DOCTORAL DISSERTATION

Development of household appliances in an energy-autonomous house

unter der Leitung von

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Dedicated to my parents, my family, my mother-in-law and friends

ZUSAMMENFASSUNG

Ein energieautonomes Haus ist ein wesentliches Konzept für ein unabhängiges Energiesystem, das nachhaltiges Leben in der Zukunft ermöglicht. Um das Konzept des energieautonomen Hauses zu realisieren, müssen Energiebedarfs- und -versorgungsmanagement berücksichtigt werden, sodass die Nutzerzufriedenheit erhalten bleibt. Die vorliegende Untersuchung präsentiert ein innovatives Design, mit dem die Nutzerakzeptanz von Haushaltsanwendungen in einem energieautonomen Haus erhöht werden kann, in welchem ein kompaktes Erneuerbare-Energie-System für die Energieversorgung eingerichtet wurde, sodass der Energiebedarf ohne Netzanbindungen gedeckt werden kann. Es gibt eine geringe Anzahl an Haushaltsanwendungen, die ausschließlich Erneuerbare-Energie-Technologien unterstützen. Design- und Entwicklungsteams haben sich an Haushaltsanwendungen gewöhnt, die nur Elektrizität nutzen, auch wenn es einige Haushaltsanwendungen gibt, die als Alternative andere Energieformen mit besserer Energieeffizienz nutzen können.

Aus diesem Grund müssen die für Haushaltsanwendungen verwendeten Energieformen sorgfältig optimiert werden, indem die tatsächliche Nachfrage und Verfügbarkeit von Energie für Haushaltsanwendungen analysiert wird. Um ein besseres Verständnis dieser Aspekte zu erhalten, enthält diese Untersuchung zwei Fallstudien, die ein innovatives Design und die Nutzerakzeptanz evaluieren: Solarkühlschrank und Solarherd.

Diese Untersuchung präsentiert ein neues Entwicklungskonzept und Kriterien für die Nutzerakzeptanz von Haushaltsanwendungen in einem energieautonomen Haus. Die Ergebnisse der Studie sind in fünf miteinander verbundenen Designkomponenten kategorisiert: 1) Auswertung der Nutzeranforderungen, 2) Energieoptimierung, 3) Produktperformance und -nutzbarkeit, 4) Kompatibilität mit einem Wohngebäude und 5) Nutzerakzeptanz.

ABSTRACT

An energy-autonomous house is an outstanding concept of an independent energy system for sustainable living in the future. To realize the energy-autonomous house concept, energy demand and supply management need to be considered to keep user satisfaction. This research presents an innovative design to increase user acceptance of household appliances in such an energy-autonomous house where a compact renewable energy system has been introduced as energy supply to serve the energy demand without grid connection. There is a low number of household appliances which solely support renewable energy technology. Design and development teams have been accustomed to household appliances using electricity only, even though there are some household appliances that can alternatively use other forms of energy with better energy efficiency.

Therefore, the types of energy input in household appliances need to be carefully optimized by analyzing actual energy requirements and availability for operating household appliances. In order to gain a better understanding of these issues, there are two case studies in this research that illustrate an innovative design and user acceptance evaluation as follows: solar refrigerator and solar cooking stove.

This research presents a new development concept and user acceptance criteria for household appliances in an energy-autonomous house. The results of this study are categorized into five related design components: 1) user needs interpretation, 2) energy optimization, 3) product performance and usability, 4) compatibility with a residential building, and 5) user acceptance.

Keywords

product development, household appliances, energy-autonomous house, user acceptance

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CONTENTS

1 INTRODUCTION

1.1 Overview

The Kyoto protocol to the United Nations Framework Convention on Climate change (UNFCC) contains a long-term commitment of EU member states to reduce energy consumption, keep the global temperature rise below 2°C and decrease overall greenhouse emissions by at least 20% below 1990 levels through establishing national roadmap plans to set targets in order to stimulate refurbishment of buildings into Nearly zero-energy buildings in the year 2020 (EU commission 2010).

Even though the use of renewable energy sources is growing, most designers are still accustomed to developing household products that are operated by electricity. As a result the increasing number of users of new efficient household appliances in the EU-27 resident sector did not reduce electricity consumption in a residential building (Layman Report 1999). An energy efficiency report reveals that electricity consumption of residential use in the EU-27 still went up by 1.7% (Paolo Bertoldi et al. 2012). “Apart from the user’s behavior, there are two complementary ways of reducing the energy consumed by products: the labeling to raise the awareness of consumers and the energy efficiency requirements imposed to products during the design phase. It is estimated that over 80% of all product-related environmental impacts are determined during the design phase of a product. On 21 October 2009, the EU adopted the Directive 2009/125/EC on eco-design. Eco-design aims at reducing the environmental impact of products, including the energy consumption throughout their entire life cycle” (EU commission 2010).

Nevertheless there are some appliances that can deliver the required energy services based on renewable thermal energy, and thus are more energy-efficient. In this regard, the energy services needed by the end user (e.g. warm air, hot water, cold drinks) have to be reconsidered in order to design the appliances that match the specific energy sources. The innovative, yet untapped design approach requires a broad range of system thinking to entail the gain of renewable energy and its supply to household appliances.

1.2 Motivation

The author of this thesis has been involved in the product design field and continues working as a professional household appliance designer in Electrolux (Thailand). I was part of a design and development team of a kitchen appliances project to bridge South East Asian user behavior and European design. Later on, I went back into the academic field as a lecturer in the industrial design department, Faculty of Architecture at King Mongkut’s Institute of Technology Ladkrabang (KMITL), where I closely worked with many architects and found out that there are some missing links between household appliances and housing design in term of energy utilization including layout design and infrastructure setting.

In addition, the researcher in a younger age experienced blackout situations many times in the rural area of Thailand. Most of the household appliances can then not be used because they are dependent on electric energy. This research could be a great chance to help residents to live comfortably without grid connection, particularly in a remote area.

1.2.1 Importance of this study

1.2.1.1 In line with EU 2020 policy level

According to the EU 2020 policy, it is important to reduce energy consumption and increase the use of renewable energy to promote security of energy supply, technological developments and regional development, in particular in remote areas.

1.2.1.2 Reduce environmental impact and global warming

The European Environment Agency (EEA) believes that the rise in electricity consumption causes a serious environmental problem because 80% of electricity generation concern fossil sources such as coal, gas, oil and nuclear sources (Wimmer and Kang 2009). Those mega-projects of electricity production have been questioned widely because of pollution and environmental impact. This research can contribute to solving these problems by reducing fossil as well as increasing renewable energy use to produce energy for the resident sector.

1.2.1.3 Increase energy shortage security

This study explores opportunities to use renewable energy in an energy-autonomous house to decrease the risk of electricity shortages. Varieties of renewable energy resources can increase energy security in the house, which is better than relying on a single energy resource for living in a house. In addition, a diversity of energy forms has more flexibility to cover different forms of energy demand.

1.2.1.4 Increase the living standard of people who live in a remote area

This project can be a role model for promoting an energy self-sufficient living concept for people who live in a remote area. They can have a better standard of living by utilizing new household appliance designs, such as replacing a fire wood stove with a solar cooking stove. There are 2.5 billion people using biomass for cooking worldwide but there are 1.5 million people who were killed by the smoke from open fire and tradition cooking stove using (Bruce et al. 2002).

1.2.1.5 The design knowledge gap

The new household appliances can be a paradigm design for the next generation of household appliances that are compatible with renewable energy technologies. This will motivate product designers, architects and engineers in a design and development team to fulfill actual user needs in an energy-autonomous house as well as to re-consider the design process for energy-efficient design.

1.3 Research questions

According to the background and problems that have previously been mentioned, the research questions are as follows:

- What is the actual energy form that residents need for living in a house?
- How to design and develop household appliances that are compatible with a renewable energy supply system in an energy-autonomous house?
- What are the key factors for user acceptance of household appliances in an energy-autonomous house?
- How to increase user acceptance of household appliances in an energy- autonomous house?

1.4 Aims of this study

This study aims to investigate actual needs and explore user acceptance criteria to develop a new household appliance design concept that can be used in an energy-autonomous house. There are five aims of this study as follows:

1) To understand the supply demand of energy utilization in an energy-autonomous house
2) To reduce electricity consumption in an energy-autonomous house by increasing the use of renewable energy
3) To replace some electric household appliances with innovative household appliance to increase energy efficiency
4) To investigate user acceptance criteria for a novel household appliance design so as to increase appliance value and user satisfaction
5) To increase the standard of living of residents in an energy-autonomous house

1.5 Expected results

A novel household appliance design concept can reduce electricity consumption in an energy-autonomous house and also increase renewable energy utilization, which can slow down environmental impact and global warming problems. Residents in remote areas can have a better standard of living through efficient household appliances. The design of cutting-edge household appliances can be introduced and promoted as a new design trend for the next generation of household appliances.

1.6 Structure of the thesis

The present study is briefly described in a conceptual framework (Figure 1). The study was divided into three main tasks as follows: 1) Understanding the energy-autonomous house concept from literature review and identifying potential household appliances that can be used in an energy-autonomous house concept. 2) Implementing a design and development principle for tangible household appliances and setting up an energy-autonomous house model for testing and monitoring. 3) Evaluating the developed design and comparing it with existing traditional household appliances such as firewood cooking stoves.

This thesis consists of six chapters. After the introductory 1st, the 2nd chapter provides the background of this study and reviews relevant literature. Chapter 3 describes the scientific methods of the work to approach the research objectives and presents two case studies of household appliances. The 4th chapter shows the significant results from literature reviews and experiments. The last two chapters 5 and 6 discuss the results, conclusions and the need for further development.

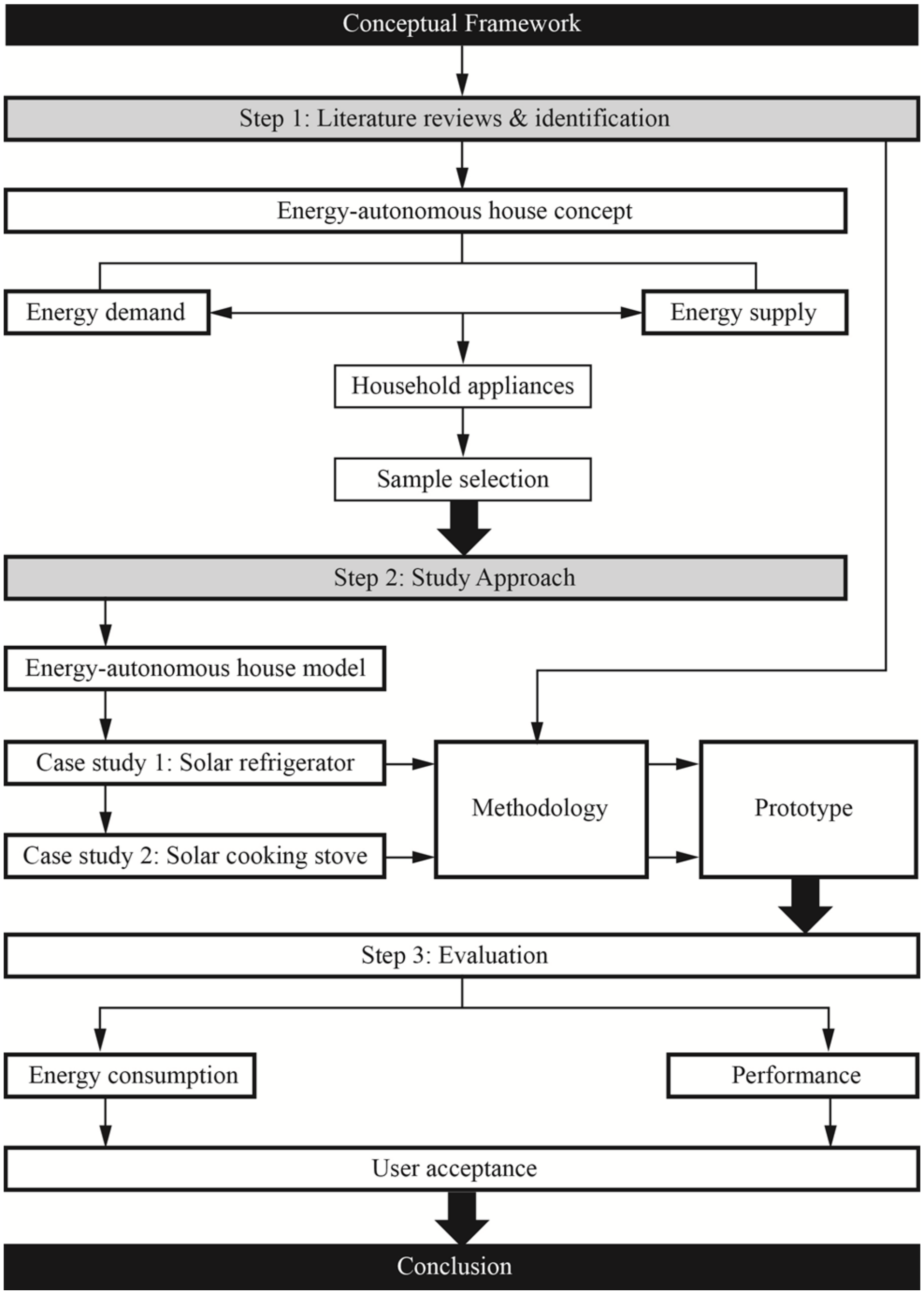


Figure 1: Conceptual framework of this dissertation

2 CONCEPTUAL BACKGROUND

2.1 Overview

This chapter describes the definition of an energy-autonomous house concept and fundamental principles to establish a better understanding of the conditions and the actual demands and user needs in an energy-autonomous house. Demand and supply were reexamined by means of literature review to identify problems and technological contradictions of existing energy systems in order to improve energy efficiency for a typical household.

2.2 Energy-autonomous house concept

The general definition of an energy-autonomous house varies depending on the purpose of particular studies. An energy-autonomous house comprises a multi-mechanism to supply energy independently, without support and service from public facilities.(Vale B and Vale R 1975) “The key characteristic of an energy autonomous house is the use of green technology to reduce environmental impact from global warming while also providing a suitable, high-quality and comfortable living” (Chen et al. 2009). “The use of clean energy and household appliances are necessary conditions for a comfortable life” (Chen 2007). Apart from resident behavior, an energy-autonomous house comprises three main components: 1) passive building, 2) renewable energy supply system, and 3) household appliances.

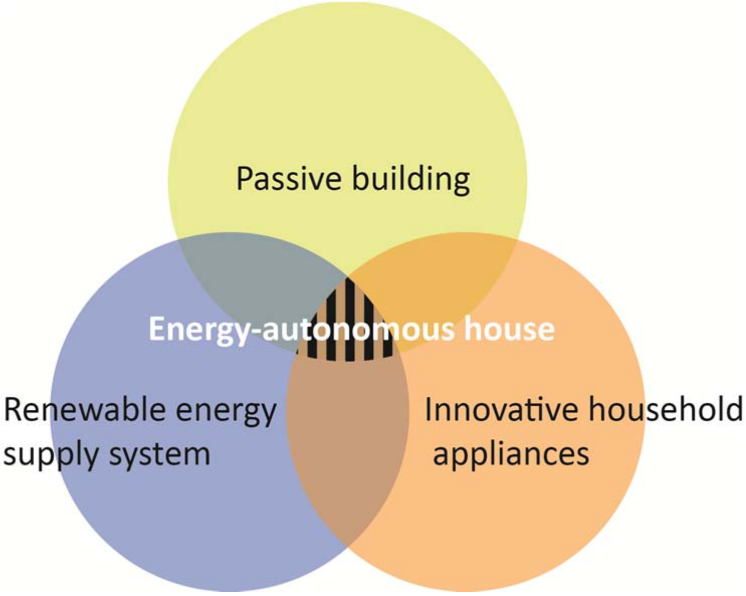


Figure 2: Energy autonomous components

2.2.1 Passive building design

A passive house design uses technical and physical principles to create comfort for the residents. There are usually six factors to control the comfort zone in a building: indoor temperature, humidity, air ventilation speed, acoustics, odor and illuminants. A passive building can reduce space heating in a standard house by almost 90% (Feist 2005).

Passive cooling is the transfer of energy from a space or from the air to a space, in order to achieve a lower temperature than that of the natural surroundings. Passive cooling is related to natural ventilation; this means it keeps the room cool without using mechanical air-conditioning systems. It can be a big factor of a building's total energy consumption. A passive building can save a huge amount of cooling energy.

2.2.2 Energy system in an energy-autonomous house

Energy consumption basically concerns energy demand and supply in a residential building. This study focuses on energy demand for household appliances covered by electricity and thermal energy. On the other hand, supply refers to a compact renewable energy supply system that can produce sufficient energy to fulfill the energy demands.

2.2.2.1 Energy demand

Worldwide economic and population growth will increase in the coming years. Therefore, the world energy consumption will increase continuously and with a growing tendency (Wimmer and Kang 2009). The energy demand in residential buildings can be clustered into two major categories: 1) electricity and 2) thermal energy. These two energy types are mainly required by household appliances in an energy-autonomous house.

Space heating accounts for 20.5%, showing the highest consumption ratio. Large domestic appliances such as stoves, ovens, washing machines, tumble dryers, and dishwashers account for 17.4% of the total electricity consumption, followed by water heating with 17.1%. Fridges and freezers are responsible for about 12% of the electricity consumption. Less than 9% are needed for lighting. The sum of all other office, entertainment and communication devices and other kitchen and domestic appliances (e.g. vacuum cleaners) accounts for less than 25%. "The challenge of energy-efficient sustainable housing consists in the reduction of heating demand by an order of magnitude in sustainable efficient way" (Steinmüller 2008).

Table 1: Breakdown of electricity consumption 2008 by categories(Statistik Austria 2009)

	Share in %
Overall consumption (based on daily meter readings)	**100**
Heating	**20.5**
Heating incl. supporting electricity	15.2
Circulation pump (for the heating system)	5.3
Large domestic appliances	**17.4**
Stove, oven	7.7
Washing machine	4.0
Dishwasher	4.0
Tumble dryer	1.7
Water heating	**17.1**
Fridge and freezers	**12.3**
Refrigerator	7.0
Freezer	5.3
Lighting	**8.6**
Office, entertainment and communication devices	**7.0**
Entertainment electronics (television etc.)	4.2
Office appliances (PC, laptop & Co)	2.2
Communication devices	0.6
Unspecified consumption	**5.2**
Stand-by consumption	**4.2**
Entertainment electronics (television etc.)	2.9
Kitchen and domestic appliances	0.7
Office appliances (PC, laptop & Co)	0.3
Stove, oven	0.3
Other kitchen and domestic appliances	**3.6**
Other relevant appliances	**2.7**
Other relevant appliances	2.3
Recharger	0.4

The bar graph below illustrates the proportion of electricity used to operate household appliances in Austrian houses.

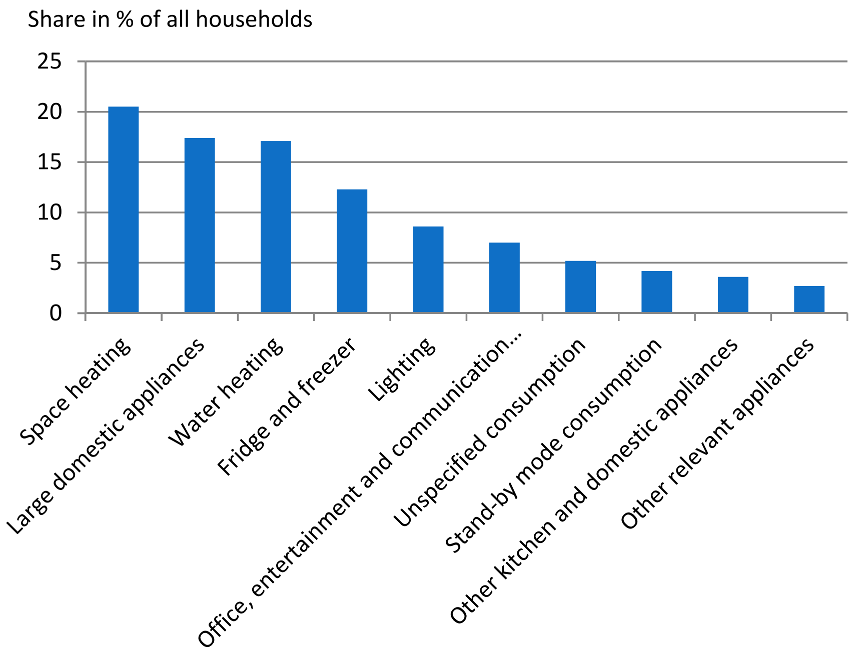


Figure 3: Breakdown of electricity consumption 2008 by categories (Statistik Austria 2009)

Electricity is a popular energy source for most household appliances because it can be converted to cover almost all energy services for domestic purposes such as lighting, electronics, thermal and mechanics. There are some traditionally non-electric appliances that increasingly also use electricity for operation, for example cooking stove, alarm clock and toothbrush. The modern design trend of appliances leads to an increase of (partly unnecessary) electric demand in the house. Figure 3 shows the electric demand of different conventional household appliances that convert electricity to thermal energy.

Table 2: Electricity consumption of household appliances clustered by energy source (MEA 2013)

Electric appliances	**Watt**
1) Fully supported by direct thermal energy	
Water heater	2,500-12,000
Space heater / Air-conditioning	1,200-3,300
Toaster	800-1,000
Iron	750-2,000
Water boiler	670
Rice cooker	450-1,500
Hair dryer	400-1,000
Cooking stove / Oven	200-1,500
Coffee machine	200-600
Refrigerator 7-10 cubic	70-145
2) Partly supported by direct thermal energy	
Dishwasher	2,100
Tumble dryer machine	1,800-5,400
Washing machine	1,200-3,000

Electric appliances	**Watt**
3) Household appliances necessarily requiring electric energy	
Vacuum cleaner	750-2,000
Battery Charger	380
Computer / Laptop	200-800
Microwave	100-1,000
Television	80-180
Lamp / Bulb	60-120
Radio	50-200
CD / DVD player	25-50

The electricity for household appliances in category 1 and 2 can be (partly) replaced by using other energy sources without conversion in thermal household appliances based on energy sources such as solar thermal, biomass, and biogas. In many cases it would increase energy efficiency if the appliances used the energy source directly, with less or without energy conversion, to serve the user needs. The electricity in the house could be reserved for the particular needs of lighting and for devices that necessarily require electricity. The household appliances in category 2 can use partly electricity and partly thermal energy.

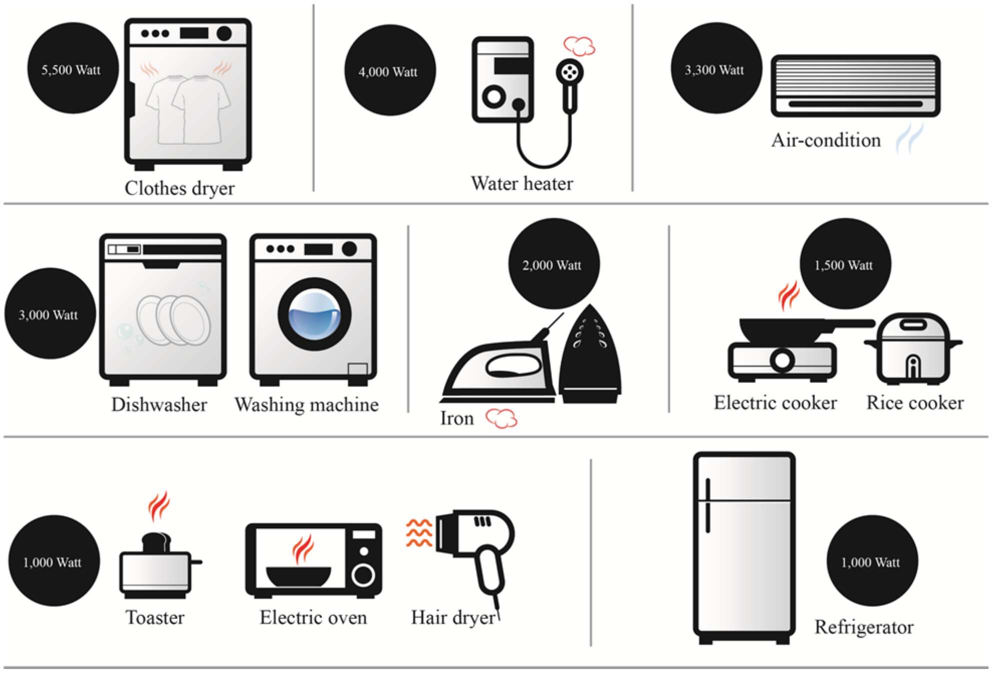


Figure 4: Electric consumption rates of thermal household appliances (MEA 2013)(Noman 2014)

Energy demands for household appliances can be categorized into two main forms which are thermal energy and electricity.

2.2.2.2 Energy supply

Renewable energy on a small scale has high potential for use in an energy-autonomous house concept (Goudarzi 2014). The different kinds of sources of renewable energy can reduce the risk of energy shortages by distributing alternative energy resource loads to avoid having only electricity as main energy resource. Figure 5 shows the alternative options to use as energy input for the energy-autonomous house concept depending on available resources in the house area such as solar energy, wind energy, geothermal and biomass.

