities are supplied by small isolated power generators whose owner has a government license to generate and distribute the electricity. Of these individual license operators, 93% of all energy production is based on expensive, imported diesel fuel. This is one of the main reasons why the electricity prices are so high and set in a wide range, as there is no centralized, efficient production, thus creating high and varied prices.
Most of the electricity goes to the urban areas. Phnom Penh is the main consumer, accounting for 61% of all electricity sold in 2010. Other leading cities are Sihanoukville, Siem Reap, Kampong Cham, Takeo and Battambang. Where urban citizens will often get their supply from a grid, a common system in rural areas is to charge car batteries at the local village generator, and use battery source for their electrical devices.

Availability

Before power import from Vietnam started in April 2009 (GMSEC.org, 2009), there was a serious gap between the supply and the demand in Cambodia, especially Phnom Penh. The 'solution' for this was rolling black-outs, a phenomenon where the city is divided into areas, each area being cut off from power for several set hours each day (Davenall, 2012; Hulst, v.d., 2012). Since April 2009 the situation has improved dramatically, although (rolling) black-outs still occur, especially in suburban areas and during the hottest part of the dry season (Questionnaire, 2012).
According to Anthony Gaglardi, many large companies that are extremely dependent on power, such as those in the Telecom business, have their own power supply (usually a generator) because they cannot rely on the grid. Add to that the information that new building projects requesting power, such as Canadia Development, 3 MW for the Diamond Island, are held off due to the scarceness of power (Gaglardi, 2012), it is obvious that the power supply still is not up there with the actual demand.
Many small power stations use poorly maintained old generators or coal for producing power, which can also lead to black-outs. Some stations have set timespans on which they operate, for example only from 17.00 to 23.00 (Electricity Authority of Cambodia, 2011).
Availability of power does not only depend on the supply: Important people, such as the Prime Minister Hun Sen, will always have power available, as EDC (Electricité Du Cambodge), will not shut his area down. This causes the black-out pattern to be seemingly very illogical; one block could suffer a black-out while the next still has power. According to the experts interviewed, and verified in the questionnaire amongst local Khmers, in general, going from downtown more into the countryside, black-outs will occur more frequently and last longer.

Quality

Aside from whether the power is available, quality can also present itself as a problem, according to expert R.J. van de Hulst, Automation Manager at ATS (Advanced Technical Supplies). Fluctuations in frequency, voltage or power efficiency due to poor maintenance and control cause a low quality power supply. For both businesses and households this raises operational costs: appliances are not made for such fluctuations and their lifespan will drop. There is no controlling organization that measures what household 'do' to the net; what kind of electricity comes in and what comes out. In Holland for example, if you reduce the power factor of the net stream you will get a fine. On top of all that: power lines are often crafted together, causing huge chaotic tangles of wiring. This will also provide a great challenge in the process of creating a national grid.

Developments

Government Plans

The Cambodian Power Development Plans, written by the Ministry of Industry, Mines and Energy in 2009, state a planned energy production expansion from 500 MW in 2009 to 3000 MW by 2020. Most of this energy is to come from hydropower, followed by coal, natural gas and import. Also the target is set for 100% of villages to have access to electricity services by 2020, with 70% of rural population having access to quality electricity services by 2030 (Ministry of Industry, Mines and Energy, 2009). Journalist Don Weinland says to be sceptical of these targets: government plans in any sector are often extremely ambitious.
However, there are plans for building many hydro dams, funded by the Chinese and Thai. In December 2011, the Kamchay dam came online, built by Sinohydro Corporation, China's leading dam builder. Construction began in 2007, costs: 280 million USD. Four more dams funded by the Chinese are under implementation, planned to be finished in 2015, producing a total capacity of 915 MW and costing 1.6 billion USD (Weinland, 2012; English.news.cn, 2011). Potentially thirteen more are on the way, the largest being the Sambor Hydro project of 2600 MW (Ministry of Industry, Mines and Energy, 2009).
Besides hydro power, coal plants are being built, such as a 200 MW plant in Sihanoukville and a planned 1800 MW plant in Koh Kong, funded by 3 billion USD coming from a Thai energy firm (The Phnom Penh Post, 2012).

Questionable Business

The ways these new dams and coal plants are being commissioned and implemented are highly questionable due to several reasons. Firstly, much of the energy will not go to Cambodia. For example, of the 1800 megawatts to be produced in Koh Kong, 1600 will go to Thailand. The same question could be asked about the Chinese projects, as all of them are BOT projects: 'Build, Operate, Transfer'. This means that the investors build the plant, have the right to operate it and sell the energy, and transfer it back to Cambodia in 40 years (Weinland, 2012). The IMF was one of the first to express worry about this, stating that power plants might not even be operational in 40 years, due to poor build or maintenance.
Secondly, there are a lot of 'under the table' politics. For investors is attractive to build power plants in Cambodia because of very little restraints or regulations that other countries might have for good reasons. Environmental reports that are supposed to be public are inaccessible and probably influenced by kickbacks. Cambodia does not have the economic independence to say no to these investors. For example, many Chinese loans are looming over the Cambodian government; giving China more influence (The Phnom Penh Post, 2012).
Another thing is that hydro dams are not necessarily a good solution: Aside from environmental issues, they are dependent on rainfall and thus cannot reach their maximum capacity the whole year round.
Lastly, these projects all depend on planning and money. A protected source for example, says that development of the 200 MW coal plant, being built in Sihanoukville and supposedly coming online in 2012, has been stopped as the funder has removed his investment.

Power Lines

The uncertainties described in the implementation of new plants account for grid expansion plans as well. There are ambitious government plans for building new power lines, but they are dependent on funding and careful planning. During the opening of Kamchay dam for example, Prime Minister Hun Sen asked Chinese Ambassador Pan Guangxue's support for a loan of 50 million USD per year for high voltage power lines.
On top of that there are incidents that perhaps Western people could not imagine: such as a bulldozer hitting a power line when digging (Verschelling, 2012), people taking out the screws of power lines to sell for petty cash or trying to shoot birds sitting on the lines, accidentally hitting the lines as well (Hun Sen, 2011). This mentality also slows down developments.

C Questionnaire

The following questionnaire was used to question the expat, middleclass Khmer and well-to-do Khmer target groups. For the middle class Khmer the questionnaire was translated to Khmer writing by a Kamworks employee, Kunthea Thorn. He also went along as a translator and guide when the questionnaire was held. In total, 19 middleclass Khmer, 15 expats and 6 well-to-do Khmer were questioned. Of the latter, only male respondents were found. The rest of the groups were mixed.

Questionnaire

As you will probably have experienced, reliable grid energy in Cambodia is not a given. The goal of this questionnaire is to get a view on which devices people find most important to use during black outs, as well as some other general information. The results will be used for designing a new product that provides households backup during power cuts. It will be presented in my Bachelor Thesis of Industrial Design Engineering, at the University of Twente, the Netherlands.

