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Occupant behaviour in buildings - electricity consumption in residential buildings

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MASTER THESIS

for

Student Karoline Dahl Fosby

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Occupant behaviour in buildings - electricity consumption in residential buildings

Brukeratferd i bygninger - strømforbruk i boligbygg

Background and objective

Energy related occupant behaviour has a significant impact on the real energy use and indoor environment quality in buildings. At the same time, energy related occupant behaviour is a key parameter for building design optimization, energy diagnosis, performance evaluation as well as for building energy performance simulation. However, scientists are pointing out that there is a significant inconsistency between the energy use calculated by means of simulations and the real-life measurements for the same building. Lack of proper occupant behaviour models for simulation purposes is pointed out as the most suspicious reason for this difference.

The objective for this master thesis is to give support to development of knowledge regarding energy related occupant behaviour that will lead to development of more accurate occupant behaviour models. Identification of household appliances and devices use is a key in occupant behaviour studies. The assignment comprise monitoring and decoding electricity consumption behaviour in residential buildings based on field study in the ZEB - Living Lab. The assignment is connected to the current PhD research entitled "Modelling and Simulation of Occupant Behaviour in Buildings".

The following tasks are to be considered:

1. Prepare a knowledge base about different device performance and characteristics of electrical energy consumption in time. Developed database will hold additional metadata regarding typical purpose of the devices.
2. Perform a survey regarding localization of different device inside residential buildings. Collected input data will support development of probabilistic heat map of device placement in residential buildings.
3. Conduct field measurements, followed by decoding of electricity consumption in test bed and previously gather data in the Living Lab. Develop the device usage timeline in various days for the detection of the usage patterns.
4. Perform a simulation of household usage, based on a collected input and developed database.
5. Make a draft proposal (6-8 pages) for a scientific paper based on the main results of the work performed in the master thesis.
6. Make proposal for further work on the same topic.

Within 14 days of receiving the written text on the master thesis, the candidate shall submit a research plan for his project to the department.

When the thesis is evaluated, emphasis is put on processing of the results, and that they are presented in tabular and/or graphic form in a clear manner, and that they are analyzed carefully.

The thesis should be formulated as a research report with summary both in English and Norwegian, conclusion, literature references, table of contents etc. During the preparation of the text, the candidate should make an effort to produce a well-structured and easily readable report. In order to ease the evaluation of the thesis, it is important that the cross-references are correct. In the making of the report, strong emphasis should be placed on both a thorough discussion of the results and an orderly presentation.

The candidate is requested to initiate and keep close contact with his/her academic supervisor(s) throughout the working period. The candidate must follow the rules and regulations of NTNU as well as passive directions given by the Department of Energy and Process Engineering.

Risk assessment of the candidate's work shall be carried out according to the department's procedures. The risk assessment must be documented and included as part of the final report. Events related to the candidate's work adversely affecting the health, safety or security, must be documented and included as part of the final report. If the documentation on risk assessment represents a large number of pages, the full version is to be submitted electronically to the supervisor and an excerpt is included in the report.

Pursuant to "Regulations concerning the supplementary provisions to the technology study program/Master of Science" at NTNU §20, the Department reserves the permission to utilize all the results and data for teaching and research purposes as well as in future publications.

The final report is to be submitted digitally in DAIM. An executive summary of the thesis including title, student's name, supervisor's name, year, department name, and NTNU's logo and name, shall be submitted to the department as a separate pdf file. Based on an agreement with the supervisor, the final report and other material and documents may be given to the supervisor in digital format.

☐ Work to be done in lab (Water power lab, Fluids engineering lab, Thermal engineering lab)
☐ Field work

Department of Energy and Process Engineering, 18. January 2018

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Vojislav Novakovic
Academic Supervisor

Research Advisor: PhD candidate Jakub Wladyslaw Dziedzic, NTNU

Preface

This master thesis is the last part of the Master of Energy and Environmental Engineering, and has been carried out at the Department of Energy and Process Engineering at the Norwegian University of Science and Technology (NTNU). The thesis is connected to the PhD research entitled "Modelling and Simulation of Occupant Behaviour in Buildings".

I would like to give a special thanks to my research advisor Jakub Wladyslaw Dziedzic for all guidance, feedback and encouragement through the thesis, I could not have done this without your help. I would also like to thank my supervisor Vojislav Novakovic.

In addition, I would like to thank Kristian S. Skeie for providing me the data from the ZEB - Living Lab, and all the participants of the survey.
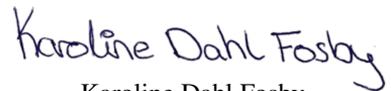
Karoline Dahl Fosby

Trondheim, June 14, 2018

Abstract

Energy-related occupant behaviour has a major impact on the energy use in buildings, and occupant behaviour is also a key parameter for building design optimization, energy diagnosis, performance evaluation and building energy performance simulation. Using today's models for occupant behaviour, there is major differences between energy use simulated and real measurements for the same building. One of the main reasons for this difference is the lack of proper occupant behaviour models. The work of this thesis will support the development of knowledge regarding occupant behaviour related to energy, which can lead to development of more accurate occupant behaviour models. The work accomplished concerns mainly the kitchen and kitchen appliances.

To get more information of household appliances, a knowledge base of typical devices in a residential has been prepared. The knowledge base contains device performance and characteristics of electrical energy consumption in time for 21 different household devices. A survey concerning use and placement of kitchen appliances have been conducted to get more information on use of devices. The results of the part of survey which dealt with placement of devices in the kitchen have been used as base for development of heat maps of device placement in the kitchen.

Field measurements from the ZEB - Living Lab have been used for decoding of electricity consumption behaviour in residential buildings. Based on this, and the developed heat maps, a simulator for household usage have been developed. The simulator has to be further developed, and suggestions for this work is given.

Sammendrag

Brukeratferd i bolighus relatert til energiforbruk har stor innvirkning på energibruken i bygninger, og brukeratferd er også en nøkkelparameter for bygningsoptimalisering, ytelsesevaluering og energisimuleringer av bygget. Ved bruk av dagens modeller for brukeratferd er det store forskjeller mellom energiforbruk simulert og gjennomførte målinger for samme bygning. En av hovedårsakene til denne forskjellen er mangelen på gode modeller for brukeratferd. Arbeidet gjennomført i denne oppgaven vil gi mer kunnskap om brukeratferd relatert til energi, som kan føre til utvikling av mer nøyaktig modeller for brukeratferd i bygninger. Arbeidet er hovedsakelig gjennomført med tanke på kjøkken og kjøkkenutstyr.

For å få mer informasjon om husholdningsapparater, har en database av typiske apparater i boliger blitt utarbeidet. Databasen inneholder informasjon om ytelse og andre egenskaper for elektrisk energiforbruk for 21 forskjellige apparater. En undersøkelse om bruk og plassering av kjøkkenapparater ble gjennomført for å få mer informasjon om bruk av kjøkkenapparater. Resultatene fra den delen av undersøkelsen som omhandler plassering av apparater på kjøkkenet, har blitt brukt som grunnlag for utvikling av varmekart over plasseringen av de forskjellig apparatene på et kjøkken.

Feltmålinger fra ZEB - Living Lab har blitt brukt til analyse av strømforbruket i bolighus. Basert på dette og de utviklede varmekartene er det utviklet en simulator for bruk av apparater i et bolighus. Simulatoren må videreutvikles, og forslag til dette arbeidet er gitt.

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Chapter 1

Introduction

1.1   Background

Energy-related occupant behaviour has a major impact on the energy use in buildings. Sonderegger found that 71% of the energy demand variation in residential buildings unexplained by conventional factors, like number of bedrooms, area of insulated glass and if the house is an end unit, are caused by occupant behaviour (Sonderegger, 1977), and Seryak showed in his study that for a given dwelling, occupant behaviour can affect the energy consumption by as much as 100% (Seryak and Kissock, 2003). In particular, lightning, plug loads, ventilation and heating are largely dependent on the occupants (D'Oca and Hong, 2015). Occupant behaviour is also a key parameter for building design optimization, energy diagnosis, performance evaluation and building energy performance simulation.

The choice of modelling approach is an important factor for predicting occupants use of appliances (Yilmaz et al., 2017), and this will affect the simulation of the energy use in the residential. Using today's models for occupant behaviour, there is major differences between energy use simulated and real measurements for the same building. One of the main reasons for this difference is the lack of proper occupant behaviour models.

Occupant behaviour includes the residents presence, movement and how they use the devices in the building (Yan et al., 2017). The International Energy Agency define energy-related occupant behaviour as "observable actions or reactions of a person in response to external or internal stimuli, or actions or reactions of a person to adapt to ambient environmental conditions" (Yoshino et al., 2017).

1.2   Objective

The objective of the work accomplished in this assignment is to provide support to the development of knowledge regarding occupant behaviour related to energy. This knowledge will lead to development of more accurate occupant behaviour models. The thesis is connected to the PhD research "Modelling and Simulation of Occupant Behaviour in Buildings".

Identification of household appliances and devices is a key in occupant behaviour studies. To get more information about this, a knowledge base about different device performance and characteristics of electrical energy consumption in time will be developed, and a survey regarding localization of different device placement in residential buildings will be conducted.

Field measurements will be conducted in test bed. Data from this measuring and data from field studies in the ZEB - Living Lab will be used for decoding of electricity consumption behaviour in residential buildings. Based on the collected input and the developed database, a simulation of household usage will be performed.

A final recommendation for further work on the subject will be proposed. The main results of the work will be presented in a scientific paper.

1.3   Limitation of scope

In the thesis, most tasks have been chosen to focus on the kitchen and kitchen devices. The database is made for devices used in the entire residential, while the survey, the electricity consumption from the field measurements and the simulation concerns just the kitchen.

1.4   Outline of thesis

In chapter 2, three existing high-resolution energy demand models are presented.

Chapter 3 describes the knowledge base and how it was made, and chapter 4 describes how the survey was constructed.

In chapter 5, the process of conducting field measurements in test bed and the ZEB - Living Lab are described. Chapter 6 presents how the data from Living Lab were processed.

Chapter 7 presents the results from the survey and the development of heat maps of device placement in the kitchen.

Chapter 8 describes the development of the simulator of household usage.

In chapter 9 the results of energy consumption in Living Lab are presented.

Chapter 10 and 11 presents, respectively, the heat maps of device placement in he kitchen, and the simulations of household usage.

Chapter 12 presents conclusion and suggestion for further work.

Chapter 2

High-resolution Energy Demand Models

The fact that the occupants behaviour and use of electrical appliances have a great impact on the pattern of electricity use in a residential building, has been a known fact for a longer period, and many models have been developed to describe and model both how residents behave and how this affects the electricity consumption. In this chapter, three models dealing with high-resolution energy demand will be introduced.

All of the models presented here are bottom-up models. That means that the energy consumption is estimated by use of information about the parts that constitute the entire aspect you want to investigate. Like, if you want to investigate the total consumption for the whole residential sector, the consumption for one, or a group of houses, is estimated using characteristics of the houses, like geometry and household devices, combined with climate, indoor temperature and occupant behaviour, and than this estimated consumption is used to find the total consumption for the whole residential sector. (Swan and Ugursal, 2009) In the models presented here, information about the appliances, like televisions, vacuum cleaners and other electricity loads, is used to find the demand for the dwellings.

2.1   Model of Domestic Electricity Use - Richardson et al.

Richardson, Thomson, Infield and Clifford developed in their study on domestic electricity use, a high-resolution energy demand model based on the combination of patterns of active occupancy, that is, whether the residents are at home and awake, and daily activity profiles showing when and for how long the residents use to perform certain activities. The model also includes sharing of appliances and correlated use of appliances.

In the study, the electricity demand, with one minute resolution, was predicted by simulating the appliance use. The input for the simulations was the daily activity profiles, population of appliances in the dwelling performed randomly using statistical ownership data, annual energy use and power characteristics of the appliances, knowledge about how

use of the appliances is related to a activity profile, for instance cooking, and information about switch-on events.

For validation of the model, the simulated demand was compared to measured demand in 22 residential houses over a year. Also the measuring was carried out with one minute resolution. Comparing a 24 hour demand profile from the simulated data with a random 24 hour demand profile from the measured data, showed that the profiles had similar characteristics with low use of electricity at night and increased use throughout the day. To make a greater validation of the model, there were simulated energy demand over one year for 22 residential houses. By comparison of the results from the simulation and the measured data, the simulated data were well matched with the results from measuring. In particular the time-coincidence of demand between multiple dwellings and the representation of the power factor from the simulation matches closely to the results from the measuring. The simulation of the annual mean daily demand profiles under-represented the demand during the night, compared to the real use. Also the seasonal variation of the electricity demand were underestimated in the model. (Richardson et al., 2010)

2.1.1   Model of Domestic Lighting

Prior to the developing of the above mentioned model, Richardson, Thomson, Infield and Clifford developed a similar model only regarding lighting. This model uses the level of natural light coming in from outdoors, and number of active occupants as input, and predict the electricity use for lighting in a dwelling with 1 minute resolution. (Richardson et al., 2009)

This model was incorporated in the model that deals with the electricity use for the whole dwelling. (Richardson et al., 2010)

2.2   Building Occupancy Model for Energy Demand Simulations - McKenna et al.

The choice of building occupancy model used in the simulation of energy demand has a great impact on the result. McKenna, Krawcynski and Thomson developed in their study a two-state active-occupancy model into a four-state model. This means that if the occupant is present or absent, and active or inactive is no longer treated combined, but separately, which gives the possible states 'not at home, and not active', 'not at home, and active', 'at home, and not active' and 'at home, and active'.

The model uses a first-order Markov chain technique. In the model, dwellings are differentiated by number of occupants, and weekdays and weekends are separated from each other. It is based on the UK time-use survey, which is 24 hours diaries with recording every 10.minute that contains location and activity fields.

To verify the model, the output from the four-state model were compared to the UK time-use survey. Considering state probability and state duration, the results from the model were close to the data from the UK time-use survey. The model under-represented

dwellings with 24 hour occupancy and dwellings that are unoccupied frequently, and the middle were over-represented. To correct for the under-representation of the residential with 24 hour occupancy, a factor was implemented in the model. (McKenna et al., 2015)

2.3 Model of Thermal-Electrical Domestic Demand - McKenna et al.

In further work, McKenna and Thomson extended CREST's existing electrical domestic demand model into an integrated thermal-electrical demand model. The change in the model is that the thermal model is integrated with the electrical model which gives that the thermal and electrical output variables are better correlated timely with the occupancy of the residential.

CREST's electrical domestic demand model is a bottom-up model based on activity, and models the diversity of end-use energy demand with high resolution, by use of stochastic programming techniques. This kind of model are based on a two-state active-occupancy model, and takes into account electricity consumption related to lighting, appliances and generation from photovoltaics. Model of Domestic Electricity Use by Richardson et al. described in 2.1 is a example of such a model.

The new new extended model consider the same as the the original model and include in addition a new occupancy model, the one described in 2.2, a model for solar thermal collector model, a low-order building thermal model, and information about stochastic external temperatures, domestic hot water consumption, thermostat and timer controls, and gas boilers.

To validate the model, the simulated output from the extended model, gas demands and hot water demands were compared to three independent data sets. The comparison showed that the model not capture all of the buildings thermal dynamics, so it should not be used for detailed buildings thermal simulations for a specific dwelling when high level of accuracy is wanted. The model under-represented the gas demand for the start of the morning peak and also the entire evening peaks were under-represented. For large changes in gas demand, the model over-represented, and for small changes in the gas demand it under-represented. Comparison also showed that for gas demands across residential houses, the model over-represented the average and under-represented the extremes, and it also under-represented the share of residential buildings with very high hot water usage. (McKenna and Thomson, 2016)

Chapter 3

Knowledge Base

To get more information of household appliances, a knowledge base of typical household appliances was prepared. The knowledge base shows different device performance and characteristics of electrical energy consumption in time. It also includes additional meta data regarding typical purpose of the device.

3.1   Preparation of the Knowledge Base

To prepare the knowledge base, Price Spy (PriceSpy, 2018) was used. Price Spy is a comparison shopping website used for comparison of price and characteristics of different products. In the search for a selected product, it is possible to filter products based on price, reviews, brand and different characteristics describing the product. What characteristics that is available, varies with what kind of product it is, and it can also vary for the same product type how much information is available for each product.

For the choice of which devices that should be included in the knowledge base, an overview of the most typical devices used in a residential house was made. This overview contains 21 different devices, ranging from hair dryers to TVs to hobs. All the devices in the knowledge base are found in the very most homes. For some devices, like freezers and fridges, the knowledge base contains different types of it, for instance both separate fridge and combined fridge and freezer. The overview of all the devices can be seen in Figure 3.1.

For each device, approximately 100 different products within different price ranges was examined regarding power and energy consumption. For the choice of which product should be included in the knowledge base, the products where sorted by popularity, and the 100 most popular products for each type of device were included.

In the knowledge base, all of the products are characterized by producer and price range in UK pound. In Figure 3.1 it is shown what other features the different product type in the knowledge base are characterized by. The empty spaces in the knowledge base implies that the information about this feature was lacking for the current product.
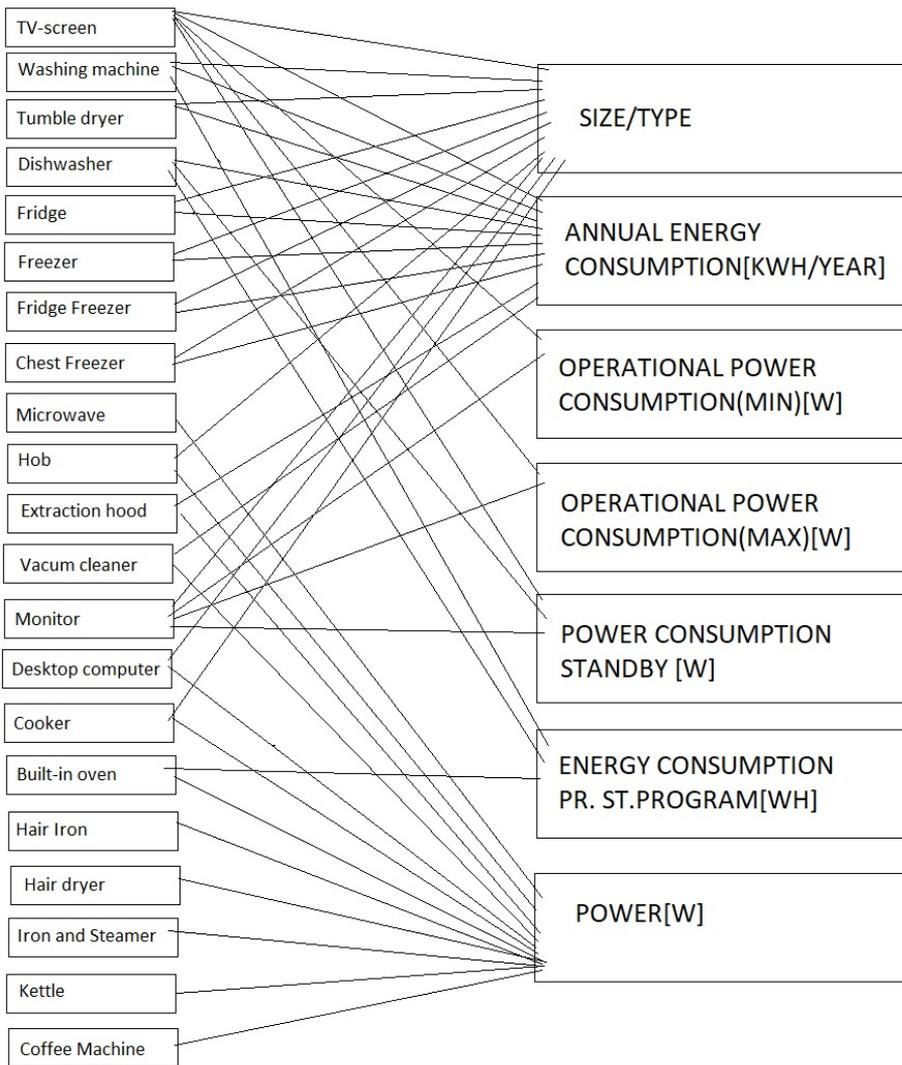
Figure 3.1: Overview over characteristics describing each device type

The knowledge base is available as an external attachment. It is made as an Excel document, with one sheet for each device, and it is possible to sort from lowest to highest or highest to lowest for all the different characteristics for each device.

In addition too device performance, the knowledge base also includes meta data. The meta data is available as the last sheet of the Excel document. The meta data includes placement, both regarding if the device need to be placed on top of something and where in the residence it's mainly located, and information about the use of the devices, like what it is that causes the user to use this device, and for how long it's typical used. For the meta

data, 1 means that the statement match the product, 0 means that it does not match the product.

3.2   Use of the Knowledge Base

From the knowledge base, a range of typical consumption for each type of device either independently of price, size and other aspects of the device, or range of consumption for devices within certain filter can be found. The knowledge base can be used in further development of the simulator of household usage, so that different fluctuation of the energy consumption based on matches of the devices can be created. Develop of the simulator of household usage will be described in chapter 8.

Chapter 4

Construction of Survey

To get more information and knowledge about household appliances and devices use, a survey regarding localization of devices inside residential buildings was performed. The survey only dealt with the kitchen and devices placed in the kitchen.

The survey is presented in Appendix A.

4.1 Questions in the Survey

In the first question of the survey, gender and age, and the age of any cohabitants were asked.

In question two, the respondents were asked about what kind of appliances they have in their kitchen, and to rank the appliances according to the importance regarding their kitchen habits, where 1 mean that it is the most used appliances. This question was made as a list of different kitchen appliances that are common in many homes, a list of all the devices asked about are shown in Table 4.1. There where also an option to write if you have any other appliances in your kitchen. Next to all the appliances, there was one square to mark if you have the device, and one circle to write the importance number. If some of the appliances where combined, for instance fridge and freezer, the respondents were asked to give those devices the same importance number.

Question three concerns the design of the kitchen. The respondents were asked about the size in square meters, and the shape of their kitchen. For the shape, the respondents were asked if the kitchen were shaped as square, rectangular, L-shaped or another shape.

In the last question, the respondents were going to draw their kitchen in a grid of 10x10. First, if they had not answered that their kitchen have a square shape, they where going to draw 'X' in in the redundant squares, so the shape of the kitchen where showed. Further they were asked to mark the location of windows by a 'W', doorways by 'D', the location of all the appliances they had marked earlier using the importance number stated in question 2, and the location of any other furniture in the kitchen, like drawers, tables, chairs etc by coloring the squares. They were also asked to indicate which direction the

kitchen is by drawing an arrow pointing the direction of north.

Devices
Fridge
Freezer
Cooker
Built-in oven
Hob
Microwave
Espresso Machine
Kettle
Fryer
Toaster
Blender
Exhaust
Sink
Dishwasher
Washing Machine
Tumble Dryer
TV
Radio

Table 4.1: Devices covered in the survey

4.2 Collection of Answers

Because the respondents of the survey were asked to draw their kitchen, the survey needed to be carried out by hand and not online. This made the collection of answers a bit harder to carry out. This was solved by the respondents putting their answers in a closed box so no one should see who answered what. In the survey there were not asked about anything that makes is possible to link the answer back to the respondents. Combined, this made the collection completely anonymous.

4.3   Outcome of the Survey

The collected data regarding the localization of the devices, combined with the direction of the kitchen, will be used for the development of probabilistic heat map of device placement for kitchen in residential buildings. Development of heat maps are described in chapter 7. Further, the heat maps along with the results from question 2 regarding what kind of devices the respondents have and the stated importance of the devices, can be used for further development of the simulator for kitchen usage. Development of the simulator are described in chapter 8, and further development of it is described in chapter 12.

Chapter 5

Field Measurements

5.1 Test Bed

According to the description of the thesis, one of the tasks to be considered was "Conduct field measurements, followed by decoding of electricity consumption in test bed and previously gather data in the Living Lab. Develop the device usage timeline in various days for the detection of the usage patterns".

The conducting and decoding of field measurements turned out to be not possible to carry out in this thesis because it proved to be much more difficult to achieve than anticipated in advance. To get the field measurements it requires more processing and preparation to get the data than we will be able to do for now.

The plan to conduct field measurements, was to measure the energy consumption in the kitchen in the test bed, an apartment for two people. For the devices that are in constant consumption, like refrigerator and freezer, the energy consumption was going to be measured for five days. For devices that are depended on action to use energy, like kettles and microwaves, ten trials per device was going to be measured.

5.1.1 Z-wave Technology

To conduct the measurements, smart plugs connected to a Z-wave gateway for smart homes was going to be used. Z-wave technology is wireless communications protocol, and besides measure electricity consumption, some of the things this technology can be used for are dimming of lightning, locking and unlocking doors, controlling of fans, A/C and heating, and feeding pets. (SmartHome.Guide, 2018)

With a Z-wave gateway, or Z-wave controller as it's also called, Z-wave technology is used to control all the different Z-wave devices that are installed in your home. The connection is done by use of a chosen software. For some gateways, external software must be used, and for other gateways there is made a special software that are linked to the gateway.

Smart plugs or smart switch are a type of Z-wave device. This are regular plugs with electronics, so they can be connected to the gateway and thus controlled or measured, and they are plugged between the device you want to control and the power outlet. Examples of other Z-wave devices one can buy are thermostats, locks and security features.