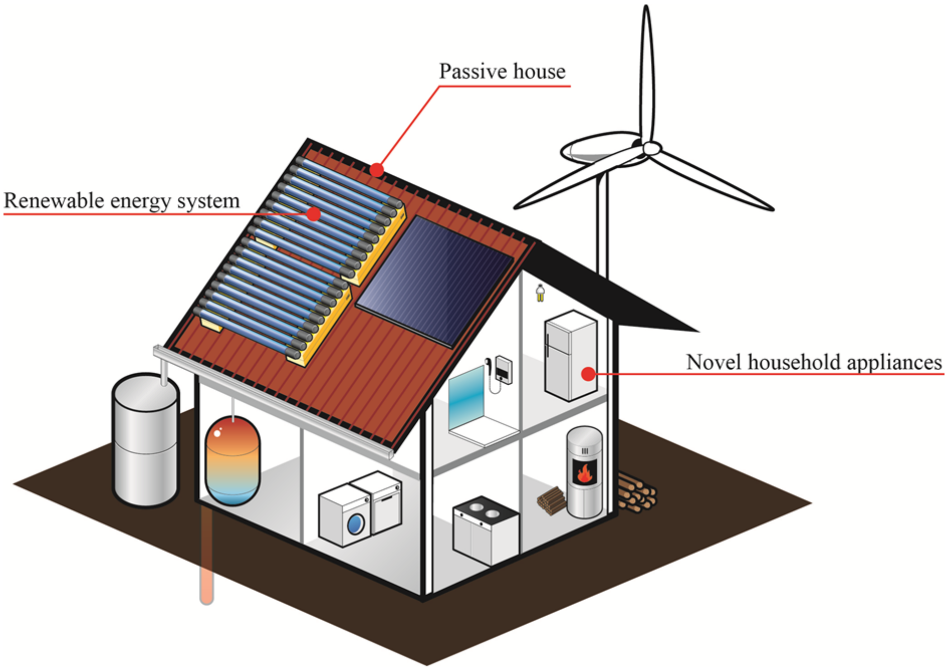


Figure 5: Illustration of an energy-autonomous house concept

2.2.2.2.1 Electricity

Electricity in an energy-autonomous house is usually generated by photovoltaic (PV) to supply appliances such as lighting bulbs, television, radio, etc. An inverter and controller for PV provides a stable power output at 220V and runs 24 hours a day (Goudarzi 2014).

The storage system for electricity in the energy-autonomous house is a back-up system that is used when not enough sun radiation is available, for example on a rainy day. The battery should be kept in a dry and cold place to ensure a long lifetime and efficient working.

2.2.2.2.2 Thermal energy

Thermal energy is the most required energy for comfortable living in a house (GrAT 2014). Most of the thermal energy in a house in a remote area usually is converted from varied energy resources such as electricity, solar, fire wood, biogas and biomass.

2.2.3 Household appliances in an energy-autonomous house

The design of household appliances designs is a key factor in achieving the energy-autonomous house concept. The general electric household appliances can be categorized into two main groups. There are 25% of household appliances in a house that only need purely electricity to operate their system, such as television, lamp and radio, etc. The remaining 75% of household appliances in a house are related to thermal energy to serve user needs, such as water heater, dish washer, washing machine, etc. Surprisingly, most modern household appliances are operated by electricity only (Wimmer and Kang 2009). This is a great opportunity to use direct thermal energy from a renewable energy source to reduce electricity consumption in a house.

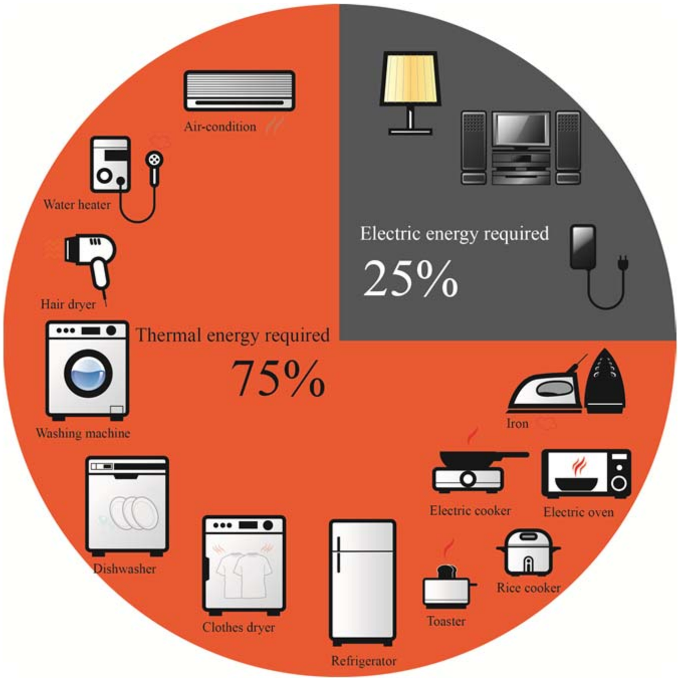


Figure 6: Thermal and electric demand ratio of total energy consumption (Statistik Austria 2009)

The illustration below (Figure 7) shows three groups of household appliance that concern different types of energy input. The left side of the illustration shows some household appliances that need only electricity to operate their system. The middle column displays two groups of household appliances which are categorized by their required temperature range as follows: low temperature range (30°C-90°C) and medium temperature range (90°C-300°C).

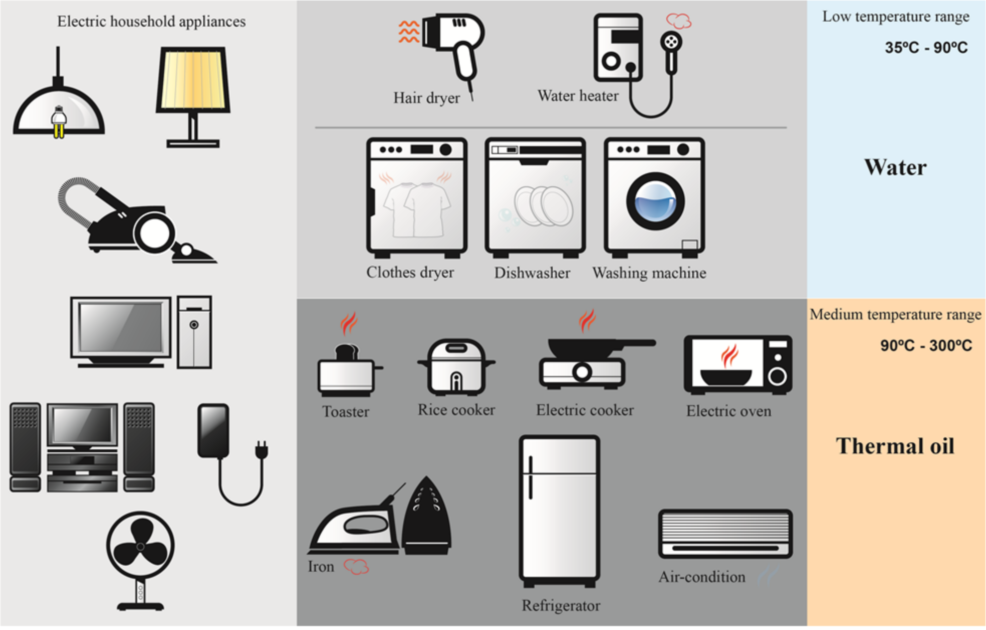


Figure 7: Household appliances' energy sources by energy type and transport media

There are two main keys to reduce the emissions footprint of our building concept: reduce the demand for energy in the building and reduce carbon emissions from the heating and cooling device (UK national plan 2012). The cooling and thermal appliances in a house play an important role in reducing the carbon footprint. The survey in this study shows two popular household appliances that almost every Austrian household has. For those two appliances there is also technology available that is compatible with renewable energy. Therefore, the selected household appliances for this study are a refrigerator and a cooking stove. The following sections describe the basic requirements of those household appliances regarding temperature, which is related to the energy supply and demand.

2.2.3.1 Refrigerator

The basic requirements of a household refrigerator and its different compartments regarding temperature are defined by an ISO standard:

"Cellar compartment: compartment intended for the storage of particular foods or beverages at a temperature warmer than that of the fresh-food storage compartment

Chill compartment: compartment intended specifically for the storage of highly perishable foodstuffs

Fresh-food storage compartment: compartment intended for the storage of unfrozen food, which may itself be divided into sub-compartments

One-star compartment: frozen-food storage compartment in which the temperature is not warmer than − 6 °C

Two-star compartment: frozen-food storage compartment in which the temperature is not warmer than − 12 °C" (ISO Standard 2005)

Table 3: Climate classed in a refrigerator

Compartment	°C
Cellar compartment	+8°C ≤ +14°C
Chill compartment	-2°C ≤ +3°C
Fresh-food storage compartment	0°C ≤ 8°C
One-star compartment/section	≤ -6°C
Two-star compartment/section	≤ -12°C

2.2.3.2 Cooking stove

A cooking stove has different requirements regarding temperature. The cooking time depends on the temperature level and food characteristics. Cooking time can be shortened by adding higher temperature. Temperatures should be between 75°C and 232°C for safe cooking. Those different temperatures can kill germs for safe food consumption. The Table 4 shows general cooking requirements between 75°C and 190°C only to make cooked foods (Canolainfo 2007). The higher range of 177-232°C is used for baking. (Degrave 2010)

Table 4: Minimum temperature requirements for safe cooking

Category	Food	Cooking method	Temperature (°C)
Meat	Beef, pork, lamb, turkey, chicken, duck and seafood	Varying	75[1]
		Deep frying	175-190[3]
		Steaming	100<
Soup	Water, stock	Boiling	100<
Bakery	Bread	Baking	218-232[2]
	Cake	Baking	177-190[2]
	Cookies	Baking	177-205[2]

(Foodsafety 2014)[1], (Degrave 2010)[2], (Canolainfo 2007)[3]

2.2.3.3 Innovative technologies for refrigerator and cooking stove

2.2.3.3.1 Innovative cooling device ("Icebook" technology)

"The Icebook is a modified absorption refrigerator that was developed by Solarfrost. The Icebook is a new type of ammonia water absorption cooling machine, operated by a cooling cycle under temperatures with a number of heat exchanger sheets. It is built with many layers of heat exchangers like a book” (Kunze 2010). The Icebook was constructed following a small and simple production concept. It only needs cheap materials which are generally available everywhere, particularly in developing countries.

Figure 8: Icebook machine

2.2.3.3.2 Innovative solar cooker

Dr Schwarzer has developed a new type of indirect solar cooker for indoor use. The solar cooker has a flat plate collector to produce heat outdoors and transport it to a cooking area inside a building by using thermal oil as a heat transport media. His innovative solar cooker was registered as German patent on 24 July 1993 (Schwarzer 1993). The cooker uses peanut oil as a heat transport media which is non-toxic. The cooking temperature can be controlled by a manual valve control. The device uses a thermosyphon to circulate the peanut oil in the system. It does not require any additional energy or electric pumping to transport the peanut oil in the system.

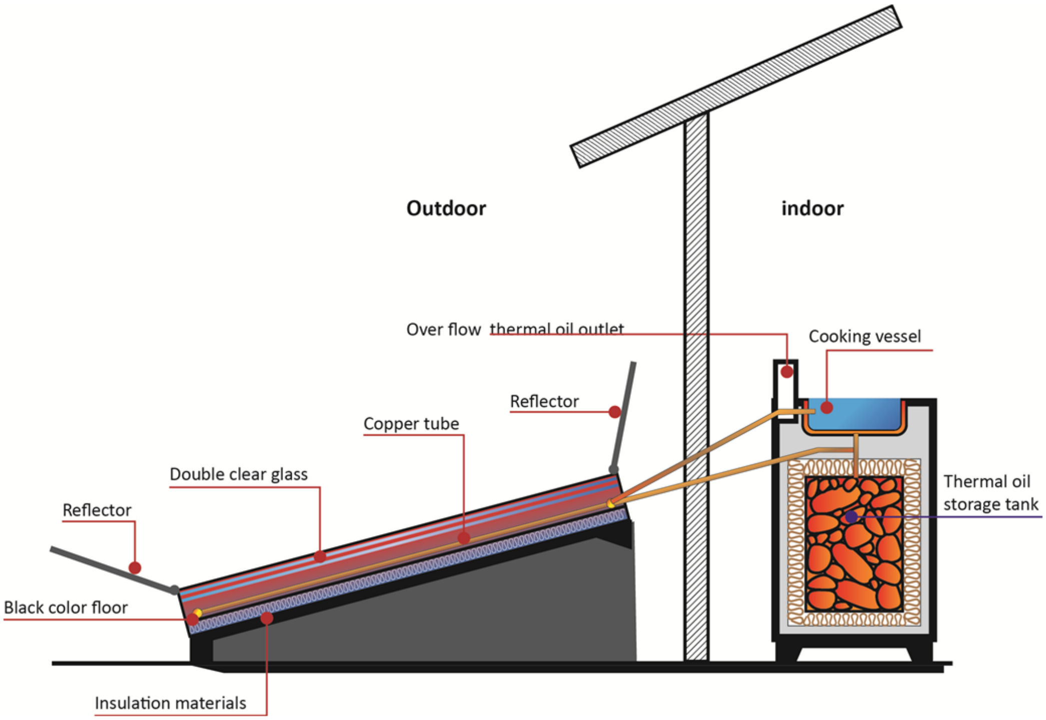


Figure 9: Dr Schwarzer's technical concept for indirect solar cooker station

2.3 Analysis of user needs

2.3.1 Model and prototype of household appliances

A model refers to "a three-dimensional representation of things or of a proposed structure, typically on a smaller scale than the original" (Oxford dictionary 2014). This study monitors the energy production capacity of solar thermal collectors in an energy-autonomous house model by measuring both quantity and quality values. This energy-autonomous house model focuses only on the low temperature range of thermal energy provided to household appliances. The results will be important information on how to manipulate the energy supply for household appliances in the energy-autonomous house.

A prototype is a fully working model for design assessment (Heufler 2004). Karl T. Ulrich and Steven D. Eppinger defined a prototype as "an approximation of the product along one or more dimensions of interest. A prototype has two characters to classify the purpose of expression; look-like prototype and work-like prototype" (Karl T. Ulrich and Steven D. Eppinger 2000). This study made two working prototypes for investigating the working performance of solar refrigerators and cooking stoves. The solar refrigerators were built for low temperature and medium temperature ranges so that they could be tested with different temperature inputs. The low temperature range system (30-90°C) uses water as thermal transport media while the medium temperature (90-300°C) uses synthetic oil to deliver thermal input to the solar fridge and cooking stove. Therefore, the low temperature solar refrigerator can share the hot water with other thermal household appliances such as washing machine, dishwasher and water heater machine. The medium temperature solar system can provide the solar fridge and solar cooking stove.

2.3.2 Kano model (satisfaction assessment)

The Kano model is a tool of user need classification which corresponds to user satisfaction (Kano et al, 1984). The Kano model was created by the Japanese Prof. Dr. Noriaki Kano (Shahin 2004). It shows also the relationship between user satisfaction and appliance quality. If the user demands are met, the user will be satisfied; if not, the user will be dissatisfied. The user will be delighted if household appliances have attractive design attributes. However, when an attractive design is expected as a basic requirement, user satisfaction will be decreased.

Dr. Kano's chart (Figure 10) describes user satisfaction in three levels as follows:

1) "Delights" refer to an attribute that the user finds pleasant if provided by the appliance. This attribute is above the user's expectations, so the user still finds the appliance satisfying if it does not possess this attribute. Over the time though, this kind of delightful innovative element becomes another basic need (Sauerwein 1996), for example if a user can get cold drinking water from a water dispenser at the fridge door without opening the door. This attribute makes the users feel delighted to have it in their fridge. However, user satisfaction will decrease over time.

2) "Satisfied" refers to an appliance attribute that the user needs to find in an appliance. The user gets more satisfaction if more of the attribute is provided by the appliance. For example, a cooking stove can cook faster and easily reaches the maximum heat.

3) "Dissatisfied" refers to appliance attributes that users show no interest in but with which, if missing, they are immediately dissatisfied. Users might not show expectations to have this attribute in their appliances. For example, a user might find it unpleasant that an egg tray is missing even though some countries have a practical egg packaging that can be directly put in a fridge. However, the attribute can be found by user feedback. This appliance attribute can be put in a basic needs category.

The user satisfaction level can change over time from delight to satisfied and dissatisfied with exactly the same attribute. An above-expectations attribute makes the users excited and impressed. However, that attribute becomes an expected basic feature over time and causes dissatisfaction when it is missing in a household. For example, an electrical cooker did originally not have a working status signal. Later on, the working status signal is one of the basic features and users will be unsatisfied if this feature is not there.

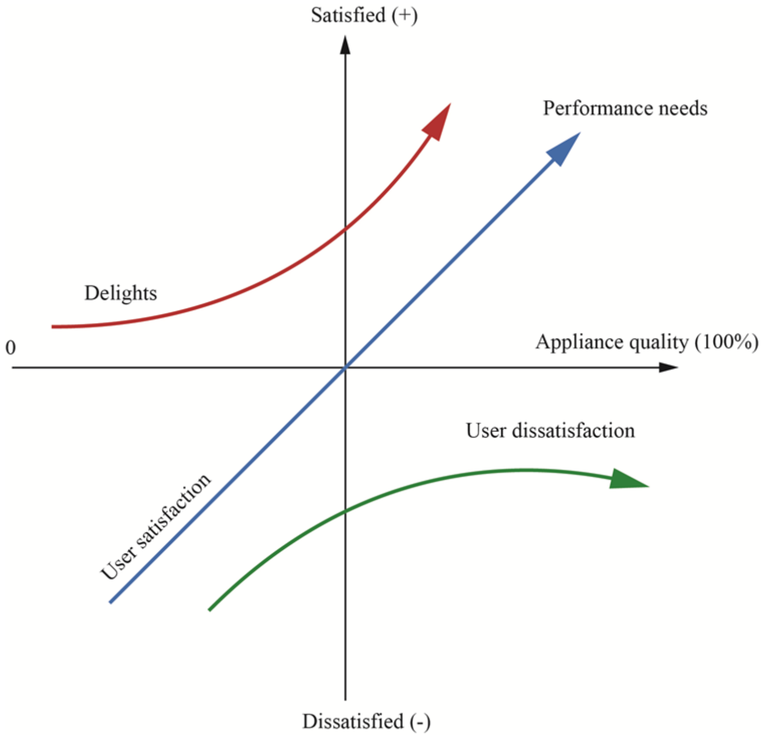


Figure 10: Kano model chart (Berger, 1993)

2.3.3 Quality Function Deployment (QFD)

QFD was developed by Dr. Yoji Akao in Japan in 1972. (E. Kasak et al. 2003) 12 years later, an American engineer adapted it for using it in the Ford motor factory, and established the American Supplier Institute (ASI). ASI defines the function of QFD as a user needs transmission system to serve the aims of companies. (Monthalee 2003) The QFD operationalizes user needs connected to tangible devices in order to increase user satisfaction. The principle of QFD is user needs identification and interpretation, and, on another stage, how to achieve the goals.

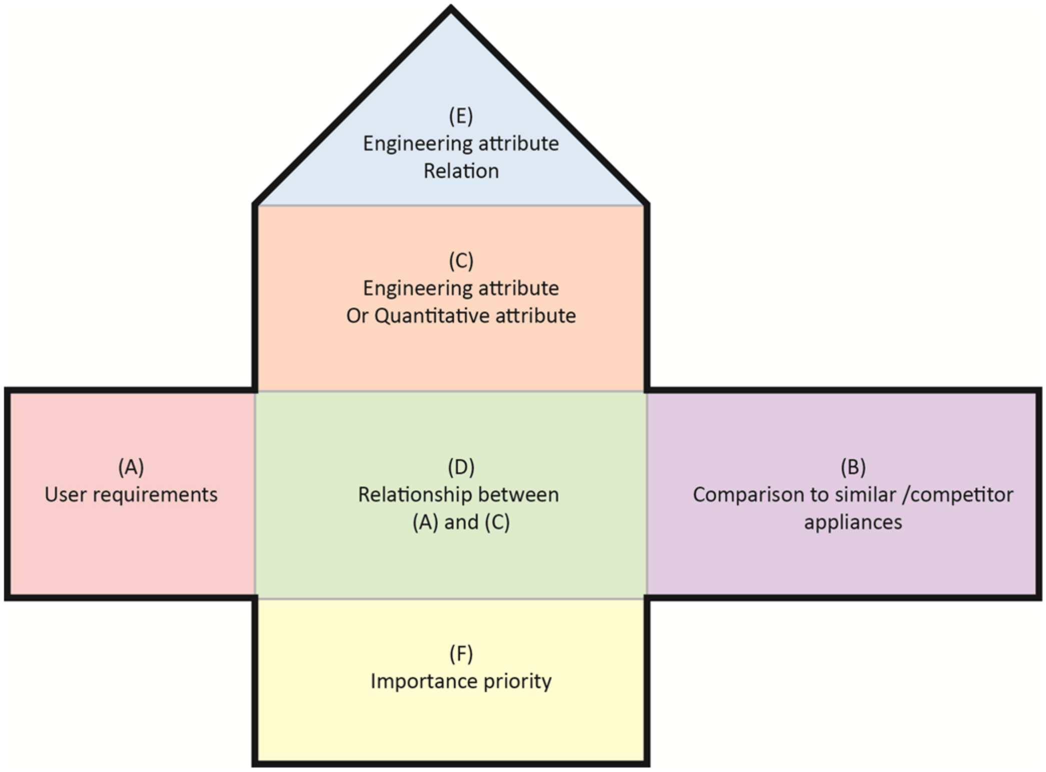


Figure 11: House of quality identification

2.4 Summary

Thermal energy is the most needed form of energy in a typical household. However, there are only a small number of household appliances available on the market that can use thermal energy directly. Low and medium temperature thermal energy can be produced by solar thermal technology to run some household appliances, such as the water heater for showering, dishwasher and washing machine.

3 METHODS

3.1 Overview

This chapter can be divided in three stages; the first is data collection by literature reviewing and user involvement. The second stage is setting up the energy system in an energy-autonomous house model for real-world experiments. The last stage describes the design and development process for household appliances via two case studies. Case study 1 presents a solar refrigerator design. Case study 2 investigates user acceptance for a solar cooking stove. Both case studies have been demonstrated with working prototypes in an energy-autonomous house model.

3.2 Hypothesis

This research investigates whether using innovative household appliances for a renewable energy system in an energy-autonomous house can meet user expectations and increase overall energy efficiency and the share of renewable energy sources.

3.3 Research methods

To identify diverse user demands, six different research methods were applied: 1) questionnaires, 2) observations, 3) in-depth interviews, 4) Kano model, 5) QFD, and 6) model and prototyping.

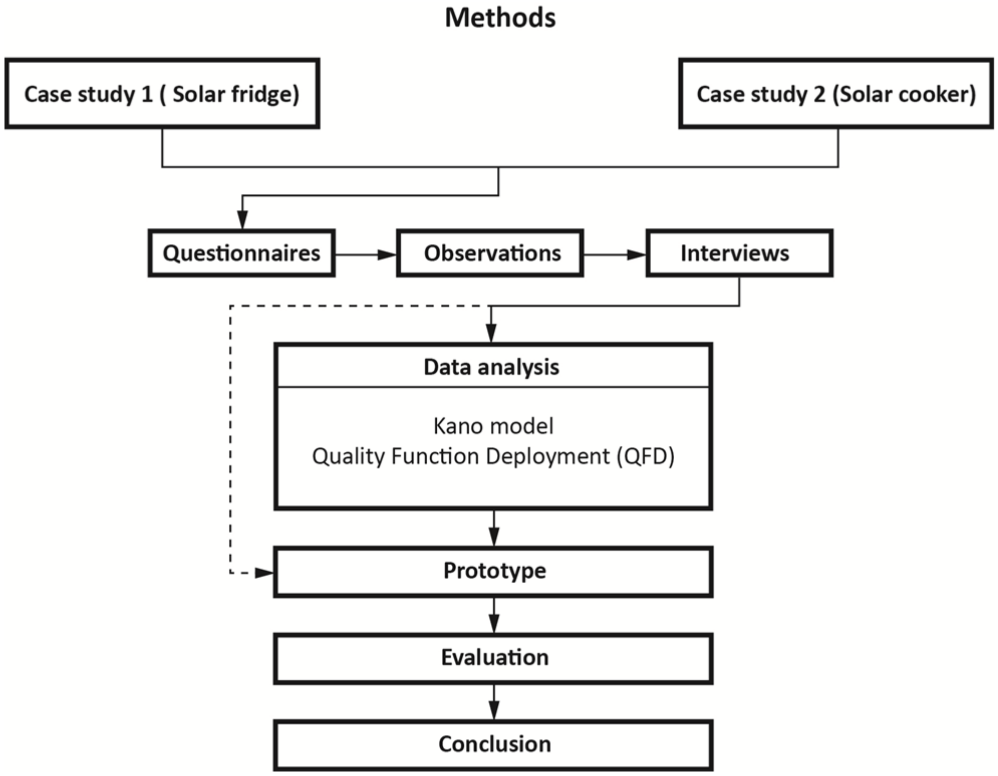


Figure 12: Study methods chart

3.3.1 Questionnaires

Two hundred sets of questionnaires (paper-based) were distributed to refrigerator and cooking stove users who were 18-65 years old. The questionnaire comprised two parts: The first part was designed to find out basic information and keywords concerning the typical usage of refrigerators and cooking stoves. The second part was designed to explore the target group's opinion on these household appliances by their rating to get qualitative data. The questionnaires were designed to be short and clear questions to avoid vague answers. The questionnaires were typed in two languages, English and German, to reach more users. The participants answered each question by selecting one of the following multiple choices to describe their satisfaction: like, expect, neutral, tolerant and dislike. The evaluation pattern is shown as a matrix. (See Table 5)

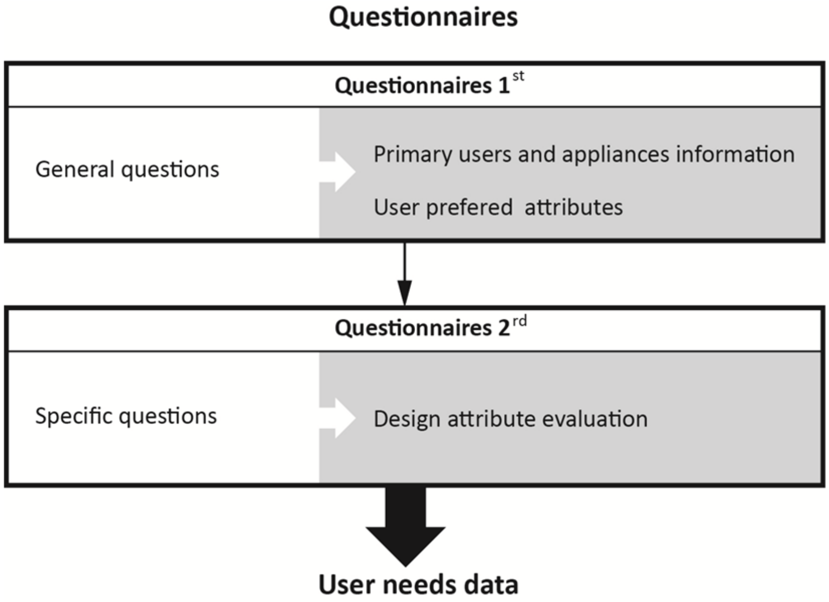


Figure 13: Questionnaires procedure chart

3.3.1.1 Target group

This study focuses on adult users because those users have enough experiences in using the devices. The target groups are international participants but most of them are Austrian users.