Thank you for taking the time to fill out this questionnaire.

General information *(please circle correct answer)*:

Age 18-25 / 26-35 / 36-45 / 46-55 / 56-65 / 66+

Gender M / F

Nationality ____________________

Contact information *(I will only use this in case I have some more questions in response to your answers.)*

Name: ____________________

E-mail adres: ____________________

Phone number: ____________________

1 How many years have you lived in Cambodia?

____________ years

2 How many years do you plan on continuing to live here?

____

3 What kind of residence do you live in?

◯ Rental appartment

◯ Rental house

◯ Own appartment

◯ Own house

4 What size is your household?

_____ Adults

_____ Children

5	**Please fill out the table below.**						
	Device	**How important is it to you to be able to use this device during a power cut?**			**How many do you have in your house?**	**How many hours do you use this device per day?**	**How many do you need at the same time?**
	Light	◯ not	◯ medium	◯ very much			
	Fan	◯ not	◯ medium	◯ very much			
	TV (colour)	◯ not	◯ medium	◯ very much			
	TV (black and white)	◯ not	◯ medium	◯ very much			
	DVD player	◯ not	◯ medium	◯ very much			
	Stereo	◯ not	◯ medium	◯ very much			
	Computer (desktop)	◯ not	◯ medium	◯ very much			
	Laptop	◯ not	◯ medium	◯ very much			
	Refridgerator	◯ not	◯ medium	◯ very much			
	Freezer	◯ not	◯ medium	◯ very much			
	Air conditioning	◯ not	◯ medium	◯ very much			
	Cell phone charger	◯ not	◯ medium	◯ very much			
	Rice cooker	◯ not	◯ medium	◯ very much			
	Electric stove	◯ not	◯ medium	◯ very much			
	Microwave	◯ not	◯ medium	◯ very much			
	Electric oven	◯ not	◯ medium	◯ very much			
	Coffee maker	◯ not	◯ medium	◯ very much			
	Blender	◯ not	◯ medium	◯ very much			
	Electric clock	◯ not	◯ medium	◯ very much			
	Hair dryer	◯ not	◯ medium	◯ very much			
	Hair straightener/curler	◯ not	◯ medium	◯ very much			
	Shaving machine	◯ not	◯ medium	◯ very much			
	(Other:)						
	____________	◯ not	◯ medium	◯ very much			
	____________	◯ not	◯ medium	◯ very much			
	____________	◯ not	◯ medium	◯ very much			

C Questionnaire

6 How frequent are powercuts at your house? How long do they last?

During rainy season (jun-sept)
- ◯ less than 1 time/month
- ◯ 1 to 4 times/month
- ◯ 1-3 times/week
- ◯ more than 3 times/week
- ◯ more than 1 time/day

During cool season (oct-jan)
- ◯ less than 1 time/month
- ◯ 1 -4 times/month
- ◯ 1-3 times/week
- ◯ more than 3 times/week
- ◯ more than 1 time/day

During hot season (jan-may)
- ◯ less than 1 time/month
- ◯ 1-4 times/month
- ◯ 1-3 times/week
- ◯ more than 3 times/week
- ◯ more than 1 time/day

Frequency
- ◯ Less than 15 minutes
- ◯ 15-30 minutes
- ◯ 1-2 hours
- ◯ 2-3 hours
- ◯ More than 3 hours

7 What is your attitude towards powercuts?
- ◯ They are convenient for me and my family
- ◯ My family and I don't really care
- ◯ They are unconvenient for me and my family

8 Do you have a generator?
- ◯ yes *(please go to question 9)*
- ◯ no *(please go to question 12)*

In case of **yes**:

9 How many kVA is it? __________ kVA

10 What is the degree of your satisfaction regarding your generator?
- ◯ Very high
- ◯ High
- ◯ Medium
- ◯ Low
- ◯ Very low

11 Do you ever have any problems with your generator? If so, please describe them:

In case of **no**:

12 Why don't you have a generator? (more than 1 answer is possible)
- ◯ It's too expensive
- ◯ I don't need a solution to power cuts
- ◯ It makes too much noise
- ◯ Environmental reasons due to the petrol consumption of generators
- ◯ Other:

Thank you very much!

Feel free to tear if you would like my contact information

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University of Twente, the Netherlands

D How Much Electricity do Appliances Use?

Here is a list of common electrical devices and their estimated power consumption. Most information was gathered online. Giving an estimate is imprecise, because one device can take up a range of power. For example, a fan can be 25 W or even 100 W. However, it being an estimate to get a feel for ratios this is not a problem. In the second table a range has been given instead of a single power for the most common devices to create a more accurate estimate.

Table 3 An estimate of the amount of power that devices use

Device	Power (W)	Device (continued from left)	Power (W)
TL light	30	Printer	100
CFL light	14	Photocopying machine	1300
LED light	10	Iron	1000
Incandescent light	60	Razors	20
Fan	80	Hair dyer	1250
Colour TV (20")	150	Hair curler	80
Black and white TV (12")	30	Hair straightener	120
Cell phone charger	25	Welding machine	12000
Electric clock	5	Grinder	2000
DVD player	35	Sewing machine	75
Stereo	70	Toaster	1250
Refridgerator (European)	450	Microwave	1200
Freezer	500	Coffee maker	800
Rice cooker	500	Blender	300
Computer	225	Internet router	6
Laptop	60	Air conditioning	1000

Table 4 A more specific estimate of the range of power that the most common devices use

Device	Min. Power (W)	Max. Power (W)
Fan	25	100
Light	10	60
Desktop computer with monitor	150	350
Internet router	5	10
TV (normal to 50-56" Plasma)	150	450
Electric clock	4	10
Laptop	45	70

E Competing Products Comparison

Below, a table comparing the competing products for a back-up system is given. Products are compared in terms of price, running costs and pros and cons.

Table 5 Competing products

Product	Low budget 1: hand fan, candle, oil lamp	Low budget 2: car battery	Generator	UPS	Solar back-up
Purchase price	$0 - $10	About $30	Starting at $100 for 1,5 kVA low-quality generator	Starting at $35 for 1.25 kVA for 15 minutes, low quality UPS	Starting at $1800 for 1800W inverter, 90W panel
Running costs	Depends on price of new oil, wood, charcoal, candle	Depends on price of diesel or gas	Depends on power and price of diesel or gas. From 0.5L/h	Price of grid electricity	$0, if using solar; price of kWh if also charging from grid
Pros	• Inexpensive • Easy to use	• Have electricity • Initial costs are more inexpensive than larger systems	• Have electricity • Does not run out (if continuous fuel is supplied) • Can start automatically if system allows it • Suitable for extremely large loads, such as machinery	• Have electricity • Starts automatically • Does not require start-up time (uninterrupable) • Soundless • No fumes • Cheaper running costs than generator	• Free electricity • Soundless • No fumes • Cheaper running costs than generator
Cons	• No electricity • Does not start automatically	• Not suitable for large loads • Does not start automatically • Runs out of power • Car batteries break down fast when used for deep discharges	• Expensive to use • Noisy • Fumes • Unreliable electric output that could damage devices • Requires start-up time to boot	• Runs out of power • For large loads and battery life it is expensive, heavy and large • Batteries could have a short lifespan	• The products described in the text are not available in Cambodia • To charge with only solar takes a long time unless you have many panels (which are expensive) • Batteries could have a short lifespan

F Technical Analysis

This appendix explains the steps taken when figuring out which functionalities a back-up system could fulfill during the market analysis phase. Also, an estimate of system costs was made in case of a three hour back-up, and compared to a cheap, low-quality generator and a more expensive high-quality generator.