5.1.2 Attempt of Conducting Measurements in Test Bed

To conduct the measurements, different controllers were tried, first the gateways Telldus Tellstick ZNet Lite V2 and Telldus Tellstick Net were tried. This worked well connecting to the software Telldus Live!, which is the software that belongs to these gateways. For smart plugs, both Aeotec Smart Switch 6 and NodOn Micro Smart Plug were tried to connect, but none of these plugs could be found in list of manufactures in the Telldus Live!, so it was not able to connect.

To fix this problem, a new gateway to match the producer of the Aeotec Smart Switch 6 was bought, Aeotec Z-stick Gen5. This is an USB-gateway which can be used to build a Z-wave gateway. To use this controller, a software from an external producer must be chosen. Various software was tried, like zVirtualScenes and HomeGenie, but both was found difficult to understand how to connect to the Z-stick. It was therefor decided to use the software openHab, this software seemed clearly and it exits many movies online that can be helpful under installation. The software was installed and the Z-stick and the Smart Switch was connected to the software, and it made successfully measurements of the consumption. The openHab software only showed the consumption as it was used, it was not possible, without a lot of processing, to find a graph or similar that showed the consumption for a given period, so it was not possible to use this software to decode the electricity consumption over a period of time.

5.1.3 Aim of Conducting Measurements in Test Bed

The aim of the conduction and the decoding of the electricity consumption was to be able ta validate the model for the simulator that's developed, to see if the simulations fits with the data. Without being able to conduct these measurements, it is not possible to make a completely simulation of the usage to confirm that the model works completely, but this can be explored more in further work. It is fully feasible to make these conduction, but it requires many hours of work. It will be written more about proposal for further work in chapter 12.

5.2 ZEB - Living Lab

5.2.1 About ZEB - Living Lab

The ZEB - Living Lab is a single family house of approximately $500m^3$ and have a floor area of approximately $100m^2$. The Living Lab is designed to reach the Zero Emission target, and state-of-the-art technologies for energy conservation, with solar thermal panels and heat pump, are integrated in the house. (Finocchiaro et al., 2014)

The Living Lab is develop with the aim to investigate different aspects of residential houses, like building equipment components, ventilation strategies and how residents interact with buildings of this kind, i.e. buildings with high indoor comfort conditions and low energy demand. The house is build with flexibility of the plan, which makes it feasible for many different resident groups to live there, making it possible to investigate differences in the interaction with the buildings for the different resident groups. (Finocchiaro et al., 2014)

In the period 12.10.2015 to 24.04.2016, 6 different groups of people stayed in the house, each group nearly 4 weeks. The groups belong to different resident group. Table 5.1 shows which resident group the different residents belong to and for how long they lived in the Living Lab (Skeie, 2015-2016).

Date	Resident Group
12.10.15 - 06.11.15	Student couple
09.11.15 - 04.12.15	2 single students
04.01.16 - 29.01.16	Family with two small children
01.02.16 - 26.02.16	Elderly couple
27.02.16 - 23.03.16	Family with two small children
20.03.16 - 23.04.16	Elderly couple

Table 5.1: Residents group living in the Living Lab

5.2.2 Field Measurements in ZEB - Living Lab

The electric energy metering in the Living Lab are conducted using the power meter C18WS by FRER, which has a accuracy of $\pm 1\%$ (Finocchiaro et al., 2014). Table 5.2 shows an overview of all the electric energy meters in the house (Skeie, 2015-2016).

In this thesis, because it is chosen to focus on the kitchen and appliances in this room, just the data from the meters for fridge, hob, oven, extraction hood, dishwasher, washing machine, tumble dryer, and the socket in the kitchen will be further analyzed.

Energy meters
Technical equipment
Monitoring and control system
Fridge
Hob
Oven
Extraction hood
Dishwasher
Washing machine
Tumble dryer
Sockets, one for each part of the house
Lighting
Shading systems
Window motors
Hydronic circuits pump and actuators
Water tanks, one for each electric coil
Ventilation AHU, also for the electric coil
Heat pump
Surface collector field
Solar thermal panel
Inverter PV

Table 5.2: Electrical energy meters in Living Lab

There are measurements from 12.of October to 23.of April, which gives 195 days of measurements. The electricity meters logged the consumption cumulative in Watthour[Wh], and frequently they were reset, by Windows updates, power outages etc, starting counting from 0 again. Sometimes the meters stopped logging and some data where lost, but the counting continued, so in most cases, this only means that the consumption will not be logged at the right time, but total consumption will be correct. The meters log with 30 second intervals, but sometimes the meter jumped one second and the data set also misses measurements sometimes, so the file is not completely continuous.

Chapter 6

Processing of Data from Living Lab

The data received from the electric energy metering in the Living Lab (Skeie, 2015-2016) contains the cumulative results from the electricity meters. To analyze this results, the consumption for every measuring point, which means for every 30.second for the periods with constant logging, were found.

To deal with the problem that the data set is not completely continuous, the time data was changed from date to numbers to find which number representing one hour in the data set. This way, there is a constant time frequency for sampling, and not dependent on how many measurement points that are within a selected period, because the length of the hour will be same regardless of number of measurements. It was found that one day is equal to 1, or 100%, and thus one hour equals 0,0417.

MatLab were used to analyze and plot the electricity consumption for the fridge, hob, oven, extraction hood, dishwasher, washing machine, tumble dryer, and socket in the kitchen in the Living Lab. The code related to this analysis can be found in Appendix B.

6.1 Explanation to MatLab-code

The analysis ha been accomplished with resolutions between 10 minutes and 60 minutes, thus between 6 and 1 analysis point per hour. It is chosen to not use higher resolution, because this can make it difficult to see the context in the consumption.

For each device that are analyzed, the sum of the consumption for each analyzing period are found.

The data from the Living Lab are received from an external part, so abnormal measurements, which can be due to various reasons, are difficult to explain. To cope with this problem and to get measurements that can be compared, measurements that are not within the standard deviation for time between each measurement, are removed. This was

done by setting the consumption for this measuring period to -1, and defining state 0 = -1. Explanation of the term state are described in chapter 6.1.1.
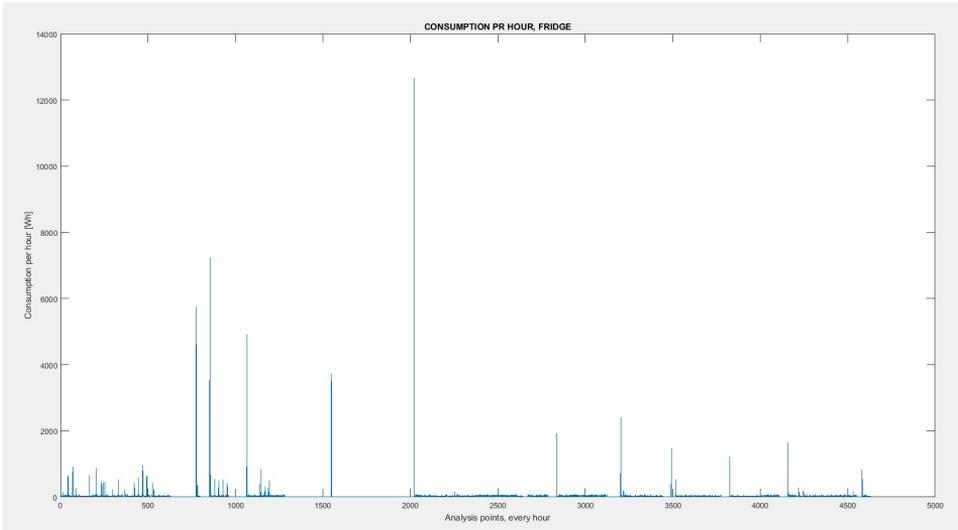
Figure 6.1: Consumption pr hour for the fridge

The plot in Figure 6.1 shows the consumption in Wh for the fridge with a resolution of 60min, thus the plot shows the consumption pr hour. The x-axis shows all the measurement points, and the y-axis shows the consumption. Throughout the plot there are some lines which shows a really high consumption, and all of these lines comes after a period when the plot shows the consumption to be zero. This is the result of the measurements to not be completely continuous. Through the whole measuring period, there were shorter or longer periods that are missed in the data set, but the meters kept logging the consumption, so when the meter started logging again, the consumption for the whole period that is missing was showed as the consumption for one period of 30 second. For the fridge, which constantly consumes energy, these high plots of consumption will be higher the longer the period of missed logging was.

Figure 6.2 shows the same plot as figure 6.1, but for all the devices. The figure shows that the plots for all the devices follows the same pattern as the fridge, which is naturally since the logging were missed for all the devices in the same periods. For the other devices, which is use dependent to have consumption, there will not be the same relation between the length of the period with missed logging and the high consumption logged.

With a resolution different from 60, the trend of the plot would look the same. The large measurements which stands out would have the same values, but the consumption per measurement point would be lower for higher resolutions, and higher for lower resolutions.
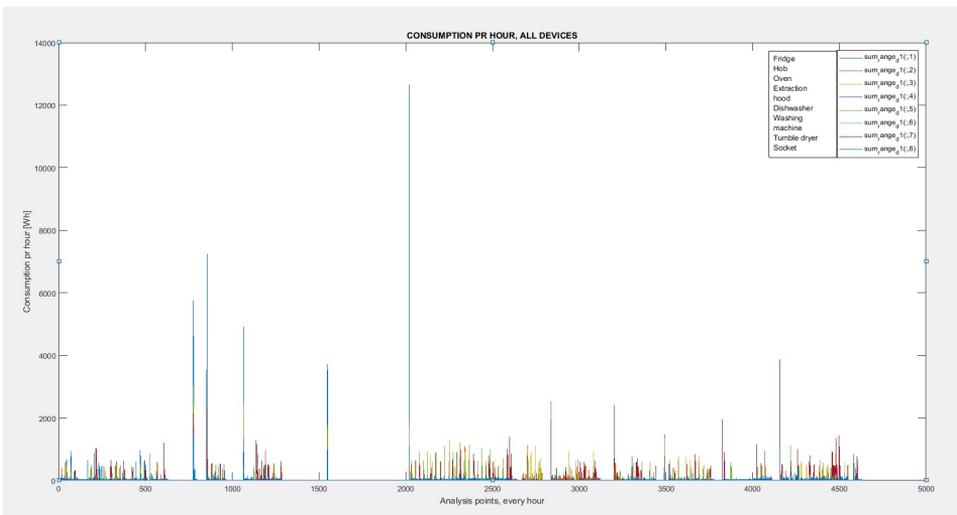
Figure 6.2: Consumption pr hour for all the devices

For each device, 4 or 5 states describing the use of the device, were established, and the times for when all the states occurred were found. Explanation of the different states and how they were determined are described in chapter 6.1.1. To be able to analyze the pattern of usage, the time values with the corresponding states were sorted by days and weeks.

6.1.1 States

For each device, different operating states were established. Dependent on the device, if it just consumes when it is used, from now called device type 1, or if it has background consumption independent of use, called device type 2, each device has respectively 4 or 5 different states.

Device type 1: Extraction hood, tumble dryer, socket

State 0 represent missing measure point.

State 1 equals 0, and represent no use, or error in the metering.

State 2 represent normal usage. This varies with device and resolution.

State 3 represent wrong metering from when the meter have not recorded for a shorter or longer period, and this big numbers is the sum of the consumption for the period not recorded. This is represented by 100 000, which is just a randomly number bigger than any of the consumption.

Device type 2: Fridge, hob, oven, dishwasher

State 0 represent missing measure point.

State 1 means error in the metering.

State 2 represent the background consumption. This varies with device.

State 3 represent normal usage. This varies with device and resolution.

State 4 represent wrong metering, from when the meter have not recorded for a shorter or longer period, and this big numbers is the sum of the consumption for the period not recorded. This is represented by 100 000, which is just a randomly number bigger than any of the consumption.

For the hob, the oven and the dishwasher, the background consumption is very low and not so easy to see in the plots, but it is important to include this consumption, otherwise it will be registered as regular usage.

In figure 6.3 to figure 6.9 the consumption for all the devices, and the different states for all the devices, with a resolution of 60 minutes, are shown. The limits for the states that varies with the resolution are also stated in the figure for resolution 10 minutes and 20 minutes.
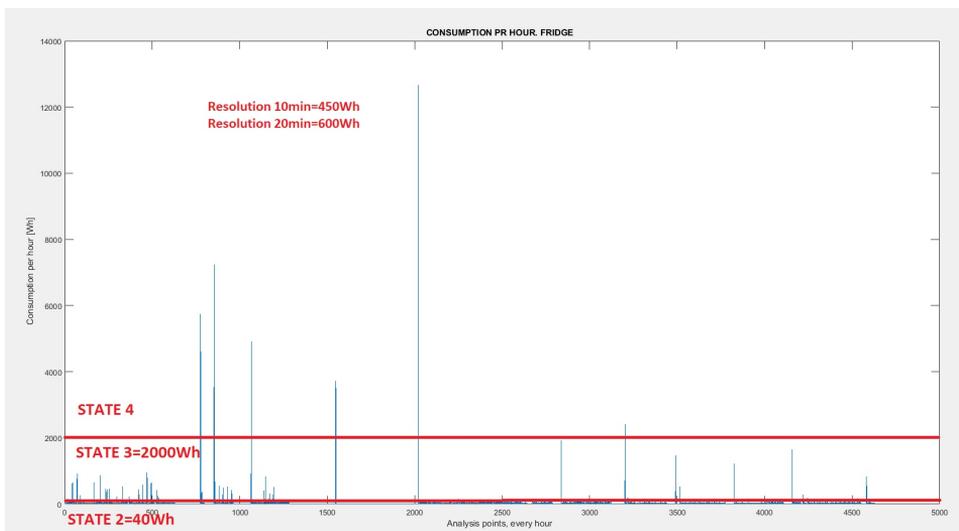
Figure 6.3: Consumption and states for fridge, resolution 60min
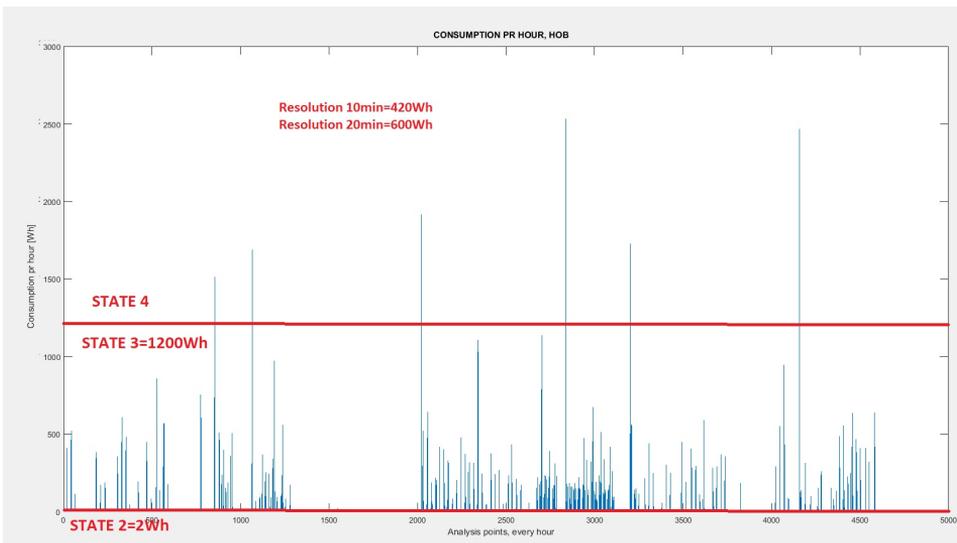
Figure 6.4: Consumption and states for hob, resolution 60min
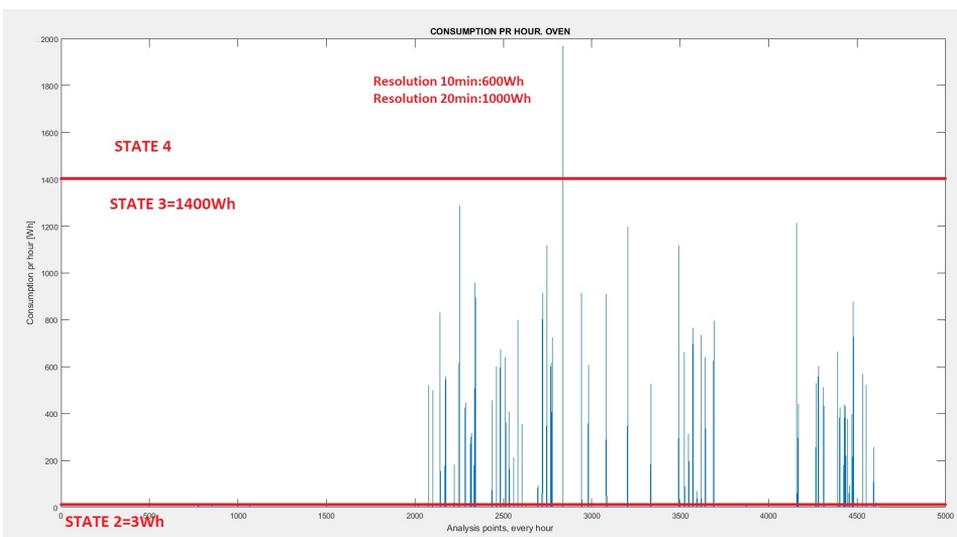
Figure 6.5: Consumption and states for oven, resolution 60min
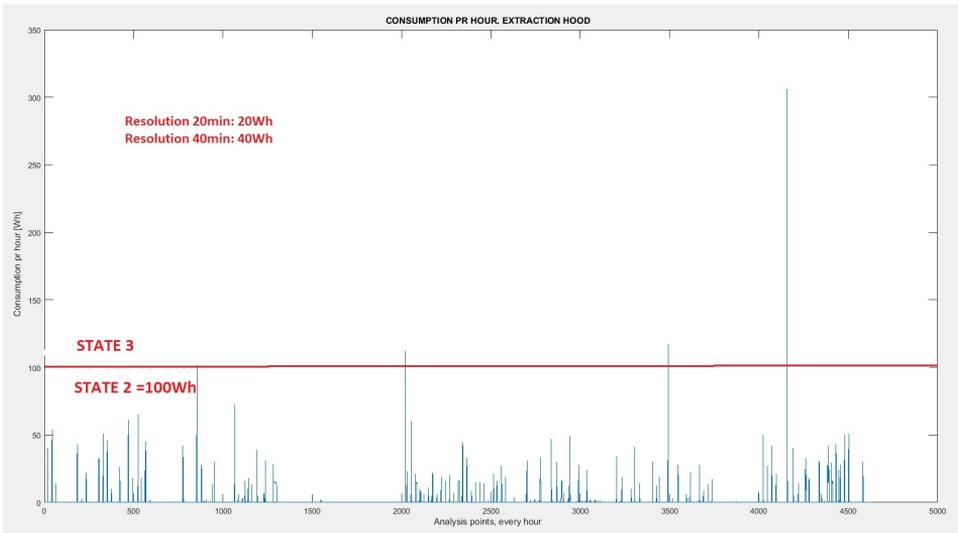
Figure 6.6: Consumption and states for extraction hood, resolution 60min
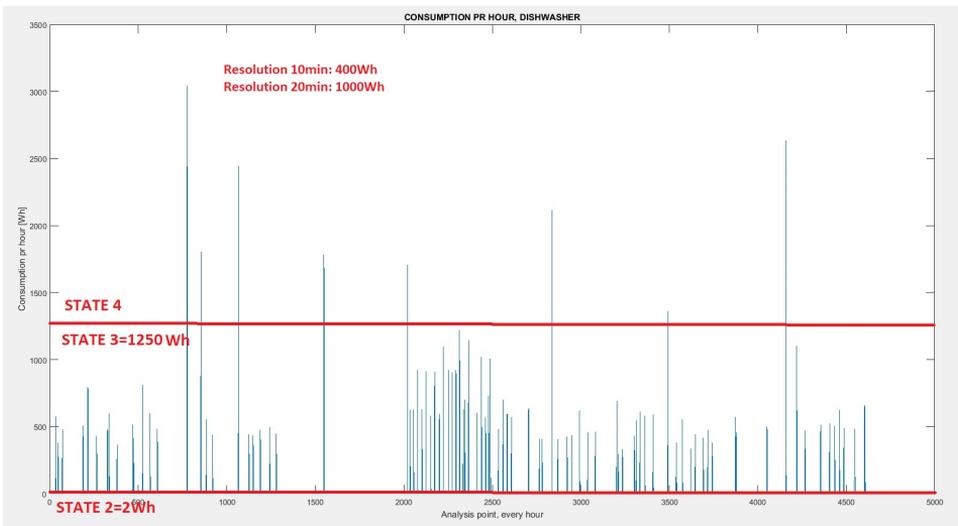
Figure 6.7: Consumption and states for dishwasher, resolution 60min
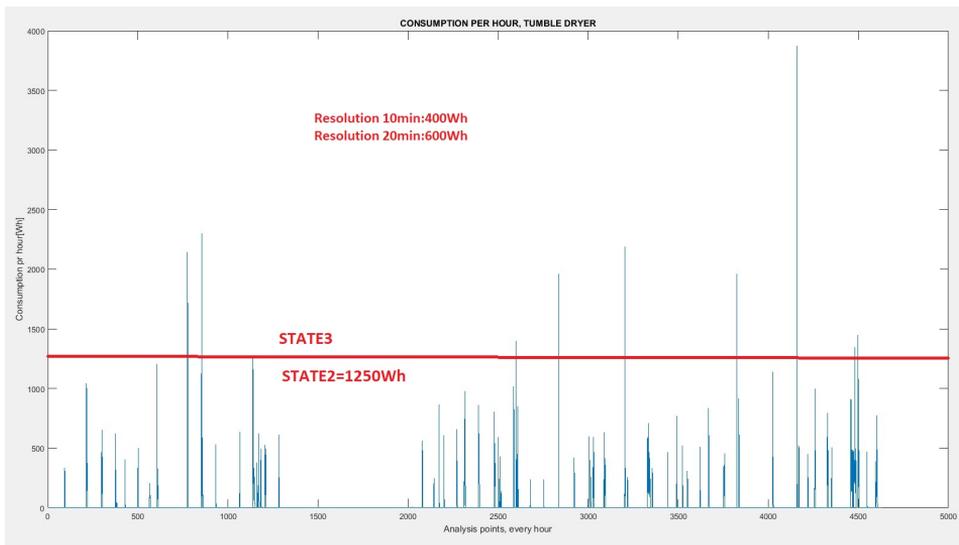
Figure 6.8: Consumption and states for tumble dryer, resolution 60min
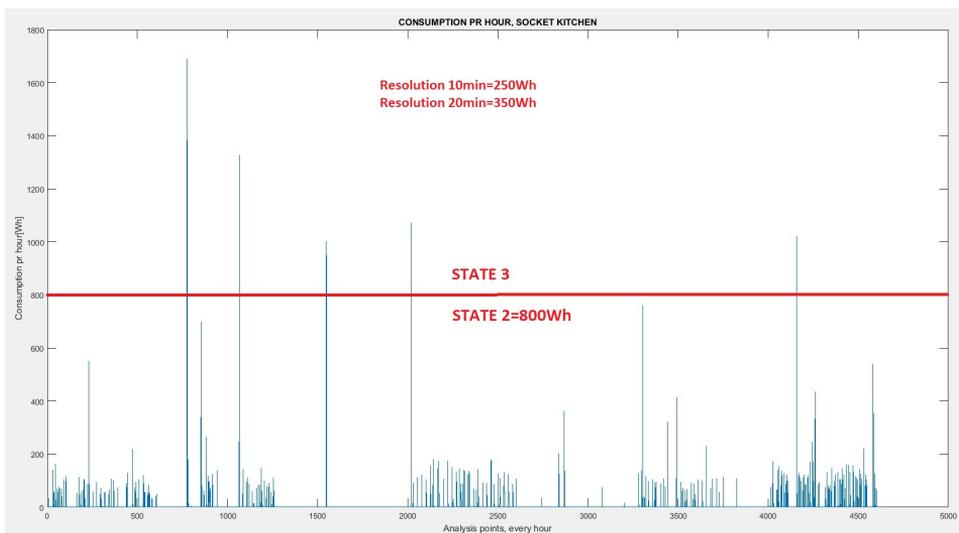
Figure 6.9: Consumption and states for socket, resolution 60min