3.3.1.2 Distribution details

The questionnaires were distributed in a public space or waiting area. The participants usually spent about 5-10 minutes to complete the answers. The distributors usually provided a pencil, a seat, a table or a writing board for the participants to fill in the questionnaires comfortably.

3.3.2 Observations

Observations were done of participants using their kitchen. The purpose of the observations was to gain a better understanding of how participants interact with the household appliances. Their kitchen should have sufficient space for 2-3 people to do the observation. Six participants agreed to such an observation: three female and three male cooks. The participants were asked to use the set household appliances. The actions of the participants were reviewed in seven stages: 1) goal establishing, 2) planning, 3) action consequence, 4) performance, 5) perception, 6) interpretation, and 7) comparison. (Norman 2013) Some participants' activities were recorded by photographs and video as well as by notes. The observer did not interrupt with questions or any action that could have interfered with the participants' behaviors.

The camera was set on a tripod at 1.5 meters above the ground. It was usually located about 2 meters away from the participants, depending on the conditions at the location. The observations took about 5-20 minutes or until the participants completed their task.

3.3.2.1 Observation procedure

The participants were asked to make an omelette for two people. The task started from cooking preparation and lasted until the omelette was ready to serve.

The researcher visits the participant's kitchen and makes a layout plan for marking a standing point. The standing point should not be too close to the participant but the observer should clearly see all participant activities. This standing point depends on the kitchen layout, space and lighting direction. An example of a kitchen layout of the study is shown in the following figure.

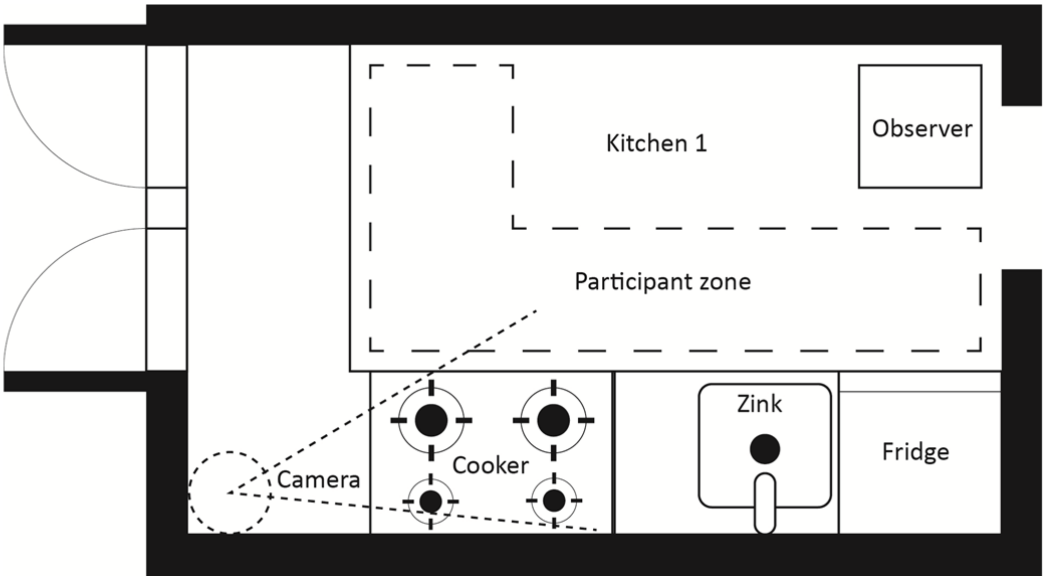


Figure 14: Example of a kitchen layout (site 1)

An observer should not interfere with a participant by asking, talking, moving or making the participant feel uncomfortable. If the observer needs to move his or her position to see the participant's activity from a different angle or point of view, he or she should move slowly and quietly. The observer can talk to the participants before an activity starts to make the participants feel comfortable and relaxed.

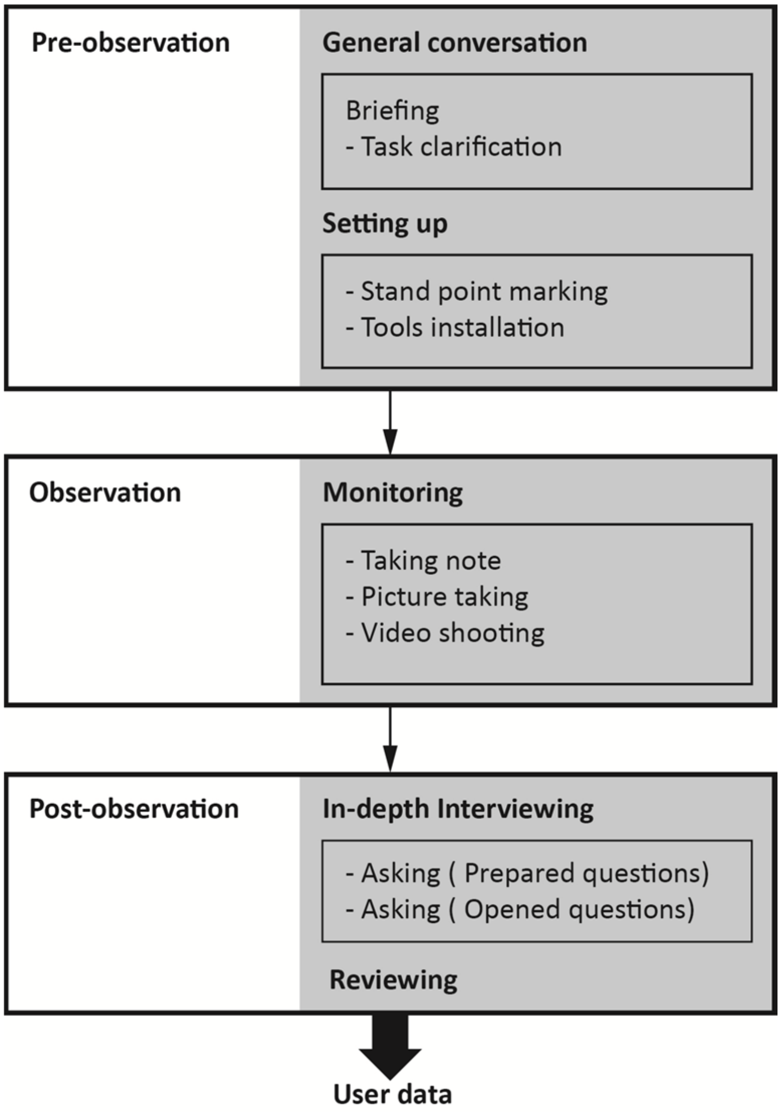


Figure 15: Observation and interview procedure chart

3.3.2.2 In-depth interviews

Interviewing is the most efficient method to gain user data (Monthalee 2003). The interviewees were the same participants who were observed. They were interviewed immediately one by one after they had used the household appliances. Prepared questions might not cover all actions so the interviewer might have some additional questions that relate to unexpected behavior during the observation. Short, direct questions may gain more information, however the interviewer should provide for a relaxed interview. The answers were collected by note taking, voice recording and video recording.

3.3.2.3 Sequence-use method

This method strongly relates to the observation stage. The interviewer asks specific questions concerning a user's action as well as the surrounding context conditions. The questions aim to get deeper insights and clarify some interesting keywords from the user. The six expert users were asked questions regarding steps from the beginning of a task to the end. This method needs experienced interviewers to get informative answers.

3.3.2.4 Like / dislike method

Like or dislike is a simple answer to a question, but it is the most helpful information input to formulate design attributes of household appliances. Then the participants were asked with more specific questions why they did like it or why they did not. The researcher used a paper form to take notes and collected data in three columns: 1) questions, 2) user voices, and 3) interpretation. (Appendix A; Interview Questions)

3.3.3 Kano implementation

There are two stages to get data input for Kano's model. The first stage explores the preferred attribute of a household appliance. Then, those attributes will be evaluated by users in the second survey. The second survey discovers user satisfaction levels of those household attributes. (Those users from the first and the second survey can be different people.) The user satisfaction levels are provided as 1) like, 2) expect, 3) neutral, 4) tolerant, 5) dislike. There are two different ways to ask users: 1) positive form question and 2) negative form question.

Table 5: Kano model sample questions to get data input

Questions	Answers
Functional from of question Sample question: If the cooker has sound signal, how do you feel?	☐ Like ☐ Expect ☐ Neutral ☐ Tolerant ☐ Dislike
Dysfunctional from of question Sample question: If the cooker does not have a sound signal, how do you feel?	☐ Like ☐ Expect ☐ Neutral ☐ Tolerant ☐ Dislike

3.3.3.1 Attribute classification

Required attributes were classified into five groups based on the Kano model to define need levels for the use of a household appliance using the table 6. The required attributes can be classified in five groups as following: 1) must-be quality, 2) one-dimension quality, 3) attractive quality, 4) indifferent quality, and 5) reverse quality. For example, for the function (positive) question: if your cooker can be used anytime, how do you feel?, the answer could be "Expect". The result in the second row can then vary depending on the answer from the dysfunctional (negative) question. Suppose the user answers "Dislike" to the following question: if your cooker cannot be used at nighttime, how do you feel? Then the result of this feature will be "M". It means a cooker must be able to work both daytime and nighttime. However, an extremely contradictory answer from the user needs to be questioned. For instance, a user answers "Like" to the positive question: if the cooker burner is of big size, how do you feel?, but then also answers "Like" to the negative question with the same attribution that asks: if the cooker burner is of small size, how do you feel? The result will be "Q" (questionable). It means this answer is not reliable.

Table 6: Household qualities classification matrix according to the Kano model (Bilsen Bilgili, Aysel Ercis, Sevtap Ünalb 2011)

Customer requirements		Dysfunctional (negative) questions				
		1 Like	2 Expect	3 Neutral	4 Tolerant	5 Dislike
Functional (positive) questions	1 Like	Q	A	A	A	O
	2 Expect	R	I	I	I	M
	3 Neutral	R	I	I	I	M
	4 Tolerant	R	I	I	I	M
	5 Dislike	R	R	R	R	Q

M = must be, O = one-dimension, A = attractive, I = indifferent, R = reverse, Q = question

3.3.3.2 User needs interpretation and classification

3.3.3.2.1 Must-be quality (M)

The first group refers to basic attributes that, when missing in a design, users will absolutely be dissatisfied with. The users immediately refuse if that attribute is not there. For example, the temperature performance is one of high importance for using a cooking stove. User do not accept the cooker if the maximum heat is high enough for cooking. However, when temperature can reach a sufficient level for cooking, it does not increase user satisfaction. The user considers it as a basic need regarding a cooking stove.

3.3.3.2.2 Attractive quality (A)

The second group consists of quality attributes that influence user acceptance of a new design. An attractive quality attribute can add user satisfaction to a device but it does not cause dissatisfaction when the device does not have this attractive quality. For example, aesthetic appearance can add more value to a refrigerator design but it does not impact user satisfaction as long as the fridge is still properly working.

3.3.3.2.3 Indifferent quality (I)

An indifferent quality attribute refers to a quality attribute that can be either positive or negative for user satisfaction. For example, a cooking stove on-off switch is a critical issue in identifying a design direction. Even though a switch that's easy to turn on and off can help a user to control the cooking stove, it can be harmful for children when unintentionally switching on the cooking stove.

3.3.3.2.4 One-dimension quality (O)

The one-dimension quality refers to a design attribute of household appliance that makes users satisfied, or dissatisfied when it is not fulfilled. User satisfaction increases proportionally with a better performance. As an example, a cooking stove that can quickly reach the expected cooking temperature will satisfy a user more than a slower cooking stove design.

3.3.3.2.5 Reverse quality (R)

The reverse quality attribute group is similar to the indifferent quality group insofar as it might satisfy one user group while it also dissatisfies another user group. For example, a high-technology refrigerator provides precise temperature for foods but users need to spend a lot of time for setting it right. Another group prefers a simple temperature control system.

3.3.4 QFD implementation

This case study uses QFD to classify and prioritize user needs for a cooking stove to cover the basic needs according to user demands. The solar cooking stove needs to be specifically designed for energy-autonomous conditions so as to use solar thermal energy without electricity and LPG gas consumption. A design and development team can apply the QFD process to find the boundaries of user demands and the capacity of an energy-autonomous supply system in the house. User data input for QFD can be shared with the second questionnaires results. The data input was interpreted from the positive function form questions as table 7 shows.

Table 7: User satisfaction value for QFD matrix

User evaluation	Value
Like	5
Expect	4
Neutral	3
Tolerant	2
Dislike	1

Data input usually comes from both the first and the second questionnaires. The user requirements come from the first questionnaires and the important values come from the second questionnaire results.

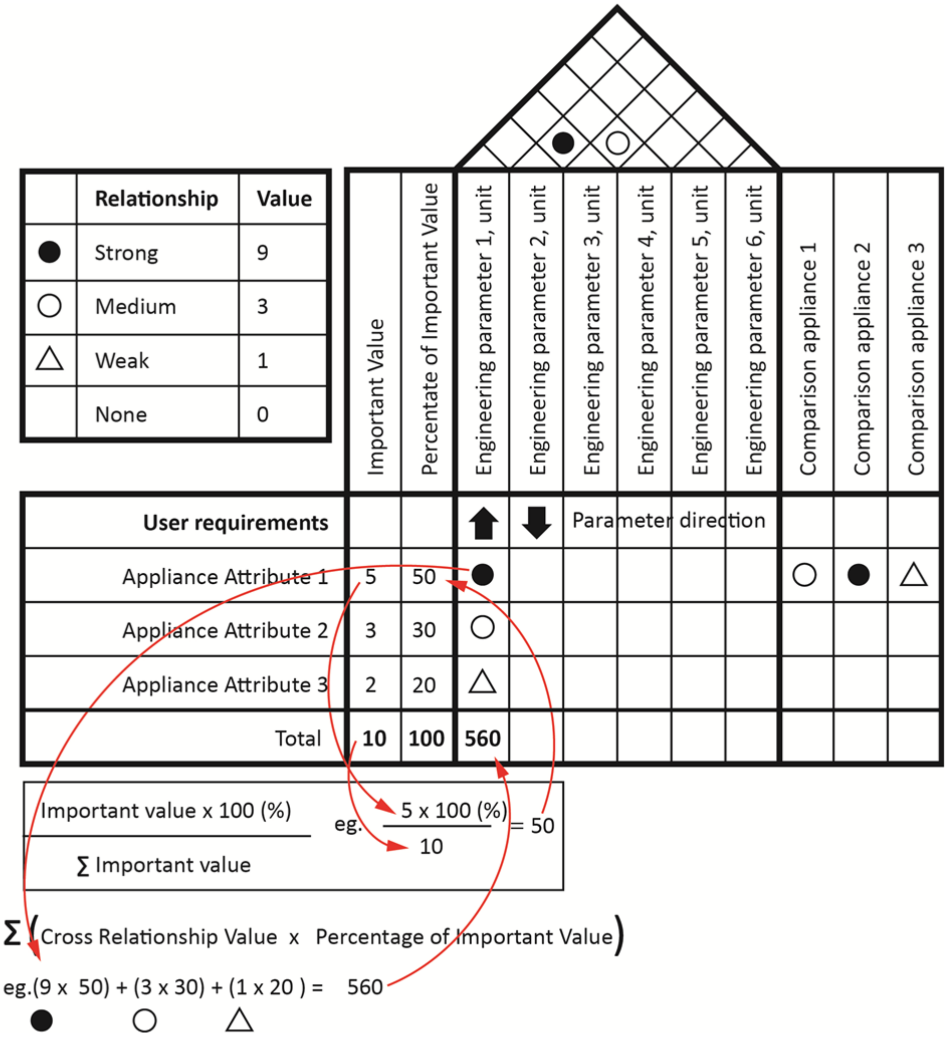


Figure 16: House of quality implementation

3.3.5 Energy-autonomous house model setup

The energy infrastructure of an old compact single-storey building was reconstructed by adding a solar collector on the roof, extra water piping and hot water storage tanks to provide direct thermal energy instead of electric conversion to some household appliances. Layers of natural materials such as reed and clay plaster were applied on the wall for insulation purposes. Copper tubes were inserted through the middle of the wall to increase the wall temperature in winter time by using hot water flow. The purpose of hot water in the energy-autonomous house is not restricted to general use in the kitchen and bathroom, but it also serves as energy input to novel household appliances. The water piping grid can be considered in another part of the house where it can be connected to the innovative appliances.

Figure 17: Hot water piping system in the energy-autonomous house model

3.3.5.1 Thermal energy supply in an energy-autonomous house

The thermal energy system in an energy-autonomous house can be separated into two temperature ranges: low temperature and medium temperature, which can be produced by a small-scale renewable energy system.

There are two different hot water circulation systems in an energy-autonomous house model. (Figure 18) The thermal storage tank in the energy-autonomous house model has the capacity to store 1500 liters of hot water, which is sufficient for 2-4 days of usage. The tank is completely covered by insulation foam (Goudarzi 2014).

3.3.5.1.1 Closed circulation systems

The hot water flows through appliances to supply heat and back to re-heat in a loop from the solar collector. This system can be used with household appliances such as a floor heating system or trump dryer.

3.3.5.1.2 Open circulation systems

Hot water in open circulation systems is involved in household appliances such as water heater, washing machine, dishwasher, etc. Dirt water will drain out from the system as waste water. New fresh water will flow into the system to replace the waste water.

The model house uses water as heat fluid because it is the most simple transport media, easy to find and of sufficient properties to hold the heat under 100 °C. The hot water loop has two temperature ranges, so it can distribute to different kinds of household appliances. On the one hand, a low temperature loop can provide hot water of 20-90 °C for general uses and household appliances such as shower, washing machine and dishwasher. On the other hand, the medium temperature thermal oil at 90-300° Celsius can be used for the refrigerator, drying machine and hairdryer. A biomass stove is expected to be a backup thermal energy system, so that hot water is continuously available in the energy system, should the solar energy be insufficient due to rainy or cloudy conditions. This is necessary for any appliance that is working 24 hours a day, such as refrigerator and heater. Fire wood is the resource to be expected to fuel the biomass stove in the energy-autonomous house. It has been a common fuel resource in Austrian houses for many generations.

The hot water piping grid has to be well designed to provide hot water with minimal heat loss. The design needs to consider engineering elements to meet habitant needs for an appropriate hot water piping layout design, heat loss minimization being critical. A compact piping layout design can even the temperature gap between the initial temperature at the solar collector and the end temperature for the household appliances. Piping length influences the temperature gap because the heat loss depends on the total surface of piping. Therefore, a piping design that features minimum length of the pipes is desirable to reduce heat loss (Wimmer and Kang 2009).

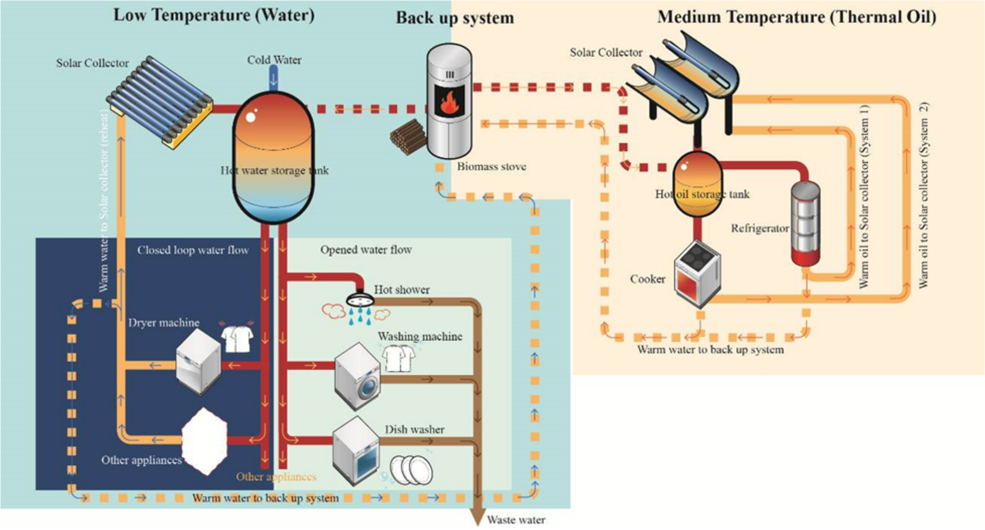


Figure 18: Layout of the thermal supply in the energy-autonomous house model

3.3.5.2 Solar collector system

Thermal solar collectors for conversion of solar energy into heat can be divided into three ranges: low, medium and high temperature. Sydney-vacuum collectors conduct low temperature water (20–90°C) for specific household appliances. The vacuum-tube collectors with 13 m² are installed on the roof.

Figure 19: Solar collector (vacuum type) on the roof of the energy-autonomous house model

Solar collectors of vacuum type conduct hot water to the energy system in the energy-autonomous house model.

Table 8: Technical data of the solar collectors (vacuum type)

Type	**Sol 50V**
Max. operating pressure [MPa]	0.05
Vacuum tube	Ø 47 mm / 37 mm, L=1500 mm
Collector frame	Aluminum profile 40/40, 30/30
Sealing rings	Silicon

Gross surface [m²]	4.88/5.96
Number of tubes	100
Dimension L*W*H[mm]	3,100 * 2,000* 210
Weight without water [kg]	100/180
Collector efficiency according to DIN EN 12975	0.756
U-value [W/m²k]	2.33

3.3.5.3 Thermal storage system

The energy storage system was prepared according to the energy needs of the energy-autonomous house model. It consists of two hot water storage tanks.

Figure 20: shows the hot water storage and piping system in the energy-autonomous house model

Figure 21: Thermal energy supply in the energy-autonomous house

3.4 Case studies

3.4.1 Overview

This chapter describes two case studies of household appliances in energy autonomous house to explore relevant information from practical uses. It explains the rational reason of case studies selection, design concept and production procedure.

3.4.2 Case study selection

The case studies were selected by establishing criteria for household appliances and reviewing possibilities to make them feasible in an energy-autonomous house. The procedure and criteria for selecting the case studies were the following:

1) The considered household appliance should play an important role for living in a house.
2) The potential household appliance should use thermal energy from a compact renewable energy supply system.
3) The relevant technology should be available on the market.
4) The appliance components should be able to be produced in a developing country.

According to Table 1, high levels of electricity consumption in a house for thermal appliances are shown by refrigerators (12.3%) and cooking stoves (7.7%). Therefore, a refrigerator and a cooking stove were selected as case studies. Both refrigerator and cooking stove are commonly used in almost every house.

3.4.3 Case study 1: solar refrigerator

3.4.3.1 Introduction

A solar refrigerator can use thermal energy from a renewable energy system, which fits the energy-autonomous house concept. This case study mainly considers aspects of energy supply and the design process to serve actual user needs. The solar refrigerator principle can probably be developed further to replace air-conditioning which shows high electric consumption.

The Zero Carbon Cooler (ZCC) project was an innovative refrigerator development, funded by FFG – Austrian Research Promotion organization to implement an absorption refrigerator for domestic purposes (GrAT 2014). The Center for Appropriate Technology (GrAT) is the project leader with marketing support by Eudora. This project aimed to implement absorption refrigerators in energy-autonomous houses to minimize electric consumption by switching the energy input from electricity to renewable thermal energy, such as solar thermal and biomass. The study explores the user needs by using basic methods such as literature review, questionnaires, interviews and user behavior observation to gain user insights. The primary information was transformed from qualitative to quantitative data by using Quality Function Deployment (QFD). The gathered information was interpreted to design a concept of the domestic appliances. The concepts were developed in order to design a feasible prototype so as to evaluate the design by testing its performance in an energy-autonomous house.

3.4.3.2 Design and development process

There are four work packages concerning the design development process to achieve the goal for these two study cases:

1) Work package 1, basic analysis and requirements

A study was conducted to understand the current situation and user needs concerning refrigerators and cooking stoves in an energy-autonomous house.

2) Work package 2, optimization of the energy supply system in an energy-autonomous house for the refrigerator

A renewable energy technology was optimized and installed into an energy-autonomous house model to provide an energy input to the device.