1 Estimate of small shops power needs

Firstly, I made a list of all devices I have seen being used in Cambodia, in the shops, restaurants and homes that I have visited. Then I looked up on the internet how much power these devices needed. This proved to be inaccurate, because one device can take up a range of power. For example, a fan can be 25 W or even 100 W. However, as this was just an estimate I tried to use common sense in combination with the sources I found to determine an estimate. I purposely did not assume the use of the most energy efficient devices, as I did not find many devices like these being used in the places I visited.

Thirdly, I looked what the power consumption was of the different shops that I visited. From this I found that even simple or deluxe restaurants, hair salons and print shops have an energy need that would need a great amount of power and battery capacity. For example:

- Simple restaurant (1100 VA): Fans, lights, rice cooker
- Small deluxe café or restaurant (4400 VA): Fans, 1 AC, lights, oven, coffee maker, blender, rice cooker, refrigerator, freezer
- Hair salon (2000 VA): Lights, fans, hairdryer, two razors, two straightening irons
- Print shop (4100 VA): Lights, fans, two printers, two photocopying machines, two desktop computers

Since I knew from the start that it was not the objective to power AC's with batteries, I made the conclusion that these kinds of numbers were not suitable for the product we are designing.

2 Estimate of households power needs

Then, I went from what was possible, taking the price list of Kamworks parts and focusing on household needs. I made three sizes:

- Small: 300 W; 3 CFL lights and 1 desktop computer.
- Medium: 600 W; 5 CFL lights, 1 desktop computer, 1 fan and 1 color TV.
- Large: 1200; 5 CFL lights, 3 fans, 1 color TV, 1 refrigerator and 1 desktop computer.

3 Estimate of back-up range costs and specifications

For each size, I selected the inverter or charger-inverter if the system was big enough, according to the power needed. Secondly I calculated the amount of battery capacity in Ampere*hours (Ah) needed in case of a three hour back-up, using the following equation:

(1) $B = (t * P)/U*0.7$

Where

B is the battery capacity needed in [Ah]
t is the time that back-up is needed [h]
P is the maximum power needed [W]
U is the voltage of the battery outlet [V], which can be set at 12V
0.7 is a correction used because it is bad for the deep cycle batteries used to discharge past 30%

This equation gave the following results:

Small: B = 107 = 110 Ah
Medium: B = 286 = 290 Ah
Large: B = 428 = 430 Ah

F Technical Analysis

Now that the needed battery capacity is known, it is wise to select a type of battery that is a common denominator of all capacities needed, as to only need to have one battery type in stock. The battery I selected for my estimate was the Ritar RA12-60. This meant that for each size the following amount of batteries were needed:
Small: 2 batteries
Medium: 5 batteries
Large: 7 batteries

Using Kamworks existing pricelists and estimates from Arjen Luxwolda for the price of the battery, which was not listed, this came to the following price estimates (including 30% margin and taxes) for the range of back-up systems:

Table 6 Estimates for specifications of a range of back-up systems

Size	Price (USD)	Power (W)	Battery life (h)	Battery weight (kg)	Battery volume (m^3)	Battery dimensions (LxWxH (mm))
S (no MultiPlus*)	500	300	3	41	0.02	520x169x235
M (no MultiPlus*)	1,050	800	3	102.5	0.05	1300x169x235
M (MultiPlus*)	1,350	800	3	102.5	0.05	1300x169x235
L (MultiPlus*)	2,150	1200	2.9**	143.5	0.07	1820x169x235

*A MultiPlus is a charger-inverter. It is more expensive than a separate charger and inverter, but has several advantages: It has a no-break functionality in case of grid failure and it is bidirectional. (As opposed to an inverter which is unidirectional.)
**Because the batteries for the large system are 420 Ah instead of 430 Ah in total, battery life is a little shorter (calculated using equation 1).

4 Comparison to a generator

Thirdly, I used this estimate to compare the price of a back-up system to the price of a generator. First I will compare it to Chinese (low quality) generators that are sold near Central Market. Secondly I will compare it to a higher quality generator, which could be said to be a better comparison, as the parts used for the back-up are also high quality. The reason I also want to compare to low-quality generators is that at the middleclass Khmer target group, these were the generators I saw people had in their house, if they had a generator at all. Also, as the most common reason for not having a generator was that it was too expensive for this target group, comparing to these low quality generators gives a good indication of to which extent people will think of the back-up systems as being expensive.

Table 7 Chinese Generators (Meer, A., 17 May 2012)

Brand	Power (kVA)	Price (USD)	Usage (L/h)	Gasoline/diesel
Yokohama	1.5	100	0.5L/h	gasoline
Yokohama	3.8	350	0,5L/h	gasoline
Self-made	3	500	-	diesel
ESCO	15	3500	3L/h	diesel
SSDMO	45	9500	4L/h	diesel

Chinese Generator
The largest back-up model is 1200W at 2,150 USD. This would compare to a real power of 1.1kVA, using a powerfactor of 0.9:

(2) $P_{real} = P * P_F$

Where:
P_{real} is the real power [kVA]
P is the power [kW]
P_F is the power factor, a dimensionless number between 0 and 1. According to Arjen this can be set at 0.9 for Cambodia.

Therefore, let's compare it to the smallest generator available, the Yokohama 1.5kVA of $100, and find out the pay-back time: how many hours one could use this generator before reaching a point where it would be cheaper to use the back-up.

The price ratio:

(3) Priceback-up / Pricegenerator = ratio
2,150/100 = 21.5

So it is 21.5 times more expensive. The next step is to calculate the price per kWh for this Chinese gen.