Figure 6.10 shows the plot for the consumption of the hob zoomed in, showing the background consumption.
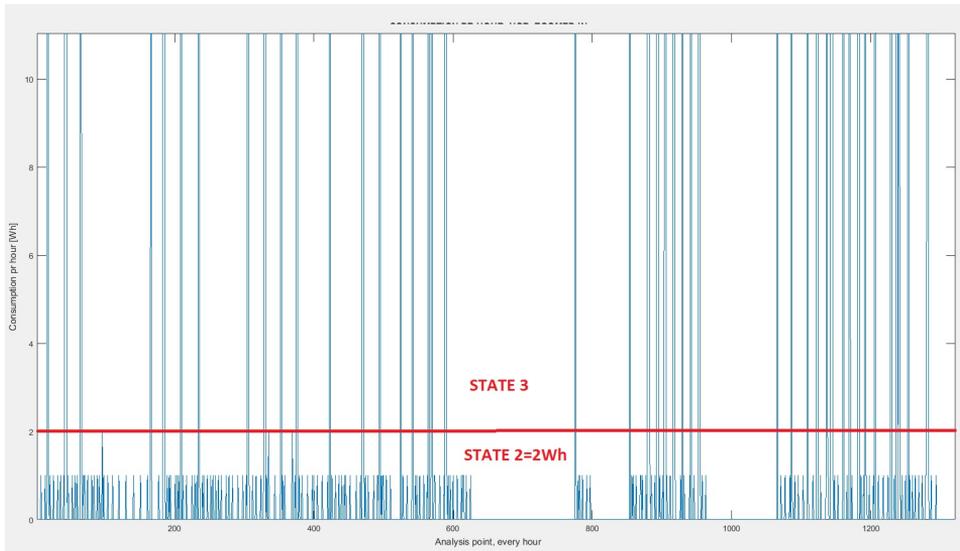
Figure 6.10: Background consumption for hob

6.2 Washing Machine

Figure 6.11 shows the consumption for the washing machine with resolution 60 min. As the the plot shows, the highest consumption for the machine pr one hour is 5Wh. For the whole measuring period from October 12 until April 23, the total consumption were 87Wh. Comparing with the data from the knowledge base, the lowest annual energy consumption for the washing machines are 97kWh, and the lowest energy consumption pr. standard program given is 440Wh. This means that it is not possible for the machine to have such low consumption, thus has the washing machine not been used or there have been something wrong with the measuring for the machine. It is unlikely that the machine has not been used, since the tumble dryer is used a lot. Thus, it may seem that the measuring for the washing machine is wrong, and the washing machine will not be analyzed more.
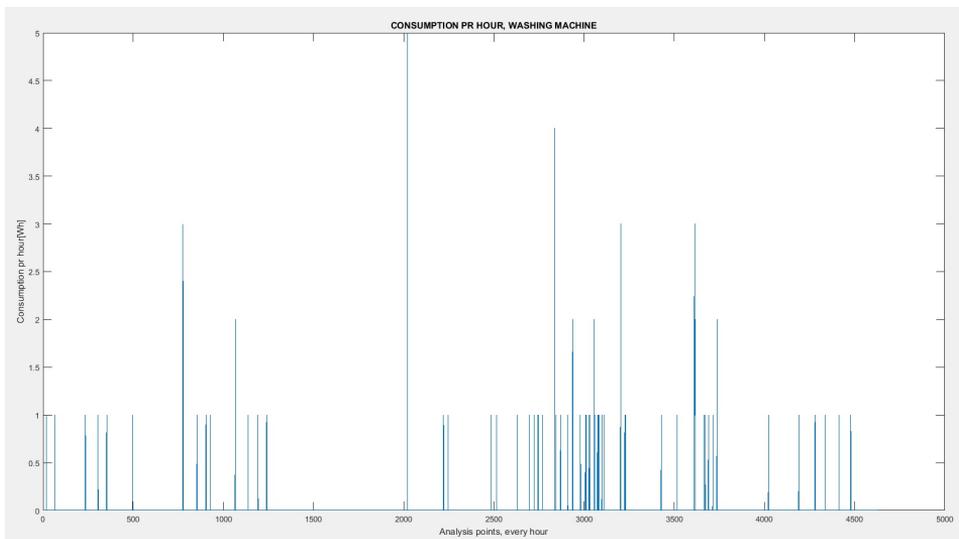
Figure 6.11: Consumption for washing machine, resolution 60min

6.3   Comments of the Consumption Plots for the Devices

The plot of the consumption for the fridge shows 'normal' use for the first approximately 650 hours by having a constant background consumption and, at uneven intervals, having increased consumption, due to the compressor turning on to keep the temperature down. From approximately 800 hours to 1200 hours there is also a period of normal use, but with some wrong metering occasionally. After this, from approximately 1200 hours and through the whole period of measuring, the consumption only consist of background consumption and wrong metering, i.e. periods of no consumption followed by points of high consumption. It is very unlikely that the compressor will not turn on for this whole period. Thus, the metering for the fridge is not satisfactory after the first 650 hours, which equals about one month.

The plot of the consumption for the oven shows almost no consumption until 2100 hours, almost 3 months, of metering. The oven has some background consumption in this period, so it may seem that the oven were not used by the two first group living in the Living Lab.

Chapter 7

Results from Survey and Development of Heat Maps

From the survey, 42 answers were collected. All the results from the survey are available in an external attachment. For question 4, where the respondents were asked to draw their kitchen, the answers for all the questions are stated as coordinates. When the kitchen shape was stated not square, the placement of the devices had to be changed according to the shape before making the heat maps. This was done by extending one of the dimensions, dependent of the shape, to make all the kitchen 10x10. Otherwise, in the making of the heat maps, the placement of the devices would be illogical. For example could the heat maps showed that many people place their fridge in the middle of the room.

Regarding the direction of the kitchen, 8 direction were used for further investigations of the results. If the direction from some of the survey answers did not resemble any of the alternatives used, the alternative closest to the answer was chosen as the direction. If no direction were stated, 0 degrees was assumed. The direction alternatives are shown in Table 7.1

Degrees
0
45
90
135
180
225
270
315

Table 7.1: Direction alternative of the kitchens

Some of the respondents misunderstood parts of the survey. In question 2.2, 4 of the respondents had not given the devices importance numbers, and in question 4, 7 of the answers had either not drawn or the drawing where not able to understand. Because of this, only 35 answers is the basis for the development of the heat maps.

7.1 Results from Survey

Table 7.2 shows the result of how many devices the respondents have in their kitchen.

Average	9.05
Standard deviation	2.09
Maximum	13
Minimum	3

Table 7.2: Survey results; How many kitchen devices have the respondents

In table 7.3, it is shown how many respondents who have each device. The result given in the bracket is the results excluded the answers that did not include importance number. 7 of the 42 respondents have combined fridge and freezer.

Device	Results
Fridge	42 [38]
Freezer	26 [25]
Cooker	26 [25]
Built-in oven	22 [20]
Hob	18 [16]
Microwave	24 [22]
Espresso Machine	10 [8]
Kettle	30 [28]
Fryer	0 [0]
Toaster	18 [16]
Blender	24 [23]
Exhaust	38 [36]
Sink	37 [34]
Dishwasher	32 [30]
Washing Machine	6 [5]
Tumble Dryer	2 [2]
TV	2 [2]
Radio	19 [18]
Other	4 [4]

Table 7.3: Survey results; How many respondents have each device

Table 7.4 shows the overview of how many times each device were stated the different importance number.

Device	1	2	3	4	5	6	7	8	9	10	11	12
Fridge	22	10	3	2	1	0	0	0	0	0	0	0
Freezer	5	2	4	5	1	3	2	0	2	1	0	0
Cooker	4	13	5	2	0	1	0	0	0	0	0	0
Built-in oven	1	5	5	2	3	0	2	1	1	0	0	0
Hob	7	6	1	1	0	1	0	0	0	0	0	0
Microwave	0	0	1	2	3	3	7	2	1	2	1	0
EspressoMachine	0	0	0	0	2	2	2	1	0	0	0	1
Kettle	2	0	0	1	4	6	5	6	3	1	0	0
Fryer	0	0	0	0		0	0	0	0	0	0	0
Toaster	0	0	0	0	0	0	1	6	2	4	3	0
Blender	0	0	0	2	1	5	3	4	5	2	1	0
Exhaust	1	2	2	8	9	5	5	2	1	0	0	0
Sink	3	4	14	3	2	3	3	1	1	0	0	0
Dishwasher	0	1	3	8	8	3	1	6	0	0	0	0
WashingMachine	0	1	0	0	1	0	0	3	0	0	0	0
Tumble Dryer	0	0	0	1	1	0	0	0	0	0	0	0
TV	1	0	0	0	0	1	0	0	0	0	0	0
Radio	0	0	0	1	2	1	1	2	6	3	2	0
Other	0	0	0	0	0	0	1	0	1	2	0	0

Table 7.4: Survey results; Importance number for each device

7.2   Development of Heat Maps

The MatLab code for development of heat maps are attached in Appendix C. There were made one heat map for each device. Because no survey answer had a fryer, and the two answers having tumble dryer did not draw the placement of the devices, there is no data for these two devices, making it impossible to include these in the further work of development of heat maps and simulations.

Since the placement of the kitchen devices were done in different directions relative to north, the answers had to be moved to be in the same direction to make it uniform. For this, 0 degrees was chosen as base, and all the answers drawn in another direction had to be moved. To move the answers, the coordinates for the grid when it was turned were found, and the placement of the devices were moved according to the turned coordinates.

To make the heat maps, the answers from question 4.5 in the survey were used. For each time the device had be placed in the given square in the survey answers, the placement for the device in the given square was increased by 1. The procedure was the same for all the devices.

To get the percentage value, all the numbers where divided by the sum of possible placement for the given device.

The heat maps for all the devices are shown in chapter 10.

Chapter 8

Simulator of Household Usage

8.1 Development of Simulator

The MatLab code for the simulator is attached in Appendix D. The code uses the heat maps as input.

The kitchen will, as earlier, be represented as a 10x10 grid. Table 8.1 shows which number represents which device in the grid.

Device	Number representing
Fridge	1
Freezer	2
Cooker	3
Built-in oven	4
Hob	5
Microwave	6
Espresso Machine	7
Kettle	8
Toaster	9
Blender	10
Exhaust	11
Sink	12
Dishwasher	13
Washing Machine	14
TV	15
Radio	16
Other	17

Table 8.1: Number representing each device in the simulator

The simulator starts by simulating the placement of the devices. First the simulator simulates the row, and then it simulates the column, and the crossing of these two are the location for the device. To generate a row, the probability for the device to be placed in this row is found and organized from smallest to largest, and a random row is found by choosing a row randomly based on this probability . The procedure for generating the row is then repeated for the column.

The procedure is repeated for all the devices, which gives the whole layout of placement of all the kitchen devices. The simulator insures that no devices are placed on top of each other by choosing a new placement for the device if the placement generated is taken. The TV has only one possible placement, because only one of the respondents having a TV draw it in the survey answer, so if this place is taken of another device than the TV, the whole process is repeated for all the devices.

Further, the direction of the kitchen is simulated. The probability for each direction are found from the answers from the survey. Based on this probability, a random direction of the kitchen are generated. To get the placement of the devices, the grid with all the placements is turned according to the direction generated. The turning is done by the opposite procedure used for turning the survey answers, described in chapter 7.

Finally, the usage of the kitchen is simulated. The simulation of usage will just be made as a vector of movement in the kitchen based on where the different devices are located. The simulation will not take into account extra walls, doors or other kitchen furniture. The simulation of usage use the overview of the states occurring for a chosen time period, e.g one day. Description of the different states and how they were found for the usage in the Living Lab are described in chapter 6.1.1. First, the coordinates for location of each device are found. If a device is registered as in normal usage, the simulator register the location of this device as were the occupant is moving. For the socket in the kitchen, the movement is set to the location of the kettle, because this is the device, which is plugged to the socket that most people own, according to the survey. The movement for the chosen time period will be presented as a plot.

To show how the simulator works, data from the Living Lab was used to make a scenario. Results from the simulations are presented in chapter 11. Only the fridge, hob, oven, exhaust, dishwasher and socket will be included in the vector showing the movement, because these 6 devices are the only ones with results from both the Living Lab and the survey.

8.2   Comments on Deficiencies in the Simulator

The simulator of household usage developed in this thesis is a very simple simulator that has to be developed further. For the placement of the devices, the relationship matrix has not been checked, the devices in this simulator are placed completely unconnected. The relationship matrix describes how each device appears, and how the placement of previous devices influence the placement of the next device. Including this in the simulator requires multidimensional analysis, and also the meta data of the device before has to be taken into account.

Another deficiency of the simulator is that all the devices with available heat maps will be placed. The survey showed that the maximum amount of devices in the kitchen among the respondents were 13, and the average amount were 9. In the simulator, 17 devices are placed, which is very unlikely to appear according to the survey. For example, both hob, built-in oven and cooker are in the simulator being placed, according to the survey, only 7% will have all these three devices in their kitchen. The simulator neither takes into account if some of the devices are combined.

For the usage of the socket, the simulator sets the movement to the location of the kettle. The usage of the socket is probably from many different devices, and the movement should vary by which device the occupant is simulated to use.

The simulator place each device in one square. In the survey, many of the respondents used 2, or more, squares to placing each device, especially the bigger devices like fridge, cooker, dishwasher. When placing the devices in the simulator, many of the devices may therefore be placed not up to the wall, although most responses have placed the given device up to the wall.

Further development of the simulator will be described in the suggestion for further work in chapter 12.

Chapter 9

Results of Energy Consumption in Living Lab

In figure 9.1 to figure 9.7 the states sorted by week for all the devices, with resolution 60 minutes, are shown. The y-axis represent the number of weeks and the x-axis shows the number of hour per week. For the devices with 4 possible states, green represent normal usage, for the devices with 5 possible states, orange represent normal usage.
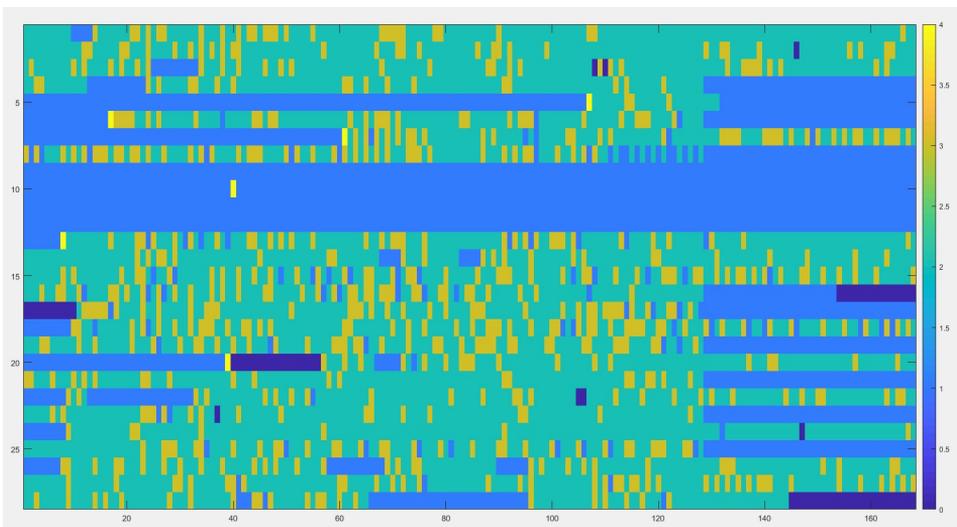
Figure 9.1: States sorted by week with resolution 60 minutes, fridge
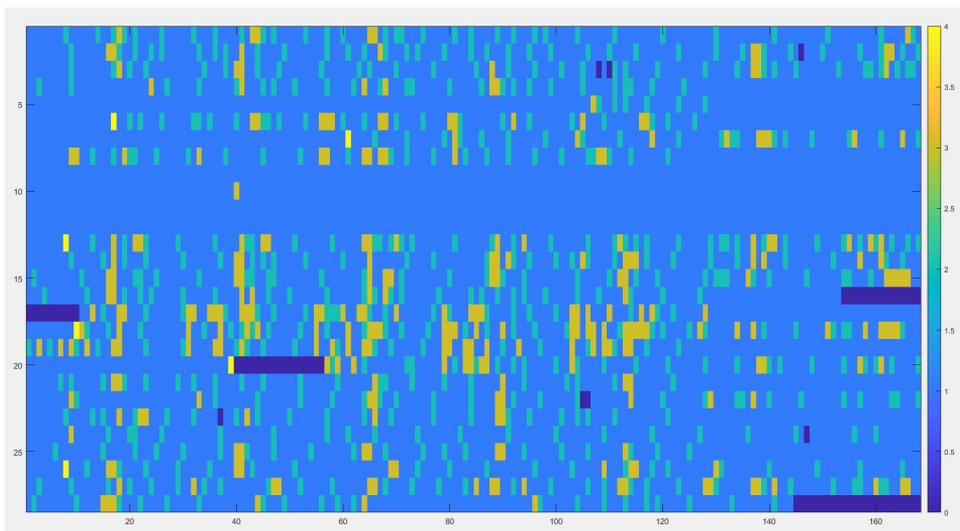
Figure 9.2: States sorted by week with resolution 60 minutes, hob
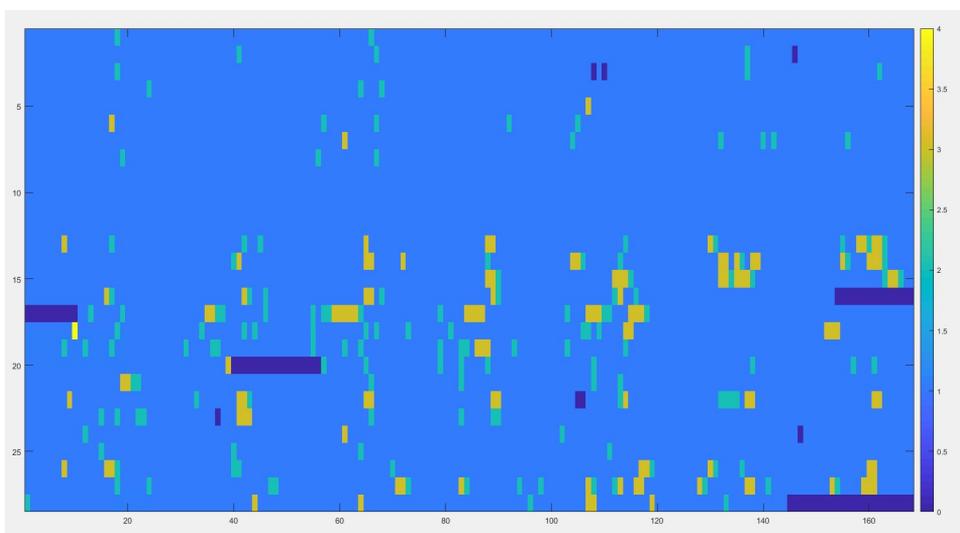
Figure 9.3: States sorted by week with resolution 60 minutes, oven
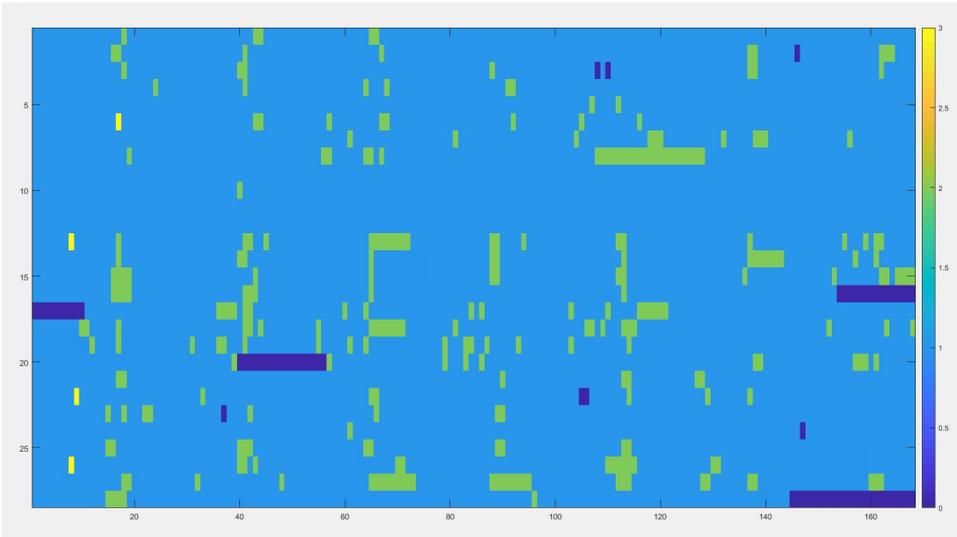
Figure 9.4: States sorted by week with resolution 60 minutes, extraction hood
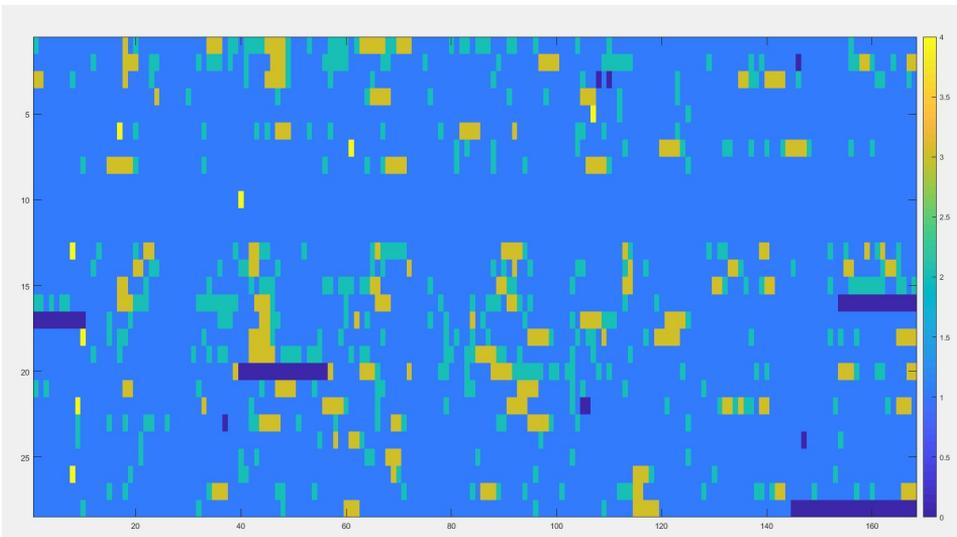
Figure 9.5: States sorted by week with resolution 60 minutes, dishwasher
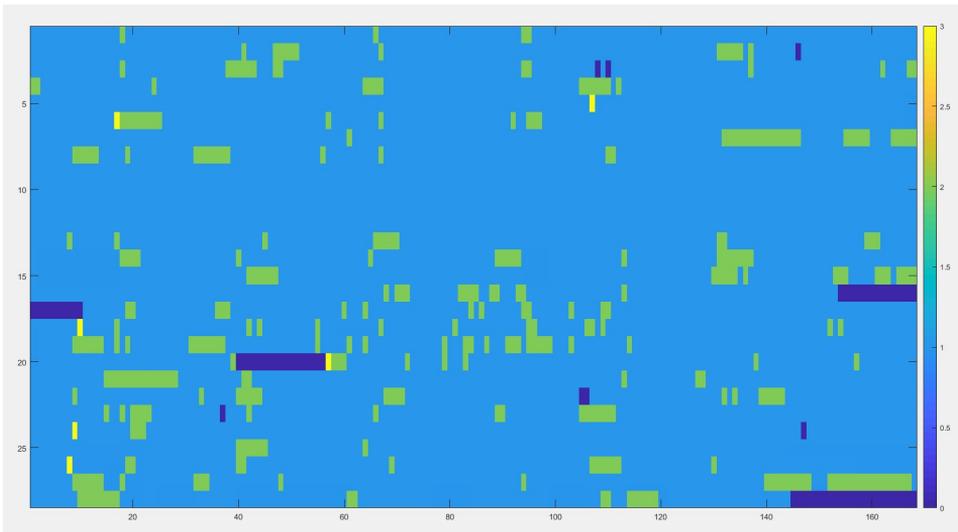
Figure 9.6: States sorted by week with resolution 60 minutes, tumble dryer
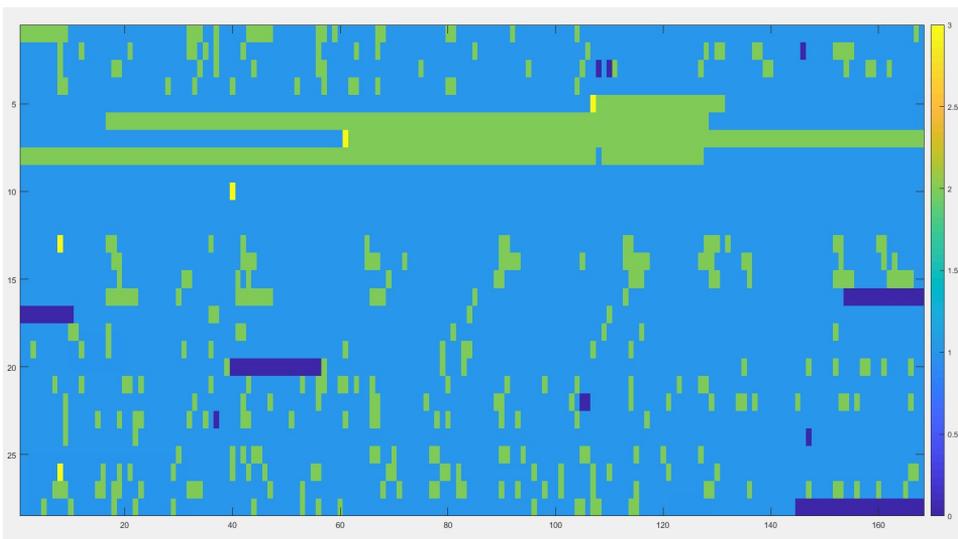
Figure 9.7: States sorted by week with resolution 60 minutes, socket kitchen

It would be expected, that there would be a trend in these plots, showing that the patterns in the usage would be the same, at least within each living period for the different groups of people living in the Living Lab. In these plots it is not possible to see any trend. All the wrong measuring is also making it harder to analyze the usage and generate a complete picture of signal from different devices. Because of this, the usage for three random days will instead be analyzed.