3) Work package 3, optimization of the key refrigerant technologies

A relevant technology was adapted to be used with potential renewable energy in the energy-autonomous house.

4) Work package 4, design integration and testing of functional models

The prototype was integrated into the energy supply system in the energy-autonomous house model to test the cooling performance.

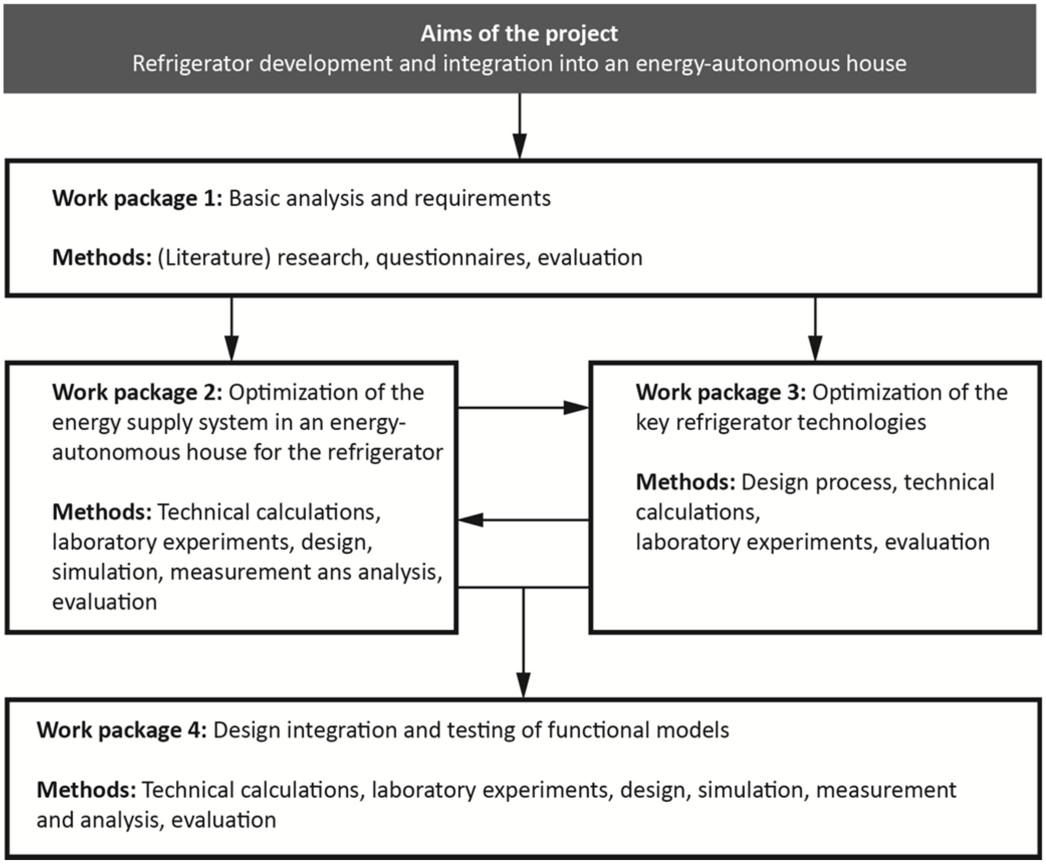


Figure 22: Project work flow for the refrigerator

The following diagram shows an exploration process to find appropriate resources to serve user needs in an energy-autonomous house. There are 3 stages to identify: 1) What kind of resources do users need for a satisfied living in an energy-autonomous house? The designer should further investigate whether these resources are available in the surrounding area or in the house. 2) Where can those resources be found: in the context, in a system, outside the system or otherwise? 3) The evaluation process: the design team needs to consider the quantity, quality and costs of the resources.

The result from this process helps the design and development team to explore appropriate resources and a new opportunity to serve resident needs in an energy-autonomous house.

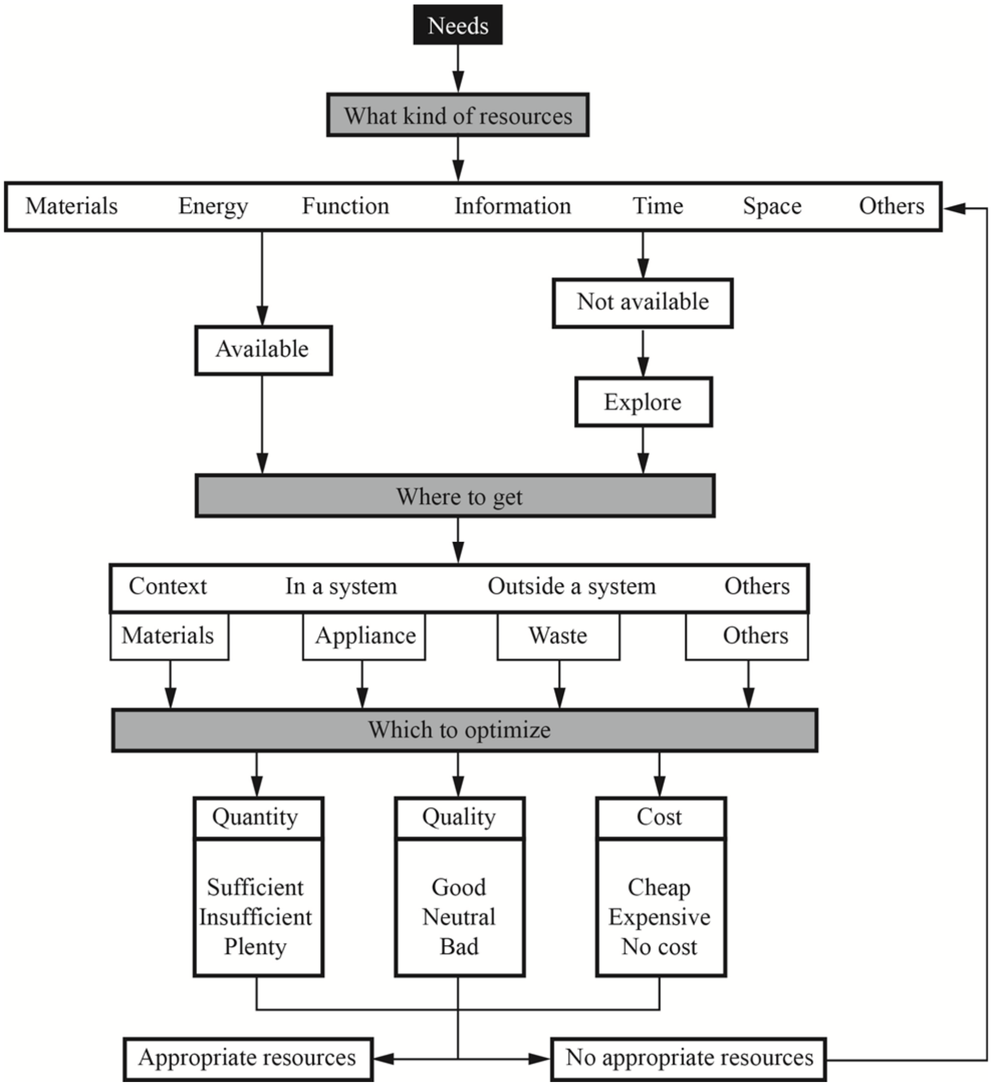


Figure 23: Adapted resources exploration diagram

3.4.3.3 Conceptual design

This study shows three different design concepts of refrigerator components such as shape of storage chamber, door type and air circulation to explore the most energy efficient potential and user acceptance.

3.4.3.3.1 Design concept A (compressor technology with new storage chamber design)

The main characteristic of this freestanding refrigerator are independent cooling control units. This refrigerator offers a flexible capacity for special events or particular requirements. Users can set an individual temperature for each unit according to their requirements.

The appearance of this design is similar to existing refrigerators on the market to keep a user-friendly image. The exterior skin is simply made from paint-coated folded metal sheets.

The chambers are designed with a curved surface and can be stacked with a small gap between them to allow air flow around a unit. The integrated handles offer comfort and firm interaction with the fridge. The fridge can be set to open either from the left or the right-hand side.

The shelf in the fridge is made from plastic grate plates to allow air flow within the fridge as well as water flow to the bottom. The chamber has a drainage hole at the bottom to keep the chamber interior dry and in hygienic condition. The evaporator is installed in the upper part.

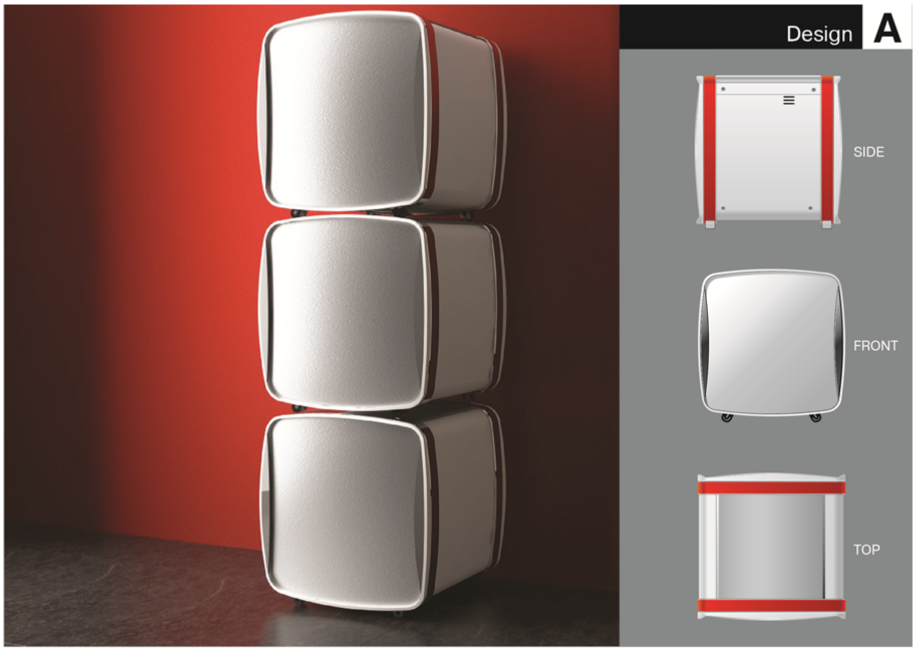


Figure 24: Design concept A

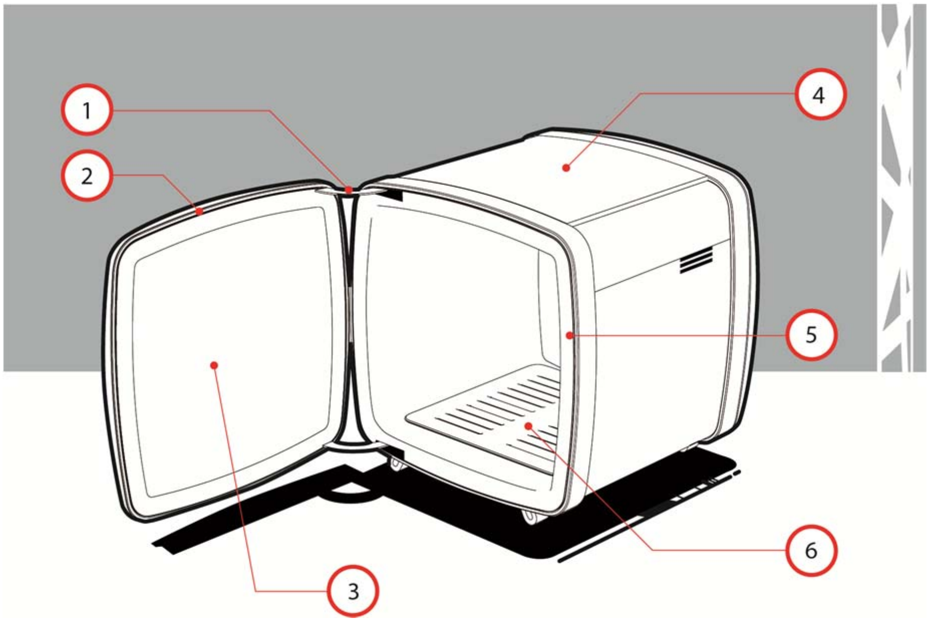


Figure 25: Specifications of design concept A
1) Door hinge, 2) Door seal, 3) Door panel, 4) Evaporator, 5) Inner wall, 6) Shelf

3.4.3.3.2 Design concept B (absorption technology with a new storage chamber design)

A drawer refrigerator was designed to be more convenient and to provide more practical access to the chamber interior. The possibility to draw the whole chamber out from the front makes it easy for the users to fill and empty the chamber. The exterior appearance presents a clean design by using handles which are integrated into the door. The top unit has an extra lid on the top. This upper lid allows users to access the interior from the top, which makes it easy to reach things in the back zone.

The interior of the chamber was designed to avoid sharp comers for ease of cleaning. The evaporator is located in the side wall to provide cooling air in the chamber. There is a drainage hole at the bottom to release water out of the chamber. This will keep the chamber dry and moisture low. The drawer type does not require an interior light inside the chamber.

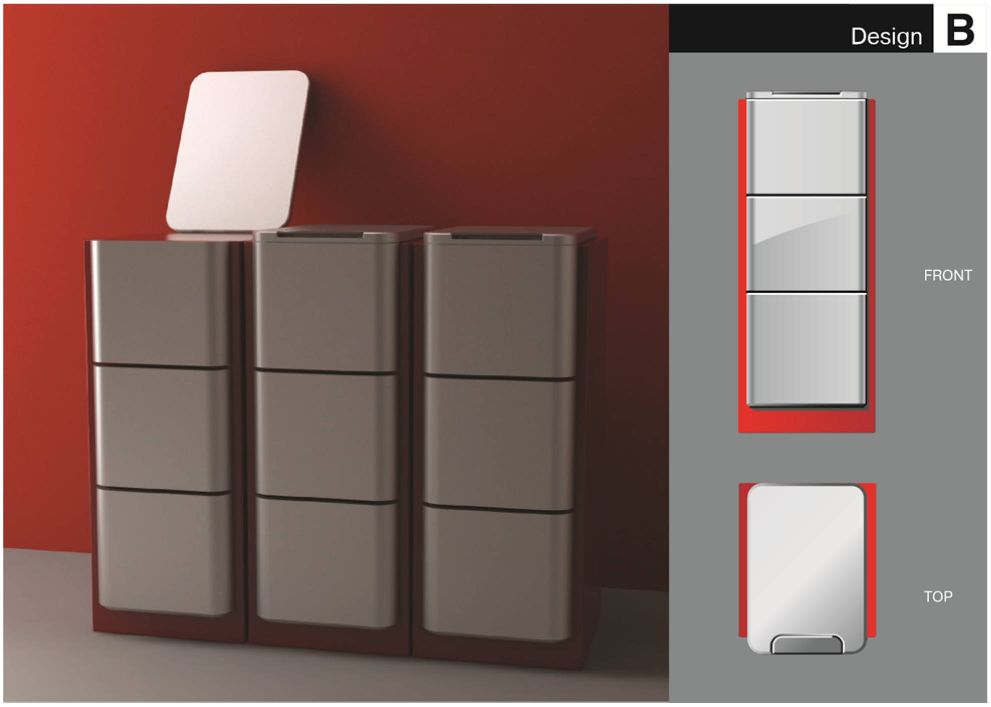


Figure 26: Exterior design concept B and elevation view

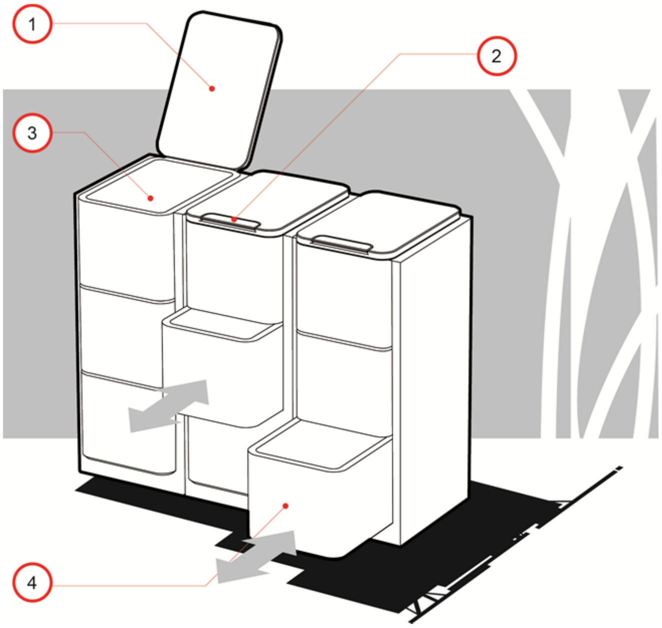


Figure 27: Part identification of design concept B
1) Upper lid, 2) Handle on the top lid, 3) Storage chamber, 4) Drawer for lower storage chamber

3.4.3.3.3 *Design concept C (innovation technology with new storage chamber design)*

The cylinder refrigerator is a unique shape that makes this design stand out from the existing general refrigerators on the market. The design can be an icon for energy-efficient refrigerators. The shape was designed following the “inside-out” principle. The exterior shape results from a round rotatable tray. The interior wall is parallel to the edge of the tray, with a gap in between to provide clearance space. The slide door requires very little clearance space when opened. It is a compact unit where cooling can be controlled independently. The refrigerator offers flexible capacity by adding or removing a unit depending on user demands.

The interior wall has a round surface that has fewer corners than a cubic shape. This helps users to clean and keep the fridge in hygienic condition. Water from melted ice can flow through a gap between the edge of the rotatable tray and the interior wall to the drainage hole at the bottom of the chamber. This can reduce the working load of the cooling system because moisture is kept to a minimum. The evaporator part is located on the upper part of the chamber to provide cooling air from the top down to the bottom.

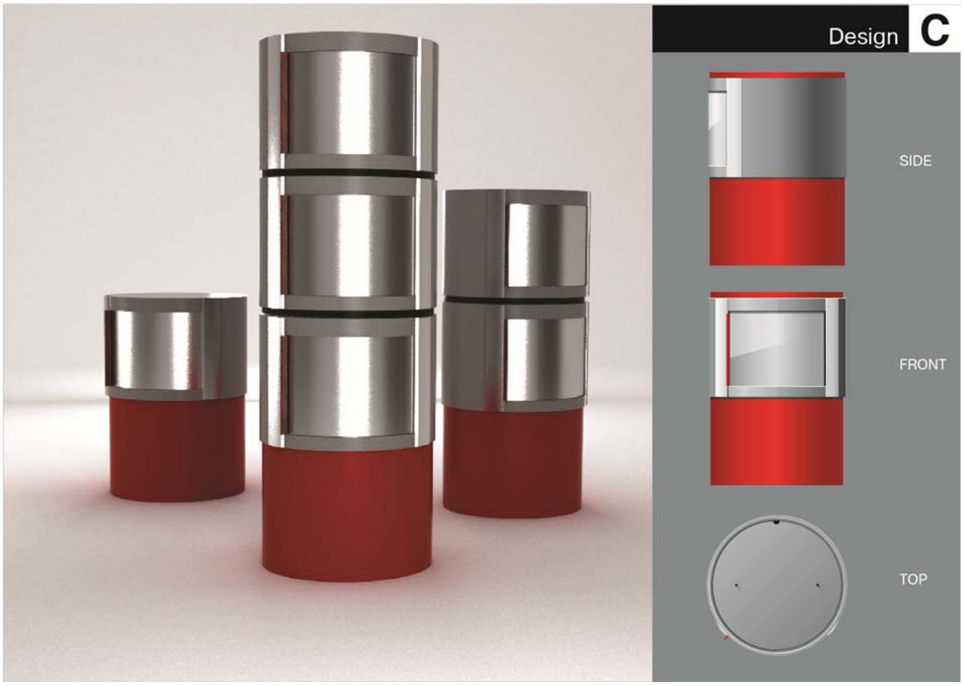


Figure 28: Exterior design concept C

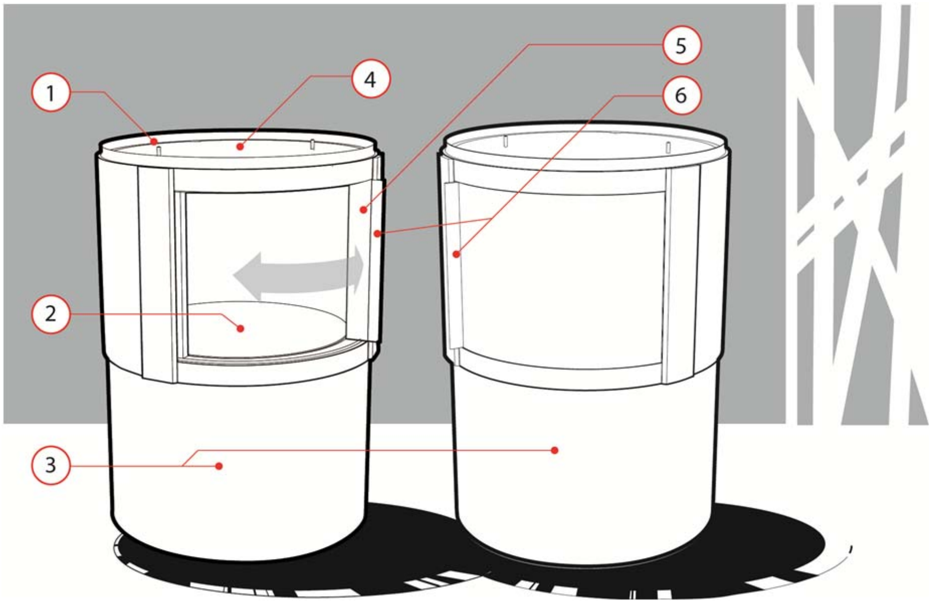


Figure 29: design concept C specification
1) Refrigerant inlet tube, 2) Rotatable tray, 3) Stand, 4) Evaporator part, 5) Door seal, 6) Handle

A double-wall glass door could provide additional benefits. The user can look through the clear glass door to see things inside the fridge before opening it. This can reduce opening time and cooling losses. The user can plan ahead to place things or take them out while the door is still closed. Nevertheless, huge temperature differences between inside and outside of the fridge can make for hazy vision. Double glass with vacuum in the middle can avoid unclear vision due to hazy glass. However, this kind of glass has high production costs. A double-wall curved glass with vacuum in the middle gap needs advanced technology and specific know-how for production.

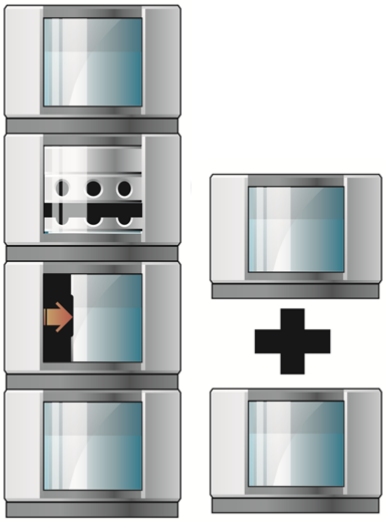


Figure 30: The initial design concept C

3.4.3.4 Refinement and design development

This follow picture shows the details of the refrigerator prototype to clarify before the production process. The details of the cylinder shape were clarified by creating models scale 1:5 mm with different materials such as plastic ABS and polystyrene foam. These models were built for checking the mechanics of the rotatable tray and the door panel. The designer also considered the locking system for stacking chamber units as well as the wall thickness. Then a full-scale 1:1 model was constructed from cardboard to compare the actual size with human scale. This full-scale model really helped the design team to make a decision on the actual size and to improve some parts of the chamber based on direct object interaction.