(4) $Price_{kWh} = Price_{gas} * Usage$
$Price_{kWh} = 0.60$ USD

Where:
$Price_{kWh}$ is the price per kWh [USD/kWh]
$Price_{gas}$ is the current gasoline price of about 1.25 USD/L
Usage is the amount of gasoline the generater uses per hour [L/h], at 0.5L/h

So the kWh price is about 0.60 USD per kWh. Let's assume the EDC price for Khmer is 0.20 USD per kWh. This means that per hour, you save 0.40 USD by using the back-up system. The difference in price is 2,050 USD. So:

(5) $t_{pay\text{-}back} = dPrice_{device} / dPrice_{kwh}$
$t_{pay\text{-}back} = 5{,}130$ h

Where:
$t_{pay\text{-}back}$ is the pay-back time [h]
$dPrice_{device}$ is the price difference between the back-up and the generator [USD]
$dPrice_{kwh}$ is the price difference per kWh of power used [USD]

Assuming that there is a 3 hour black-out every day, this means that it would take 4.7 years before pay-back time kicks in. In reality there would probably be less or shorter black-outs, getting the time up even more. Imagine a situation of 3 black-outs of 2 hours per week (which is still a very negative situation), the pay-back time would be up to 16 years. The average middleclass Cambodian does not think that far ahead and sees it as quite a risky investment because both devices could break. Therefore, even if the Chinese generator breaks sooner, to this target group it still seems a cheaper option, because the investment is so much smaller.

Quality Generator
Now let's make the same comparison to a European quality SiP generator, a UK based company. Their 900W generator was rated the best of 8 European models in a product review by Auto Express (UK). SiP has a 900W and a 2.0kVA model. For comparison, the following price will be used:

F Technical Analysis

(6) $\text{Price}_{comparison} = (\text{Price900W} + \text{Price}_{2.0kVA})/2 * \text{Import.tax} * \text{USDex.rate}$

$\text{Price}_{comparison} = 520$ USD

Where:

$\text{Price}_{comparison}$	is the price that will be used for comparison to the back-up and the Chinese generator (USD)
Price_{900W}	is the price of the SiP 04739 Medusa T1000 (900W), at 225 GBP
$\text{Price}_{2.0kVA}$	is the price of the SiP 03921 Medusa T2401 (2.0kVA), at 423 GBP
Import.tax	is the 7% import taxes to be paid over imported products to Cambodia, thus 1.07
USDex.rate	is the exchange rate between USD and GBP, at 1 GBP = 1.5 USD (Google Valuta Calculator, June 2012)

Following the same steps as with the Chinese generator, this lead to the following conclusions (see table). Assuming that there is a 3 hour black-out every day, this means that it would take 1.4 years before pay-back time kicks in. In reality there would probably be less or shorter black-outs, getting the time up more. Imagine a situation of 3 black-outs of 2 hours per week (which is still a very negative situation), the pay-back time would be up to 5 years.

Conclusion generator comparison

Table 8 Comparison of a three hour back-up system with two types of generators

Generator	Price (USD)	Price percentage of the 1200W back-up	Price per kWh (USD)	Pay-back time (h)
Chinese 1.5kVA (Yokohama)	100	5%	0.60	5000
UK 1.5kVA (SiP Medusa)	520	25%	1.25	1500

G Other Product Ideas

For the purpose of looking at the design problem from a broader perspective, some time was spent creating more product ideas than the back-up system that Kamworks originally had in mind. However, after exploring, it was decided to go with the original idea. These other design ideas can be found on the following pages, along with a discussion of why they were not chosen as product directions.

Portable solar charger

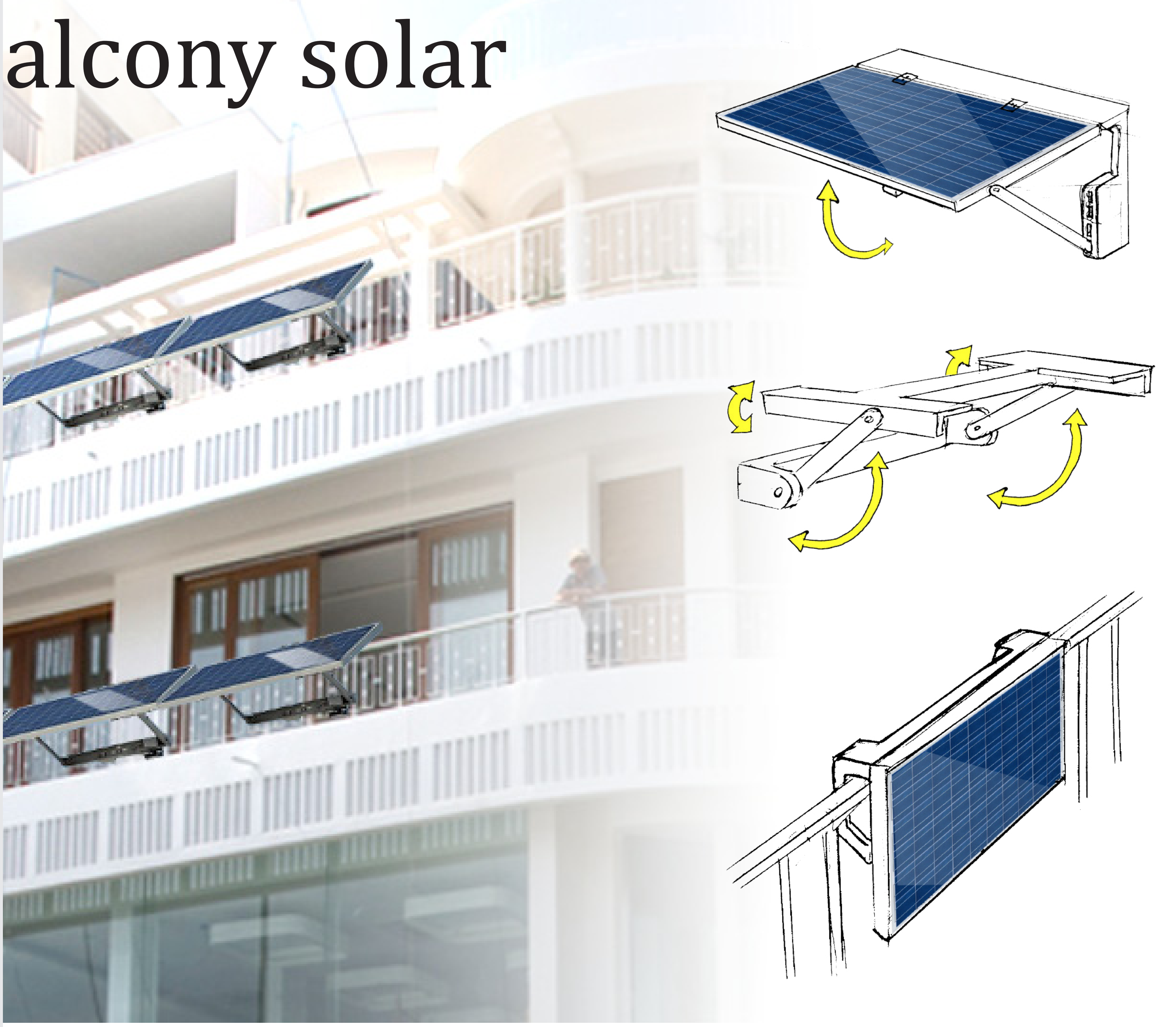
A charger that you can carry with you in your bag or as a bag; small for your phone or larger for even a laptop. A cool gadget for people to show that they are up-to-date with technology.