Table 9.1 shows which three days that was used for analyzing.

Number	Date	Day
1	29.10.15	Thursday
2	11.02.16	Thursday
3	09.04.16	Saturday

Table 9.1: Days used for analyzing of usage

For analyzing, a plot showing the different states for all the devices throughout the day, and a plot showing the consumption for all the devices will be used. In the figures showing the different states throughout the chosen days the x-axis represents the different devices, and the y-axis represent the different measuring periods. Use of the device will be represented by yellow for the fridge (line 1), hob (line 2), oven (line 3), dishwasher (line 5) and tumble dryer (line 6). For the exhaust (line 4) and the socket (line 7), turquoise will represent use of the device.

9.1 Analysis of Day 1

Figure 9.8 shows the different states for all the devices throughout the day. In figure 9.9, the consumption for all the devices are shown.

Figure 9.8: The states throughout the day for all devices, day 1
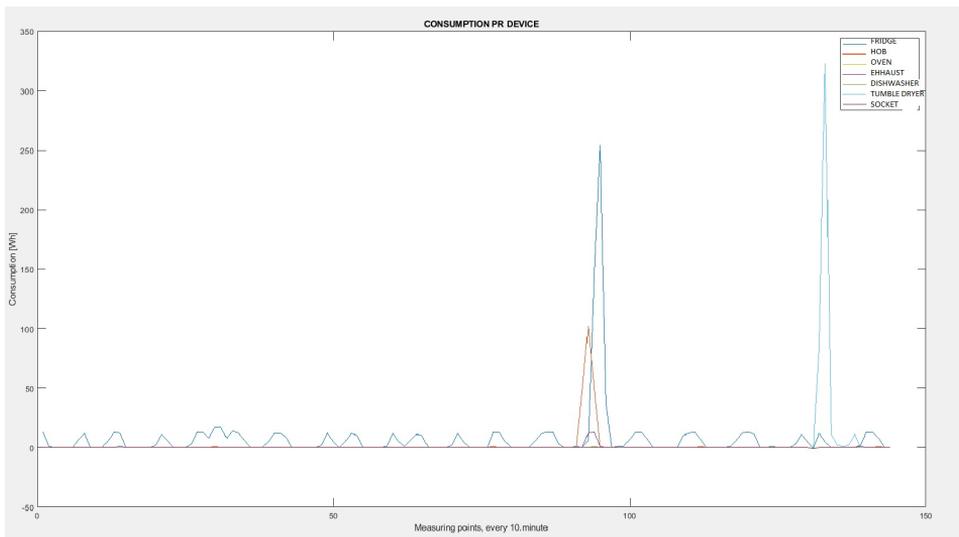
Figure 9.9: Consumption for all devices, day 1

The fridge, the hob, the exhaust, the tumble dryer and the socket are in use this day. As figure 9.9 shows, the fridge has a background consumption through the whole day, and approximately around the 95. measure point, it has a increased consumption for a period, which means that the compressor turns on to keep the temperature down, probably because the fridge door has been opened. This is around the same time as the hob is used, which is naturally, because the occupants have probably picked up food from the fridge or put something in the fridge when they are cooking. The consumption from the exhaust is so low that it can't be seen in figure 9.9, but figure 9.8 shows that the exhaust is used at the same time as the hob. 95.measuring point equals around 4 in the afternoon, which means that dinner is probably made. The tumble dryer is used approximately between 10 and 11.30 in the evening. Also the consumption of the socket is really low, just 1Wh for each of the two period it is registered as used, so it's difficult to say what this can be.

9.2 Analysis of Day 2

Figure 9.10 shows the different states for all the devices throughout the day. In figure 9.11, the consumption for all the devices are shown.
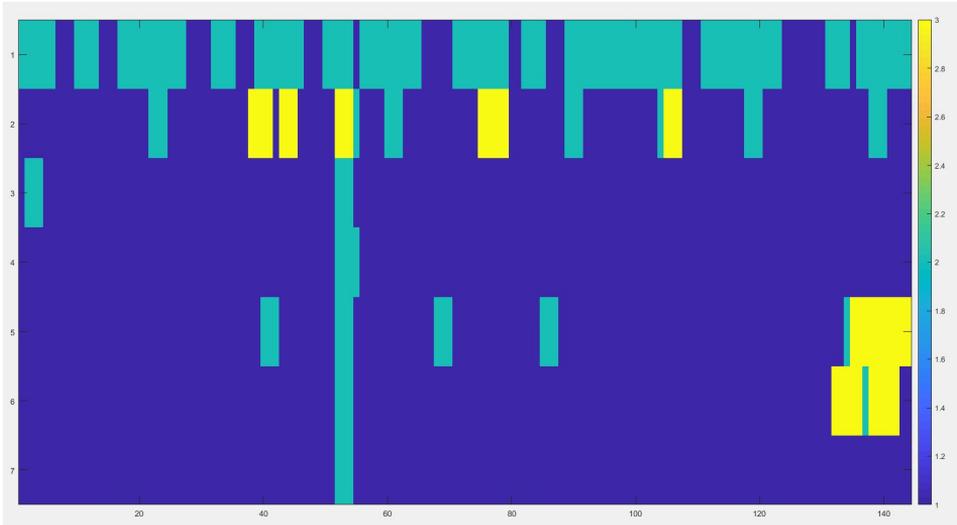
Figure 9.10: The states throughout the day for all devices, day 2
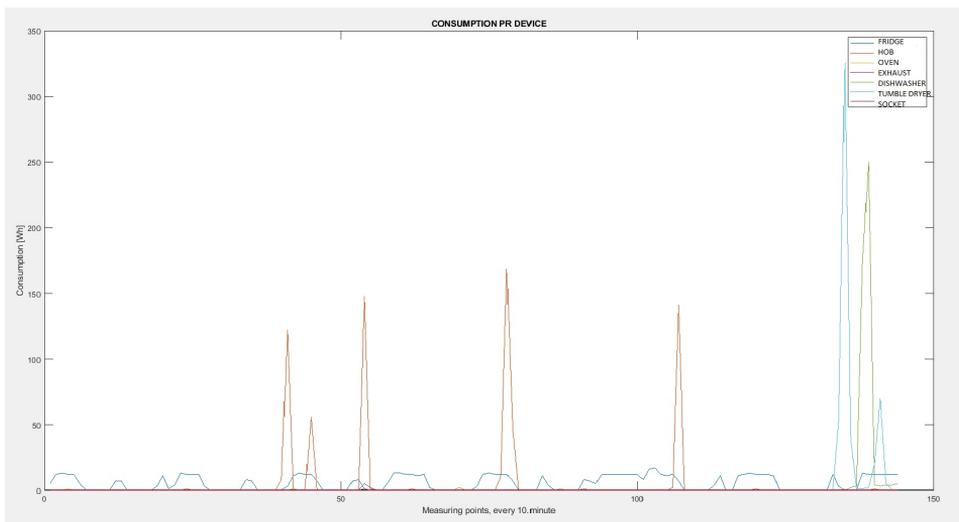
Figure 9.11: Consumption for all devices, day 2

The hob, the exhaust, the dishwasher, the tumble dryer and the socket have been used this day. Figure 9.11 shows that the fridge has a background consumption the whole day. The hob is used 5 times during the day, one of this time, the third one, the exhaust is used the same time. The three first times the hob is used is between 6.30 and 9.30 in the morning, this is probably use connected to breakfast-making. The fourth time the hob is used, is between 12 and 1 in the noon, so this use is probably connected to making of lunch, and the last time the hob is used this day is about 6.30 in the evening, this is probably dinnertime for the occupants. The dishwasher is turned on 10.30 in the evening. Also for this day, the consumption of the socket is just 1Wh for the period. The tumble dryer is used a little bit earlier than the dishwasher, around 9.30 in the evening. After a little period with no consumption, the tumble dryer get a little consumption again, which indicates that it is probably turned on again for a shorter period.

9.3   Analysis of Day 3

Figure 9.12 shows the different states for all the devices throughout the day. In figure 9.13, the consumption for all the devices are shown.
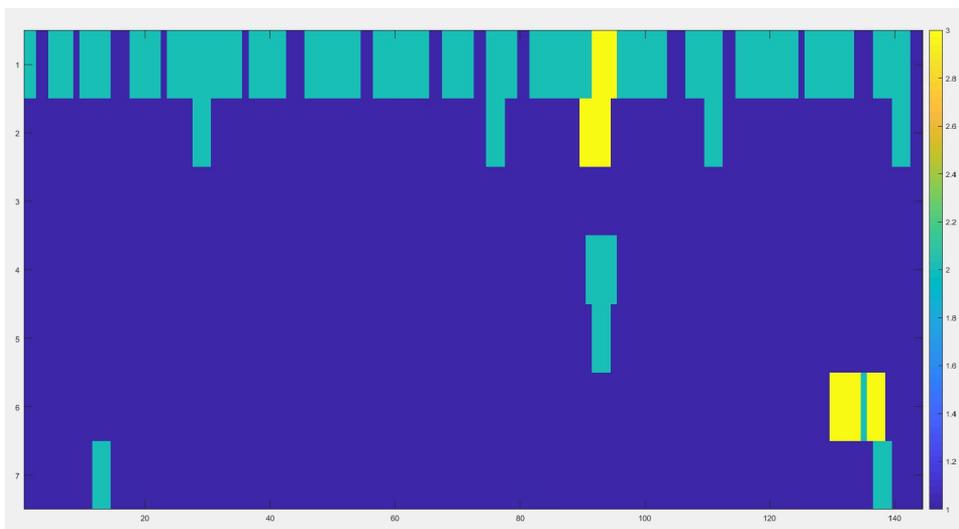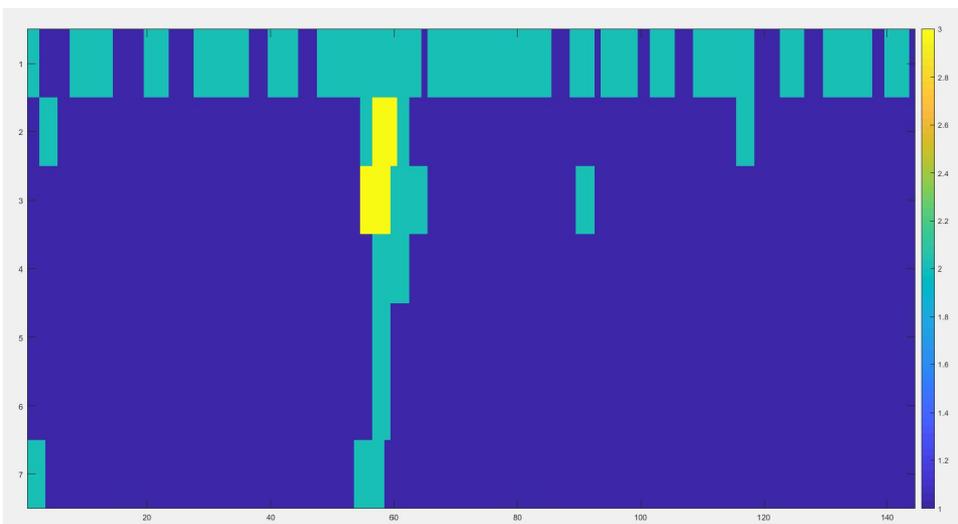

**Figure 9.12:** The states throughout the day for all devices, day 3
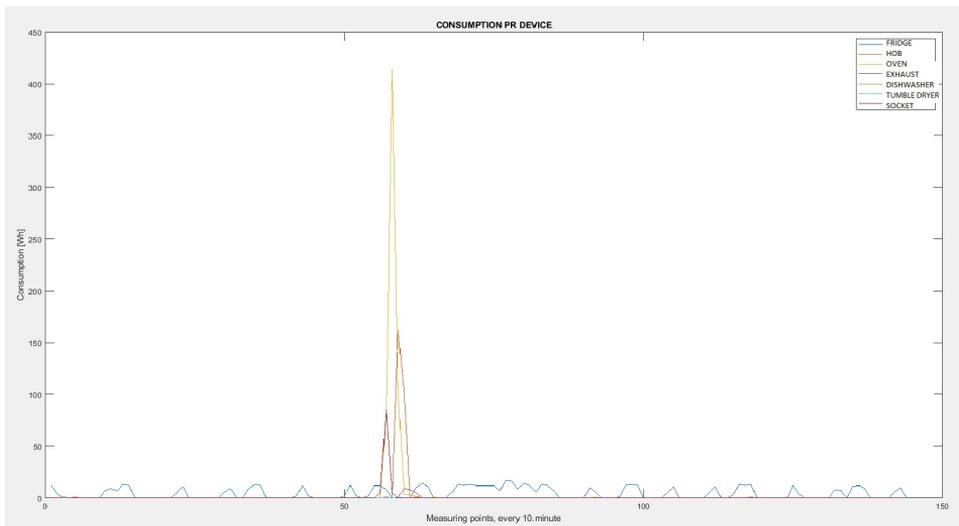
Figure 9.13: Consumption for all devices, day 3

The hob, the oven, the exhaust are used one time each, and the socket is registered as used two times this day. As for the other days, the fridge has a background consumption during the whole day. The hob, the oven, the exhaust and the socket is used at the same time, around measuring point 58 to 62, which means 9.30 to 12 in the morning. This day is a Saturday, so probably breakfast is made. The consumption of the load plugged in the socket is 85Wh for a period of 10 minutes, which gives a power of 510W. Comparing with the knowledge base, this may be a coffee machine. The first time the socket is used this day, again the consumption is only 1Wh.

Chapter 10

Heat Maps of Device Placement in Kitchen

In figure 10.1 the heat map of the placement of the fridge when the shape of the kitchen is not taken into consideration, is shown. Thus this heat map shows how the respondents placed the fridge without any kind of processing. Comparison with figure 10.2, which shows the heat map of the fridge when the placement of the device is processed in view of the shape of the kitchen, figure 10.1 is more messy with more possible placements in the middle of the room. In figure 10.2 the placement is more concentrated to the walls, which is as expected.
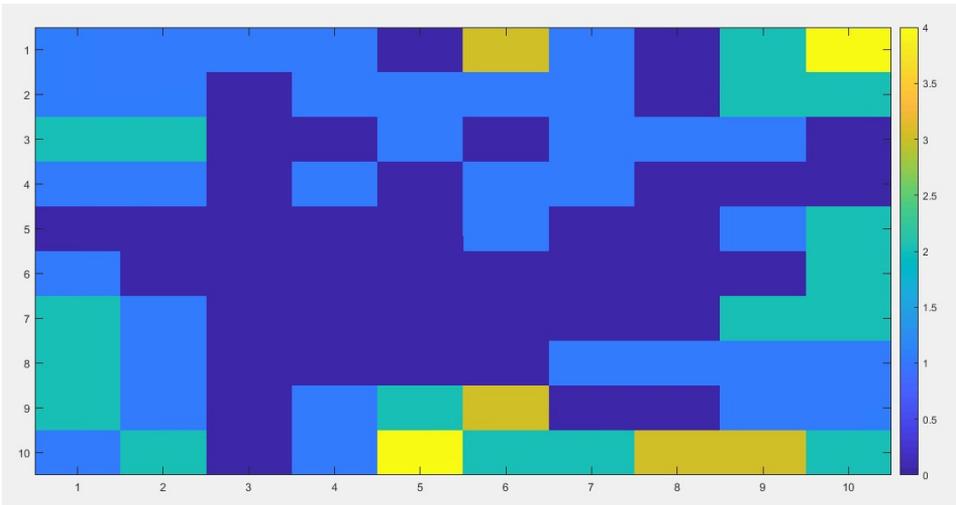
Figure 10.1: Heat map of placement of the fridge, shape of kitchen is not taken into account