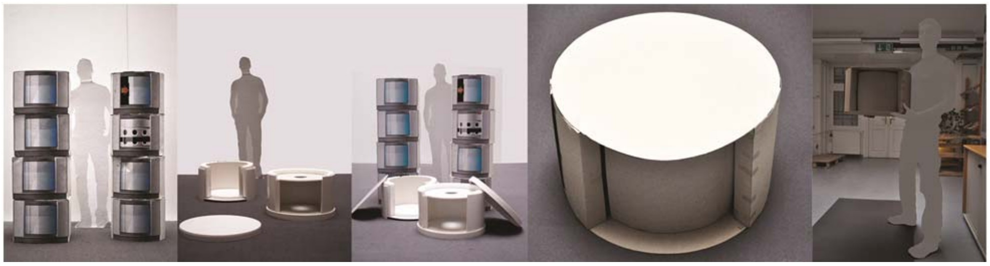


Figure 31: Scale models from paper and plastic (1:5 and 1:1)

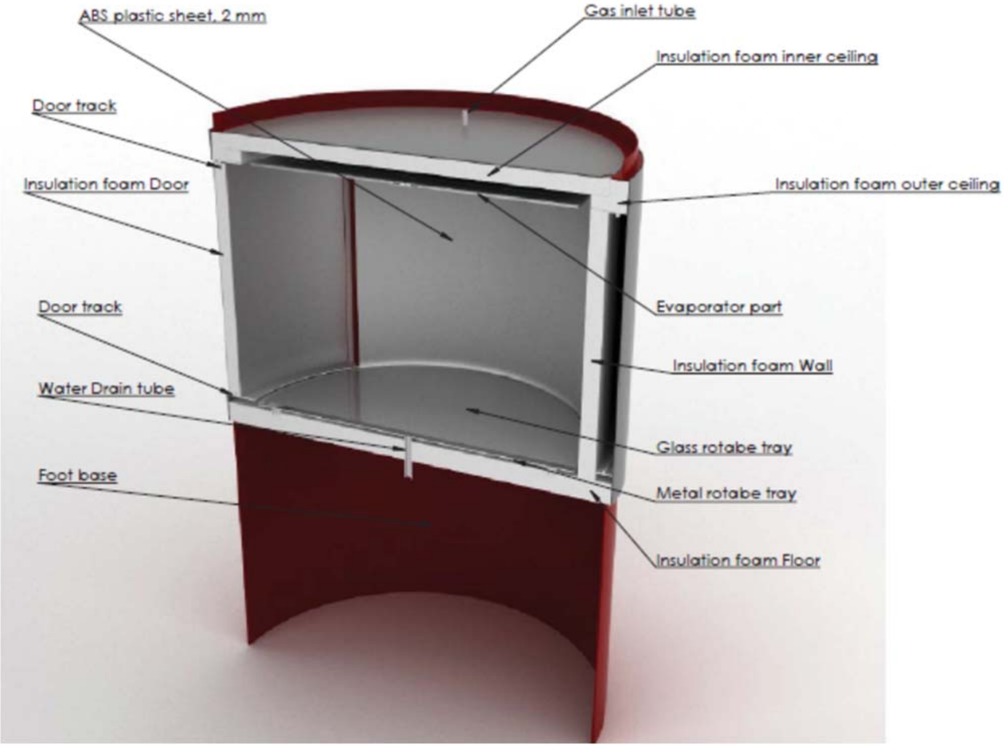


Figure 32: Section picture of refrigerator prototype

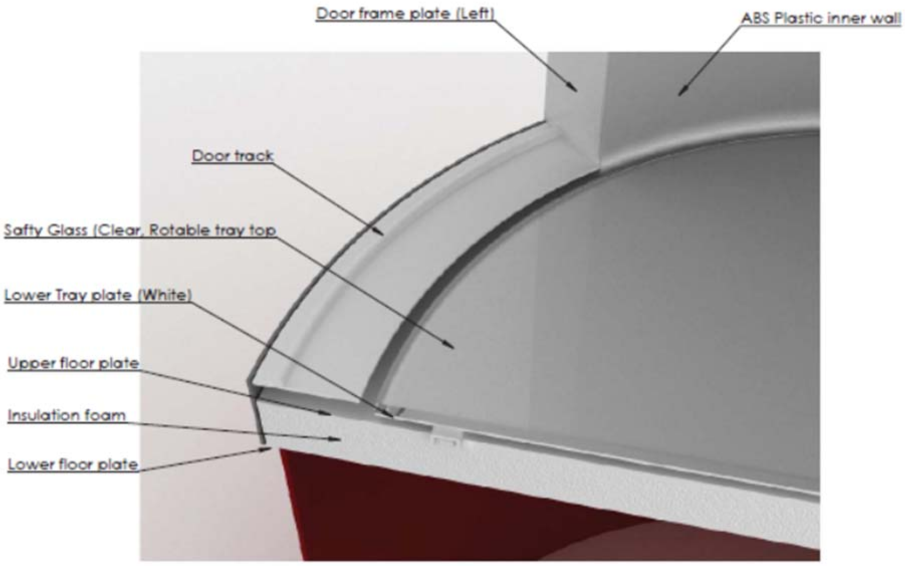


Figure 33: Section picture of refrigerator chamber with rotate tray (lower view)

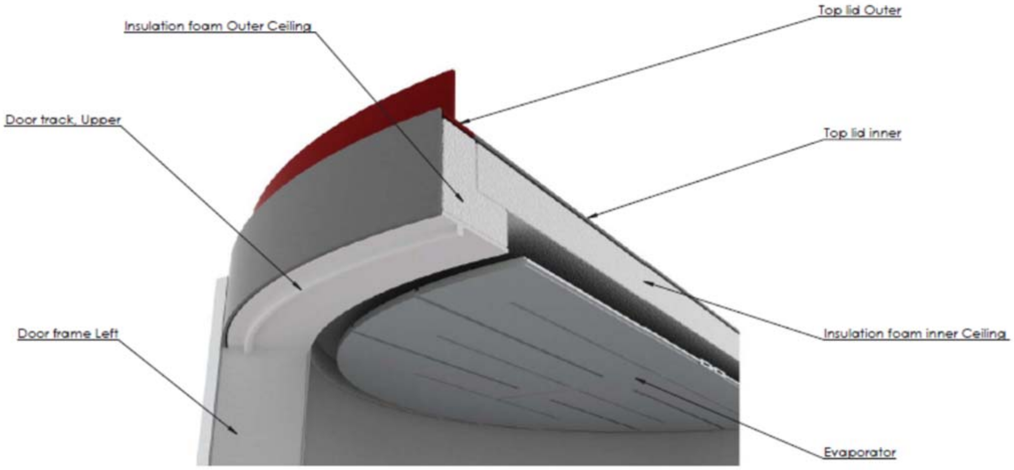


Figure 34: Section picture of refrigerator chamber with evaporator plate (upper view)

The design of the refrigerator uses low-friction materials between door and track instead of a small wheel for sliding. This can reduce production costs and time for maintenance. In addition, a single emboss door track is easier to clean than a groove track. It is difficult to remove dirt and water from a small groove track, which can lead to hygienic and smell problems in a storage chamber.

The advantage of an emboss track is to block cool air from moving from inside to outside.

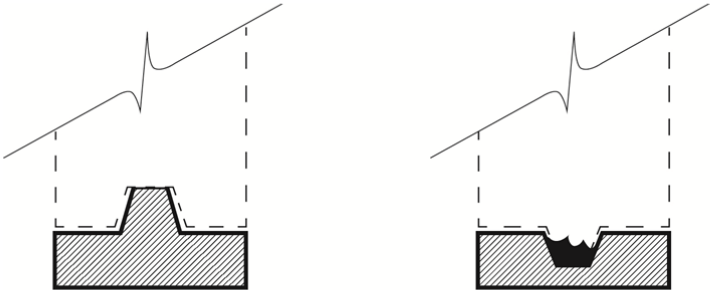


Figure 35: Left: increased guide rail for the sliding door; right: milled guide rail

Top-down cooling has the potential to cover the whole area of a storage chamber and evenly transmit cold from the top to items inside the chamber. This direction of cold moving down is a natural phenomenon.

A cooling source at the side of a storage chamber cannot cover all areas in a storage chamber. Moreover, the degree of cooling also depends on the distance between an item and the evaporator. Particularly, the edge of the tray receives cooler temperatures than the middle area.

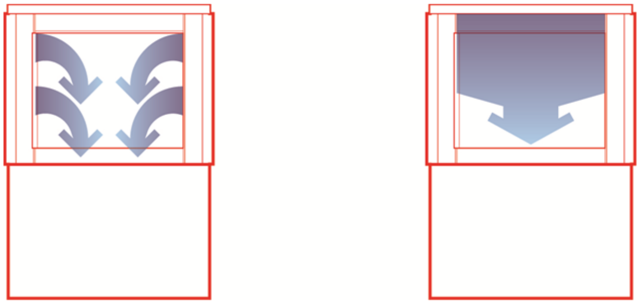


Figure 36: Air circulation of various cooling flow directions – left: from side to bottom, right: from top to bottom

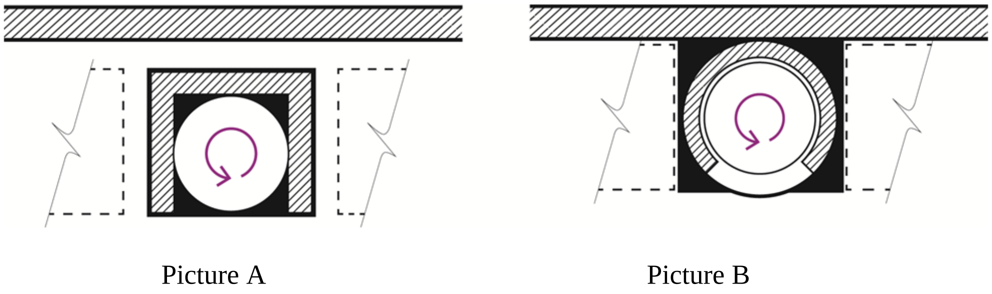
The evaporator is installed in the upper area of the storage chamber to provide top-down cooling and cover the whole interior space of the chamber. Individual temperature control can reduce energy consumption compared to common use.

A number of models were made to check size, proportion and some moving parts of the storage chambers. The models were made from paper and acrylonitrile butadiene styrene (ABS) sheets, which are similar to actual production with cutting, bending and folding. (Please see Figure 31 .) There were two designs of this development to check the exterior shape and proportion of the chamber. The first paper model with a square shape can be put well next to furniture which is usually square-shaped. However, the square shape does not fit in well with the round tray inside the chamber. There are some areas between the corners and the rotatable tray that cannot be used for storage. (Please see the black area in

Picture (A) of Figure 37.) Even though these gaps increase interior volume inside the chamber, they also raise the working load for the cooling system without any benefit.

The cylinder shape fits the rotatable tray better than the square chamber. Nevertheless, the cylinder shape also has some gaps at the corners between chamber exterior and ambient furniture. (Please see the black area in Picture B of Figure 37.) However, those gaps can be used for releasing heat from the chamber.

To sum up, both shapes have gaps at the corners. The square shape has those gaps on the inside where the space cannot be used for any purpose, whereas the cylinder shape has them at the outside where they can be used for air ventilation. (Figure 37)


Picture A

Picture B

Figure 37: The pictures compare usage areas in the corners between rectangular (left) and round shape (right)

3.4.3.5 Cooling machine testing

Testing was set in a laboratory to control the air flow and to keep the indoor temperature between 21°C and 27°C. The temperature of the input hot water was 80°C to drive the cooling system in the cooling machine.

The Icebook was connected to a working model of the storage chamber which was made from two metal cylinders of different size. The chamber was cut at the side wall to put in a slide door. 30 mm thick polystyrene (PS) foam was inserted as an insulation material into the double wall including the door panel. The evaporator was installed at the top to provide cold inside the cylinder.

This test setup included 4 temperature sensors to monitor the following temperatures inside the chamber: 1) evaporator inlet connector, 2) evaporator outlet connector, 3) upper storage chamber at the center of the cylinder, and 4) lower storage chamber at the center of the storage chamber floor.

Figure 38: Cooling machine performance testing with a working model in a laboratory

Air pressure in the evaporator part was tested by sealing the outlet tube with a metal cap. Then the evaporator was put under water and air was blown into the evaporator for 30 seconds to check for bubbles. If there were no air bubbles from the evaporator part, then the air pressure was gently increased from 1 bar to 5 bars. (See Figure 39)

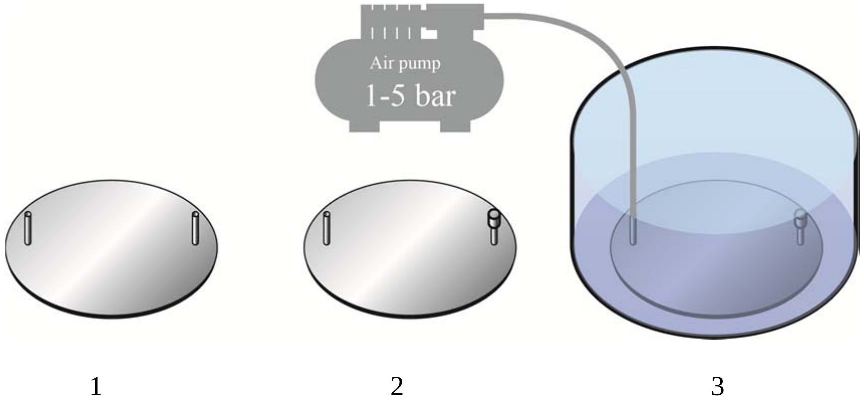


Figure 39: Evaporator air pressure testing method

3.4.3.6 Prototyping process

A production process overview is shown in

Figure 40. (The bills of material are shown in the appendix.)

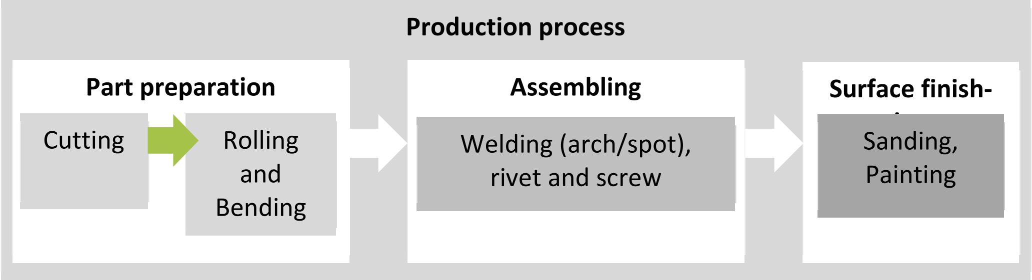


Figure 40: Prototype production process overview

The storage chamber can be produced in four stages as follows: cutting, rolling/bending, assembling and surface finishing.

3.4.3.6.1 Cutting process

The cutting process can be categorized into two methods. The first is manual cutting. This method uses cutting tools such as hand saw, flame cutting, plasma cutting and manual milling. These cutting methods are low-cost but may take time and show less accuracy depending on the skills and experience of the cutter. A second method of cutting is Computer Numerical Control (CNC). This automated cutting needs Computer Aided Design (CAD) and Computer Aided Machine (CAM) to accomplish the cutting task. It provides a neat result and is less time consuming. The investment costs for CNC cutting are high for a small production volume but they may be economical for a great volume. In this project, the metal sheets were cut with a laser cutting machine to save time and allow easy revision. For the real production, the metal sheets can be cut by hand sawing or any available technology that is mentioned above. This stage represents the part preparation before the actual forming process.

3.4.3.6.2 Bending process

Rolling and bending are low-cost processes for metal forming. The shape of the chamber is a geometric form which can be easily made by these processes.

3.4.3.6.3 Assembly process

The prototype makers used arc-welding, spot-welding and screw techniques to assemble the chamber. Arc-welding was used to achieve a firm bond. This process uses very high temperature to bond two pieces of metal. It is possible to have an unwanted bending if the metal sheet is too thin. This process needs experience and skills to accomplish the task. It also requires a surface treatment after work by grinding or sanding. Therefore, spot-welding is also used for non-heavy load and visible areas. This kind of welding does not need a surface treatment afterwards. Some screws were used in invisible areas because they make connection easy, with flexible adjustment afterwards.

3.4.3.6.4 Surface finishing

Surface treatment is the final stage to complete the prototype making. The arc-welding line needs grinding and sanding to remove unwanted parts from the work pieces. In addition, the metal surface also needs light sanding before spray painting for better paint adhesion. The smooth surface can reduce germ and dirt which is one of the most important criteria.

3.4.4 Case study 2: solar cooking stove

3.4.4.1 Introduction

Much research was conducted that proved that a solar-based cooking stove can provide high temperatures sufficient for cooking foods. However, a solar-based cooking stove has not been widely used in households yet. This case study aims to investigate the reasons for the low acceptance of solar cooking stoves on the part of the households, based on an analysis of the user needs related to a traditional cooking stove and the cooking behavior. It suggests a design guideline to design a cooking stove which is more likely to be accepted by households. The Kano model was used to classify user needs regarding an electric cooking stove in order to determine necessary features of a solar-based cooking stove. The result of this study is to improve user acceptance by using a design that bridges user needs and cooking stove features.

The main question which initiated this research was why a solar cooking stove is not widely used in households although it meets the technical requirement of providing a certain temperature for cooking.

3.4.4.2 Technical components and optimizations of solar cooker prototype

A prototype was developed based on the solar cooker of Dr. Schwarzer's design (Schwarzer 1993) which is a flat plate collector of indirect use type (Schwazer and Silva 2008). The new design has different linear piping designs and insulation materials.

3.4.4.2.1 Solar collector

A solar flat plate type was used in a working prototype to measure the solar cooker performance. This type of solar collector is economical in both design and production. Black painted copper tubes were assembled in a wooden box with insulation at the bottom and double clear glass on the top. The solar collector was set with an angle about 30-40 degree to the ground. There are four reflector panels to reflect more sun light into the solar collector box. Those reflector panels can also protect the glass on the solar collector when it is not in operation.

3.4.4.2.2 Thermal storage

A thermal storage tank was made from steel oil barrels with 50 liters capacity. The heat storage was filled with round stones to reduce the thermal oil volume in the system. The stones in the barrel can help heat to remain in a system longer with less quantity of thermal oil. This can also keep production costs low because thermal oil is costly. The thermal storage barrel is covered with burned rice hush or glass wool for insulation.

3.4.4.2.3 Cooking area

The cooking area was designed by using a double-wall cooking vessel with a gap between the walls for thermal oil to run through. The thin wall is more sensitive to fluctuation in temperature than a thicker wall. However, a thick wall takes more time than a thinner wall for gaining sufficient heat for cooking. The thermal oil can slowly move without an electric pump by using a thermal siphon where hot oil will rise to the top part and cooler oil will go down in a loop.

3.4.4.3 Testing methodology

Thermal sensors (Volcraft DL-111K Data logger) were installed into the prototype on the surface of the cooking vessel. The input sensor was attached to the middle of the cooking vessel surface. (See Figure 41) The sensors were set to record every 30 minutes from 9:00 to 17:00. The sensor was firmly attached to the surface of the cooking vessel. The cooking vessel was closed with the lid during monitoring. The prototype was located in an open area without any shadow from buildings or trees.

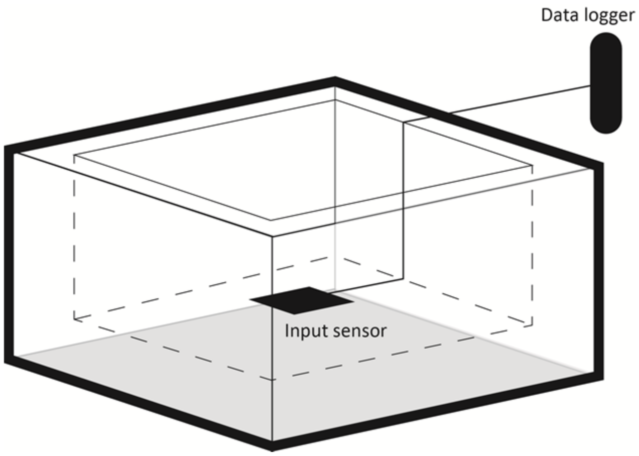


Figure 41: the thermal input sensor position on the surface of cooking vessel

3.4.4.4 Test 1

The prototype's performance was tested the first time on a sunny day with clear sky with average surrounding air temperature at 10°C, wind speed at 10 km/h and humidity at 43% in Böheimkirchen, Austria.

Table 9: Solar cooking stove test 1 conditions

Date	13 February 2014 (09:00-17:00)
Air temperature	10°C
Wind speed	10 km/h
Humidity	43%
Sky condition	Clear and sunny day
Place	Böheimkirchen, Austria

3.4.4.5 Test 2

The second test used an improved oil flow knob for better control. Mechanical parts of the first knob had been made from metal which enlarges at high temperatures. This problem made it difficult to turn and caused some oil leaking. Therefore, the new test replaced the metal control knob with a ceramic control knob which is highly heat-resistant. In addition, the insulation material around the hot oil storage tank was condensed to fill some gaps between surface and air. This test was made on a sunny day with clear sky with average surrounding air temperature at 19°C, wind speed at 2 km/h and humidity at 73% in Böheimkirchen, Austria.

Table 10: Solar cooking stove test 2 conditions

Date	28 August 2014 (07:00-17:00)
Air temperature	19°C
Wind speed	2 km/h
Humidity	73%
Sky condition	Clear and sunny day
Place	Böheimkirchen, Austria

3.4.5 Integrated prototype

The prototype combined the cooking stove and the solar refrigerator to share the solar collector and the heat storage tank. The solar collector box was built from wood, black painted copper tubes and clear glass. This solar collector box was topped with double glass with an air gap in between the surface to protect the skin from burning by touching the surface. The copper tube was painted in black color to maximize heat absorption from the sun radiation.

This solar collector uses reflector film on three foldable polystyrene foam boards on the edges of the solar collector box. The reflector can be folded and adjusted to get maximum sun radiation or to close the solar collector box.

The storage tank was filled with stones to reduce the oil volume in the heat transport system. The tank was covered completely with insulation materials to keep the heat inside the storage part.

The pipeline should be kept straight and show as few joints as possible to improve the hot oil flow rate since there is not much pressure from the thermal syphon. A curve in vertical direction might cause a problem due to air bubbles blocking the hot oil circulation flow. The pipeline also has an over-flow container to prevent oil from spilling when it is getting hot and increasing in volume. This integrated prototype contains a modified LPG Gas- refrigerator and solar cooker. These devices share the heat sources from solar collector and heat storage tank.

There are two possible ways to connect the pipeline to the heat source. 1) The solar refrigerator or cooking stove can use direct heat from the solar collector when sun radiation is available. 2) Those appliances can use the heat from the storage tank when sun radiation is not available.

Figure 42: Prototype of solar refrigerator and solar cooking stove

4 RESULTS

4.1 Overview

The results of this research will be addressed in three sections. The first section focuses on the derived results from the literature review and surveys to get a better understanding of the demand regarding household appliances in energy-autonomous house conditions, which responds to the first study aim. The second section concentrates on user acceptance criteria for household appliances in an energy-autonomous house, which contributes to the second study aim. The user acceptance of a novel household appliance is discussed in the third section to increase user satisfaction and appliance value.

4.2 Energy demand in an energy-autonomous house

Gaining an understanding of the demand and energy-autonomous house conditions allowed the researcher to identify design requirements for household appliances. These requirements were used to create a design and development direction for novel household appliances. User understanding does not focus only on household appliances (please see case study 1, 2), but it includes energy needs for living in an energy-autonomous house.

The literature review from this research reveals that thermal energy is needed by approximately 75% of all household appliances. This is an opportunity to use thermal energy for a household appliance directly without electric conversion which is inefficient in terms of energy consumption. Thermal energy for household appliances can be classified into two temperature ranges: 1) low temperature range (30-90°C) and 2) medium temperature range (91-300°C).

4.2.1 Low temperature range

The low temperature range refers to 30-90°C. This range uses water as a heat transfer media because it is a simple resource which is already available in a building. Moreover, hot water can be shared with other household appliances with open loop circulation such as washing machine, dish washer machine and hot water shower machine.

4.2.2 Medium temperature range

The medium temperature range refers to 91-300°C. This range cannot use water as heat transport media because temperatures over 100°C can be harmful to the regular infrastructure system and residents because the water vaporizes and the pressure will damage the sealing and piping system. So, the medium temperature range uses thermal oil such as synthetic oil or organic oil, peanut oil, avocado oil to transfer heat because it has a higher boiling point than water. However, the medium temperature range system is more expensive than the low temperature range system because of the material and installation costs. It is usually used for closed loop circulation.

4.3 Results of case study 1: solar refrigerator

4.3.1 Market survey and actual user needs

Survey results show the number of refrigerators owned in Austrian households. Almost every Austrian household (99%) has at least one refrigerator. 42.7% among these households have more than one. The single door with freezer is the most popular type with 48.5%. The second most popular type is a refrigerator with two doors and lower freezer with 26%.

Refrigerator buyers usually purchase a bigger capacity than they actually need. They buy a fridge for their future uses, making sure that they have sufficient capacities for special events. Capacity considerations involve dynamic numbers such as the number of users, special events and incomes. The fridge is usually purchased for long term use. 65.5% of the fridge owners have been owning their fridge for more than four years.

The trend regarding new refrigerator design is going towards an enormous size. Competition is very strong in the marketing of refrigerators and producers attract buyers by providing the largest capacity. Leading brands compete to provide the largest size on the market. One good example is that LG Electronics launched a new side-by-side refrigerator model with 801 liters in March 2010. Then, seven months later, Samsung Electronics launched their new model with 840 liters in October the same year. In 2011, LG launched another model with 850 liters in March. Six months later, Samsung launched 860 liters in September and LG launched a bigger capacity model again with 870 liters about 30 days after Samsung had launched their last model. The competition also keeps continuously going, as 2012 Samsung launched a refrigerator with 900 liters in July and LG topped this with 910 liters in August. It’s obvious to see that in the last three years the capacity has been raised almost by 100 liters. This design direction might lead to electric overconsumption in a house (Statistik Austria 2012)**.**

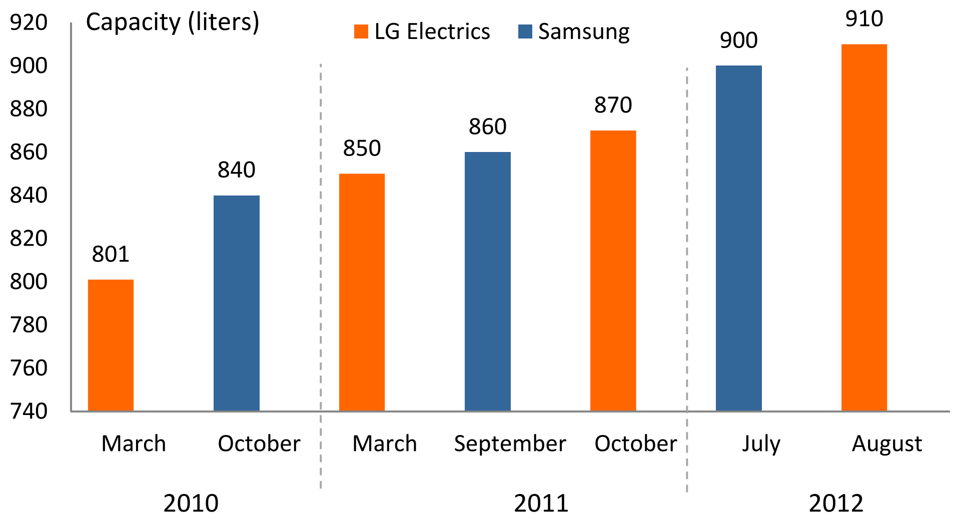


Figure 43: Capacity of a new model refrigerator comparison between years 2010 – 2012 from LG Electronics and Samsung Electronics (Park 2012)

The interview and questionnaire results show that fridge buyers want to have a big capacity, but they cannot purchase an expensive huge fridge. The number of side-by-side fridges has the smallest share, only 1% of all fridges in Austria. Buyers might need a flexible-capacity fridge that can respond to their current requirements. For example, freshly graduated students might need a single compact fridge for starting their independent life. A few years later, they can buy more units when they have a higher income. They can later have an additional unit when they get married and have a baby.