Discussion

A good gadget takes a lot of development time and will be relatively difficult to generate profit. As gadgets are more of a commodity than a solar system is, price will be lower and many must be sold to many to pay off. Secondly, there are already many solar gadgets out there; perhaps if Kamworks wanted one they should just source it and have their logo printed on it.

Balcony solar

As many people in the city live in an apartment, access to putting a solar panel the roof is not a given. Creating a system where the panel can be on the balcony is a solution to make solar energy available to a larger group of urban people. As Cambodia is almost on the equator, a balcony solar panel could still absorb a good deal of energy.

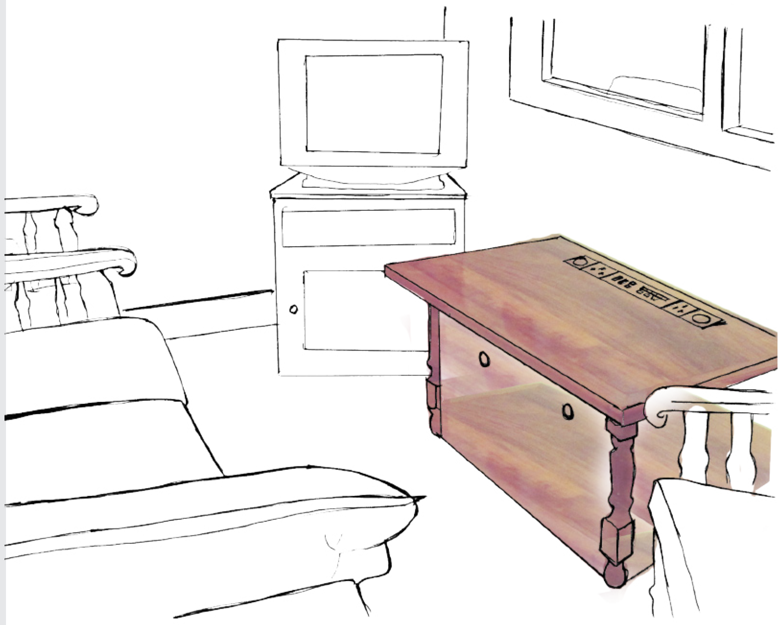


Discussion

There are many balconies in Phnom Penh, so this could open up a large market. Also, being simply a solar product, it would fit with the other products and core business of Kamworks. However, where the energy will go to? Is this product an add-on to a back-up system for example or will it just be plugged into the net to reduce bills? Kamworks liked this idea but decided not to continue with it in this project.

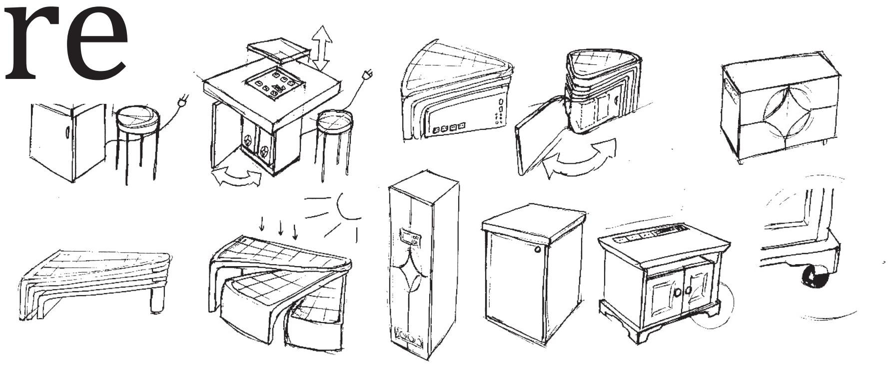
Back-up furniture

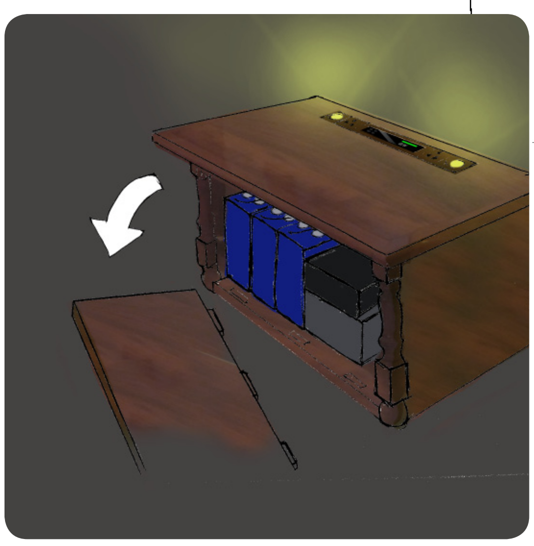
If you can embed your back-up system into furniture used every day, there is no need to have extra space to store it. On top of that, the back-up system can be placed in a central position in a room, creating a subtle and easy access to a power outlet that can always provide.