Figure 10.2 to figure 10.18 shows the probabilistic heat maps for all the devices from the survey when the shape of the kitchen is taken into account. As mentioned, there were no available data for fryer and tumble dryer, so there are no heat maps for these devices. In the survey, many of the respondents used more than one square to place one device, maximum number of squares to place one device were 9. The difference in how many squares that was used to place each device, will influence the results of the heat maps.
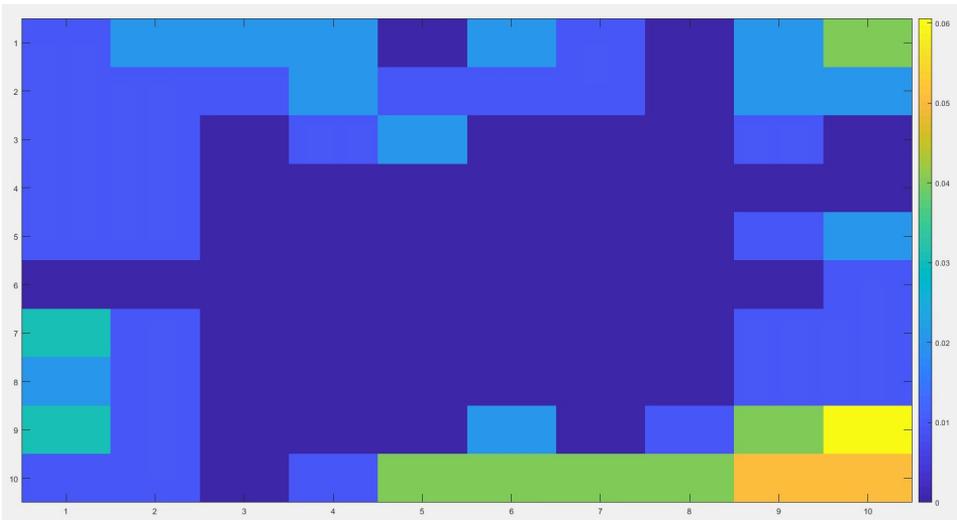
Figure 10.2: Probabilistic heat map of placement of the fridge
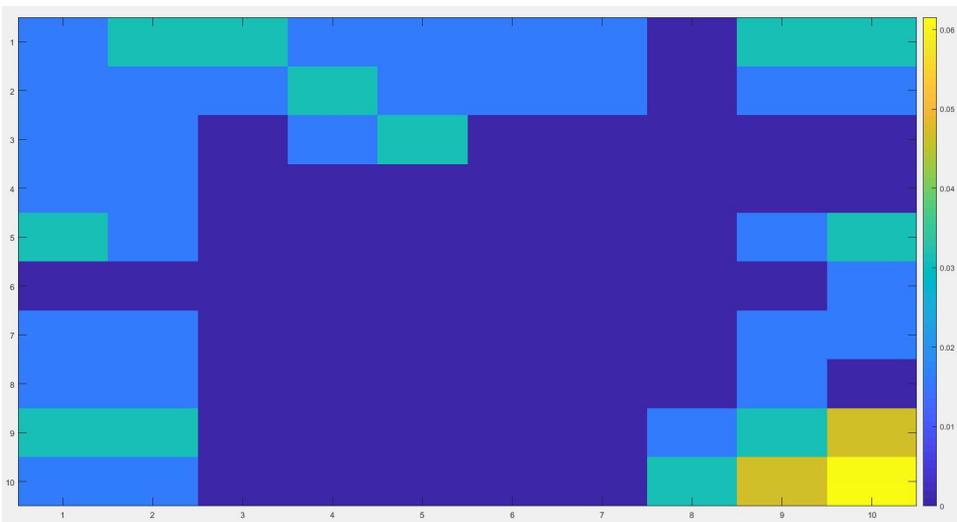
Figure 10.3: Probabilistic heat map of placement of the freezer
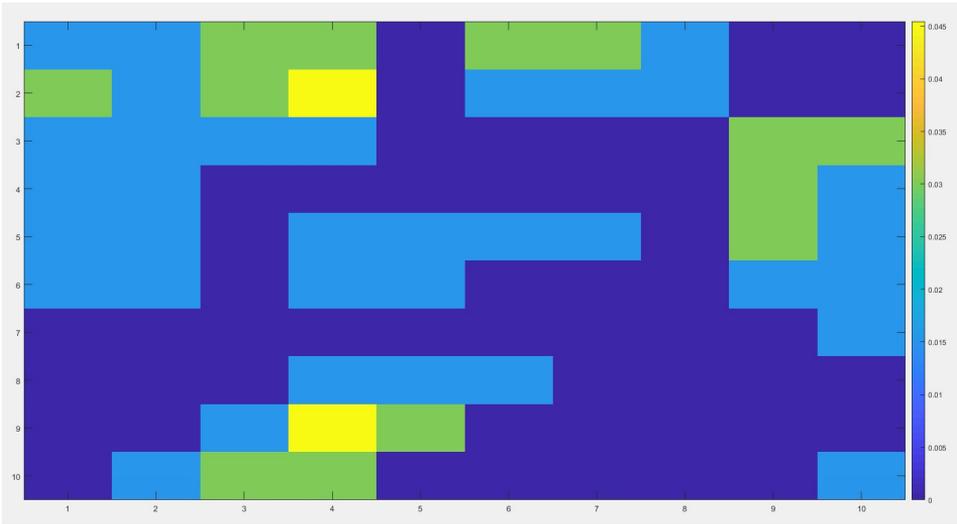
Figure 10.4: Probabilistic heat map of placement of the cooker
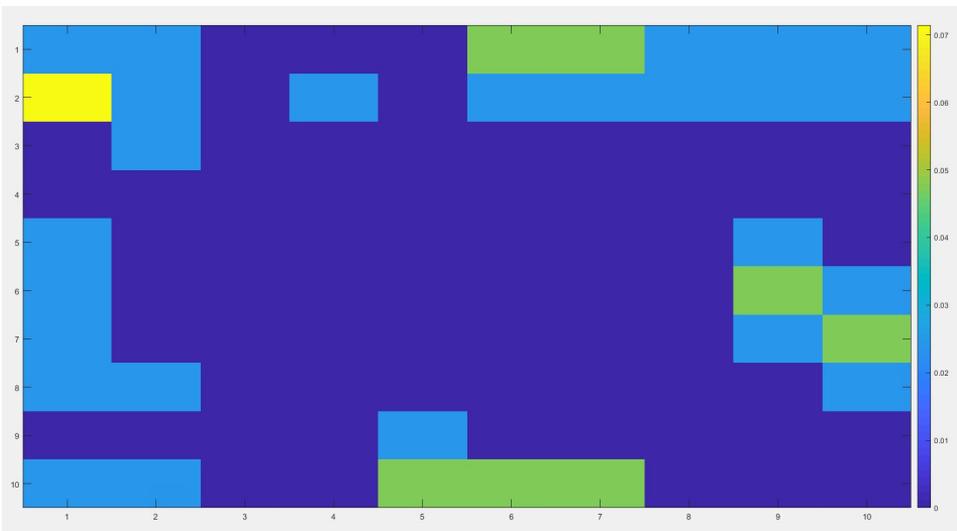
Figure 10.5: Probabilistic heat map of placement of the built-in oven
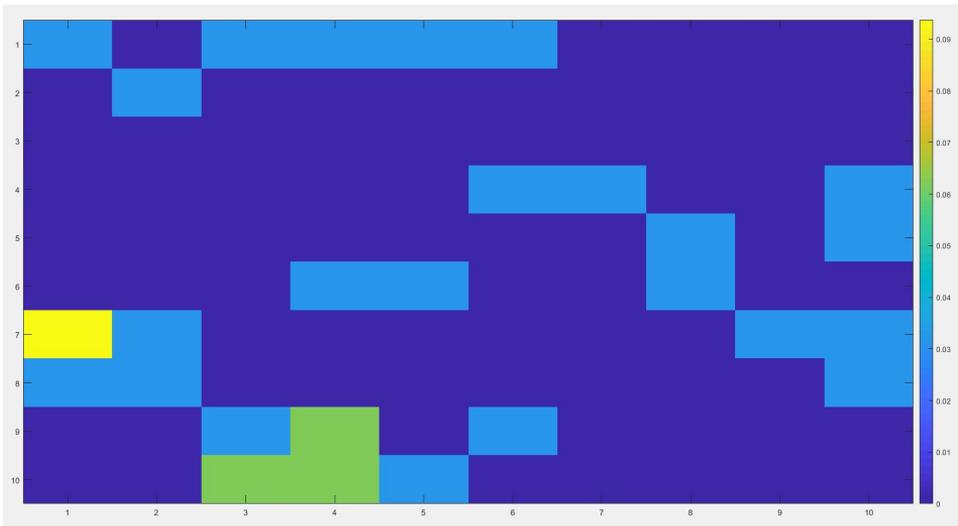
Figure 10.6: Heat map of placement of the hob
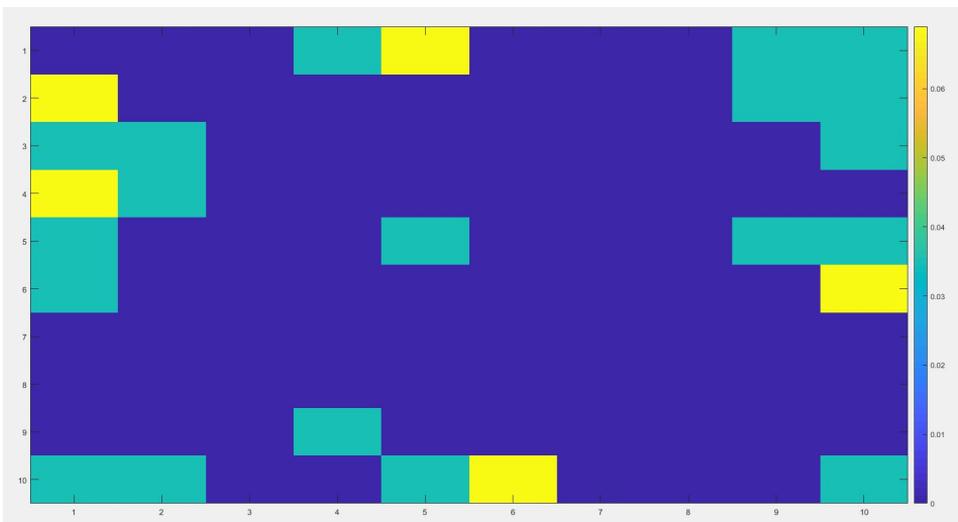
Figure 10.7: Probabilistic heat map of placement of the microwave
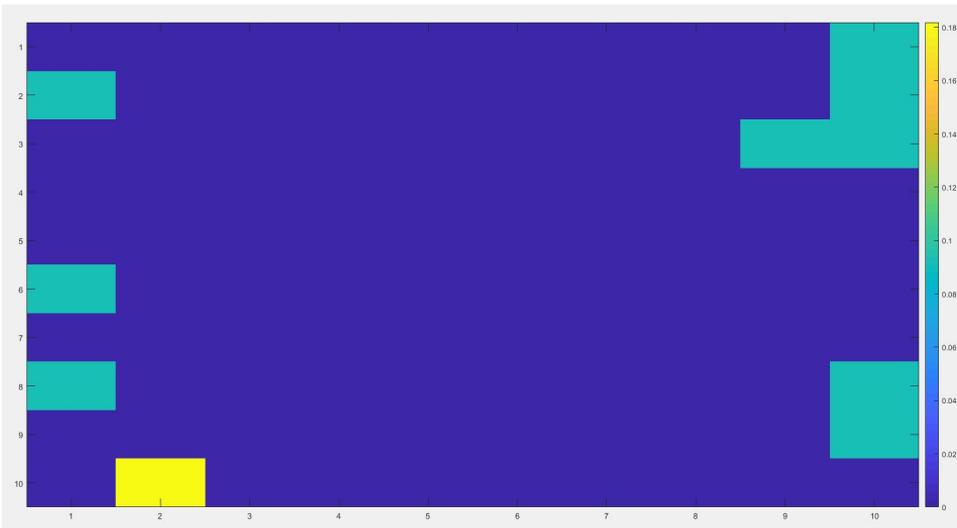
Figure 10.8: Probabilistic heat map of placement of the espresso machine
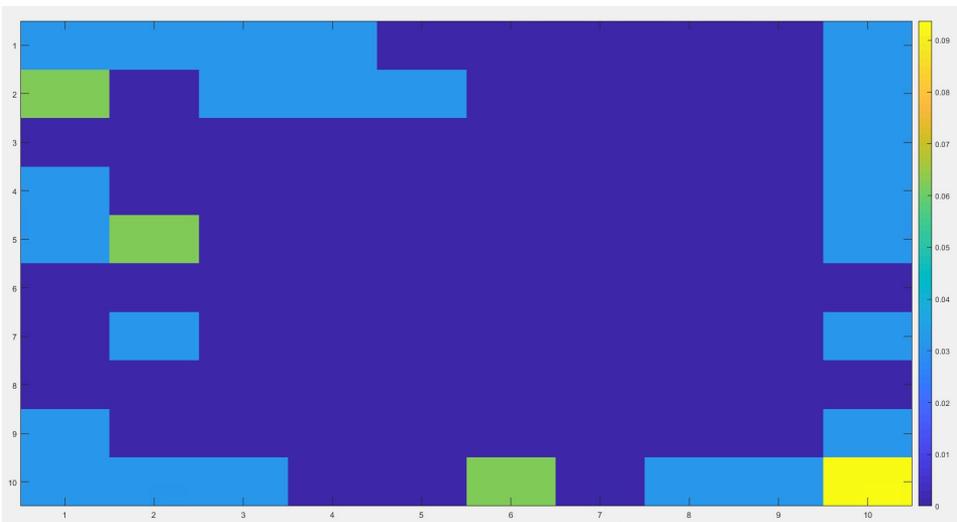
Figure 10.9: Probabilistic heat map of placement of the kettle
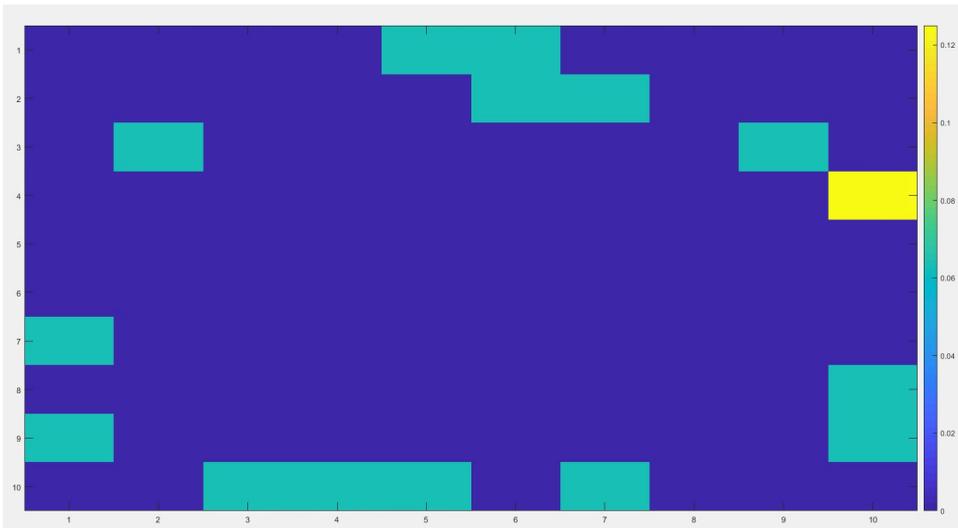
Figure 10.10: Probabilistic heat map of placement of the toaster
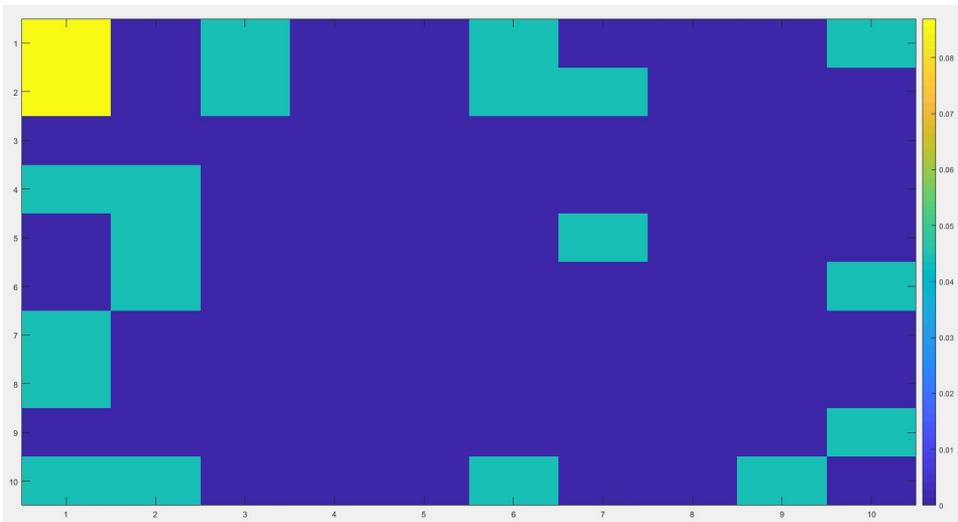
Figure 10.11: Probabilistic heat map of placement of the blender
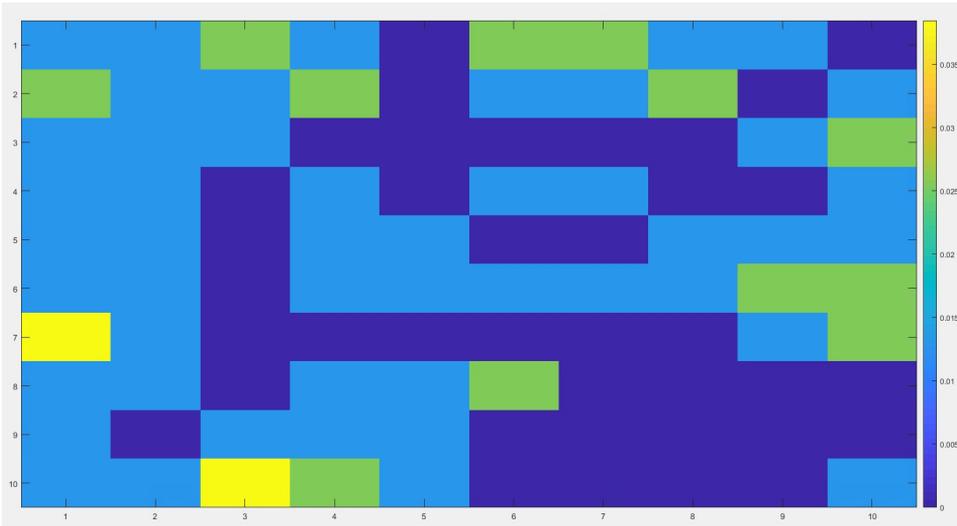
Figure 10.12: Probabilistic heat map of placement of the exhaust
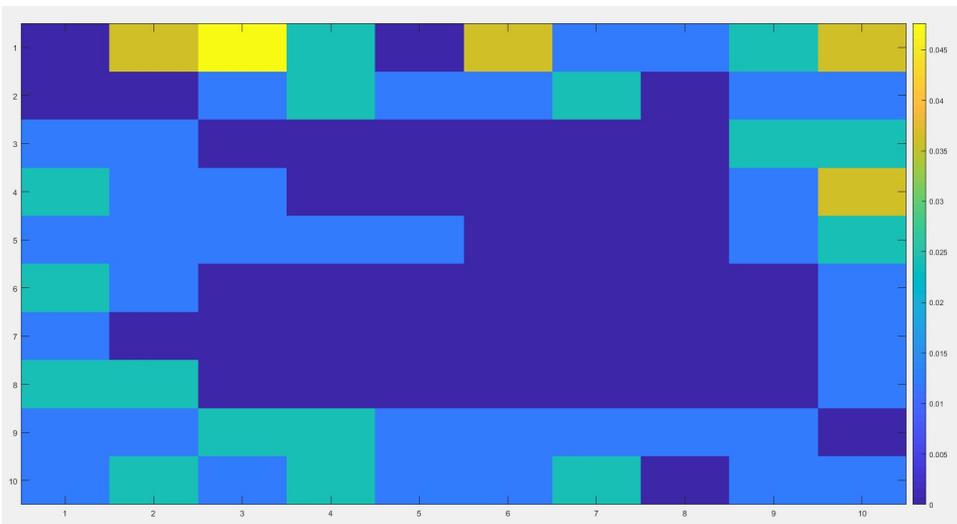
Figure 10.13: Probabilistic heat map of placement of the sink
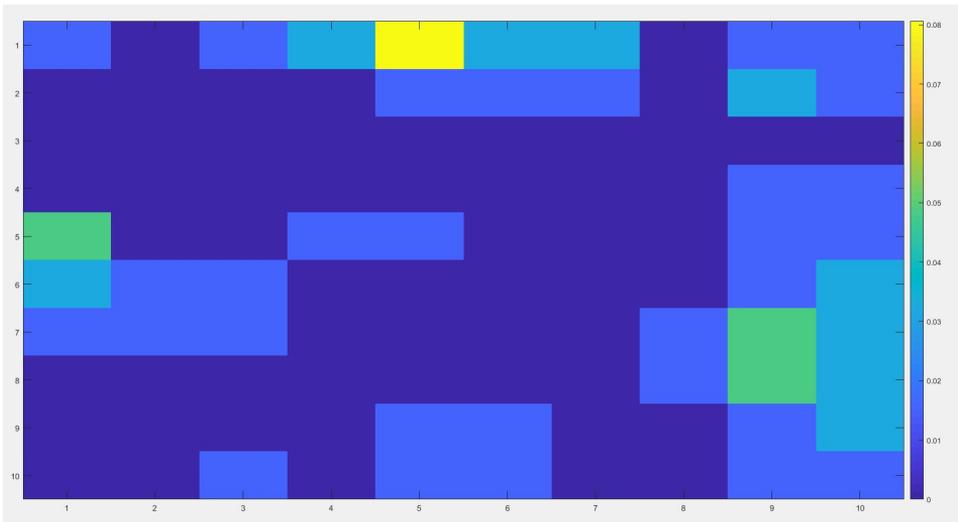
Figure 10.14: Probabilistic heat map of placement of the dishwasher
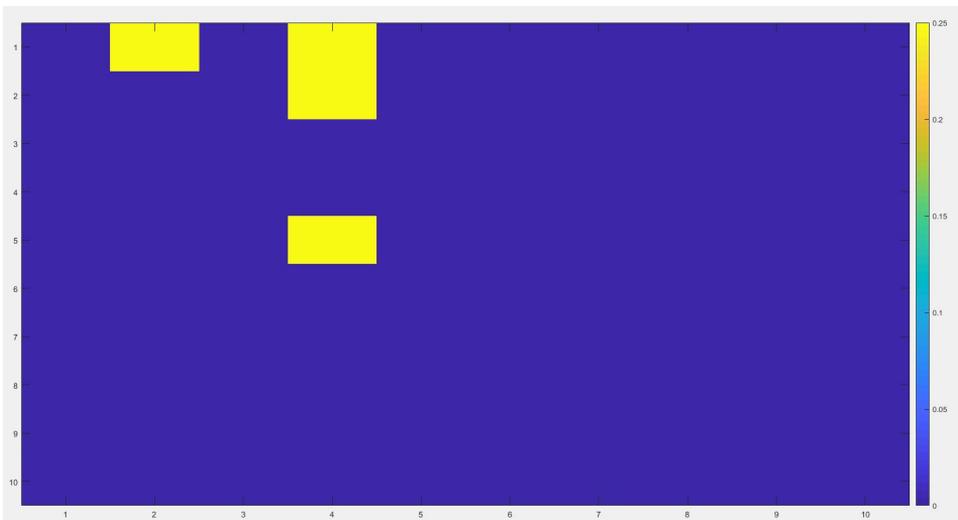
Figure 10.15: Probabilistic heat map of placement of the washing machine
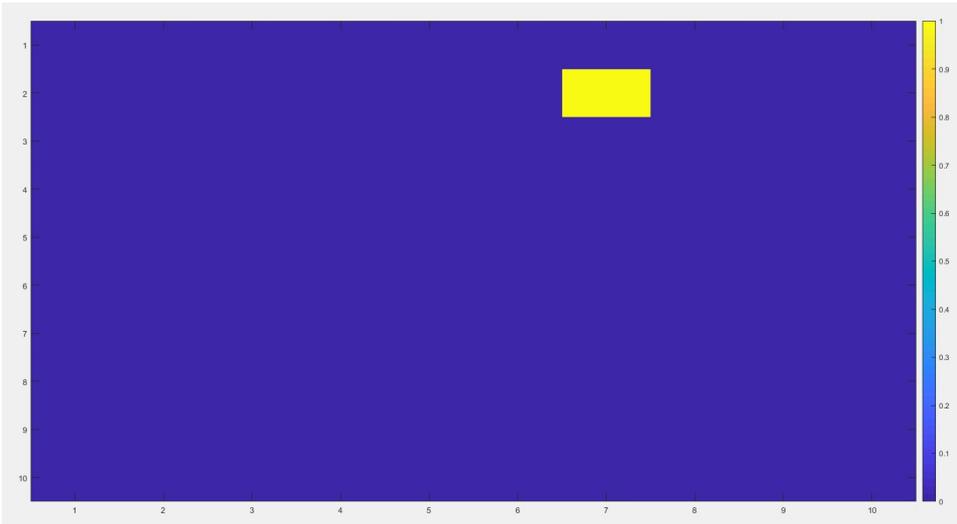
Figure 10.16: Probabilistic heat map of placement of the TV
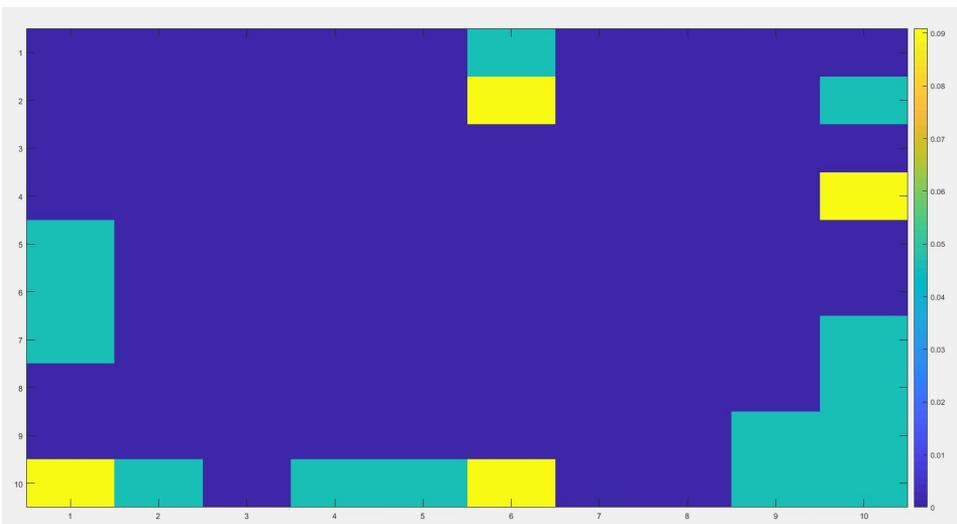
Figure 10.17: Probabilistic heat map of placement of the radio
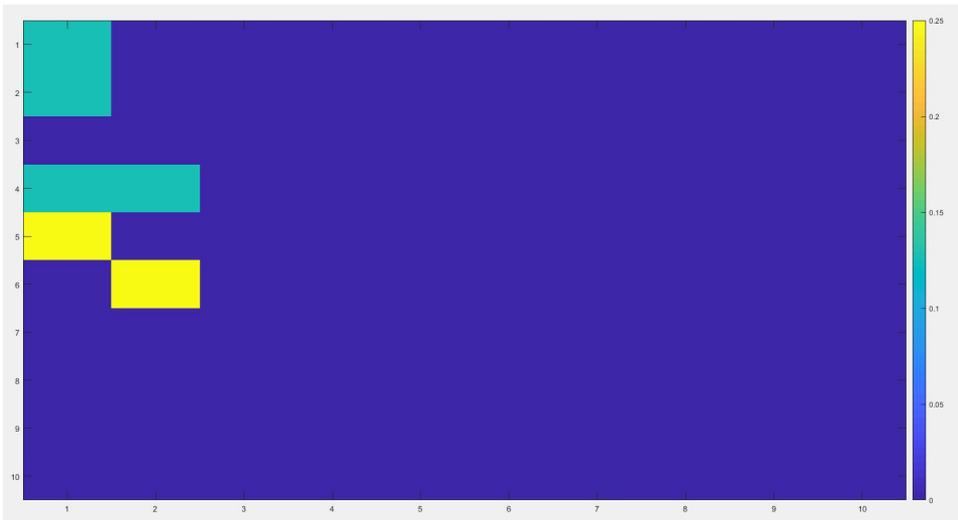
Figure 10.18: Probabilistic heat map of placement of other kitchen devices

Some of the heat maps have a slightly unexpected results. The cooker, figure 10.4, has some placement in the middle of the room, and some illogical placement out from the wall. This may be explained by someone having a kitchen island. The same is for the hob, figure 10.6. The heat map of the exhaust, figure 10.12, would be assumed to be in relation to the heat map of the cooker and the hob, which it partly is. The placement of the exhaust looks a bit messy, but because both the cooker and the hob have some illogical placements, it make sense that the heat map of the exhaust also is a bit illogical. The sink, figure10.13, the dishwasher, figure10.14, and the washing machine, figure10.14, all have one placement in the middle of the room, this can may also be explained by having a kitchen island.

Chapter 11

Results of Simulation of Household Usage

To show how the simulator of kitchen usage works, data from the Living Lab for three random days were used. The same days as the analysis in chapter 9 is used. The data is with resolution 10 minutes, which means 6 measuring periods per hour, thus 144 measuring periods per day.

In the figures showing the different states throughout the chosen days the x-axis represents the different devices, and the y-axis represent the different measuring periods. Use of the device will be represented by yellow for the fridge (line 1), hob (line 2), oven (line 3) and dishwasher (line 5), for the exhaust (line 4) and the socket (line 7), turquoise will represent use of the device. Line 6 represent the tumble dryer, but since there is no heat map for this device, the tumble dryer can not be taken into account when simulating the movement.

Table 11.1 is the same as table 8.1, and shows which number representing each device in the simulator of the layout of the kitchen.

Device	Number representing
Fridge	1
Freezer	2
Cooker	3
Built-in oven	4
Hob	5
Microwave	6
Espresso Machine	7
Kettle	8
Toaster	9
Blender	10
Exhaust	11
Sink	12
Dishwasher	13
Washing Machine	14
TV	15
Radio	16
Other	17

Table 11.1: Number representing each device in the simulator

11.1 Simulation of Day 1

Figure 11.1 shows the different states for all the devices throughout the day, figure 11.2 shows the placement of the devices in the kitchen, and figure 11.3 shows how the occupant move in the kitchen based on how the devices are used.