4.3.2 User requirements and identification

The design concept was formulated from the users' input obtained by interviewing, questionnaires and observation. The primary information was collected in both qualitative and quantitative data. (See Appendix A) Then the designer and engineer transformed those data to realize a tangible device. This chapter presents three different design proposals to fulfill user needs.

4.3.2.1 Multi-temperature requirements

Foods require different temperature for preparing and cooking.

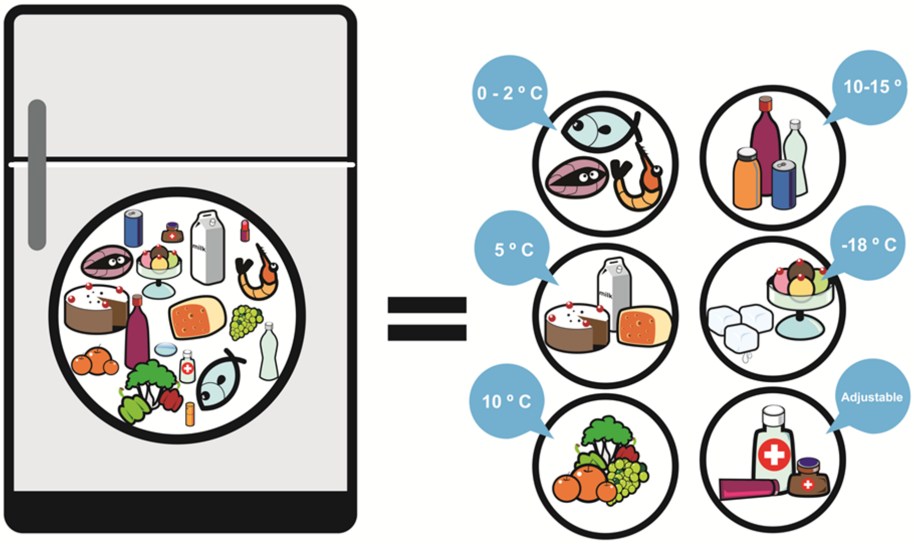


Figure 44: Different foods require different ranges of temperature

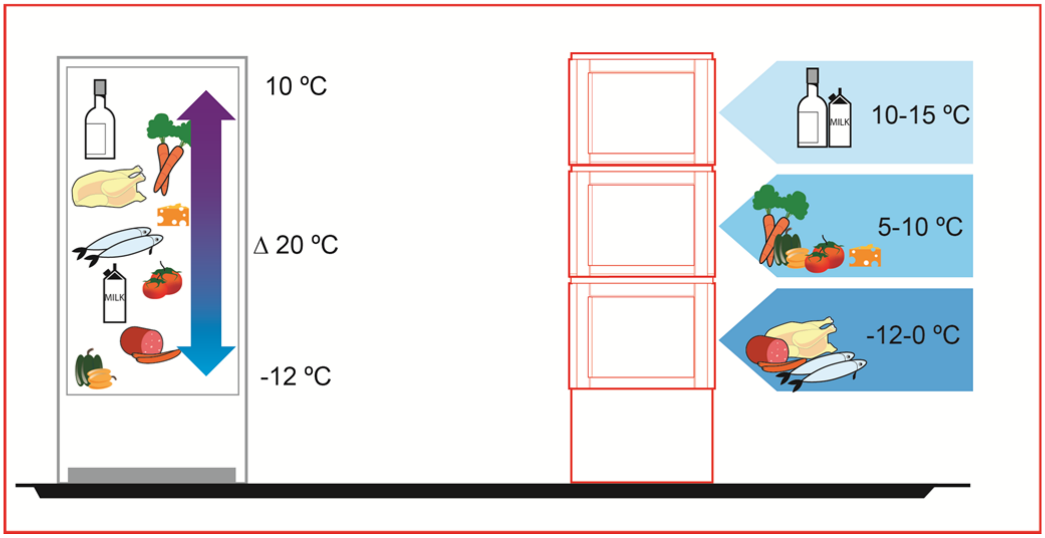


Figure 45: Temperature cluster to reduce temperature range in a chamber

4.3.2.2 Multi-storage chambers

The refrigerator has several compact storage chambers to separate things that require different temperatures and smell controlling. The user can set the temperature individually in each storage chamber, responding to the various food requirements.

4.3.2.3 Difficult-to-reach zone

Expired food is often found in the back zone of a shelf. The user has some difficulties in reaching and searching through the back zone, because it is blocked by other items and there's a long reaching distance. Many users usually "push and place" their food in their fridge: they push the food in stock into the back area and place new things in the front zone. Then, most of the users always take food from the front zone, instead of the older food in the back zone (if it’s the same food type). As a result, there is a lot of old food remaining in the back zone until it goes bad.

4.3.2.4 Easy access to all areas

Design C follows an “inside-out” and “form follows function” principle. The special feature of this design is a rotatable tray that helps users to get comfortable access to the whole interior area by turning the tray. The users had difficulties reaching things in the back zone both because of the distance and vision blocking. (See Figure 46-1) The users took a longer time opening the fridge to unblock the front zone in order to access the back zone. (See Figure 46-2) The rotatable tray can distribute things from the back zone to the convenience zone. (See Figure 46-3 and Figure 46-4.)

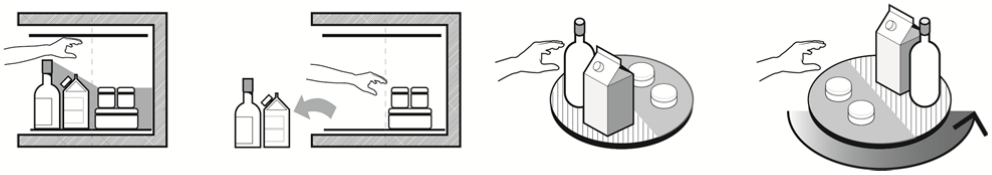


Figure 46: Back zone approaching

Figure 46-1 Blocking by big things in the front zone; Figure 46-2 Unblocking the front zone to access the back zone; Figure 46-3 Easy access from front zone; and Figure 46-4 Turning the rotatable tray from back zone to front zone so that users can easily reach things both in the front and back zone of the fridge chamber.

4.3.2.5 Flexible capacity

The refrigerator is designed to be of flexible storage volume by adding more chambers or decreasing the cooling volume. It is not possible to change the cooling volume in a single big unit. The cooling volume of a fridge is a non-static demand during different periods of time. (The survey shows that people always buy a bigger fridge than actually needed to secure extra capacity for the future.)

The individual cooling system offers flexible capacity by the possibility of adding an extra unit or decreasing the cooling volume by activation or de-activation of cooling systems. The amount of things inside the fridge is always changing depending on the time and events. On the one hand, users may need more space e.g. for their Christmas party. On the other hand, they might need less space while they are travelling abroad. The refrigerator capacity can be extended according to specific situations in life. For instance, freshly graduated students from university might have a compact unit for their initial independent living. They can add more units for a couple life without dumping the old fridge. An extra unit can be added when they receive a new family member. This idea is also in line with their actual income growths. Every unit has an individual control system to activate or de-activate them, depending on the demand.

Figure 47: Flexible capacity according to user requirements

4.3.2.6 Flexible layout

The storage chambers can be placed horizontally or vertically, depending on purposes and product conditions. The position of the chambers can be arranged taking into account the frequency of usage and ergonomic considerations. They can be vertically stacked on top of each other for multi-user accessibility. This way, kids can access a lower unit to get their food. If a user consumes more ice cream in summer than in winter, then the ice cream can be placed at the most comfortable height to access the fridge in the summer. This can be changed in winter time to store different things there, such as vegetables, meat and cheese.

In addition, those chambers can be installed horizontally on the wall at an appropriate height so that users do not have to bend their backs to use the fridge. The horizontal installation on the wall might be a good ergonomic position for user accessibility. For example, cooks do not have to bend down their backs to search for ingredients in the fridge during their cooking preparation.

4.3.2.7 Hygienic design

The design avoids sharp corners and small gaps in order to reduce dirt in the storage chamber. The interior wall is constructed with a smooth surface and waterproof to keep the chamber clean from germs. The bottom of the chamber has a water drain hole in the center to keep the chamber dry at all times. The water may come from melted frost at the evaporator part.

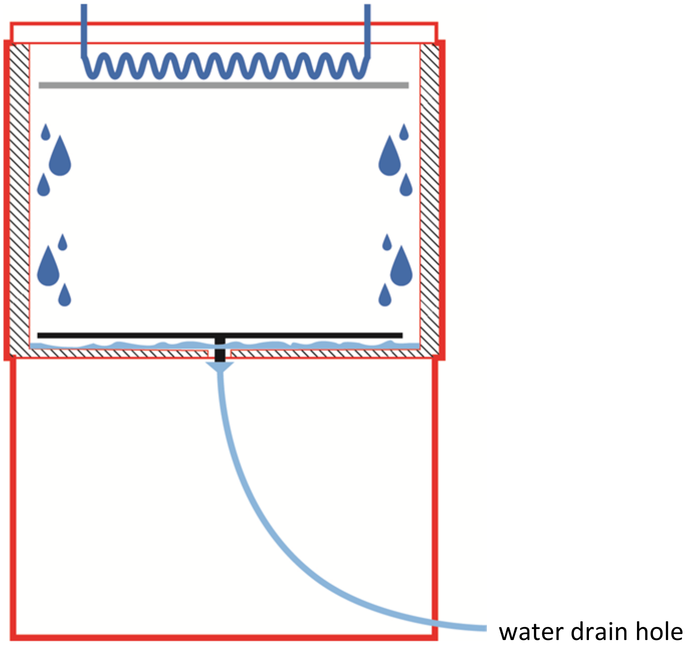


Figure 48: Section view shows the draining principle of refrigerator

4.3.2.8 Cleaning

The number and size of the corners in a chamber are relevant in terms of cleaning. It is more difficult to wipe in a sharp corner than on a flat surface. Dirt always remains in the small corners rather than in curves of a larger radius. The cubic appearance of designs A and B has a similar number of corners in the chamber. However, the cylinder shape of design C is smoother and has fewer corners to clean.

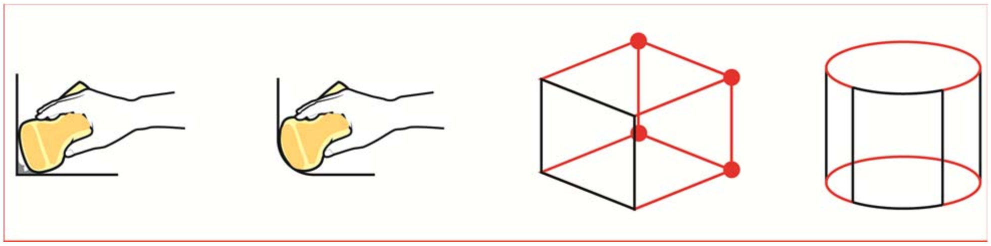


Figure 49: Cleaning difficulties in the interior of storage chambers

4.3.2.9 Noise

A cooling machine shouldn't be noisy and interfere with regular activities in a house. The buzz sound from an electric compressor can annoy users. For instance, sound from the fridge can disturb the sleeping time of users if they live in a small house.

In general, an absorption refrigerator uses a source of heat, such as combustion of liquefied petroleum gas, solar thermal energy or an electric heating element. These heat sources are much quieter than the compressor motor in a typical refrigerator. In case of the ZCC, the unwanted sound from the working system is minimized.

4.3.2.10 Improved ergonomics

Physical actions related to refrigerators and freezers are: door opening, bending the back to access the targeted foods or beverages, loading, and cleaning. The smart design of the storage body will help users reduce hard physical movements. For example, vegetable units can be placed at an eye level for a vegetarian user. Units for alcoholic beverage, medicine, and cosmetics can be fixed at a higher level, to keep children away for safety reasons.

4.3.2.11 Cooling air circulation and emission

The position of the evaporator in the chamber influences air circulation and cooling performance. There are two possible places to install the evaporator in the chamber: in the upper part or in the sidewall.

On the one hand, the designs A and C have the evaporator in the upper part of the chamber. Cool air usually flows down to the bottom part while hot air goes up to the upper part. The distance between refrigerated items and the evaporator plate is equal for all items placed anywhere in the chamber. (Please see Figure 50 below)

On the other hand, the design B has the evaporator in the sidewall to provide cool air to the interior space. Items that are close to the wall will get colder than items in the middle of the chamber. Particularly, items located close to the door will get less cool temperature than items that are located close to the wall. Moreover, the drawer wall also blocks cool temperature from getting inside the storage area.

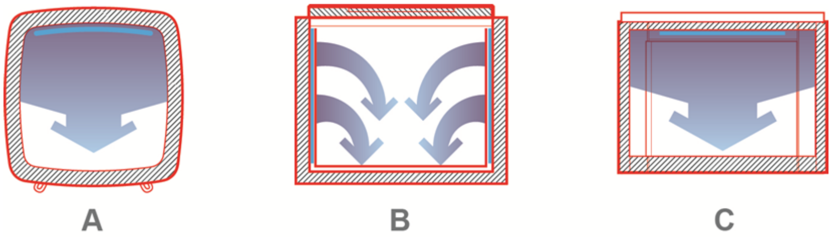


Figure 50: The illustration compares the air circulation of designs A, B and C

4.3.2.12 Less clearance space for door opening

The sliding door of the cylinder shape does not require clearance space beside and in front of the fridge for door opening. Because of its cylinder shape the door can hide in the sidewall. This design can be used in a small room or limited area.

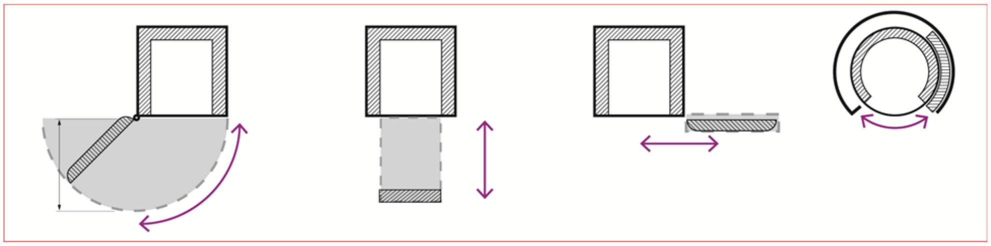


Figure 51: Comparison of refrigerator door types

These 10 required refrigerator attributes can be categorized in 5 different groups based on Kano's model. (See 2.3.2)

Table 11: Needs classification of cooking stoves according to the Kano model

Needs	Category
1 Multi-temperature requirements	**A**
2 Multi-storage chambers	**A**
3 ease of access	**M**
4 Flexible capacity	**A**
5 Flexible layout	**A**
6 Ease of cleaning	**M**
7 Noise	**O**
8 Less clearance space	**I**
9 Energy saving	**O**
10 Durability	**O**

4.3.3 Cooling performance results Test 1

In the first test, hot water of about 63.2°C (mean) was fed into the Icebook machine to produce cool temperature. The temperature in the refrigerator chamber was below zero. The temperature was quite stable. The Icebook machine can produce cool temperature of -3°C to -1°C. The refrigerant temperature difference between input and output is approximately 3°C to 5°C. The output refrigerant temperature is lower than the input temperature. The used hot water temperature fluctuates between 42°C and 50°C.

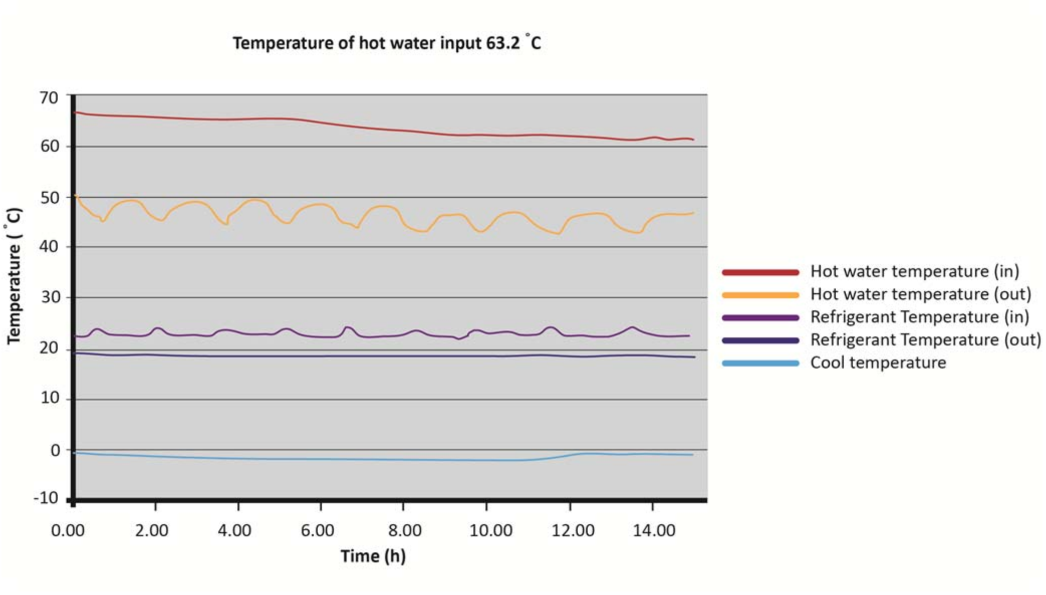


Figure 52: Cooling performance result from the first test

4.3.4 Cooling performance results Test 2

The Icebook machine was tested with hot water input at 71.4°C (mean) to see the different output performance. The cool temperature line graph shows that the cool temperature is similarly at about -1°C to 1°C but is less stable than in the first test. The output of the hot water and refrigerant temperature still fluctuates, even more than in the first test. The machine can continuously run for 6 hours to produce cool temperature.

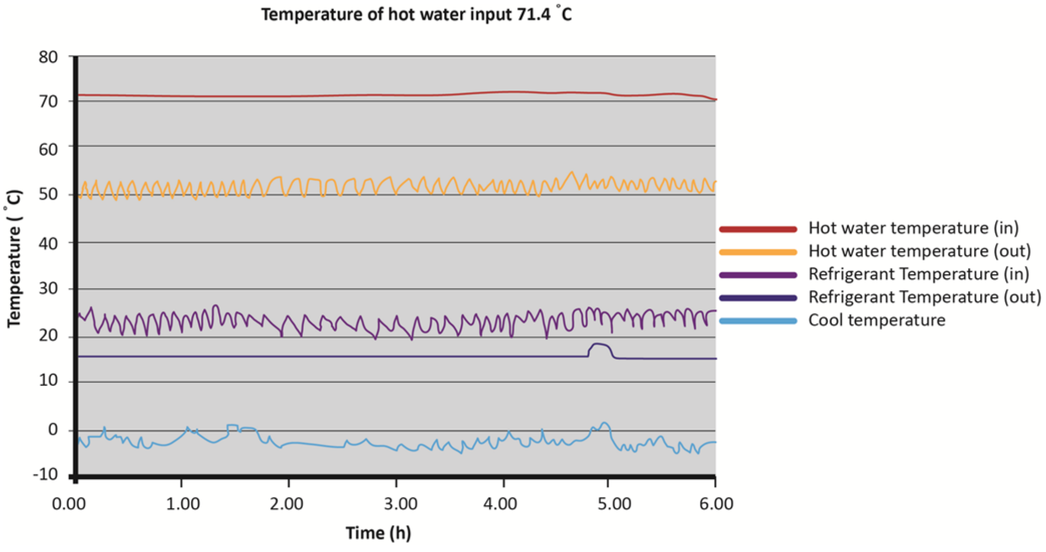


Figure 53: Cooling performance result from the second test

4.3.5 Cooling performance results Test 3

The last test fed hot water at 80°C (mean) into the cooling machine for 1.4 hours. The machine produced a cool air temperature between -1°C and 1°C which is similar to the previous two tests. However, input water of lower temperature makes for a more stable output temperature than input water of higher temperature (at 80°C).

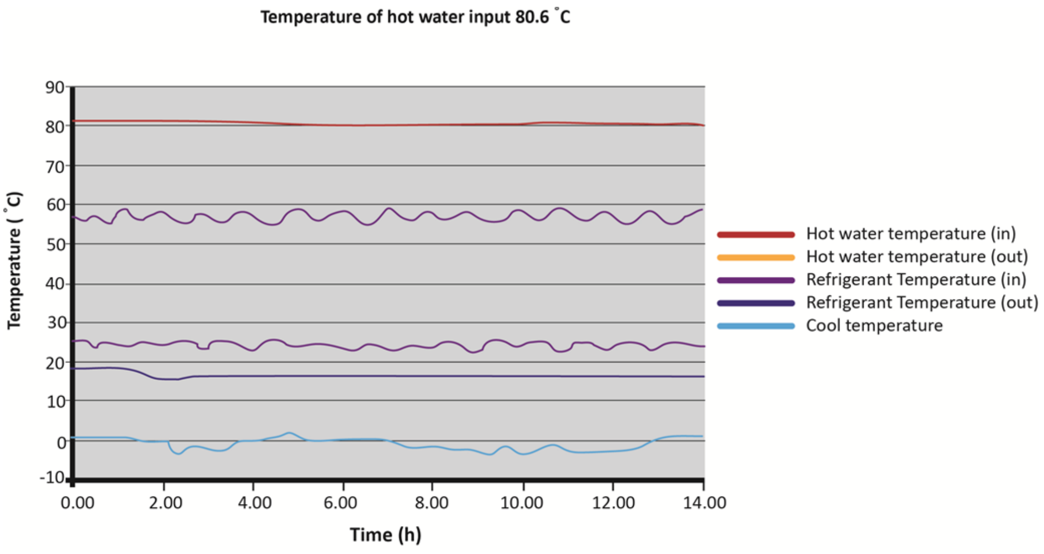


Figure 54: Cooling performance result from the third test

4.3.6 Cooling performance results with storage chamber model

The results show a good potential for generating cold for refrigerating purposes. The cooling machine takes about 30 minutes to reach 0°C. The temperature decreased continuously for about half an hour to reach -10 which is sufficient for the expected temperature in a fridge. However, the cooling machine needs to maintain more stable temperature to keep foods in the chamber in a good condition.

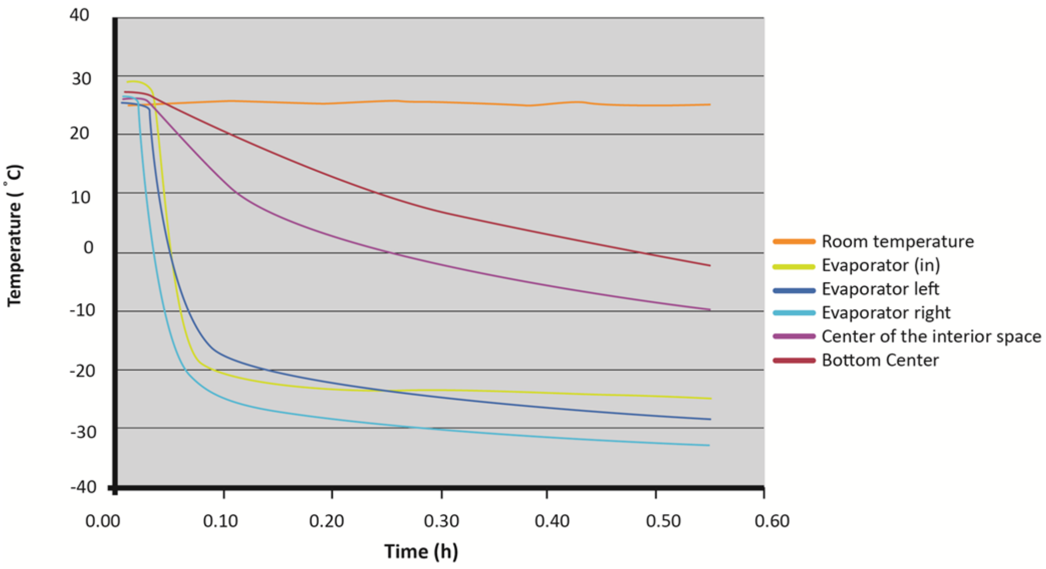


Figure 55: Performance of the NH_3 and water evaporator in a storage chamber model

4.3.7 Conclusion

The new solar refrigerator design C concept provides more alternative options to serve the user demands; it reduces energy consumption by switching the energy input to solar thermal and adds some practical features that support user behavior in reducing waste of energy during usage.

4.4 Results of case study 2: solar cooking stove

4.4.1 Market survey and actual user needs

It is crucial to gain market acceptance for the solar cooking stove because it is a new concept of household appliances that are powered by a renewable energy source without conversion into electrical energy. The survey consists of varied methods to gain information about using cooking stoves, such as questionnaires, observation, interviewing and experiments.

4.4.1.1 Fast reaching of high temperature

Users prefer to shorten their cooking time. The average cooking time in 1960 was one and a half hour. Twenty years later, cooking took an hour. Nowadays, modern cooking needs only 38 minutes. (Kirkova , 2013) Our survey showed that 76% of the participants spent only about 20-30 minutes for using a cooking stove. They need a high performance cooking stove to achieve this goal. The tendency is to spend less time for cooking in a kitchen.