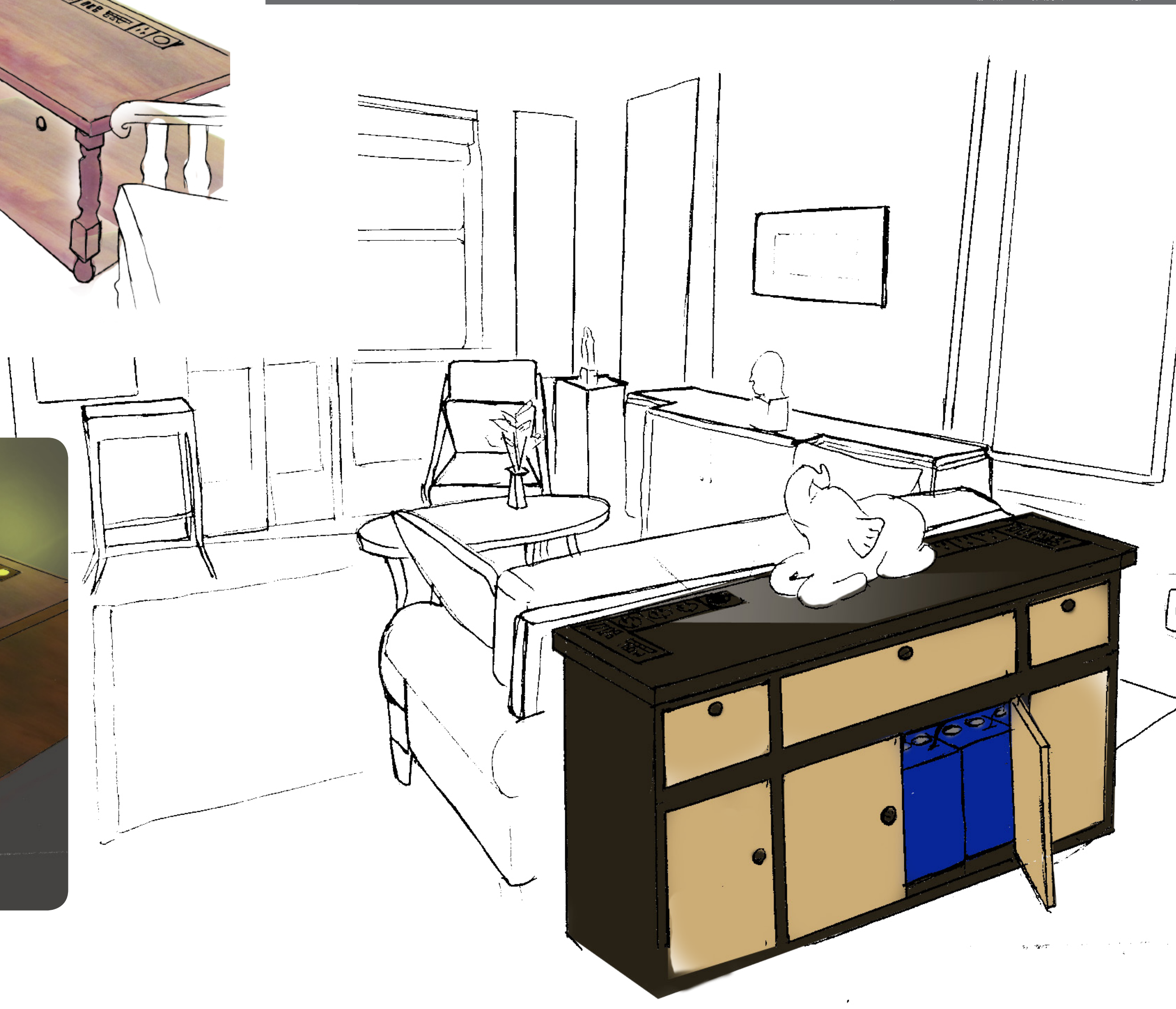


Discussion

Taking the two functionalities of furniture and a back-up could also be a risk: what if these functionalities clash? Also, decorating tastes vary; how to deal with this? A solution would be to make a product that a joiner could integrate into different pieces of furniture. Another downside of this concept might be that it does not easily match the rest of Kamworks' products, which could send out a distorted message to consumers.



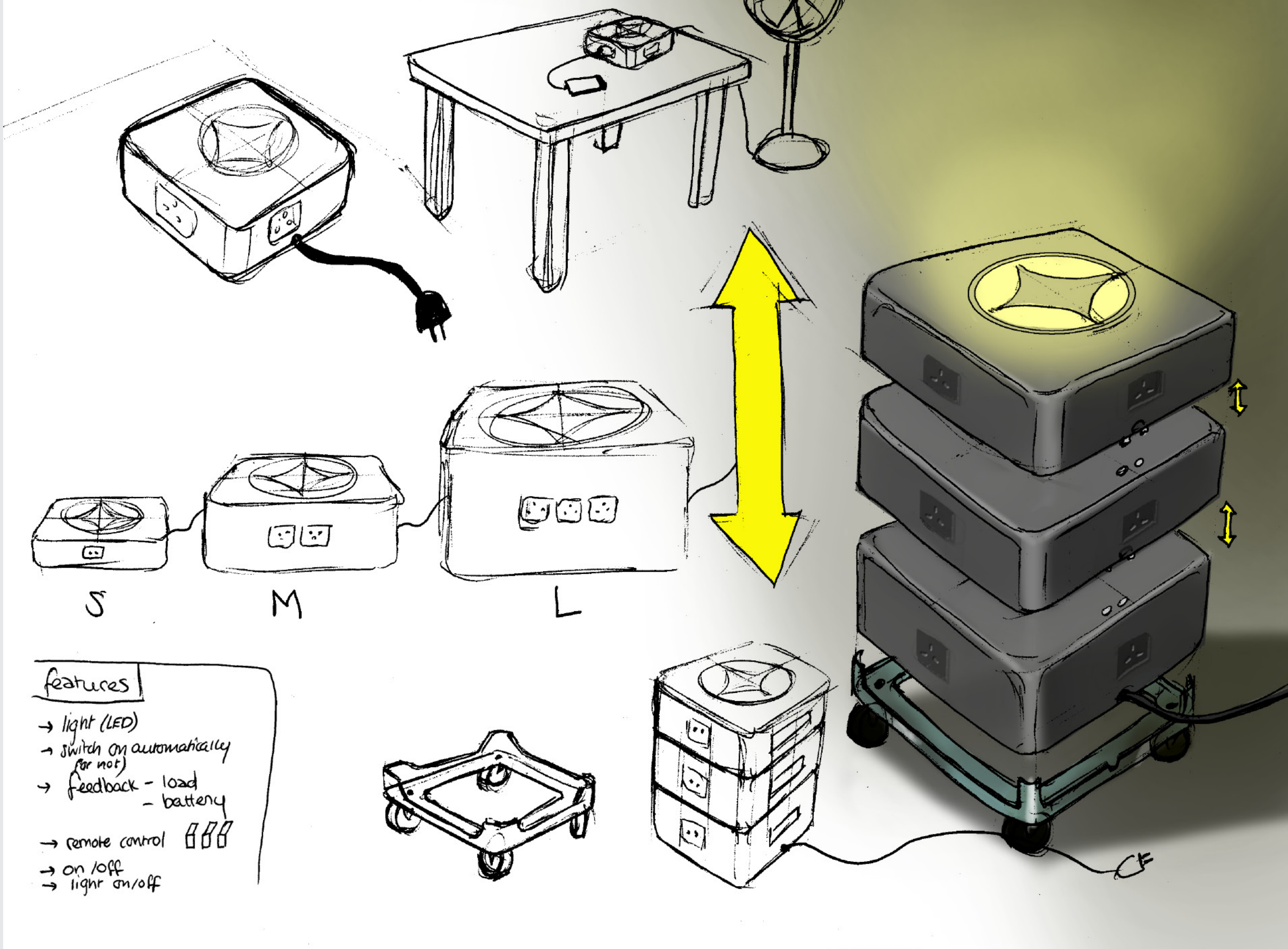




Flexible back-up

A simple back-up system: a chargeable battery box with an outlet or two and a display showing how much battery you have left how much time before it runs out. To make it an attractive, compatible product range, one could make these battery boxes attachable to one another. That way, users can choose to combine several for more power, or to split them up to use them in different places of the house.