Figure 11.1 shows that the fridge, hob, the exhaust and the socket is in use this day. When more than one device is used, like fridge, hob and exhaust, the movement is first set to location of fridge, than location of hob, and than location of exhaust, before the vector goes no the next measuring period.
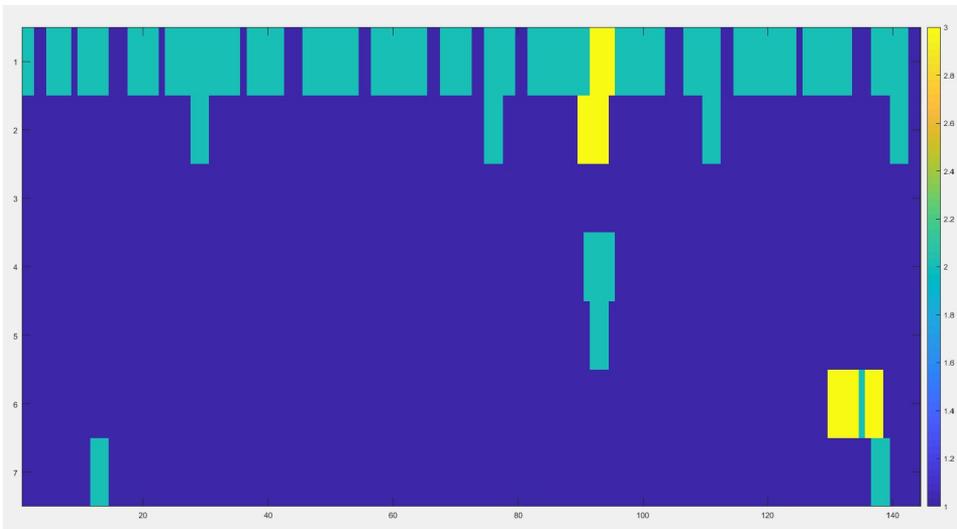
Figure 11.1: The states throughout the day for all devices, day 1
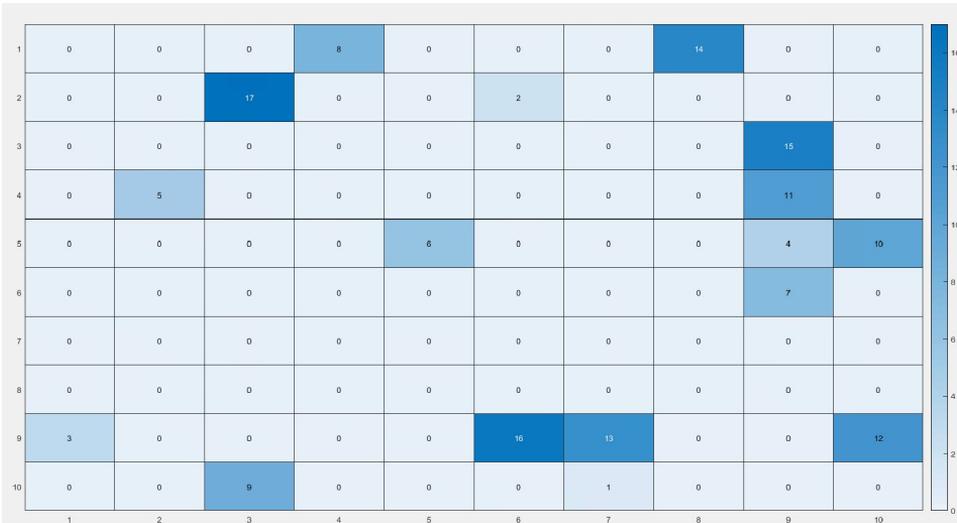
Figure 11.2: Placement of each device, day 1
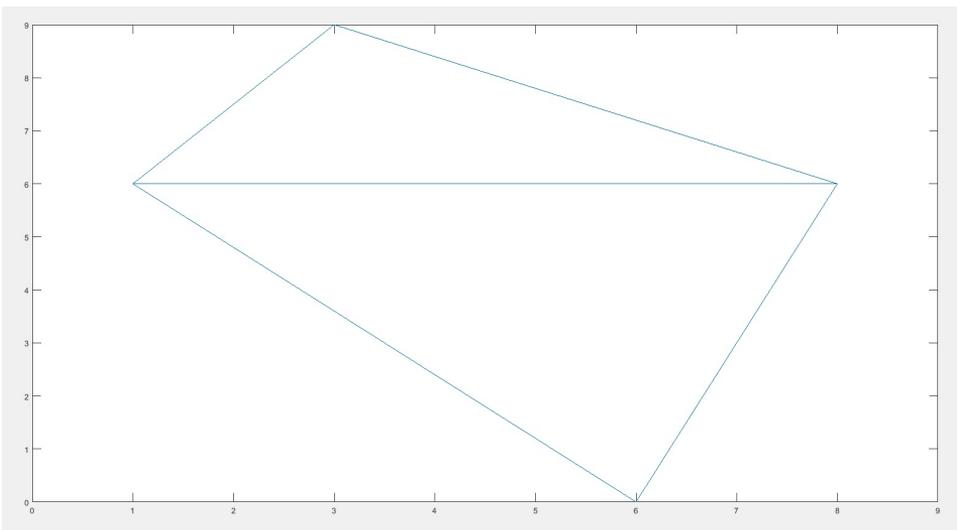
Figure 11.3: Movement of the occupant in the kitchen, day 1

11.2 Simulation of Day 2

Figure 11.4 shows the different states for all the devices throughout the day, figure 11.5 shows the placement of the devices in the kitchen, and figure 11.6 shows how the occupant move in the kitchen.
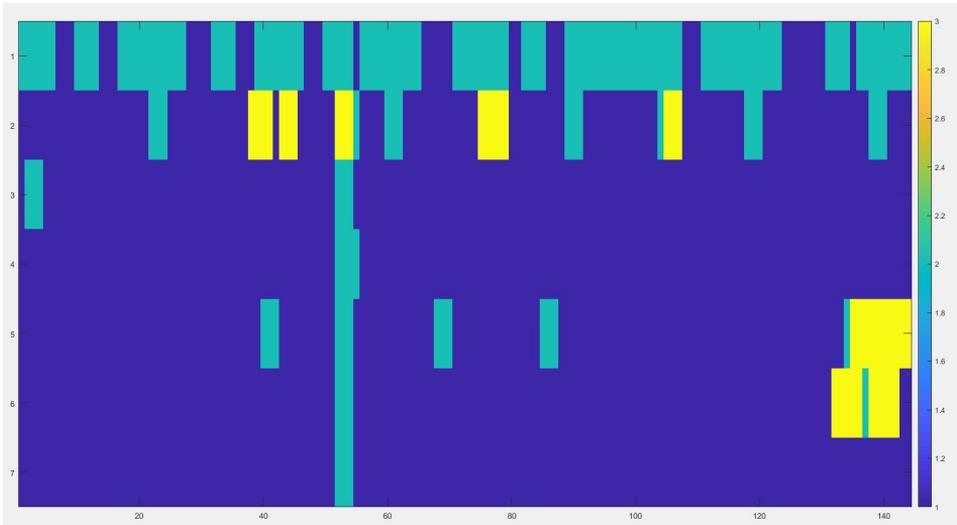
Figure 11.4: The states throughout the day for all devices, day 2
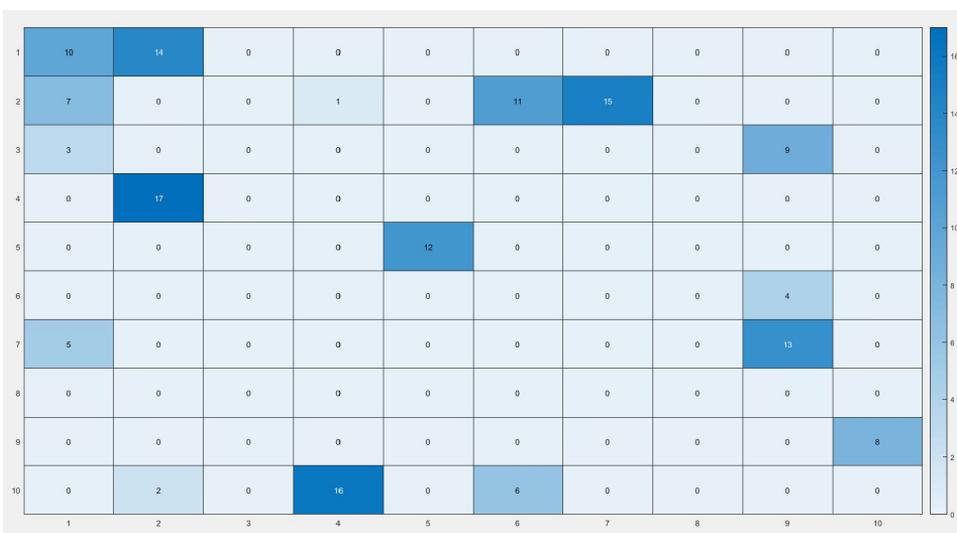
Figure 11.5: Placement of each device, day 2
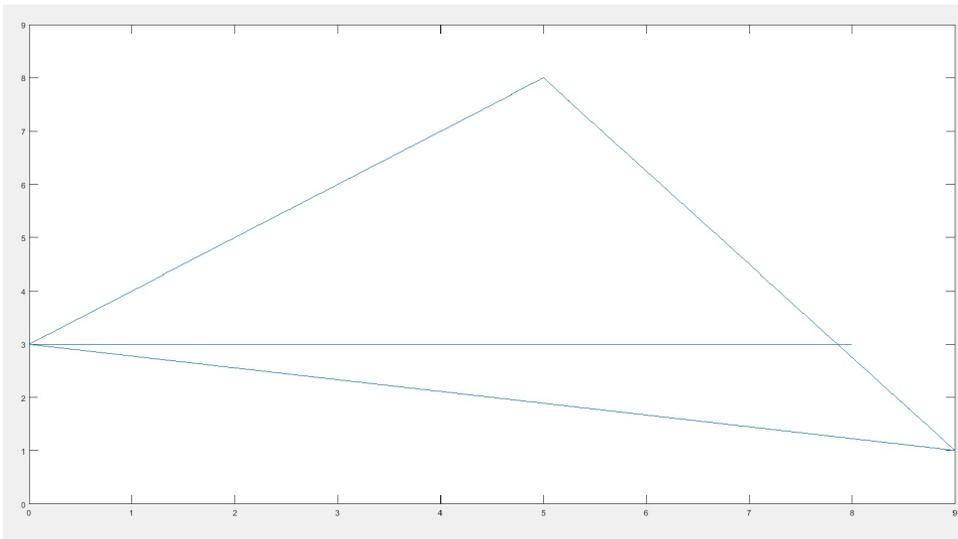
Figure 11.6: Movement of the occupant in the kitchen, day 2

11.3   Simulation of Day 3

Figure 11.7 shows the different states for all the devices throughout the day, figure 11.8 shows the placement of the devices in the kitchen, and figure 11.9 shows how the occupant move in the kitchen.
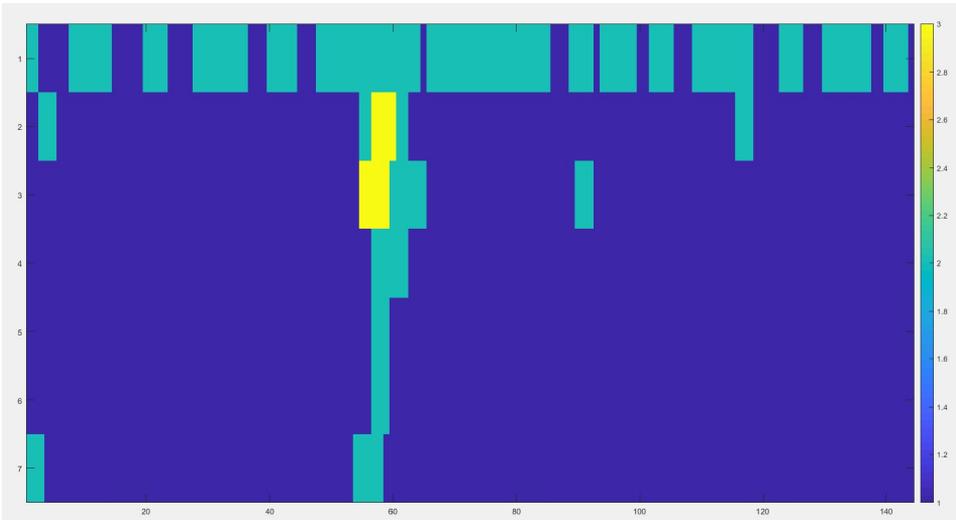
Figure 11.7: The states throughout the day for all devices, day 3
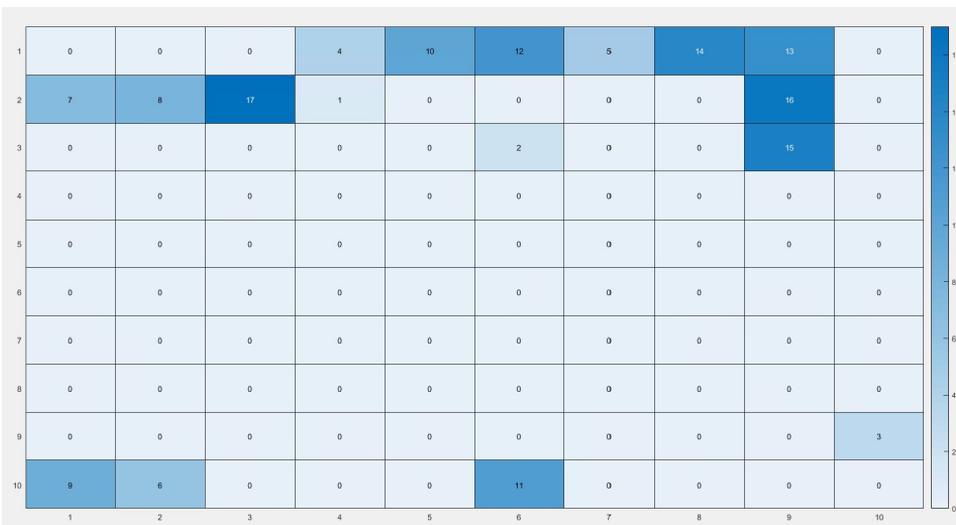
Figure 11.8: Placement of each device, day 3
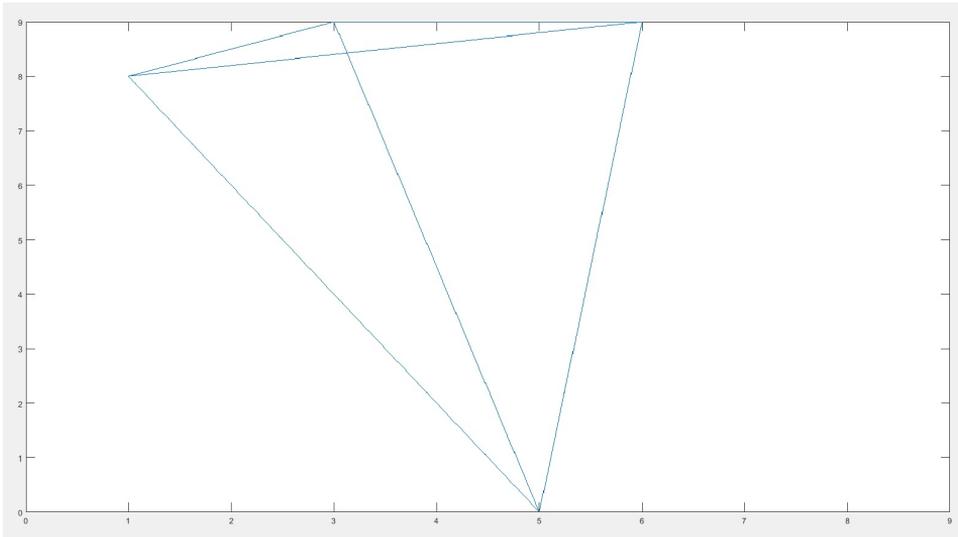
Figure 11.9: Movement of the occupant in the kitchen, day 3

Chapter 12

Conclusion and Suggestion for Further Work

12.1 Conclusion

To get more information of household appliances, a knowledge base of typical devices in a residential has been prepared. The knowledge base contains device performance and characteristics of electrical energy consumption in time for 21 different household devices.

A survey concerning use and placement of kitchen appliances were conducted to get more information on use of devices. 18 devices, plus the opportunity to state if one have other kitchen devices, were asked about. Of a total of 42 responses, 22 thought that the fridge is the most important device in the kitchen. 26 responses have a cooker in their kitchen, and 13 of these meant that the cooker is the second most important kitchen device. The answers from the survey showed that the average number of kitchen devices in a home is 9, with a standard deviation of 2. The results of the part of survey which dealt with placement of devices in the kitchen was used as base for development of heat maps of device placement in the kitchen. The heat maps of all the devices asked about in the survey showed that most devices are placed along the walls in the kitchen.

Results of field measurements of the energy consumption in the ZEB - Living Lab were used for decoding of electricity consumption behaviour in residential buildings and analyzed. The analysis showed that it was difficult to find a trend in the consumption when comparing the usage each week with each other. Based on the analysis of the field measurements and the developed heat maps, a simulator of household usage were developed. The simulator developed is a very simple simulator that has to be further developed before it can be used for analysis. The simulator was partly validated by use of 3 scenarios from the Living Lab.

12.2 Suggestion for Further Work

Suggestion on further work on the same topic concerns the simulator. The simulator will have to be further developed, the simulator developed in this thesis has a very simple approach, and do not take into consideration many aspects of household usage. The main deficiencies of the simulator are related to the simulation of placement of the devices. The more developed simulator should consider the relationship matrix, so that the placement of each device will be dependent of the placement and the meta data of the previous devices. The simulator should also place different numbers of devices, because this will vary a lot for different kitchens, and also simulate that some devices can be combined. For simulating the movement when the socket is used, the simulator should be developed to vary between many different devices plugged into the socket, dependent on the consumption of the socket for the given time. The knowledge base can be used for this.

The simulator also has to be validated more closely. For this, measurements from test bed will be needed, thus field measurements will also have to be conducted.

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Appendix

A. Survey

"Kitchen is the heart of the home" - survey

We would like to invite you to participate in a survey aiming to investigate your home space usage. The scope of this study seeks information regarding kitchen appliances placement and how it is organized. The goal is to check the diversity of kitchen space usage in residential buildings. Collected data will be used to investigate the possibility of generating a kitchen layout simulator.

1.1 Your gender/sex

A.   Female   B.   Male

1.2 Write your age in rectangle nr.1 below. If you are living with other occupants, write their age in the following squares. If you are uncertain about their age, write an approximate value.

1	2	3	4	5	6	7

2. The overview below lists appliances that may be located in kitchens. On the next page, they are presented by icon-graphics.

2.1 Put marks 'X' in squares with appliances that you have in your kitchen.

2.2 Give each marked appliance, importance numbering in an increasing order. No. 1 is the most important one, regarding your habits of the kitchen usage. If same appliances are combined, give them the same number. Write number inside the circle

❑ ◯ Fridge   ❑ ◯ Toaster
❑ ◯ Freezer   ❑ ◯ Blender
❑ ◯ Cooker   ❑ ◯ Exhaust
❑ ◯ Built-in Oven   ❑ ◯ Sink
❑ ◯ Hob   ❑ ◯ Dishwasher
❑ ◯ Microwave   ❑ ◯ Washing Machine
❑ ◯ Espresso Machine   ❑ ◯ Tumble Dryer
❑ ◯ Kettle   ❑ ◯ TV
❑ ◯ Fryer   ❑ ◯ Radio
                                        ❑ ◯ Other ………….

3.1 Approximate size of your kitchen is _____ [m²]

3.2 Your kichen is shaped like

A. Square ☐   B. Rectangle ☐   C. L-Shaped ⌐   D. Other ▱

4. For all questions below, use the grid below to answer

4.1 If the answer from 3.2, was other than A, mark „X" on the squares to show proportional shape of your kitchen   ☒

4.2 Mark the location of windows in the kitchen, using the grey rectangles. Write "W" inside.   W

4.3 Mark the location of doorways in the kitchen, using the grey rectangles. Write "D" inside.   D

4.4 Draw an arrow pointing the direction of the north, inside the „N" circle,

4.5 Write numbers inside the squares to position all of the appliances in your kitchen. Use numbering from 2.2. One feature may take more than one rectangle.

4.6 Color the squares representing positions of other kitchen features like drawers, tables, chairs etc.   ■

N

❑ ◯ Fridge

❑ ◯ Freezer

❑ ◯ Cooker

❑ ◯ Built-in Oven

❑ ◯ Hob

❑ ◯ Microwave

❑ ◯ Espresso Machine

❑ ◯ Kettle

❑ ◯ Fryer

❑ ◯ Toaster

❑ ◯ Blender

❑ ◯ Exhaust

❑ ◯ Sink

❑ ◯ Dishwasher

❑ ◯ Washing Machine

❑ ◯ Tumble Dryer

❑ ◯ TV

❑ ◯ Radio

❑ ◯ Other ………….

B. MatLab-code for Processing of Data from Living Lab

```
clc
clear
load data2;
%data2:  consumption for every measuring point for fridge, hob, oven,
%extraction hood, dishwasher, washing machine, tumble dryer, and
%kitchen-socket

start_V=min(Data1(:,1)); %Value of the starting time for measuring period
end_V=max(Data1(:,1)); %Value of the end time for measuring period

res=60; %Resolution
ch=(res/60)/24; %step size
sort_row(:,1)=(start_V:ch:end_V);
%Vector with all time values wanted to analyze with the chosen resolution

for i=1:length(Data1)
operator_row(i,1)=i; %Row numbering
end
%Find the number of column in data2 for all the timevalues for start and
%end for all the periods wanted to investigate with the chosen resolution:
for i=1:length(sort_row)%Find the endvalue of the periods
  h_B=double(Data1(:,1)<sort_row(i,1));
  h_B=h_B.*operator_row;
  data_range(i,2)=max(h_B);
end
data_range1(:,:)=data_range(2:end,:);
data_range1(1,1)=1;
for i=2:length(data_range1)%Find the startvalue of the periods
    data_range1(i,1)= data_range1(i-1,2)+1;
end
for i=1:length(data_range1)%Find the number of measurepoint in the periods
    data_range1(i,3)=data_range1(i,2)-data_range1(i,1);
end

%Find statistical values to remove unlogical measurepoints:
range_stats1(1,1)=mean(data_range1(:,3));
range_stats1(1,2)=std(data_range1(:,3));
range_stats1(1,3)=floor(range_stats1(1,1)-range_stats1(1,2));
range_stats1(1,4)=floor(range_stats1(1,1)+range_stats1(1,2));
data_range1(:,4)=double(data_range1(:,3)>range_stats1(1,3));
data_range1(:,5)=double(data_range1(:,3)<range_stats1(1,4));
data_range1(:,6)=data_range1(:,4).*data_range1(:,5);


Data1(isnan(Data1))=0;

%Find the sum of the consumption for each measuring period with chosen
%resolution:
for i=1:length(data_range1)
    for j=1:8
sum_range_d1(i,j)=sum(Data1(data_range1(i,1):data_range1(i,2),j+1));
    end
end

%Unlogical measurepoints from datarange 1 are removed, by setting the
```

```matlab
%state to zero, meaning we don't have any measuring for this point:
for i=1:length(data_range1)
    if data_range1(i,6)==0
        sum_range_d1(i,:)=-1;
    end
end
%The procedure is the same for all the devices

% Device 1, Fridge, data analyze
div=sum_range_d1(:,1); %Consumption for the fridge
state0=-1; %Removed meausuring because illogical
state1=0; %No use or error in metering
state2=40; %Constant background consumption
if res==10
    state3=450; %Normal usage
elseif res==20
    state3=600;
elseif res==60
    state3=2000;
end
state4=100000; %Wrong metering

%Find the state for each period for the chosen resolution:
state_ref(:,1)=double(div==state0);
state_ref(:,2)=double(div==state1);
op(:,1)=double(div>state1);
op(:,2)=double(div<=state2);
state_ref(:,3)=(op(:,1).*op(:,2));
op1(:,1)=double(div>state2);
op1(:,2)=double(div<=state3);
state_ref(:,4)=(op1(:,1).*op1(:,2));
state_ref(:,5)=(div>state3);

add=1;
regist=zeros(max(sum(state_ref)),5);
for j=1:5
for i=1:length(div)
    if state_ref(i,j)==1
    regist(add,j)=i;
    add=add+1;
    end
end
add=1;
end
%Relate the states to timevalues:
for j=1:5
for i=1:length(regist)
    if regist(i,j)==0
        regist_time1(i,j)=0;
    else
    regist_time1(i,j)= start_V+((regist(i,j)-1)*ch);
end
end
end
```

```matlab
% Device 2, Hob, data analyze
div=sum_range_d1(:,2);
state0=-1; %Removed meausuring because illogical
state1=0;
state2=2;
if res==10
    state3=420; %Normal usage
elseif res==20
    state3=600;
elseif res==60
    state3=1200;
end
state4=100000;
state_ref(:,1)=double(div==state0);
state_ref(:,2)=double(div==state1);
op(:,1)=double(div>state1);
op(:,2)=double(div<=state2);
state_ref(:,3)=(op(:,1).*op(:,2));
op1(:,1)=double(div>state2);
op1(:,2)=double(div<=state3);
state_ref(:,4)=(op1(:,1).*op1(:,2));
state_ref(:,5)=(div>state3);
add=1;
regist=zeros(max(sum(state_ref)),5);
for j=1:5
for i=1:length(div)
    if state_ref(i,j)==1
    regist(add,j)=i;
    add=add+1;
    end
end
add=1;
end
for j=1:5
for i=1:length(regist)
    if regist(i,j)==0
        regist_time2(i,j)=0;
    else
    regist_time2(i,j)= start_V+((regist(i,j)-1)*ch);
end
end
end

% Device 3, Oven, data analyze
div=sum_range_d1(:,3);
state0=-1; %Removed meausuring because illogical
state1=0;
state2=3;
if res==10
    state3=600; %Normal usage
elseif res==20
    state3=1000;
elseif res==60
    state3=1400;
```

```
end
state4=100000;

state_ref(:,1)=double(div==state0);
state_ref(:,2)=double(div==state1);
op(:,1)=double(div>state1);
op(:,2)=double(div<=state2);
state_ref(:,3)=(op(:,1).*op(:,2));
op1(:,1)=double(div>state2);
op1(:,2)=double(div<=state3);
state_ref(:,4)=(op1(:,1).*op1(:,2));
state_ref(:,5)=(div>state3);
add=1;
regist=zeros(max(sum(state_ref)),5);
for j=1:5
for i=1:length(div)
    if state_ref(i,j)==1
    regist(add,j)=i;
    add=add+1;
    end
end
add=1;
end
for j=1:5
for i=1:length(regist)
    if regist(i,j)==0
        regist_time3(i,j)=0;
    else
    regist_time3(i,j)= start_V+((regist(i,j)-1)*ch);
end
end
end

% Device 4,Extraction hood, data analyze
div=sum_range_d1(:,4);
state0=-1; %Removed meausuring because illogical
state1=0;
if res==10
    state2=20; %Normal usage
elseif res==20
    state2=40;
elseif res==60
    state2=100;
end
state3=100000;
state_ref(:,1)=double(div==state0);
state_ref(:,2)=double(div==state1);
op(:,1)=double(div>state1);
op(:,2)=double(div<=state2);
state_ref(:,3)=(op(:,1).*op(:,2));
state_ref(:,4)=(div>state2);
add=1;
regist=zeros(max(sum(state_ref)),4);
for j=1:4
for i=1:length(div)
```

```matlab
    if state_ref(i,j)==1
    regist(add,j)=i;
    add=add+1;
    end
end
add=1;
end
for j=1:4
for i=1:length(regist)
    if regist(i,j)==0
        regist_time4(i,j)=0;
    else
    regist_time4(i,j)= start_V+((regist(i,j)-1)*ch);
end
end
end

% Device 5, Dishwasher, data analyze
div=sum_range_d1(:,5);
state0=-1; %Removed meausuring because illogical
state1=0;
state2=2;
if res==10
    state3=400; %Normal usage
elseif res==20
    state3=1000;
elseif res==60
    state3=1250;
end
state4=100000;

state_ref(:,1)=double(div==state0);
state_ref(:,2)=double(div==state1);
op(:,1)=double(div>state1);
op(:,2)=double(div<=state2);
state_ref(:,3)=(op(:,1).*op(:,2));
op1(:,1)=double(div>state2);
op1(:,2)=double(div<=state3);
state_ref(:,4)=(op1(:,1).*op1(:,2));
state_ref(:,5)=(div>state3);
add=1;
regist=zeros(max(sum(state_ref)),5);
for j=1:5
for i=1:length(div)
    if state_ref(i,j)==1
    regist(add,j)=i;
    add=add+1;
    end
end
add=1;
end
for j=1:5
for i=1:length(regist)
    if regist(i,j)==0
        regist_time5(i,j)=0;
```

```matlab
    else
    regist_time5(i,j)= start_V+((regist(i,j)-1)*ch);
end
end
end

% Device 7, Tumble dryer, data analyze
div=sum_range_d1(:,7);
state0=-1;
state1=0;
if res==10
    state=400; %Normal usage
elseif res==20
    state2=600;
elseif res==60
    state2=1500;
end
state3=100000;
state_ref(:,1)=double(div==state0);
state_ref(:,2)=double(div==state1);
op(:,1)=double(div>state1);
op(:,2)=double(div<=state2);
state_ref(:,3)=(op(:,1).*op(:,2));
state_ref(:,4)=(div>state2);
add=1;
regist=zeros(max(sum(state_ref)),4);
for j=1:4
for i=1:length(div)
    if state_ref(i,j)==1
    regist(add,j)=i;
    add=add+1;
    end
end
add=1;
end
for j=1:4
for i=1:length(regist)
    if regist(i,j)==0
        regist_time7(i,j)=0;
    else
    regist_time7(i,j)= start_V+((regist(i,j)-1)*ch);
end
end
end

% Device 8, socket kitchen, data analyze
div=sum_range_d1(:,8);
state0=-1;
state1=0;
if res==10
    state2=250; %Normal usage
elseif res==20
    state2=350;
elseif res==60
    state2=800;
```

```
end
state3=100000;

state_ref(:,1)=double(div==state0);
state_ref(:,2)=double(div==state1);
op(:,1)=double(div>state1);
op(:,2)=double(div<=state2);
state_ref(:,3)=(op(:,1).*op(:,2));
state_ref(:,4)=(div>state2);

add=1;
regist=zeros(max(sum(state_ref)),4);
for j=1:4
for i=1:length(div)
    if state_ref(i,j)==1
    regist(add,j)=i;
    add=add+1;
    end
end
add=1;
end
for j=1:4
for i=1:length(regist)
    if regist(i,j)==0
        regist_time8(i,j)=0;
    else
    regist_time8(i,j)= start_V+((regist(i,j)-1)*ch);

end
end
end


%The states can be sorted both by days and by week, the method for weeks
%are in this code commented out

% %Matrix with all the measurement points for each day:
% A=zeros(195,(60/res)*24);
% start_day=start_V;
% end_day=start_day+1-ch;
% add=1;
% for i=1:195
%     for j=start_day:ch:end_day
%         A(i,add)=j;
%         add=add+1;
%     end
%     start_day=end_day+ch;
%     end_day=start_day+1-ch;
%     add=1;
% end

%Matrix with all the measurementspoints for each week:
A=zeros(28,(60/res)*24*7);
start_week=start_V;
end_week=start_V+7-ch;
```