4.4.1.2 Precise control

A user needs to know the current temperature for cooking. An interaction between displays and control design is very important for the user perception. The surveys reveal that 67% of participants do not know the cooking temperature during their cooking. There are three methods to perceive the current cooking temperature: 1) users monitor a flame characteristic of gas cooking stoves, 2) users look at the lighting signal from an electric cooking stove to predict cooking temperature from their experience, 3) users use a knob position and graphics to indicate a cooking temperature level. A solar cooking device needs to show the current temperature level or preferred temperature to help control the cooking temperature. The results of the surveys also reveal that cooks do not need to know an exact temperature for their cooking. Three temperature ranges were suggested from the participants that are sufficient for cooking as follows: high, medium and low heat. The user also needs to know the temperature status on the cooking surface after turning it on/off as well as a signal of sufficient cooking temperature when it is ready to start cooking.

4.4.1.3 Easy temperature controlling

A good ergonomic design can help users to control the temperature during cooking. A good relation between displays and control can help users to easily control the cooking temperature. A good grip on a control knob should consider: shape, size, movement direction, position, color and non-slip materials. The materials of mechanic parts inside a knob control must resist high temperature to avoid obstructive turning or shape deformation.

4.4.1.4 Prompt use

The results of the survey showed that the participants use their cooking stove at least twice a day. They need on average 30 minutes per cooking time. A cooking stove should have sufficient energy input and a backup system for that basic need.

4.4.1.5 Safety

Heat and physical sharp edges can harm users during cooking activities. Product designers should avoid using ambiguous cooking zoning that causes skin burns from touching. Warning graphics or interface designs are needed to clearly indicate a hot zone on a cooking stove surface. A cooking stove design should avoid small corners and gaps which are difficult for cleaning. A sharp edge can also harm users when they clean a cooking stove surface. Users need a clear visual sign for security reasons.

4.4.1.6 Number of burners

The survey result showed that all participants would like to have more than one burner. 85% of those have four burners on their cooking stove. It clearly indicates that users need a multi-burner with different sizes for their cooking. Users can cook with two burners at the same time to save cooking time. However, users give negative feedback on a cooking stove that has more than four burners.

4.4.1.7 Easy to clean

There are 41% of the participants who clean their cooking stove every day after cooking. One fourth of the participants are not satisfied with their cooking stove because it is very difficult to clean. The interview indicated that users need a dirt-free surface during their cooking. The users are satisfied with a flat and smooth surface on their cooking stove because it is comfortable for removing dirt stains.

4.4.1.8 Energy saving and alternative energy used

The feedback from the surveys showed that the participants would like to use alternative energy input for their cooking stove to reduce electricity load and to increase self-sufficient living by decreasing fossil energy consumption.

4.4.1.9 Aesthetics and appearance design

There is a broad range of definitions among participants for what makes an attractive physical appearance of a cooking stove. For the most part, it can be assumed that the design should be simple and compatible with the furniture and the surrounding environment, furthermore show practical utilities, ease of maintenance, low cost and energy saving.

4.4.1.10 Durability and maintenance

Users are satisfied with their cooking stove if it has a long working life with regular maintenance such as cleaning to keep the stove in good condition. The participants expect that their cooking stove should work at least five years. Increase in satisfaction is directly linked to working life time of the cooking stove.

Table 12: Needs classification of cooking stoves according to the Kano model

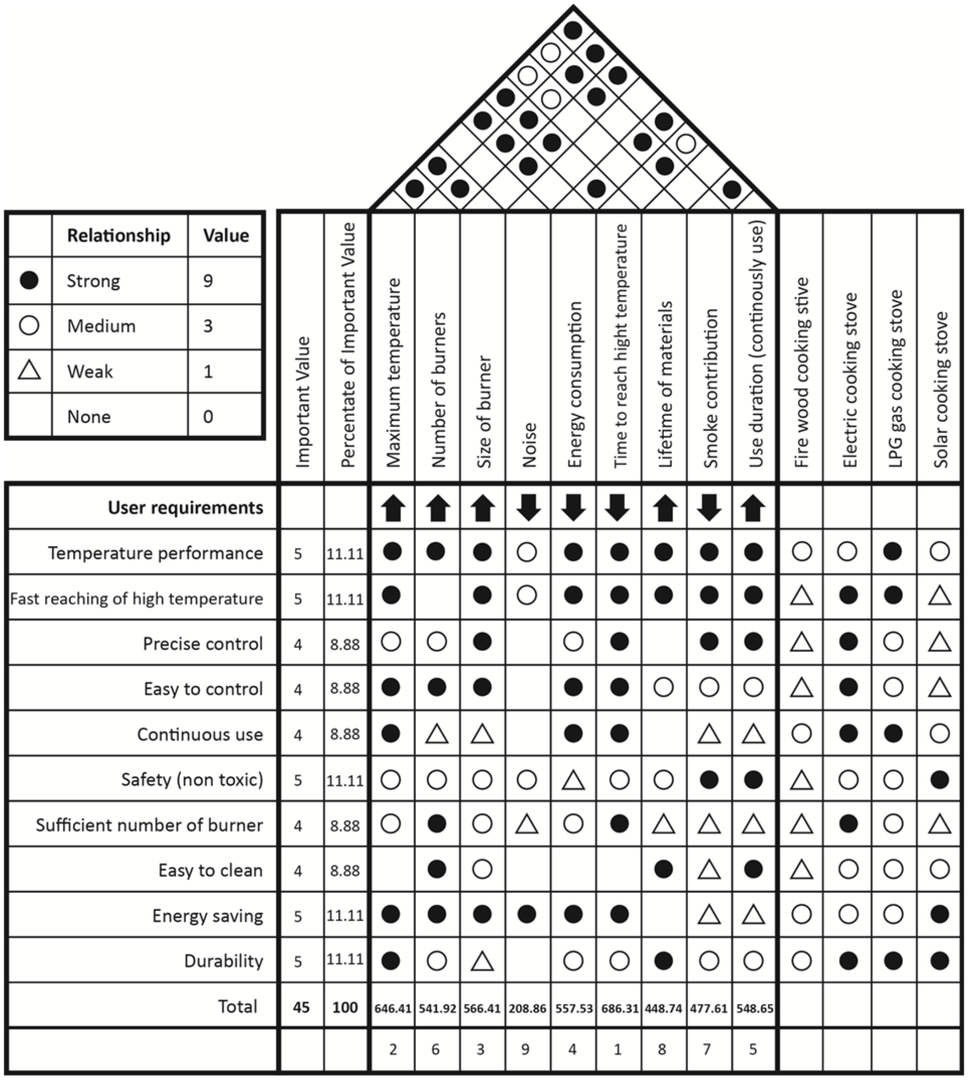
Needs	Category
1 Temperature performance	**M**
2 Fast reaching of high temperature	**O**
3 Precise control	**M**
4 Easy to control (switch on/off)	**I**
5 Prompt use	**M**

6 Safety – non-toxic	**M**
7 Number of burners	**I**
8 Easy to clean	**A**
9 Energy saving	**O**
10 Aesthetic appearance	**I**
11 Durability	**O**

M: Must be, O: One dimension, A: Attractive, I: Indifferent, R: Reverse

4.4.2 QFD analysis

The results from Figure 56 show that the time to reach high temperature is the most important consideration for using a cooking stove. The temperature performance is the second priority in using a cooking stove. The solar cooking stove shows a great potential to be used in an energy-autonomous house in terms of energy independence, indoor-air quality and environmental friendliness.



	Relationship	Value
●	Strong	9
○	Medium	3
△	Weak	1
	None	0

User requirements	Important Value	Percentate of Important Value	Maximum temperature	Number of burners	Size of burner	Noise	Energy consumption	Time to reach hight temperature	Lifetime of materials	Smoke contribution	Use duration (continously use)	Fire wood cooking stive	Electric cooking stove	LPG gas cooking stove	Solar cooking stove
			⬆	⬆	⬆	⬇	⬇	⬇	⬆	⬇	⬆				
Temperature performance	5	11.11	●	●	●	○	●	●	●	●	●	○	○	●	○
Fast reaching of high temperature	5	11.11	●		●	○	●	●	●	●	●	△	●	●	△
Precise control	4	8.88	○	○	●		○	●		●	●	△	●	○	△
Easy to control	4	8.88	●	●	●		●	●	○	○	○	△	●	○	△
Continuous use	4	8.88	●	△	△		●	●		△	△	○	●	●	○
Safety (non toxic)	5	11.11	○	○	○	○	△	○	○	●	●	△	○	○	●
Sufficient number of burner	4	8.88	○	●	○	△	○	●	△	△	△	△	●	○	△
Easy to clean	4	8.88		●	○				●	△	●	△	○	○	○
Energy saving	5	11.11	●	●	●	●	●	●		△	△	○	○	○	●
Durability	5	11.11	●	○	△		○	○	●	○	○	○	●	●	●
Total	45	100	646.41	541.92	566.41	208.86	557.53	686.31	448.74	477.61	548.65				
			2	6	3	9	4	1	8	7	5				

Figure 56: QFD matrix of cooking stove

4.4.3 Results of test 1

In the first two hours, the temperature of the pan surface rose rapidly from 25°C to 70°C and then slightly increased by another 10°C to the peak temperature at 80°C at 14:30. The temperature declined between 14:30 and 15:30 and rapidly dropped to 10°C at 17:00.

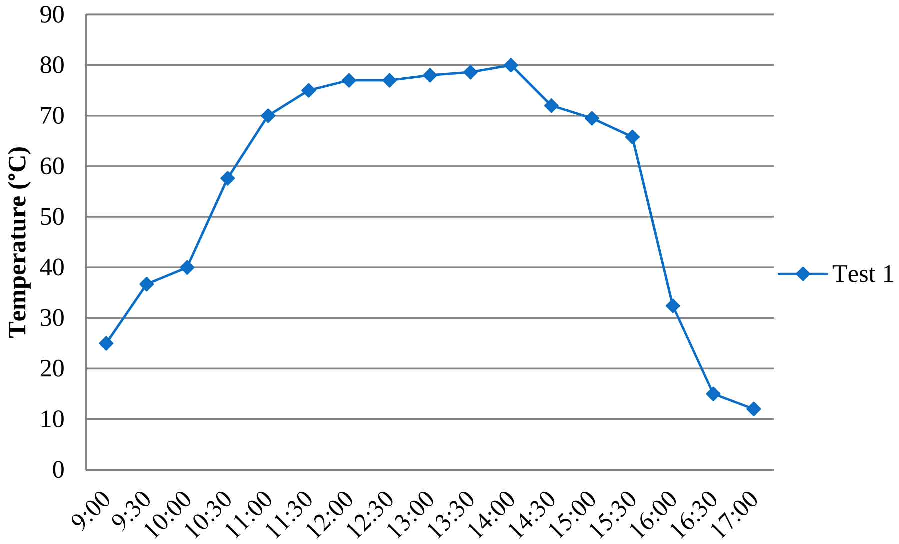


Figure 57: Temperature in the cooking vessel during test 1

4.4.4 Results of test 2

The temperature on the pan surface slightly dropped in the first 30 minutes. The temperature then rose up slowly for half an hour and quickly increased from 25°C to 160°C in one and a half hours. The temperature slightly decreased between 11:30 and 12:00 and reached the peak of 165°C at 13:00. The temperature on the surface suddenly dropped by 20°C to 145°C in 30 minutes and slightly bounded up to 150°C. After that the temperature dramatically went down until 15:30. It dropped continuously to reach 70°C at 17:00.

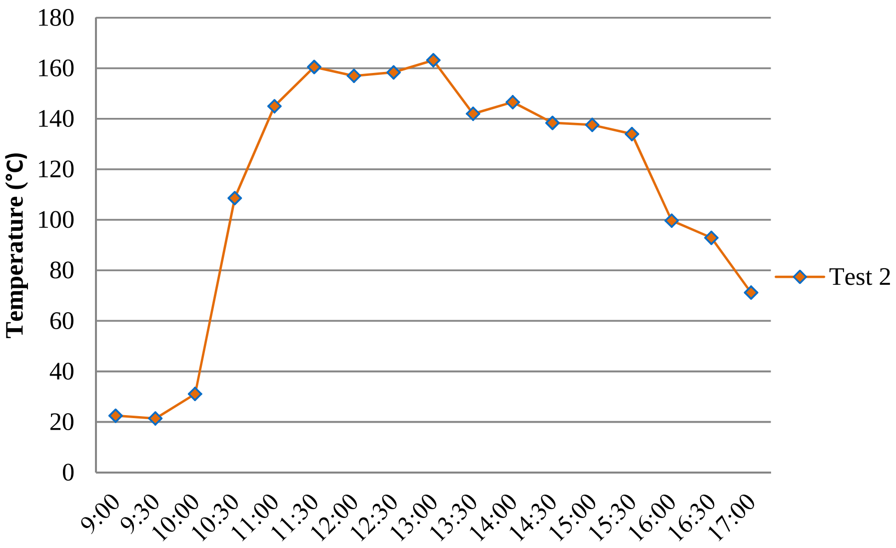


Figure 58: Temperature in the cooking vessel during test 2

4.5 Summary of acceptance criteria

The acceptance criteria in this study focus on five categories to assess a household appliance value as following; 1) objective of appliance usage, 2) preferred attribution, 3) internal condition (appliance specification), 4) external conditions and usage and 5) performance and utilities outcome.

Table 13: Summary of research results regarding acceptance criteria

Acceptance criteria	**Case study 1** **(Solar Fridge)**	**Case study 2** **(Solar cooker)**
Objective/ user expectation	Produce and keep continuously temperature inside the storage chamber between ≤12°C - +8°C	Provide continuously heat between 80°C - 232°C
Condition (internal)	10 attributes - Multi temperature - Multi storage chambers - Ease of access - Flexible capacity - Flexible layout - Ease of cleaning - Noise - Less clearance space - Energy saving - Durability	10 attributes - Temperature performance - Fasting reaching of high temperature - Precise control - Easy to control - Continuous use - Safety - Sufficient number of burners - Easy to clean - Energy saving - Durability
Condition (External)	Using Solar Energy medium temperature	Using Solar Energy medium temperature

Acceptance criteria	Case study 1 (Solar Fridge)	Case study 2 (Solar cooker)
Usage, safety	Similar to a traditional fridge, No Freon	Slightly different from a traditional cooker No smoke, no soot
Performance, Utilities (outcome)	Partly response to user needs	Partly response to user needs

4.6 Thermal energy integration into the energy-autonomous house

The findings show that a compact design of a thermal energy supply system can reduce heat losses and material costs by classifying thermal household appliances, temperature ranges and types of circulation flows. The prototype shows the combination of a cooling and a heating provider by using the same solar thermal technology.

A thermal energy system can be designed so as to prioritize flow to appliances in descending order. Appliances that require high temperature should be placed closer to the thermal source or heat storage tank than lower temperature demanding ones. The appliances can be clustered into three different zones: 1) low temperature with open loop, 2) low temperature with closed loop, and 3) medium temperature zone with closed loop. This is not mandatory but it can reduce heat losses from the thermal delivery path to the ambient environment, unless the energy delivery system has very good insulation materials to keep the heat in the system.

5 DISCUSSION

The result of this study reveals that innovative appliance development and integrating to energy-autonomous house should focus on three components to improve a user acceptance as following; 1) accuracy user need identification 2) delivered basic needs and 3) conditions that make user accepted their appliance. However, these three components can be changed under some circumstances such as behavior changing during observation, usage adaptation according to energy capability.

5.1 Accurate user needs identification

To understand the user plays an important role in identifying user needs. Careless survey methods can lead to distorted results. Inaccurate data input may lead into a wrong design and development direction.

5.1.1 Data from questionnaires

The answer from the questionnaires might not be accurate, du to vague questions, location and time of distribution. The questions should be clear and short to complete the questionnaires. Clustering the questions in a section can make the participant better understand the questions. In addition, there are some personal questions that the participants might be uncomfortable to answer, such as income, age and cooking hours. These questions should provide range answers to get the required data.

Some questions require basic technical knowledge or product specifications which the participants might not know or cannot recognize, for example what their appliance model's number is or what the capacity of their appliance is or what the main material of their appliance is. As a result, some answers were missing in the questionnaires.

It is very difficult to get information from participants in a public area unless they are waiting for something or someone. The most questionnaires were answered in a playground of a university park where people were sitting. Almost all people who were walking on the street usually denied answering the questionnaires.

5.1.2 Change of participant behavior during observation

Every participant usually changes their behavior during an observation, in particular in front of the observer. This may distort some observed actions. Friendly talk before the observation can reduce these distorted behaviors. An observer should minimize moving and noise during the observation. The observer can ask the participants to repeat their action again to get more information. The participants usually are more comfortable after they have repeated their action a few times.

5.1.3 User acceptance

The level of user acceptance strongly relates to the appliance performance and external parameters. Even though users evaluate exactly the same appliance, they might show a difference in acceptance or perception of the appliance at a different time. Therefore, a user needs to know the appliance specifications and performance clearly before making a decision about an appliance. A design and development concept

Design and development of household appliances in an energy-autonomous house can be classified into three related layers for practical working and user satisfaction as follows: 1) energy infrastructure in a building layer, 2) appliance design layer, and 3) user satisfaction layer.

5.1.4 Energy infrastructure in a building layer

The layer of energy infrastructure in a building is a bridging system between energy supply system and household appliances. It concerns building infrastructure design and engineering work. The layer basically should be a common design for all thermal household appliances in an energy-autonomous house. Criteria of this standard design layer are derived from energy system requirements such as maximum of temperature range, location of thermal output and joints mechanism. This layer is analogous to plugging and wiring of an electricity system. Nevertheless, an electricity system has more flexibility to place and connect household appliances.

The energy infrastructure can be integrated into an appliance or separated from an appliance. This depends on the size and location of a device in a building.

5.1.5 Appliance design layer

The layer of appliance design refers to a design for the main structure of a device so as to fulfill user needs. This can be designed by a conventional design process to make the device compatible with energy infrastructure and user satisfaction criteria.

5.1.6 User satisfaction layer

The layer of user satisfaction refers to a design that foresees changeable parts and provides options for adjustments according to various user needs. This layer is supposed to serve the user with different designs by changing a few components.

5.2 Technology optimization

Technology is one of the major key factors for household appliances' working performance and energy saving rate in order to satisfy users. There are three potential technologies to consider as follows.

5.2.1 Available technological components

The study reveals that using available technological components for household appliances can satisfy users on a low-moderate acceptance level. Most of the users can easily understand how to operate the household appliance in order to maximize working performance and energy efficiency. However, some users feel unsatisfied with adapting their behavior to the existing technology for energy saving or under energy-autonomous house conditions.

Using existing technological components for a new household appliance can reduce time consumption and investment in the design and development process.

5.2.2 Known technical principle with modifications

The feedback from the survey shows moderate up to high levels of user acceptance of household appliances that are operated by known technological principles which are modified. The users can mostly understand how to operate a new household appliance by referring to experience from the original technology. A modified technology can show a better performance than an existing technology because it was improved by adding or removing some parts to solve a particular problem to satisfy users. Users show acceptance of a new household appliance by slightly adjusting their behavior according to the refreshed technology because they might get some obvious benefit from adapting.

Known technological principles might take a little bit longer for developing, implementing and testing them with a household appliance than using a prompt-use, available technology. It is also more expensive to accomplish the development than to use an existing technology.

5.2.3 New technological principle

User acceptance of using a new technological principle for household appliance depends on several factors and conditions. Users need to learn completely new how to understand and use a novel device effectively for their purpose and in an energy-efficient manner. They might take a while to learn and operate an innovative device simultaneously with adapting their behavior. It usually consumes more time to understand how to use a new device than the above-mentioned technologies.

Even though an innovative household appliance might successfully come into use in an energy-autonomous house, it is still a risk to invent a new technology during a design and development process.

5.3 Discussion of test results of the solar refrigerator

All prototype components are custom-made according to the design and engineering requirements. Particularly the heat exchanger part needs to be realized in a precise and rigid manner. Therefore those components need to pass some tests before assembling the prototype.

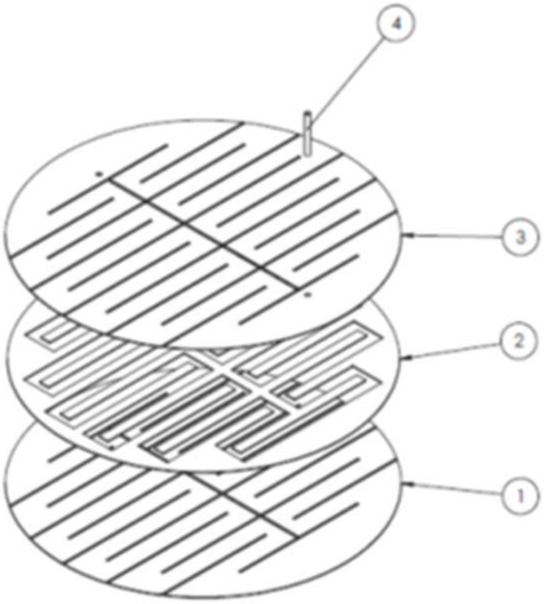


Figure 59: The new evaporator concept: 1) lower, 2) middle, 3) upper, 4) inlet tube

5.3.1 Glue

The first experiment of the aluminum sheets attachment used special glue (Loctite 94555 A&A) to seal the gaps. The glue was expected to resist air pressure at 5 bars. The part was tested by putting it under water and blowing air inside the evaporator going from low to high pressure. The result of the experiment shows that the seal broke at 2 bars. Some visible bubbles came out from the crack lines. So it needs stronger attachment.

Figure 60: The aluminum evaporator sheet attachment with the special glue

5.3.2 Glue and rivets

For the second test we added some rivets along the edge line to close the gap between those sheets, and we also sealed it with glue. The line of attachment was a thick line of 5 mm to have sufficient space for a cohesive glue area. Then we tested it again under water with air pressure of 5 bars. This version can successfully resist air pressure at 5 bars but the surface of the evaporator is not smooth and flat.

Figure 61: Evaporator seal with glue

5.3.3 Welding with aluminium

In the third version the evaporator was attached to the aluminum sheets by welding. Due to the aluminum sheets' thickness of only 3 mm, the shape was badly deformed from the welding heat. Thus, attaching together those sheets should avoid direct massive heat.

The next experiment used welding methods to attach the 3 layers of aluminum sheets with a flat surface in a firm and cohesive manner. A few versions of the cutting line were made to simplify the production process. The line was narrowed down from 5 mm to 1 mm in order to reduce working time and costs. The number of welding lines can be decreased from a double line to a single line when the gap is smaller. The red lines in Figure 62 represent the welding line produced to attach the aluminum sheets together. The single line welding can save approximately 50% of time and costs compared to the double line welding.

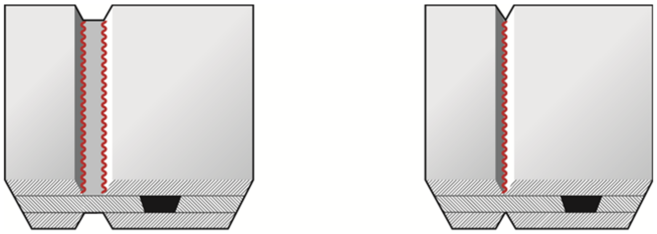


Figure 62: The picture shows the comparison between a double welding line for the big gap and a single welding line for the small gap

The result of this process was that the work piece was badly deformed. There were two reasons to explain this result. First, the aluminum was deformed due to very high temperature in a large area. Second, the thickness of the aluminum sheets was too thin with only 3 mm. The researcher decided to keep the thickness at 3 mm and reduce the temperature in a large area by using laser welding. Laser welding is very precise and strong enough for 5 bar pressure. The outcome showed that the work piece had a slight deformation with very strong cohesive attachment.

5.3.4 Steel sheets for the evaporator

Steel sheets are one of the possible materials for the evaporator. Even though steel doesn’t show as good heat transfer properties as aluminum, it is stronger at the same thickness. Steel sheets can better resist deformation caused by welding heat than aluminum. They don’t bend due to internal air pressure (5 bars) while the ammonia changes its state between liquid and gas. Welding thin aluminum sheets needs high skills. Steel welding is much easier than aluminum welding because aluminum sheets get easily deformed by the high temperature of the welding process. In addition, steel sheets are cheaper than aluminum sheets.

5.4 Discussion of test results of the cooking stove

It is assumed that the low temperature results from hot oil leaking around the control knob after two hours. The leak became stronger when the oil reached higher temperatures. This leaking may cause temperature decline and some air to get inside the pipeline and block the oil flow inside the system. Moreover, the control knob was very difficult to turn for controlling the quantity of hot oil for the cooking area.

The temperature slightly dropped in the first 30 minutes because the oil temperature in the oil storage tank was lower than the pan surface. Then, the temperature began to increase to its peak after the oil absorbed heat from the solar collector. The temperature suddenly dropped from the peak temperature (165°C) by 20°C to (145°C) because the researcher was cooking between 13:00 and 14:00. Then the temperature slightly bounced up by about 5°C (150°C) after the cooking finished. This phenomenon can be explained by the pan surface losing a little bit of heat during the cooking. Then the temperature depended on the sun radiation and weather condition. The temperature rapidly changed during cooking, which may depend on the thickness of the pan. A thinner pan wall is more sensitive to external parameters. A thick pan wall might hold a constant heat better than a thin pan wall. However, the thick pan wall might take longer time to reach high temperatures.

Figure 63: Cooking experiment with the solar cooker

5.4.1 Conceptual design

The cooking stove illustration below shows a recommended design of a cooking stove using a simple design with round corners and smooth surfaces to reduce dirt and germ. The overflow display is located in a visible position to show the level of the oil volume in the system.