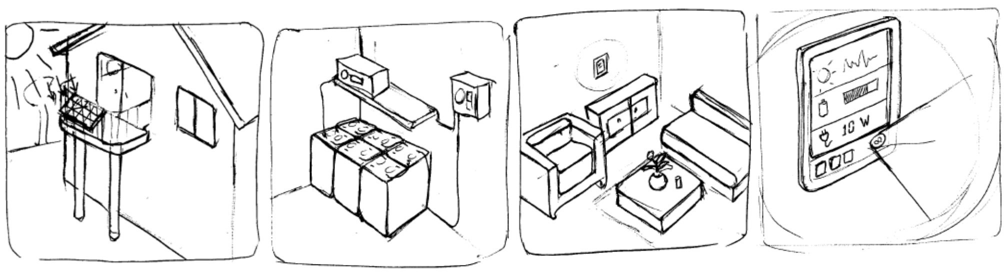
Discussion
The modularity of this concept goes around the difficulties of having wires throughout the house or needing to rewire the house to install the product. It is the most similar to the back-up system Kamworks originally had in mind. It was decided to take this product idea into further concept development, though eventually it was not chosen (see 3.5 Concepts).

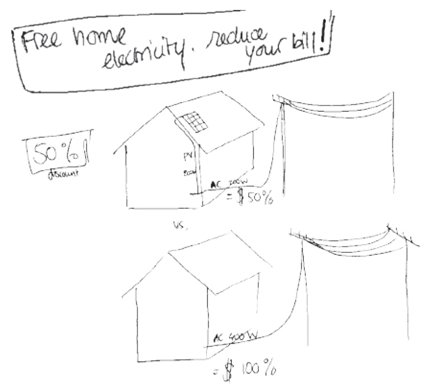


Custom solar

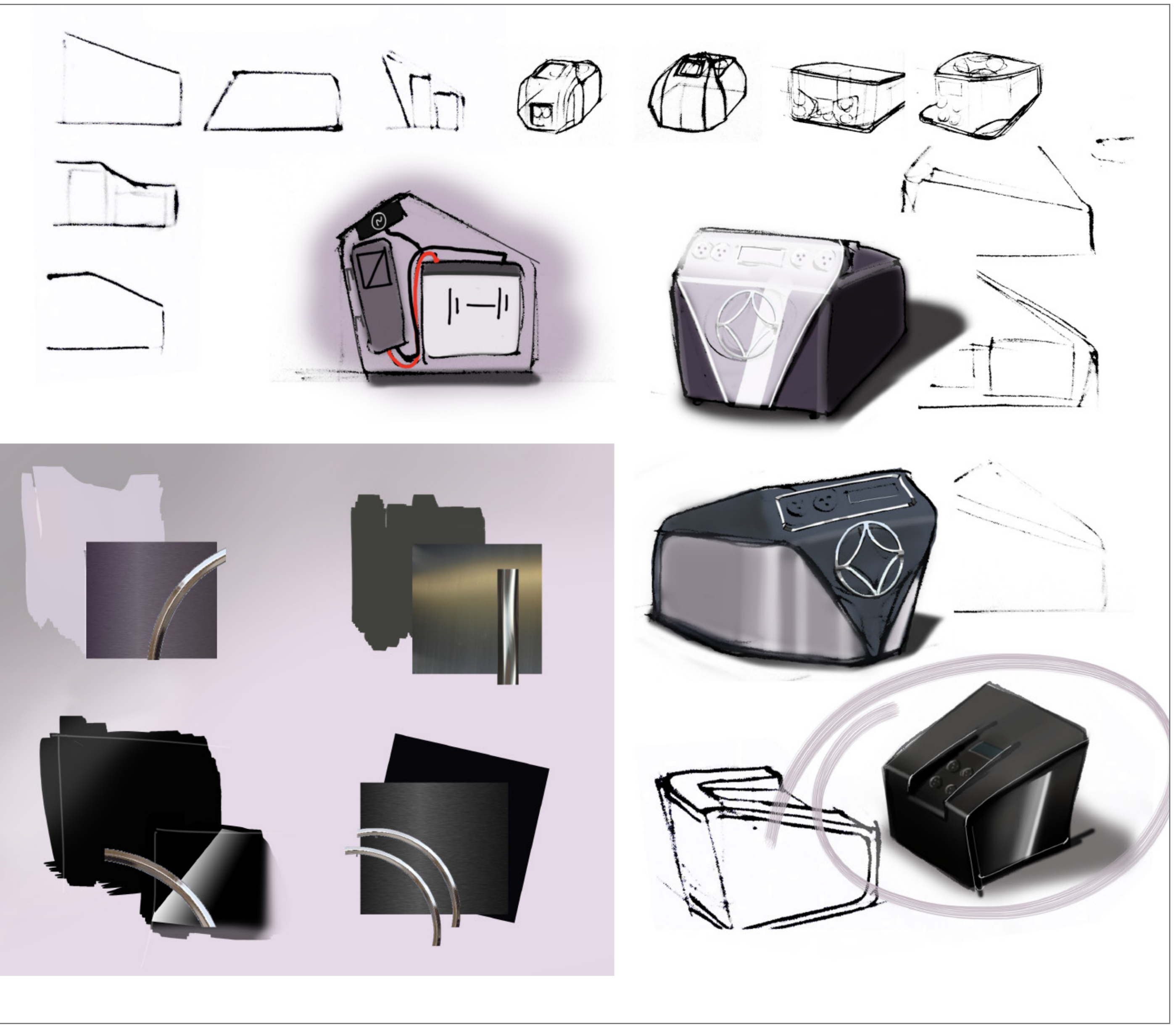
Instead of fixing all of the elements of a solar back-up system, why not leave some choices up to the user? Structurize this, so that the choices seem very easy and managable; like ordering a meal at McDonalds: Which burger, which drink, which side order? Mass customization in other words.

Discussion
Developing this concept would take a lot of work as it requires software development, working out logistics, sourcing many components and designing how they could be compatible with each other and many users' houses. Therefore it is perhaps not suitable for this bachelor project. Kamworks also thought Cambodian people would not be susceptible to such a modern solution at the moment. However, the company did like this idea as something to keep in mind for the future.





H Some Sketch Studies of the Final Concept



I Components Used per Model

S30

Part	Name	Price*	Weight (kg)	Dimensions (HxWxL) (mm)
Inverter	Phoenix 12/350 Schuko outlet**	98.87	3.5	72x155x237
Battery	RA12-33	35.31	10.2	180x130x195
Charger	Blue Power Charger 12/7 IP20 (1)	68.53	1.3	60x90x210
Battery monitor	BMV 600S	99.44	insignificant	31x69x69

S90

Part	Name	Price*	Weight (kg)	Dimensions (HxWxL) (mm)
Inverter	Phoenix 12/350 Schuko outlet**	98.87	3.5	72x155x237
Battery	RA12-100	105.82	29.0	235x169x307
Charger	Blue Power Charger 12/7 IP20 (1)	68.53	1.3	60x90x210
Battery monitor	BMV 600S	99.44	insignificant	31x69x69

L30

Part	Name	Price*	Weight (kg)	Dimensions (HxWxL) (mm)
Inverter/Charger	MultiPlus C 12/1200/50-16	693.77	10.0	375x214x110
Battery	RA12-100	105.82	29.0	235x169x307
Battery monitor	BMV 600S	99.44	insignificant	31x69x69
Charge controller	BlueSolar 12/24-PWM, 10A	21.91	0.15	70x133x34

L90

Part	Name	Price*	Weight (kg)	Dimensions (HxWxL) (mm)
Inverter/Charger	MultiPlus C 12/1200/50-16	693.77	10.0	375x214x110
Battery	RA12-100	105.82	29.0	235x169x307
Battery	RA12-100	105.82	29.0	235x169x307
Battery	RA12-100	105.82	29.0	235x169x307
Battery monitor	BMV 600S	99.44	insignificant	31x69x69
Charge controller	BlueSolar 12/24-PWM, 20A	51.12	0.23	76x153x37

* These costs include 7% import tax. They do not include the 30% margin. They are based on the price for the batteries, charger, inverter, charge controller (if used), and battery monitor. They do not include shell and manufacturing costs.