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```
add=1;
for i=1:1:28
    for j=start_week:ch:end_week
        A(i,add)=j;
        add=add+1;
    end
    start_week=end_week+ch;
    end_week=start_week+7-ch;
    add=1;
end

%Same procedure for all the devices:
%Device 1, Fridge
%States1=zeros(195,(60/res)*24); %Matrix with all the states per day
%For week:
States1=zeros(28,(60/res)*24*7);

C=zeros(length(div),2); %Matrix with all the measurmentpoints and the
                        %corresponding state
add=1;

%Matrix with timevalue in first column and state in second column
for j=1:5 %number of states
    for i=1:length(regist_time1)
        if regist_time1(i,j)==0
        else
            C(add,1)=regist_time1(i,j);
            C(add,2)=j-1;
            add=add+1;
        end
    end
end
%Sort the timevalues
sizeA=size(A,2);
for i=1:28 %For week: i=1:28
    for j=1:sizeA
    for k=1:length(C)
        A1=A(i,j)-0.01; %-0.01 to allow a small error rate
        A2=A(i,j)+0.01; %+0.01 to allow a small error rate
      op2(:,1)=double(A1<=C(k,1)); %check if it's within the day
      op2(:,2)=double(C(k,1)<=A2); %check if it's within the day
      day(:,1)=(op2(:,1).*op2(:,2)); %check if it's within the day
        if day(:,1)==1
            States1(i,j)=C(k,2);
        end
    end
    end
    end
end

%Device 2, Hob
%States2=zeros(195,(60/res)*24); %Matrix with all the states per week
%For week:
States2=zeros(28,(60/res)*24*7);
add=1;
for j=1:5 %number of states
```

```matlab
        for i=1:length(regist_time2)
            if regist_time2(i,j)==0
            else
                C(add,1)=regist_time2(i,j);
                C(add,2)=j-1;
                add=add+1;
            end
        end
end
%Sort the timevalues
sizeA=size(A,2);
for i=1:28 %For week: i=1:28
    for j=1:sizeA
    for k=1:length(C)
        A1=A(i,j)-0.01; %-0.01 to allow a small error rate
        A2=A(i,j)+0.01; %+0.01 to allow a small error rate
       op2(:,1)=double(A1<=C(k,1)); %check if it's within the day
       op2(:,2)=double(C(k,1)<=A2); %check if it's within the day
       day(:,1)=(op2(:,1).*op2(:,2)); %check if it's within the day
        if day(:,1)==1
            States2(i,j)=C(k,2);
        end
    end
    end
end


%Device 3, Oven
%States3=zeros(195,(60/res)*24); %Matrix with all the states per week
%For week:
States3=zeros(28,(60/res)*24*7);
add=1;
for j=1:5 %number of states
    for i=1:length(regist_time3)
        if regist_time3(i,j)==0
        else
            C(add,1)=regist_time3(i,j);
            C(add,2)=j-1;
            add=add+1;
        end
    end
end
%Sort the timevalues
sizeA=size(A,2);
for i=1:28 %For week: i=1:28
    for j=1:sizeA
    for k=1:length(C)
        A1=A(i,j)-0.01;
        A2=A(i,j)+0.01;
       op2(:,1)=double(A1<C(k,1)); %check if it's within the day
       op2(:,2)=double(C(k,1)<A2); %check if it's within the day
       day(:,1)=(op2(:,1).*op2(:,2)); %check if it's within the day
        if day(:,1)==1
            States3(i,j)=C(k,2);
        end
    end
```

```
        end
        end
end

%Device 4, Extraction Hood
%States4=zeros(195,(60/res)*24); %Matrix with all the states per week
%For week:
States4=zeros(28,(60/res)*24*7);
add=1;
for j=1:4 %number of states
    for i=1:length(regist_time4)
        if regist_time4(i,j)==0
        else
            C(add,1)=regist_time4(i,j);
            C(add,2)=j-1;
            add=add+1;
        end
    end
end
%Sort the timevalues
sizeA=size(A,2);
for i=1:28 %For week: i=1:28
    for j=1:sizeA
    for k=1:length(C)
        A1=A(i,j)-0.01;
        A2=A(i,j)+0.01;
      op2(:,1)=double(A1<C(k,1)); %check if it's within the day
      op2(:,2)=double(C(k,1)<A2); %check if it's within the day
      day(:,1)=(op2(:,1).*op2(:,2)); %check if it's within the day
        if day(:,1)==1
            States4(i,j)=C(k,2);
        end
    end
    end
end

%Device 5, Dishwasher
%States5=zeros(195,(60/res)*24); %Matrix with all the states per week
%For week:
States5=zeros(28,(60/res)*24*7);
add=1;
for j=1:5 %number of states
    for i=1:length(regist_time5)
        if regist_time5(i,j)==0
        else
            C(add,1)=regist_time5(i,j);
            C(add,2)=j-1;
            add=add+1;
        end
    end
end
%Sort the timevalues
sizeA=size(A,2);
for i=1:28 %For week:i=1:28
    for j=1:sizeA
```

```matlab
    for k=1:length(C)
        A1=A(i,j)-0.01;
        A2=A(i,j)+0.01;
      op2(:,1)=double(A1<C(k,1)); %check if it's within the day
      op2(:,2)=double(C(k,1)<A2); %check if it's within the day
      day(:,1)=(op2(:,1).*op2(:,2)); %check if it's within the day
        if day(:,1)==1
            States5(i,j)=C(k,2);
        end
    end
    end
end

%Device 7, Tumble dryer
%States7=zeros(195,(60/res)*24); %Matrix with all the states per week
%For week:
States7=zeros(28,(60/res)*24*7);
add=1;
for j=1:4 %number of states
    for i=1:length(regist_time7)
        if regist_time7(i,j)==0
        else
            C(add,1)=regist_time7(i,j);
            C(add,2)=j-1;
            add=add+1;
        end
    end
end
%Sort the timevalues
sizeA=size(A,2);
for i=1:28 %For week: i=1:28
    for j=1:sizeA
    for k=1:length(C)
        A1=A(i,j)-0.01;
        A2=A(i,j)+0.01;
      op2(:,1)=double(A1<C(k,1)); %check if it's within the day
      op2(:,2)=double(C(k,1)<A2); %check if it's within the day
      day(:,1)=(op2(:,1).*op2(:,2)); %check if it's within the day
        if day(:,1)==1
            States7(i,j)=C(k,2);
        end
    end
    end
end

%Device 8, Socket kitchen
%States8=zeros(195,(60/res)*24); %Matrix with all the states per week
%For week:
States8=zeros(28,(60/res)*24*7);
add=1;
for j=1:4 %number of states
    for i=1:length(regist_time8)
        if regist_time8(i,j)==0
        else
            C(add,1)=regist_time8(i,j);
```

```matlab
            C(add,2)=j-1;
            add=add+1;
        end
    end
end
%Sort the timevalues
sizeA=size(A,2);
for i=1:28 %For week:i=1:28
    for j=1:sizeA
    for k=1:length(C)
        A1=A(i,j)-0.01;
        A2=A(i,j)+0.01;
      op2(:,1)=double(A1<C(k,1)); %check if it's within the day
      op2(:,2)=double(C(k,1)<A2); %check if it's within the day
      day(:,1)=(op2(:,1).*op2(:,2)); %check if it's within the day
        if day(:,1)==1
            States8(i,j)=C(k,2);
        end
    end
    end
end
```

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C. MatLab-code for Heat Maps

```
clc
clear
%Results from the survey for each answer:
Degrees=xlsread('surv_res','4.4'); %direction of the kitchen
Data=xlsread('surv_res','Placement pr device'); %placement of each device

%%%%%%% MAKING OF HEATMAPS %%%%%%%
%Move all the data to be in the same direction, north is chosen as base
%Assumed to be turned to north if no direction is specified

%M0:matrix of placement for direcion north
M0=[10 11 12 13 14 15 16 17 18 19
20 21 22 23 24 25 26 27 28 29
30 31 32 33 34 35 36 37 38 39
40 41 42 43 44 45 46 47 48 49
50 51 52 53 54 55 56 57 58 59
60 61 62 63 64 65 66 67 68 69
70 71 72 73 74 75 76 77 78 79
80 81 82 83 84 85 86 87 88 89
90 91 92 93 94 95 96 97 98 99
100 101 102 103 104 105 106 107 108 109];
%M45: matrix of placement for direction north-east
M45=[14 15 16 17 18 19 29 39 49 59
13 24 25 26 27 28 38 48 58 69
12 23 34 35 36 37 47 57 68 79
11 22 33 44 45 46 56 67 78 89
10 21 32 43 54 55 66 77 88 99
20 31 42 53 64 65 76 87 98 109
30 41 52 63 73 74 75 86 97 108
40 51 62 72 82 83 84 85 96 107
50 61 71 81 91 92 93 94 95 106
60 70 80 90 100 101 102 103 104 105];
%M135: matrix of placement for direction south-east
M135=[60 50 40 30 20 10 11 12 13 14
70 61 51 41 31 21 22 23 24 15
80 71 62 52 42 32 33 34 25 16
90 81 72 63 53 43 44 35 26 17
100 91 82 73 64 54 45 36 27 18
101 92 83 74 65 55 46 37 28 19
102 93 84 75 76 66 56 47 38 29
103 94 85 86 87 77 67 57 48 39
104 95 96 97 98 88 78 68 58 49
105 106 107 108 109 99 89 79 69 59];
%M225: matrix of placement for direction south-west
M225=[105 104 103 102 101 100 90 80 70 60
106 95 94 93 92 91 81 71 61 50
107 96 85 84 83 82 72 62 51 40
108 97 86 75 74 73 63 52 41 30
109 98 87 76 65 64 53 42 31 20
99 88 77 66 55 54 43 32 21 10
89 78 67 56 46 45 44 33 22 11
79 68 57 47 37 36 35 34 23 12
69 58 48 38 28 27 26 25 24 13
59 49 39 29 19 18 17 16 15 14];
%M315: matrix of placement for direction north-west
```

```matlab
M315=[59 69 79 89 99 109 108 107 106 105
49 58 68 78 88 98 97 96 95 104
39 48 57 67 77 87 86 85 94 103
29 38 47 56 66 76 75 84 93 102
19 28 37 46 55 65 74 83 92 101
18 27 36 45 54 64 73 82 91 100
17 26 35 44 43 53 63 72 81 90
16 25 34 33 32 42 52 62 71 80
15 24 23 22 21 31 41 51 61 70
14 13 12 11 10 20 30 40 50 60];
Ans.nr=0; %counter
for i=1:length(Degrees)
deg=Degrees(i,2);
    if deg==45 %move direction for answers turned to north-east
        for j=1:9
            for k=1:19
    a=Data(k,(j+Ans.nr));
                for l=1:10
                    for m=1:10
    if a==M0(l,m)
    Data(k,(j+Ans.nr))=M45(l,m);
    end
                    end
                end
            end
        end
    elseif deg==90 %move direction for answers turned to east
        for j=1:9
            for k=1:19
    a=Data(k,(j+Ans.nr));
    y=floor(a/10);
    x=a-(y*10);
    Data(k,(j+Ans.nr))=(10*(10-x))+(y-1); %y_new=10-x, x_new=y-1
            end
        end
    elseif deg==135 %move direction for answers turned to south-east
        for j=1:9
            for k=1:19
    a=Data(k,(j+Ans.nr));
                for l=1:10
                    for m=1:10
    if a==M0(l,m)
    Data(k,(j+Ans.nr))=M135(l,m);
    end
                    end
                end
            end
        end
    elseif deg==180 %move direction for answers turned to south
        for j=1:9
            for k=1:19
    a=Data(k,(j+Ans.nr));
    y=floor(a/10);
    x=a-(y*10);
    Data(k,(j+Ans.nr))=(10*(11-y))+(9-x); %y_new=11-y, x_new=9-x
```

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```
                    end
            end
    elseif deg==225 %move direction for answers turned to south-west
        for j=1:9
            for k=1:19
    a=Data(k,(j+Ans.nr));
                for l=1:10
                    for m=1:10
    if a==M0(l,m)
    Data(k,(j+Ans.nr))=M225(l,m);
    end
                    end
                end
            end
        end
    elseif deg==270 %move direction for answers turned to west
        for j=1:9
            for k=1:19
    a=Data(k,(j+Ans.nr));
    y=floor(a/10);
    x=a-(y*10);
    Data(k,(j+Ans.nr))=(10*(10-x))+(y-1); %y_new=x+1, x_new=10-y
            end
        end
    elseif deg==315 %move direction for answers turned to north-west
        for j=1:9
            for k=1:19
    a=Data(k,(j+Ans.nr));
                for l=1:10
                    for m=1:10
    if a==M0(l,m)
    Data(k,(j+Ans.nr))=M315(l,m);
    end
                    end
                end
            end
        end
    else %direction north
    Data(k,(j+Ans.nr))=Data(k,(j+Ans.nr));
    end
%Each answer has 9 column to describe placement for each device:
Ans.nr=Ans.nr+9;
end

%Making heatmaps for each device
%Same procedure for all devices, just changing the row in the dataset
A=zeros(10,10); %Fridge
B=zeros(10,10); %Freezer
C=zeros(10,10); %Cooker
D=zeros(10,10); %Built-in oven
E=zeros(10,10); %Hob
F=zeros(10,10); %Microwave
G=zeros(10,10); %Espresso Machine
H=zeros(10,10); %Kettle
I=zeros(10,10); %Fryer
```

```matlab
J=zeros(10,10); %Toaster
K=zeros(10,10); %Blender
L=zeros(10,10); %Exhaust
M=zeros(10,10); %Sink
N=zeros(10,10); %Dishwasher
O=zeros(10,10); %Washing machine
P=zeros(10,10); %Tumble Dryer
Q=zeros(10,10); %TV
R=zeros(10,10); %Radio
S=zeros(10,10); %Other

for i=1 %Fridge
    for j=1:size(Data,2)
        for k=1:10
            for l=1:10
    a=Data(i,j);
%Find the x- and y-coordinates
    y=floor(a/10);
    x=a-(y*10)+1; %need +1 beacuse the data for the x goes from 0 to 9
%Counts how many times the device is placed in each square:
    if y==k && x==l
    A(k,l)=A(k,l)+1;
    end
            end
        end
    end
A=A/sum(sum(A)); %percentage
end

for i=2 %Freezer
    for j=1:size(Data,2)
        for k=1:10
            for l=1:10
    a=Data(i,j);
    y=floor(a/10);
    x=a-(y*10)+1;
    if y==k && x==l
    B(k,l)=B(k,l)+1;
    end
            end
        end
    end
B=B/sum(sum(B)); %percentage
end

for i=3 %Cooker
    for j=1:size(Data,2)
        for k=1:10
            for l=1:10
    a=Data(i,j);
    y=floor(a/10);
    x=a-(y*10)+1;
    if y==k && x==l
    C(k,l)=C(k,l)+1;
    end
```

```
                    end
                end
            end
C=C/sum(sum(C)); %percentage
end

for i=4 %Built-in oven
    for j=1:size(Data,2)
        for k=1:10
            for l=1:10
    a=Data(i,j);
    y=floor(a/10);
    x=a-(y*10)+1;
    if y==k && x==l
    D(k,l)=D(k,l)+1;
    end
            end
        end
    end
D=D/sum(sum(D)); %percentage
end

for i=5 %Hob
    for j=1:size(Data,2)
        for k=1:10
            for l=1:10
    a=Data(i,j);
    y=floor(a/10);
    x=a-(y*10)+1;
    if y==k && x==l
    E(k,l)=E(k,l)+1;
    end
            end
        end
    end
E=E/sum(sum(E)); %percentage
end

for i=6 %Microwave
    for j=1:size(Data,2)
        for k=1:10
            for l=1:10
    a=Data(i,j);
    y=floor(a/10);
    x=a-(y*10)+1;
    if y==k && x==l
    F(k,l)=F(k,l)+1;
    end
            end
        end
    end
F=F/sum(sum(F)); %percentage
end

for i=7 %Espresso Machine
```

```matlab
    for j=1:size(Data,2)
        for k=1:10
            for l=1:10
    a=Data(i,j);
    y=floor(a/10);
    x=a-(y*10)+1;
    if y==k && x==l
    G(k,l)=G(k,l)+1;
    end
            end
        end
    end
G=G/sum(sum(G)); %percentage
end

for i=8 %Kettle
    for j=1:size(Data,2)
        for k=1:10
            for l=1:10
    a=Data(i,j);
    y=floor(a/10);
    x=a-(y*10)+1;
    if y==k && x==l
    H(k,l)=H(k,l)+1;
    end
            end
        end
    end
H=H/sum(sum(H)); %percentage
end

for i=9 %Fryer
    for j=1:size(Data,2)
        for k=1:10
            for l=1:10
    a=Data(i,j);
    y=floor(a/10);
    x=a-(y*10)+1;
    if y==k && x==l
    I(k,l)=I(k,l)+1;
    end
            end
        end
    end
I=I/sum(sum(I)); %percentage
end

for i=10 %Toaster
    for j=1:size(Data,2)
        for k=1:10
            for l=1:10
    a=Data(i,j);
    y=floor(a/10);
    x=a-(y*10)+1;
    if y==k && x==l
```

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```matlab
    J(k,l)=J(k,l)+1;
    end
            end
        end
    end
J=J/sum(sum(J)); %percentage
end

for i=11 %Blender
    for j=1:size(Data,2)
        for k=1:10
            for l=1:10
    a=Data(i,j);
    y=floor(a/10);
    x=a-(y*10)+1;
        if y==k && x==l
    K(k,l)=K(k,l)+1;
    end
            end
        end
    end
K=K/sum(sum(K)); %percentage
end

for i=12 %Exhaust
    for j=1:size(Data,2)
        for k=1:10
            for l=1:10
    a=Data(i,j);
    y=floor(a/10);
    x=a-(y*10)+1;
    if y==k && x==l
    L(k,l)=L(k,l)+1;
    end
            end
        end
    end
L=L/sum(sum(L)); %percentage
end

for i=13 %Sink
    for j=1:size(Data,2)
        for k=1:10
            for l=1:10
    a=Data(i,j);
    y=floor(a/10);
    x=a-(y*10)+1;
    if y==k && x==l
    M(k,l)=M(k,l)+1;
    end
            end
        end
    end
M=M/sum(sum(M)); %percentage
end
```

```matlab
for i=14 %Dishwasher
    for j=1:size(Data,2)
        for k=1:10
            for l=1:10
    a=Data(i,j);
    y=floor(a/10);
    x=a-(y*10)+1;
    if y==k && x==l
    N(k,l)=N(k,l)+1;
    end
            end
        end
    end
N=N/sum(sum(N)); %percentage
end

for i=15 %Washing Machine
    for j=1:size(Data,2)
        for k=1:10
            for l=1:10
    a=Data(i,j);
    y=floor(a/10);
    x=a-(y*10)+1;
    if y==k && x==l
    O(k,l)=O(k,l)+1;
    end
            end
        end
    end
O=O/sum(sum(O)); %percentage
end

for i=16 %Tumble Dryer
    for j=1:size(Data,2)
        for k=1:10
            for l=1:10
    a=Data(i,j);
    y=floor(a/10);
    x=a-(y*10)+1;
    if y==k && x==l
    P(k,l)=P(k,l)+1;
    end
            end
        end
    end
P=P/sum(sum(P)); %percentage
end

for i=17 %TV
    for j=1:size(Data,2)
        for k=1:10
            for l=1:10
    a=Data(i,j);
    y=floor(a/10);
```

```matlab
    x=a-(y*10)+1;
    if y==k && x==l
    Q(k,l)=Q(k,l)+1;
    end
            end
        end
    end
Q=Q/sum(sum(Q)); %percentage
end

for i=18 %Radio
    for j=1:size(Data,2)
        for k=1:10
            for l=1:10
    a=Data(i,j);
    y=floor(a/10);
        x=a-(y*10)+1;
    if y==k && x==l
    R(k,l)=R(k,l)+1;
    end
            end
        end
    end
R=R/sum(sum(R)); %percentage
end

for i=19 %Other
    for j=1:size(Data,2)
        for k=1:10
            for l=1:10
    a=Data(i,j);
    y=floor(a/10);
    x=a-(y*10)+1;
    if y==k && x==l
    S(k,l)=S(k,l)+1;
    end
            end
        end
    end
S=S/sum(sum(S)); %percentage
end
```

D. MatLab-code for Simulator

```matlab
%%%%%% SIMULATOR %%%%%%
clc
clear
%Loading the heatmaps for all the devices:
%Fryer and tumble dryer are omitted beacuse they are zero
load heatmaps;
Kitchen=zeros(10,10); %Grid representing the kitchen
%In the grid the devices will be represented as follows:
%1=Fridge, 2=Freezer, 3=Cooker, 4=Built-in oven, 5=Hob, 6=Microwave,
%7=Espresso Machine, 8=Kettle, 9=Toaster, 10=Blender, 11=Exhaust, 12=Sink,
%13=Dishwasher, 14=Washing Machine, 15=TV, 16=Radio, 17=Other

    %SIMULATE THE PLACEMENT OF THE DEVICES IN THE KITCHEN

j=1;
while j<=17 %17 devices
A=heatmaps(1:10,(10*j-9):10*j);
%Data aggregator_vertical
B=double(A>0);%Find the squares which is not zero
for i=1:10
sum_B_v(i,1)=sum(B(i,:)); %Sum of number of placement for each row
end
%Classifiaction vector
class_v=(min(sum_B_v):1:max(sum_B_v));
for i=1:length(class_v)
class_v(2,i)=sum(double(class_v(1,i)==sum_B_v)); %Each row
end
class_v_test=double(class_v(2,:)~=0); %Which probability is zero
add=0;
for i=1:length(class_v)%Sort it without the one with zero
if class_v_test(1,i)==1
add=add+1;
class_v_corr(:,add)=class_v(:,i);
end
end
for i=1:length(class_v_corr) %Divid it by the sum of possible placement
v_select(1,i)=class_v_corr(1,i)/sum(class_v_corr(1,:));
end
for i=1:length(class_v_corr)
v_select(2,i)=sum(v_select(1,1:i));
end
%Pre random selection
a=rand;
rand_select_v_pre=sum(double(v_select(2,:)<a))+1;
for i=1:10
row_test_s1(1,i)=i;
row_test_s1(2,i)=sum_B_v(i,1);
end
row_test_s1(3,:)= double(row_test_s1(2,:)==class_v_corr(1,rand_select_v_pre));
row_test_s2(1,:)=nonzeros(row_test_s1(3,:).*row_test_s1(1,:));
row_test_s2(2,:)=1;
%Row selection
if sum(row_test_s2(2,:))==1
row_select=row_test_s2(1,:);
else
```