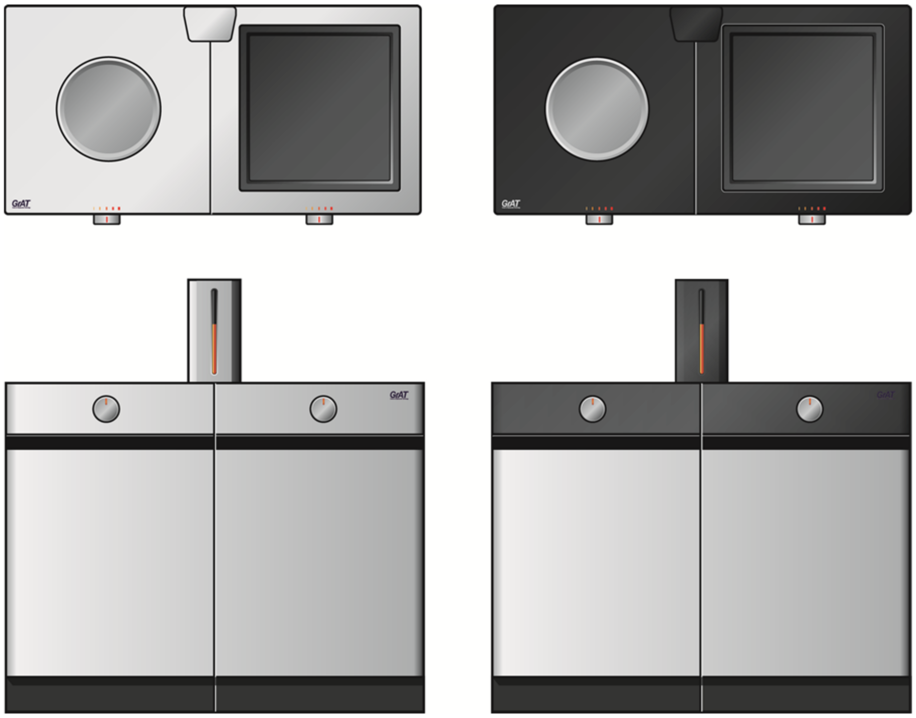


Figure 64: Solar cooking stove design concept

5.4.2 Production simplifier

The developed absorption refrigerator represents a mid-technology. In other words, it is neither high-tech, which requires large financial and resource investments, nor low-tech, which everyone can easily make with locally available materials. This means that the production of parts and the product should remain within the capacity and level of an SME. A small-scale local factory with trained engineers should be able to produce all components with ordinary machinery and tools. Thus, the design of the refrigerator and solar cooking stove take into consideration the production process and simplifies it to fall in between mass production and craft.

5.4.3 User acceptance

Based on the analysis of the research conducted with conventional cooking stoves, this study showed that solar cooking stoves have not been widely used in the residential sector because of three main reasons:

The solar cooking stove can partly respond to basic attributes that users expect to have in their cooking stove, particularly timing such as prompt using and fast temperature responding.

Users only partly accept solar technology for cooking because most of the prototypes in research still show mechanical components. A solar cooking stove still needs further ergonomics design and aesthetics to increase user satisfaction.

A solar cooking stove requires an extra infrastructure in conventional buildings. A solar thermal energy system installation is not associated with a number of products that use medium temperature. However, sharing the infrastructure with other household appliances might increase investment value.

An accepted solar cooking stove design must consist of four attributes as follows: temperature performance, precise control, prompt use and safety. There are four attributes that can increase user acceptance for a cooking stove: fast reaching of high temperature, energy saving ability, ease of cleaning and aesthetic appearance. In addition, an energy infrastructure system in a building can be adapted for supply and can be shared with other household appliances to reduce building integration costs.

5.5 Combining cooler and cooking stove

The prototype shows possibilities to combine the cooler and the cooking stove by using the same energy source. This combination is a very good energy design example for other new household appliances in the future to provide cooling and heating by sharing the same heat source, thermal oil. This system can get benefits from switching between hot and cold in a radical loop. An example is producing hot water from an air-conditioner condenser. Another good example is that the used thermal oil from the solar cooking stove can be utilized continuously in lower temperature-requiring appliances or to heat up water in the storage tank for another purpose.

6 CONCLUSIONS

6.1 Research conclusions

The overall purpose of this research was to explore actual needs and implement them in household appliances under conditions of an energy-autonomous house. This research introduced a novel design of household appliances to accomplish an energy-autonomous concept as well as to meet user acceptance criteria.

The study shows that thermal energy is the most demanded energy for household appliances for general living in a resident building, rather than electricity. There are a lot of energy losses during the energy conversion from electricity to thermal energy.

Renewable energy shows the potential to provide thermal energy to fulfill user needs when thermal household appliances switch from the use of electricity to thermal energy. This can retain electricity for some electrical household appliances for which the energy form cannot be replaced, such as lighting bulbs, television, computer, radio etc. The thermal energy system in resident buildings is recommended to have two different temperature ranges, low temperature range and medium temperature range, to cover all household appliances requirements.

The new household appliances design concept should be able to deliver at least the design criteria to meet user expectations. Additional functions and extra performances can also increase user satisfaction, however, they may become expected by users over time. Therefore the new design concept of household appliances can be developed further to improve performance and alternative options to fit more user needs within the energy-autonomous concept.

There were two case studies to represent the practical design and development of household appliances. The first case study was a solar refrigerator. This study included experiments by implementing different technologies in a refrigerator. There are three different technologies to explore the working potential: 1) available technological components, 2) known technical principle with modifications, and 3) new technological principle. The results revealed that modified technology for household appliances’ design and development has more potential to achieve the energy-autonomous house concept.

The second case study was an indoor solar cooking stove. This study investigated the user acceptance value through the Kano model and Quality Function Deployment (QFD) methods in order to review a new solar cooking stove design. The results of the study revealed that the new solar cooking stove consists of three different design layers which have to be considered to increase user acceptance: 1) energy infrastructure, 2) appliance design, and 3) user satisfaction.

A solar cooking stove which can be used in an energy-autonomous house in rural off-grid areas is positively accepted if the environmental impact compared to firewood cooking stoves is considered. Changing the design and development can remarkably contribute to solving environmental problems such as energy scarcity, shortage of electricity, or global warming. Moreover, these new design concepts will be healthier to use and cheaper to maintain.

Overall, the energy-autonomous house concept can reduce electric consumption over 96%. With this minimized consumption it becomes more feasible, practical, sustainable, environmentally friendly and affordable to supply the remaining electricity demand with solar energy.

6.2 The study's scientific contributions

The study provides basic criteria to increase user acceptance of household appliances that use thermal energy as main energy input. The proposed alternative design and development that can be a paradigm design concept for replication with other household appliances to reduce electricity consumption in a residential building.

The research provides information on thermal energy demand and working performance of a solar refrigerator and a solar cooking stove. This information can help architects, product designer and engineers in planning working capacity as well as in designing a solar thermal supply system.

This knowledge can be applied to other household appliances and also thermal energy supply systems in an energy-autonomous house.

6.3 Limitation of this study

This study was limited to two household appliances that use medium temperature only; the number of case studies can be extended to other household appliances in the same or a different temperature range, such as iron, rice cooker, and water heater for shower or washing machine.

The present study has experimented with a specific energy-autonomous house model to investigate the potential of a thermal energy supply system. The thermal energy production can be extended to various sources such as biomass, stirling engine and parabolic collectors. Expanding the energy-autonomous house model to full scale might provide precise information for other replications because the total length of the thermal piping system might influence the thermal energy system and household devices' capacity.

Further study in a different climate is also interesting for further experiments. This research has been done only in Austria which is located in a temperate climate zone. The device has more potential for practical use in a tropical country with more sunshine such as the Philippines and Thailand. This comprehensive design concept can be a very useful paradigm for tourism industries in terms of environmental issues and customer satisfaction.

The prototypes were tested in a short period of time to get a good performance. They should also be monitored during a longer period of time to get actual capacity and appliance performance data throughout a whole year.

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APPENDIX

A. Questionnaires

1st questionnaire

Number

Fragebogen

Name of household appliance:	Name of distributor:
Brand/Model:	Date:
Name of participant:	Time:
☐ Male ☐ Female	
Age: Occupation:	
Contact	

Fragebogen zu Kühl- und Gefriergeräten

Vielen Dank für Ihre Teilnahme an unserer Befragung! Das Ausfüllen wird ca. 10 Minuten dauern. Mit diesen Fragen versuchen wir, mehr über Ihre Nutzungsgewohnheiten und Ihre Zufriedenheit mit Ihrem Kühlgerät zu erfahren und Ihre Präferenzen kennenzulernen. Ihre Angaben und Daten werden anonymisiert und nur für die wissenschaftliche Auswertung verwendet.

Einige Fragen beziehen sich auf Ihren derzeitigen Kühl-/Gefrierschrank (Größe, Marke etc.), daher empfehlen wir Ihnen, den Fragebogen bei sich zuhause auszufüllen

Part1 Bitte beantworten Sie uns einige Fragen über Ihr Kühl-/Gefriergerät

1 Wie viele Kühl-/Gefriergeräte haben Sie zuhause?

☐ 1 ☐ 2 ☐ 3 ☐ Mehr als 3

2 Welchen Typ Kühlschrank haben Sie? (Wenn Sie mehr als ein Gerät haben, beziehen Sie sich bitte auf den hauptsächlich verwendeten)

☐ Eintürige Minibar ☐ Eintürig ohne Gefrierfach ☐ Eintürig mit Gefrierfach

☐ Zweitürig (Gefrierschrank oben) ☐ Zweitürig (Gefrierschrank unten)

☐ Gerät mit Flügeltüren ☐ Andere (bitte angeben…………………………….)

3 Wie alt ist Ihr Kühlschrank? (Wenn Sie mehr als ein Gerät haben, beziehen Sie sich bitte auf den hauptsächlich verwendeten)

☐ Less than 1 Jahr ☐ 1-2 Jahre ☐ 2-3 Jahre ☐ 4-5 Jahre

☐ weiß nicht genau, aber älter als 5 Jahre ☐ weiß nicht

4 Bitte geben Sie die Energieeffizienzklasse Ihres Kühlschranks an. (Sie können diese am Etikett an/in dem Gerät oder in der Gebrauchsanweisung finden.)

☐ A++ ☐ A+ ☐ A ☐ B ☐ C ☐ weiß nicht

☐ Andere (bitte angeben)………………………………………………………

5 Wo ist Ihr hauptsächlich genutztes Kühl-/Gefriergerät aufgestellt?

☐ Küche ☐ Wohnzimmer ☐ Keller ☐ Gang

☐ Andere (bitte angeben)…………………………………………………………

6 Wie oft tauen Sie Ihr Kühl-/Gefriergerät ab?

☐ Wöchentlich ☐ Monatlich ☐ Halbjährlich ☐ Jährlich

☐ Nie

7 Welche Art von Temperaturanzeige hat Ihr Kühl-/Gefriergerät?

☐ Digital ☐ Grafisch ☐ Thermometer ☐ Haben keine

☐ Andere (bitte angeben)……….……………………………………………..

8 Kennen Sie die Temperatur Ihres Kühl-/Gefriergeräts?

☐ Ja (bitte angeben): Kühlschrank……. °C, Gefriergerät…….°C ☐ weiß nicht

9 Wann benutzen Sie gewöhnlich Ihren Kühlschrank? (Sie können mehrere Optionen auswählen.)

☐ AM: 00:01-03:00 ☐ 03:01-06:00 ☐ 06:01-09:00 ☐ 09:01-12:00

☐ PM: 12:01-15:00 ☐ 15:01-18:00 ☐ 18:01-21:00 ☐ 21:01-24:00

10 Mit welchen Eigenschaften Ihres Kühlschranks sind Sie zufrieden? (Mehrfachnennung möglich)

☐ Großes Fassungsvermögen ☐ Design ☐ Kühl ☐ funktion Wenig Lärm

☐ Leicht zu reinigen ☐ Keine Frostansammlung ☐ Art der Türöffnung

☐ Andere (bitte beschreiben) …………………………..………………………….

11 Mit welchen Eigenschaften Ihres Kühlschranks sind Sie nicht zufrieden? (Mehrfachnennung möglich)

☐ Geringes Fassungsvermögen ☐ Design ☐ Kühlfunktion ☐ Viel Lärm

☐ Schwierig zu reinigen ☐ Frostansammlung ☐ Art der Türöffnung

☐ Andere (bitte beschreiben) ………………………….……………………………..

12 Welche Funktionen und Eigenschaften hätten Sie gerne in Ihrem Kühl-/Gefriergerät? (Mehrfachnennung möglich)

☐ Wasserspender ☐ Eismaschine ☐ Transparente Tür Temperaturanzeige in °C

☐ Schöner Griff ☐ Unsichtbarer Griff Geruchlos ☐ Energiesparend

☐ Andere (bitte beschreiben) ………………………….…………………………..

13 Wie viele Personen leben in Ihrem Haushalt/nutzen Ihren Kühlschrank (inklusive Sie selbst)?

☐ 1 Person ☐ 2 Personen ☐ 3 Personen ☐ 4 Personen

☐ mehr als 4 Personen

14 Wohnen Sie in einem Haus oder einer Wohnung?

☐ Haus ☐ Wohnung

15 Wie groß ist Ihre Wohnung/Haus?

☐ Kleiner als 30m^2 ☐ 31-50 m² ☐ 51-80 m² ☐ 81-120 m²

☐ Größer als 120m^2

Part 2) Bitte beantworten Sie uns einige Fragen über Ihren Herd.

16 Welchen Typ Herd haben Sie?

☐ Freistehender Herd (“Stand-alone”) ☐ Eingebaute Herdfläche

☐ Andere (bitte beschreiben) ………………………….………………………….

17 Welche Energiquelle nutzt Ihr Herd?

☐ Charcoal/Brennholz/Kohle ☐ Gas ☐ Elektrizität

☐ Solarthermie ☐ Andere (bitte beschreiben) …………………………….…………

18 Aus welchem Material ist die Oberfläche Ihres Herdes?

☐ Metall,Stahl ☐ Glas,Keramik ☐ Andere (bitte angeben) …………

19 Wie viele Kochflächen hat Ihr Herd?

☐ 1 ☐ 2 ☐ 3 ☐ 4

☐ Mehr als 4 (bitte Anzahl angeben)………………………………………………..

20 Welches Kochgeschirr verwenden Sie auf Ihrem Herd? (Mehrfachnennung möglich)

☐ Topf ☐ Pfanne ☐ Wok ☐ Kessel

☐ Andere (bitte beschreiben) ……………………….………………………………

21 Wie oft kochen Sie?

☐ Seltener als 7-mal pro Woche ☐ Täglich ☐ Mehr als 7-mal pro Woche

☐ Andere (bitte beschreiben) ……………………….………………………………

22 Wie oft reinigen Sie Ihren Herd?

☐ Nie ☐ Täglich ☐ 2- bis 5-mal pro Woche ☐ Wöchentlich

☐ Monatlich ☐ Jährlich ☐ Andere (bitte beschreiben) ………………………..

23 Wie reinigen Sie Ihren Herd?

☐ Trockenes Abwischen ☐ Seife und Schwamm

☐ Reinigungsmittel und harter Schwam/Bürste ☐ Starkes Schrubben

☐ Andere (bitte beschreiben) ……………………….………………………………

24 Wie lang lassen Sie Ihren Herd im Durchschnitt aufgedreht?

☐ 1-10 Minuten ☐ 10-20 minutes ☐ 20-30 minutes

☐ Mehr als 30 Minuten

☐ Andere (bitte beschreiben) ……………………….…………………………….

25 Kennen Sie die Kochtemperatur?

☐ Nein ☐ Ja

26 Woher kennen Sie die Kochtemperatur?

☐ Schätzung aufgrund des Schalters ☐ Schätzung aufgrund von Erfahrung

☐ Schätzung aufgrund der Reaktion des Gargutes

☐ Andere (bitte beschreiben) ……………………….……………………………

27 Wie schützen Sie Ihre Herdoberfläche vor Schmutz?

☐ Keine speziellen ☐ Vorsichtsmaßnahmen ☐ Folie auf der Oberfläche

☐ Vorsichtiges Kochen ☐ Andere (bitte beschreiben) ……………………….……………

28 Welche Garmethode verwenden Sie hauptsächlich? Bitte reihen Sie die Methoden von 1 (am öftesten) bis 5 (am seltensten).

	1	2	3	4	5
Kochen	☐	☐	☐	☐	☐
Braten	☐	☐	☐	☐	☐
Frittieren	☐	☐	☐	☐	☐
Garen	☐	☐	☐	☐	☐
Grillen	☐	☐	☐	☐	☐

29 Zu welcher Zeit kochen Sie üblicherweise? (Mehrfachnennung möglich)

☐ AM: 00:01-03:00 ☐ 03:01-06:00 ☐ 06:01-09:00

☐ 09:01-12:00

☐ PM: 12:01-15:00 ☐ 15:01-18:00 ☐ 18:01-21:00

☐ 21:01-24:00

Nutzerpräferenzen

30 Was mögen Sie an Ihrem Herd?

☐ Starke Hitze ☐ Hitze gut kontrollierbar ☐ Energiesparend

☐ Leicht auf- und abzudrehen ☐ Sicherheit ☐ Beständigkeit

☐ Leicht zu reinig ☐ Andere (bitte beschreiben) ……………………….………

31 Was mögen Sie nicht an Ihrem Herd?

☐ Unzureichende Hitze
☐ Hitze schlecht Kontrollierbar
☐ Hoher

☐ Energieverbrauch
☐ Schwierig auf- und abzudrehen
☐ Oft kaputt

☐ Schwierig zu reinigen
☐ Andere (bitte beschreiben) ………………………..

35 Welche Funktion hätten Sie gerne an Ihrem Herd? (bitte angeben)

………

………

………

………………………………………………………………………………………………………

Date:…………………………………. Time:……………………………

Recorder Name: …………………………………………………………..

Place:………………………………………………………………………

Vielen Dank für Ihre Zeit!

Falls Sie an weiteren Informationen interessiert sind, kontaktieren Sie bitte die Gruppe Angepasste Technologie (GrAT) an der TU Wien (contact@grat.at, Tel: 01-58801-49523).

GrAT
Center for Appropriate Technology

TU WIEN
TECHNISCHE
UNIVERSITÄT
WIEN
Vienna University of Technology

2nd questionnaire

Fragebogen

Number

Name of household appliance: Name of distributor:

Brand/Model: Date:

Name of participant: Time:

☐ Male ☐ Female

Age: Occupation:

Contact

Bitte geben Sie die Wichtigkeit von Kochherd und Kühlschrank an.

5 = Äußerst wichtig, 4 = Recht wichtig, 3 = Moderat wichtig 2, = Weniger wichtig

1, = Nicht wichtig

Kochherd

1) Leicht zum An- und Ausschalten

5 ☐ ☐4 ☐ 3 ☐ 2 ☐ 1

2) Beständige Hitze

5 ☐ ☐4 ☐ 3 ☐ 2 ☐ 1

3) Leichtigkeit beim Hitze Regulieren

55 ☐ ☐4 ☐ 3 ☐ 2 ☐ 1

4) Warnsignal bei Überhitzung

5 ☐ ☐4 ☐ 3 ☐ 2 ☐ 1

5) Energieeinsparung

5 ☐ ☐4 ☐ 3 ☐ 2 ☐ 1

6)Schnelles Kochen

5 ☐ ☐4 ☐ 3 ☐ 2 ☐ 1

7) Schnelles Erhitzen

5 ☐ ☐4 ☐ 3 ☐ 2 ☐ 1

8) Leichtigkeit beim Putzen

5 ☐ ☐4 ☐ 3 ☐ 2 ☐ 1

9) Kratzer-resistente Materialien

5 ☐ ☐4 ☐ 3 ☐ 2 ☐ 1

10) Chemisch-resistente Materialien

5 ☐ ☐4 ☐ 3 ☐ 2 ☐ 1

11) Pflegeleichtigkeit

5 ☐ ☐4 ☐ 3 ☐ 2 ☐ 1

12) Möglichkeit verschiedene Pfannen ,Töpfe u. Woks zu verwenden

5 ☐ ☐4 ☐ 3 ☐ 2 ☐ 1

13) Möglichkeit verschieden große Pfannen, Töpfe u. Woks zu verwenden

5 ☐ ☐4 ☐ 3 ☐ 2 ☐ 1

14) Sicherheit

5 ☐ ☐4 ☐ 3 ☐ 2 ☐ 1

15) Nicht-toxische Materialien

55☐ ☐4 ☐ 3 ☐ 2 ☐ 1

16) Beständigkeit

55☐ ☐4 ☐ 3 ☐ 2 ☐ 1

17) Langlebigkeit

5 ☐ ☐4 ☐3 ☐2 ☐ 1

18) Ohne Rauchbildung (z.B. elektrisch)

5 ☐ ☐4 ☐3 ☐2 ☐1

19) Ohne Ruß

5 ☐ ☐ 4 ☐3 ☐2 ☐1

20) Niedrige (Erhaltungs-)kosten

5 ☐ ☐ 4 ☐3 ☐2 ☐1

21) Umweltfreundlichkeit

5 ☐ ☐ 4 ☐ 3 ☐ 2 ☐ 1

22) Anpassung an umliegende Möbel

5 ☐ ☐ 4 ☐ 3 ☐ 2 ☐ 1

Kühlschrank

1) Leichte Zugänglichkeit

5 ☐ ☐ 4 ☐ 3 ☐ 2 ☐ 1

2) Leicht beim Öffnen und Schließen

5 ☐ ☐ 4 ☐ 3 ☐ 2 ☐ 1

3) Ausreichender Abstellraum

5 ☐ ☐ 4 ☐ 3 ☐ 2 ☐ 1

4) Leicht zu säubern

5 ☐ ☐ 4 ☐ 3 ☐ 2 ☐ 1

5) Energieeinsparung

5 ☐ ☐ 4 ☐ 3 ☐ 2 ☐ 1

6) Leichte Erhaltung

5 ☐ ☐ 4 ☐ 3 ☐ 2 ☐ 1

7) Temperaturangabe

5 ☐ ☐ 4 ☐ 3 ☐ 2 ☐ 1

8) Einordnungshinweise für Produktklassen

5 ☐ ☐ 4 ☐ 3 ☐ 2 ☐ 1

9) Leichte Temperatureinstellungsmöglichkeit

5 ☐ ☐ 4 ☐ 3 ☐ 2 ☐ 1

10) Variierender Platz (dem Verbrauch angepasst)

5 ☐ ☐ 4 ☐ 3 ☐ 2 ☐ 1

11) Erhaltung der Produkte in gutem Zustand

5 ☐ ☐ 4 ☐ 3 ☐ 2 ☐ 1

12) Geruchskontrolle

5 ☐ ☐4 ☐3 ☐2 ☐1

13) Pflegeleichtigkeit

5 ☐ ☐4 ☐3 ☐2 ☐1

14) Trockenhaltung

5 ☐ ☐4 ☐3 ☐2 ☐1

15) Kältebeibehaltung

5 ☐ ☐4 ☐3 ☐2 ☐1

16) minimale Geräuschbildung

5 ☐ ☐4 ☐3 ☐2 ☐1

17) Beständigkeit

5 ☐ ☐4 ☐3 ☐2 ☐1

18) Zuverlässigkeit

5 ☐ ☐4 ☐3 ☐2 ☐1

19) Ohne Frost

5 ☐ ☐4 ☐3 ☐2 ☐1

20) Gleichbleibende Kälte

5 ☐ ☐4 ☐3 ☐2 ☐1

21) Energieeinsparung

5 ☐ ☐4 ☐3 ☐2 ☐1

22) Sicherheit

5 ☐ ☐4 ☐3 ☐2 ☐1

23) Umweltfreundlich

5 ☐ ☐4 ☐3 ☐2 ☐1

24) Anpassung an umliegende Möbel

5 ☐ ☐4 ☐3 ☐2 ☐1

Thank you for your time

B. Interview questions

Name of household appliance:

Brand/Model:

Name of participant:

☐ Male ☐ emale

Age: Occupation:

Contact

Name of interviewer:

Date:

Time:

Questions	User voices	Interpretation
General function		
Like		
Dislike		
Improvement notices		

C. Remark:

Curriculum vitae

Name: Chaipipat Pokpong

Date of birth: 2 April 1974

Nationality: Thai

Address: Theresianumgasse 5/2/28 A 1040 Vienna, Austria

Education:

Primary school

1977 – 1984 Jaipienwittayanusorn school

1984 – 1986 Watphromsakorn school

Junior school

1986 – 1988 Darunpittaya school

1988 – 1989 RajvinjBangkwew school

High school

1989 – 1992 Surasakmontri school

Bachelor degree

1992 – 1996 Bachelor of Fine and applied Art (BFA), Product design, Rangsit University, Thailand

Master degree

2000 – 2002 Master of Industrial Design (MID), The University of New South Wales, Australia

Work Experiences:

1995 Internship, Saha union, Head office

1996 Internship, SilpUdom manufacturing

1996 – 2000 Displays designer, Neo exhibit Ltd.

2002 – 2004 Regional Industrial designer assistance, Electrolux (Thailand)

2003 – 2004 Guest lecture, Department of Industrial design, Rajabhat Suandusit University

Guest lecture, Department of Industrial design, Faculty of Art and Design, Rangsit University

2004 – Present Lecturer, Department of Industrial design, Faculty of Architecture, King Mongkut’s Institute of Technology Ladkrabang (KMITL)

2009 – Present Research fellow, Center for Appropriate Technology, Vienna University of Technology (TU Wien