**Victron Energy BV is working on a new size for this component, 400W instead of 350. Therefore some specifications of this part could change in the near future.

J Lifespan Calculation

Battery lifespan can be defined as the number of complete charge - discharge cycles a battery can perform before its nominal capacity falls below x% of its initial rated capacity. A common value used for x is 80% (Electropaedia, 2009). Kamworks requires a lifespan of 5 years for this product. The weakest link herein is the battery. Thus the question is asked: Is it realistic to assume that after five years of use the battery capacity will have been reduced by less than 80%?

How many power cuts will users experience?

Using the questionnaire as a source for making an estimate, the worst case scenario is 320 black-outs a year, which is 1600 cycles. However, the most average case is 36 black-outs a year, which is 180 in five years.

What causes capacity loss by how much?

Capacity loss depends on:

1. Charge voltage: In case of over voltage capacity loss will occur faster. Due to the adaptive charging process used we will assume that over voltage is not a cause.
2. Charge current: In case of over current capacity loss will occur faster. Due to the adaptive charging process used we will assume that over charge is not a cause.
3. Ambient temperature: We will assume that the ambient temperature is 30°C, as days with lower and higher temperatures will compensate each other.
4. Depth of Discharge (DOD): We will assume maximum DOD (70%) for the worst case scenario and 50% DOD for the average case scenario.
5. Humidity: This is not taken into account as the batteries are sealed.

Worst Case Scenario

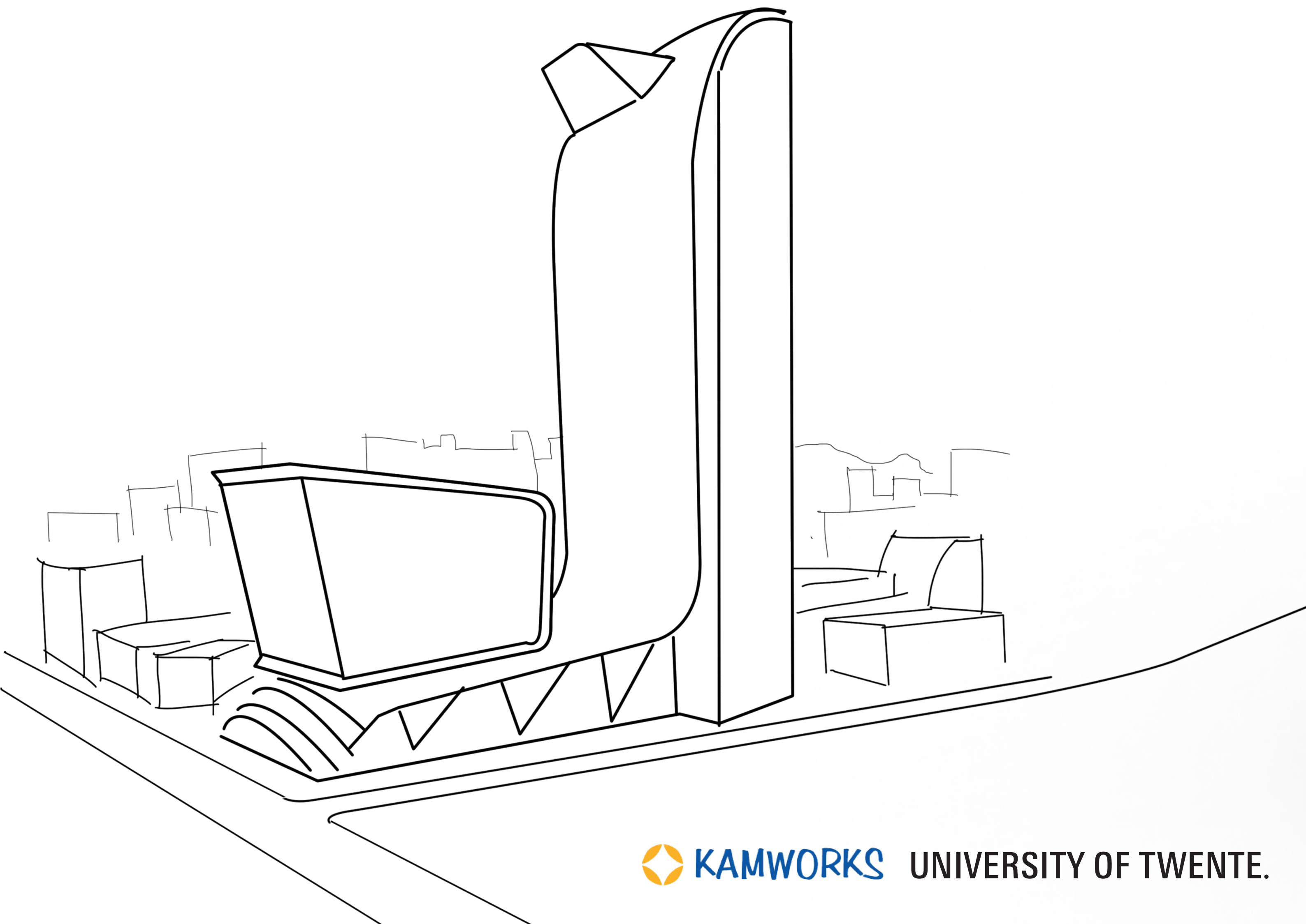
In the worst case scenario the battery will be at 35% of its original capacity after five years.
At 25°C and 70% DOD an assumption would be that 700 cycles are needed to diminish capacity to 80% (Electropaedia, 2009; Arizona Wind&Sun, 1998-2012). Corrected for 30°C, this is 30% less at about 500 cycles. According to Electropaedia the aging rate continues at the same pace, leading to a diminishment of 65% after 1600 cycles.

Average Case Scenario

Using the same method it can be estimated that in the average case scenario the battery will be at 95% of its original capacity after five years.

Conclusion

As the average case scenario was much more common than the worst case scenario and also leaves 15% room for further loss of capacity, it is realistic to assume that after five years of use the battery will have been reduced by less than 80%. Therefor a 20% overcapacity will be used when calculating battery sizes needed.



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