```matlab
for i=1:sum(row_test_s2(2,:))
row_test_s2(3,i)=sum(row_test_s2(2,1:i))/sum(row_test_s2(2,:));
end
a=rand;
rand_select_v_post=sum(double(row_test_s2(3,:)<a))+1;
row_select=(row_test_s2(1,rand_select_v_post));
end
%Column selection
%Same procedure as for row
C=A(row_select,:);
level_c=max(C);
for i=1:level_c
C_level(i,:)=double(C>=i);
c_select(1,i)=i/level_c;
end
a=rand;
level_select=sum(double(c_select(1,:)<a))+1;
for i=1:10
columne_test_s1(1,i)=C_level(level_select,i)*i;
end
columne_test_s2(1,:)=nonzeros(columne_test_s1);
columne_test_s2(2,:)=columne_test_s2(1,:)>=1;
if sum(columne_test_s2(2,:))==1
columne_select=columne_test_s2(1,:);
else
for i=1:sum(columne_test_s2(2,:))
columne_test_s2(3,i)=i/sum(columne_test_s2(2,:));
end
a=rand;
level_select_end=sum(double(columne_test_s2(3,:)<a))+1;
columne_select=columne_test_s2(1,level_select_end);
end
%Places the devices in a grid representing the kitchen:
%Make sure nothing is placed on top of each other
if Kitchen(row_select,columne_select)==0
Kitchen(row_select,columne_select)=j;
j=j+1;
elseif j==15 %TV has just one square to be placed, if this is taken,
%the code start over
j=1;
Kitchen=zeros(10,10); %Reset the grid for placement
else
j=j;
end
%Clear all variables which may change size:
class_v=[];
class_v_test=[];
class_v_corr=[];
v_select=[];
rand_select_v_pre=[];
row_test_s1=[];
row_test_s2=[];
rand_select_v_post=[];
C_level=[];
c_select=[];
```

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```
level_select=[];
columne_test_s1=[];
columne_test_s2=[];
end

    %SIMULATE THE DIRECTION OF THE KITCHEN

%M0:matrix of placement for direcion north
M0=[10 11 12 13 14 15 16 17 18 19
20 21 22 23 24 25 26 27 28 29
30 31 32 33 34 35 36 37 38 39
40 41 42 43 44 45 46 47 48 49
50 51 52 53 54 55 56 57 58 59
60 61 62 63 64 65 66 67 68 69
70 71 72 73 74 75 76 77 78 79
80 81 82 83 84 85 86 87 88 89
90 91 92 93 94 95 96 97 98 99
100 101 102 103 104 105 106 107 108 109];
%M45: matrix of placement for direction north-east
M45=[14 15 16 17 18 19 29 39 49 59
13 24 25 26 27 28 38 48 58 69
12 23 34 35 36 37 47 57 68 79
11 22 33 44 45 46 56 67 78 89
10 21 32 43 54 55 66 77 88 99
20 31 42 53 64 65 76 87 98 109
30 41 52 63 73 74 75 86 97 108
40 51 62 72 82 83 84 85 96 107
50 61 71 81 91 92 93 94 95 106
60 70 80 90 100 101 102 103 104 105];
%M90: matrix of placement for direction east
M90=[100 90 80 70 60 50 40 30 20 10
101 91 81 71 61 51 41 31 21 11
102 92 82 72 62 52 42 32 22 21
103 93 83 73 63 53 43 33 23 13
104 94 84 74 64 54 44 34 24 14
105 95 85 75 65 55 45 35 25 15
106 96 86 76 66 56 46 36 26 16
107 97 87 77 67 57 47 37 27 17
108 98 88 78 68 58 48 38 28 18
109 99 89 79 69 59 49 39 29 19];
%M135: matrix of placement for direction south-east
M135=[60 50 40 30 20 10 11 12 13 14
70 61 51 41 31 21 22 23 24 15
80 71 62 52 42 32 33 34 25 16
90 81 72 63 53 43 44 35 26 17
100 91 82 73 64 54 45 36 27 18
101 92 83 74 65 55 46 37 28 19
102 93 84 75 76 66 56 47 38 29
103 94 85 86 87 77 67 57 48 39
104 95 96 97 98 88 78 68 58 49
105 106 107 108 109 99 89 79 69 59];
%M180: matrix of placement for direction south
M180=[109 108 107 106 105 104 103 102 101 100
99 98 97 96 95 94 93 92 91 90
89 88 87 86 85 84 83 82 81 80
```

```
79 78 77 76 75 74 73 72 71 70
69 68 67 66 65 64 63 62 61 60
59 58 57 56 55 54 53 52 51 50
49 48 47 46 45 44 43 42 41 40
39 38 37 36 35 34 33 32 31 30
29 28 27 26 25 24 23 22 21 20
19 18 17 16 15 14 13 12 11 10];
%M225: matrix of placement for direction south-west
M225=[105 104 103 102 101 100 90 80 70 60
106 95 94 93 92 91 81 71 61 50
107 96 85 84 83 82 72 62 51 40
108 97 86 75 74 73 63 52 41 30
109 98 87 76 65 64 53 42 31 20
99 88 77 66 55 54 43 32 21 10
89 78 67 56 46 45 44 33 22 11
79 68 57 47 37 36 35 34 23 12
69 58 48 38 28 27 26 25 24 13
59 49 39 29 19 18 17 16 15 14];
%M270: matrix of placement for direction west
M270=[19 29 39 49 59 69 79 89 99 109
18 28 38 48 58 68 78 88 98 108
17 27 37 47 57 67 77 87 97 107
16 26 36 46 56 66 76 86 96 106
15 25 35 45 55 65 75 85 95 105
14 24 34 44 54 64 74 84 94 104
13 23 33 43 53 63 73 83 93 103
12 22 32 42 52 62 72 82 92 102
11 21 31 41 51 61 71 81 91 101
10 20 30 40 50 60 70 80 90 100];
%M315: matrix of placement for direction north-west
M315=[59 69 79 89 99 109 108 107 106 105
49 58 68 78 88 98 97 96 95 104
39 48 57 67 77 87 86 85 94 103
29 38 47 56 66 76 75 84 93 102
19 28 37 46 55 65 74 83 92 101
18 27 36 45 54 64 73 82 91 100
17 26 35 44 43 53 63 72 81 90
16 25 34 33 32 42 52 62 71 80
15 24 23 22 21 31 41 51 61 70
14 13 12 11 10 20 30 40 50 60];
%Number of each direction:
N0=13; %0 %assume north when nothing is written
NE45=4; %45
E90=7; %90
SE135=4; %135
S180=6; %180
SW225=1; %225
W270=6; %270
NW315=1; %315

TOTD=N0+NE45+E90+SE135+S180+SW225+W270+NW315;
%Probality of each direction to occur:
PD=[0 45 90 135 180 225 270 315
N0/TOTD NE45/TOTD E90/TOTD SE135/TOTD S180/TOTD SW225/TOTD W270/TOTD NW315/TOTD];
```

```matlab
%Generate a direction from the probabilty in PD:
Dir=randsrc(1,1,[PD(1,:);PD(2,:)]);

%Making new kitchen-grid to be turned
Kitchen_turned=zeros(10,10);
%Move the grid to the generated direction:
if Dir==0
for i=1:10
for j=1:10
Kitchen_turned(i,j)=Kitchen(i,j);
end
end
elseif Dir==45 %move grid to north-east
for i=1:10
for j=1:10
logi_t=double(M0(:,:)==M45(i,j));
Kitchen_turned=logi_t*Kitchen(i,j);
end
end
elseif Dir==90 %move grid to east
for i=1:10
for j=1:10
logi_t=double(M0(:,:)==M90(i,j));
Kitchen_turned=logi_t*Kitchen(i,j);
end
end
elseif Dir==135 %move grid to south-west
for i=1:10
for j=1:10
logi_t=double(M0(:,:)==M135(i,j));
Kitchen_turned=logi_t*Kitchen(i,j);
end
end
elseif Dir==180 %move grid to south
for i=1:10
for j=1:10
logi_t=double(M0(:,:)==M180(i,j));
Kitchen_turned=logi_t*Kitchen(i,j);
end
end
elseif Dir==225 %move grid to south-west
for i=1:10
for j=1:10
logi_t=double(M0(:,:)==M225(i,j));
Kitchen_turned=logi_t.*Kitchen(i,j);
end
end
elseif Dir==270 %move grid to west
for i=1:10
for j=1:10
logi_t=double(M0(:,:)==M45(i,j));
logi_t1=logi_t*Kitchen(i,j);
Kitchen_turned=Kitchen_turned+logi_t1;
end
end
```

```matlab
elseif Dir==315 %move grid to north-west
for i=1:10
for j=1:10
logi_t=double(M0(:,:)==M315(i,j));
Kitchen_turned=logi_t*Kithcen(i,j);
end
end
end

    %SIMULATE THE USAGE:

%Chosen two random days, resolution=10min
%Loaded data contains states for each measuring point thrugh that day
load day1; %Day 18, 29.10.15
%load day2; %Day 123, 11.02.16
%load day3; %Day 181, 09.04.16

%Need to know the placement for each device

for i=1:10
    for j=1:10
if Kitchen_turned(i,j)==1
    Fridge_x=j;
    Fridge_y=i;
end
if Kitchen_turned(i,j)==2
    Freezer_x=j;
    Freezer_y=i;
end
if Kitchen_turned(i,j)==3
    Cooker_x=j;
    Cooker_y=i;
end
if Kitchen_turned(i,j)==4
    Oven_x=j;
    Oven_y=i;
end
if Kitchen_turned(i,j)==5
    Hob_x=j;
    Hob_y=i;
end
if Kitchen_turned(i,j)==6
    Micro_x=j;
    Micro_y=i;
end
if Kitchen_turned(i,j)==7
    Espresso_x=j;
    Espress_y=i;
end
if Kitchen_turned(i,j)==8
    Kettle_x=j;
    Kettle_y=i;
end
if Kitchen_turned(i,j)==9
    Toaster_x=j;
```

```matlab
        Toaster_y=i;
    end
if Kitchen_turned(i,j)==10
    Blender_x=j;
    Blender_y=i;
end
if Kitchen_turned(i,j)==11
    Extraction_x=j;
    Extraction_y=i;
end
if Kitchen_turned(i,j)==12
    Sink_x=j;
    Sink_y=i;
end
if Kitchen_turned(i,j)==13
    Dishwasher_x=j;
    Dishwasher_y=i;
end
if Kitchen_turned(i,j)==14
    Washingmachine_x=j;
    Washingmachine_y=i;
end
if Kitchen_turned(i,j)==15
    TV_x=j;
    TV_y=i;
end
if Kitchen_turned(i,j)==16
    Radio_x=j;
    Radio_y=i;
end
if Kitchen_turned(i,j)==17
    Other_x=j;
    Other_y=i;
end
    end
end

%The coordinate system for plotting of movement is differnet from the one
%used in the heatmap; x=0:9, y:9:-1:0. To get the correct coordinates:
%x=x-1, y=9-y
add=1;
for i=1:length(States1)
    if States1(1,i)==3 %Fridge, State 3 represent normal usage
        Movement(add,1)=Fridge_x-1;
        Movement(add,2)=10-Fridge_y;
        add=add+1;
    end
    if States1(2,i)==3 %Hob, State 3 represent normal usage
        Movement(add,1)=Hob_x-1;
        Movement(add,2)=10-Hob_y;
        add=add+1;
    end
    if States1(3,i)==3 %Oven, State 3 represent normal usage
        Movement(add,1)=Oven_x-1;
        Movement(add,2)=10-Oven_y;
```

```
        add=add+1;
    end
    if States1(4,i)==2 %Extraction hood, State 2 represent normal usage
        Movement(add,1)=Extraction_x-1;
        Movement(add,2)=10-Extraction_y;
        add=add+1;
    end
    if States1(5,i)==3 %Dishwasher, State 3 represent normal usage
        Movement(add,1)=Dishwasher_x-1;
        Movement(add,2)=10-Dishwasher_y;
        add=add+1;
    end
    if States1(7,i)==2 %Socket kitchen, State 2 represent normal usage
        Movement(add,1)=Kettle_x-1;
        Movement(add,2)=10-Kettle_y;
        add=add+1;
    end
end

plot(Movement(:,1),Movement(:,2))
xlim([0 9])
ylim([0 9])
```

```
Error using load
Unable to read file 'heatmaps'. No such file or directory.

Error in Simulator (line 6)
load heatmaps;
```

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E. Scientific Report

Occupant Behaviour in Buildings – Electricity Consumption in Residential Buildings

Karoline Dahl Fosby

ABSTRACT

Today, one of the main reasons for the major difference between energy use simulated and real measurements for the same building is the lack of proper occupant behaviour models. The development of knowledge regarding occupant behaviour related to energy, can lead to development of more accurate occupant behaviour models. To get more information of household appliances and use of appliances, a knowledge base of typical devices in a residential has been prepared, and a survey concerning use and placement of kitchen appliances have been conducted. The results of the survey have been used as base for development of heat maps of device placement in the kitchen. Based on the heat maps and decoding of electricity consumption behavior in residential buildings, a simulator for household usage has been developed.

1. INTRODUCTION

Energy-related occupant behaviour has a major impact on the energy use in buildings. Sonderegger found that 71% of the energy demand variation in residential buildings un-explained by conventional factors, like number of bedrooms, area of insulated glass and if the house is an end unit, are caused by occupant behaviour (Sonderegger, 1977), and Seryak showed in his study that for a given dwelling, occupant behaviour can affect the energy consumption by as much as 100% (Seryak and Kissock, 2003). In particular, lightning, plug loads, ventilation and heating are largely dependent on the occupants (D'Ocaand Hong, 2015). Occupant behaviour is also a key parameter for building design optimization, energy diagnosis, performance evaluation and building energy performance simulation.

The choice of modelling approach is an important factor for predicting occupants use of appliances (Yilmaz et al., 2017), and this will affect the simulation of the energy use in the residential. Using today's models for occupant behaviour, there is major differences between energy use simulated and real measurements for the same building. One of the main reasons for this difference is the lack of proper occupant behaviour models. Occupant behaviour includes the residents presence, movement and how they use the devices in the building (Yan et al., 2017). The International Energy Agency define energy-related occupant behaviour as "observable actions or reactions of a person in response to external or internal stimuli, or actions or reactions of a person to adapt to ambient environmental conditions" (Yoshino et al., 2017). There have been many attempt to make more accurate models, e.g. McKenna, Krawcynski and Thomson developed in their study a two-state active-occupancy model into a four-state model (McKenna et al., 2015) and then McKenna and Thomson used this model in their work of extending CREST's existing electrical domestic demand model into

an integrated thermal-electrical demand model, but this model did not represent all possible outcome so good (McKenna and Thomson, 2016).

2. AIM

The objective of the work accomplished is to provide support to the development of knowledge regarding occupant behaviour related to energy. This knowledge can lead to development of more accurate occupant behaviour models. Identification of household appliances and devices is a key in occupant behaviour studies. To get more information about this, a knowledge base about different device performance and characteristics of electrical energy consumption in time has been developed, and a survey regarding localization of different device placement in residential buildings has been conducted. Data from field studies in the ZEB - Living Lab has been used for decoding of electricity consumption behaviour in residential buildings. Based on the collected input, a simulation of household usage has been performed.

3. METHODS

3.1 Knowledge base

The knowledge base shows different device performance and characteristics of electrical energy consumption in time. It also includes additional metadata regarding typical purpose of the device. To prepare the knowledge base, Price Spy (PriceSpy, 2018) was used. For the choice of which devices that should be included in the knowledge base, an overview of the most typical devices used in a residential house was made. This overview contains 21 different devices, ranging from hair dryers to TVs to hobs. All the devices in the knowledge base are found in the very most homes. For each device, approximately 100 different products within different price ranges was examined regarding power and energy consumption. In the knowledge base, all of the products are characterized by producer and price range in UK pound, and different characteristics of the electrical energy consumption, dependent on what was available information for the different devise.

3.2 Survey

The survey only dealt with the kitchen and devices placed in the kitchen. The survey asked of gender and age, and the age of any cohabitants. Question two dealt with what kind of appliances you have in your kitchen, and the importance regarding kitchen habits. Question three concerned the design of the kitchen. In the last question, the respondents were going to draw their kitchen with all devices, windows, doors, and other furniture in a grid of10x10, and show the direction of the kitchen related to north.

3.3 Probabilistic heat maps

The results from the survey regarding placement of all the devices, there were made one heat map for each device. Since the placement of the kitchen devices were done in different directions relative to north, the answers had to be moved to be in the same direction to make it uniform. Fort his, 0 degrees was chosen as base, and all the answers drawn in another

direction had to be moved. To make the heat maps, the number of placement in every square were counted. To get the percentage value, all the numbers where divided by the sum of possible placement for the given device.

3.4 Simulator of household usage

The simulator first simulate the placement of the devices based on the probabilistic heat maps. The simulator insures that no devices are placed on top of each other by choosing a new placement for the device if the placement generated is taken. Further, the direction of the kitchen is simulated based on the probability for each direction, which is found from the survey answers .Finally, the usage of the kitchen is simulated. The simulation of usage is made as a vector of movement in the kitchen based on where the different devices are located. The simulation will not take into account extra walls, doors or other kitchen furniture. The movement is moved to the location of a device when it is registered as in normal usage. For the socket in the kitchen, the movement is set to the location of the kettle, because this is the device, which is plugged to the socket that most people own, according to the survey. The movement for the chosen time period will be presented as a plot. To validate the simulator, data from the Living Lab was used to make a scenario.

4. RESULTS

4.1 Survey

Of a total of 42 responses, 22 thought that the fridge is the most important device in the kitchen. 26 responses have a cooker in their kitchen, and 13 of these meant that the cooker is the second most important kitchen device. The answers from the survey showed that the average number of kitchen devices in a home is 9, with a standard deviation of 2. The results of the placement of the devices were used to develop heat maps for each device.

4.2 Probabilistic heat maps

The heat maps of all the devices showed a trend that most devices are placed along the walls in the kitchen. Figure 1 shows an example of a heat map, this is for the fridge. For the heat map for the exhaust, looked like having a relation the heat map of the hob and the cooker.
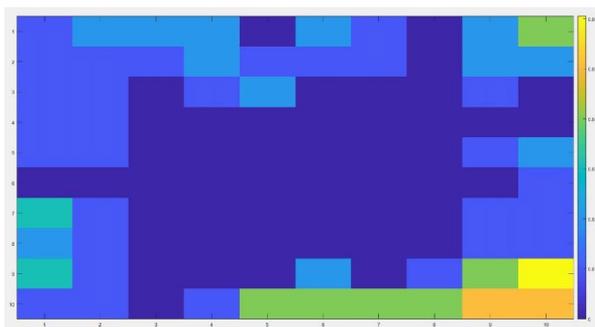
Figure 1: Probabilistic heat map of fridge

4.3 Simulations of household usage

Scenarios with data from three random days from the data from the field measurements in the ZEB – Living Lab were used to simulate the household usage. Only fridge, hob, oven, exhaust, dishwasher and socket will be included in the vector showing the movement, because these 6 devices are the only ones with results from both the Living Lab and the survey. The simulation was done with data with resolution 10 minutes, giving 6 measuring periods every hour. Figure 2 shows the simulation of the layout of the kitchen. Which number representing each device is shown in table 1. Figure 3 shows the simulation of the movement.

Device	Number
Fridge	1
Freezer	2
Cooker	3
Built-in oven	4
Hob	5
Microwave	6
Espresso Machine	7
Kettle	8
Toaster	9
Blender	10
Exhaust	11
Sink	12
Dishwasher	13
Washing Machine	14
TV	15
Radio	16
Other	17

Table 1: Number representing device

	1	2	3	4	5	6	7	8	9	10
1	0	0	0	4	10	12	5	14	13	0
2	7	8	17	1	0	0	0	0	16	0
3	0	0	0	0	0	2	0	0	15	0
4	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	3
10	9	6	0	0	0	11	0	0	0	0

Figure 2: Simulation of placement of kitchen devices

Figure 3: Simulation of movement in kitchen
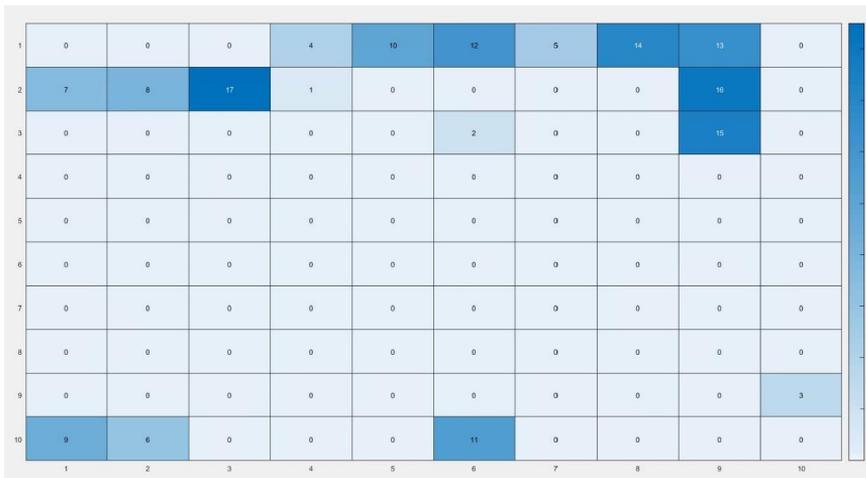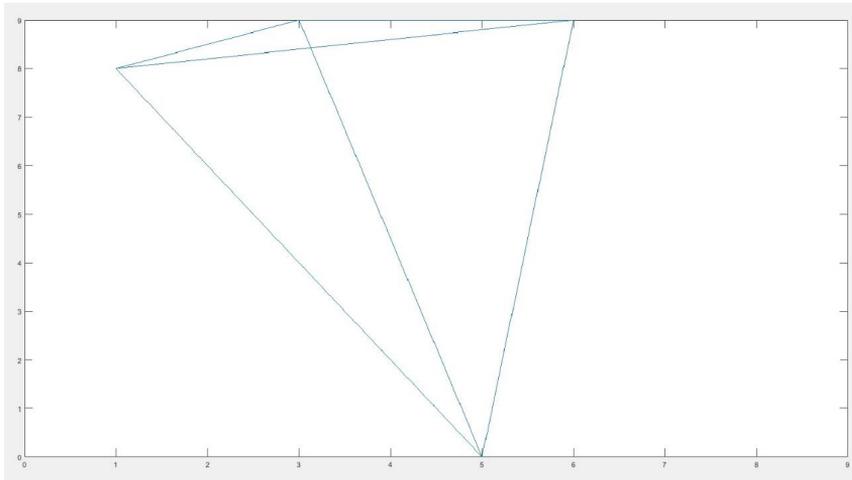
5. CONCLUSION

To get more information of household appliances, a knowledge base of typical devices in a residential has been prepared. The knowledge base contains device performance and characteristics of electrical energy consumption in time for 21 different household devices. A survey concerning use and placement of kitchen appliances were conducted to get more information on use of devices. The results of the survey was used as base for development of heat maps of device placement in the kitchen. Based on the developed heat maps, a simulator of household usage were developed. The simulator developed is a very simple simulator that has to be further developed before it can be used for analysis. The simulator was partly validated by use of 3 scenarios with data the Living Lab.

6. FURTHER WORK

The simulator will have to be further developed, the simulator developed in this thesis has a very simple approach, and do not take into consideration many aspects of household usage. The main deficiencies of the simulator are related to the simulation of placement of the devices. The more developed simulator should consider the relationship matrix, so that the placement of each device will be dependent of the placement and the meta data of the previous devices. The simulator should also place different numbers of devices, be-cause this will vary a lot for different kitchens, and also simulate that some devices can be combined. For simulating the movement when the socket is used, the simulator should be developed to vary between many different devices plugged into the socket, dependent on the consumption of the socket for the given time. The knowledge base can be used for this. The simulator also has to be validated more closely. For this, measurements from testbed will be needed, thus field measurements will also have to be conducted

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F. Risk Assessment

NTNU		Prepared by	Number	Date
⬛	Hazardous activity identification process	HSE section	HMSRV2601E	09.01.2013
		Approved by		Replaces
HSE		The Rector		01.12.2006

Unit: Department of Energy and Process Engineering

Date: 25.01.2018

Line manager: Terese Løvås

Participants in the identification process (including their function): Student Karoline Dahl Fosby, Co-supervisor Jakub Wladyslaw Dziedzic

Short description of the main activity/main process: Master project for student Karoline Dahl Fosby. Occupant behaviour in buildings - electricity consumption in residential buildings.

Is the project work purely theoretical? (YES/NO):   *Answer "YES" implies that supervisor is assured that no activities requiring risk assessment are involved in the work. If YES, briefly describe the activities below. The risk assessment form need not be filled out.*

Signatures: *Responsible supervisor:* _Nogislaw Stutt_   *Student:* Karoline Dahl Fosby

ID nr.	Activity/process	Responsible person	Existing documentation	Existing safety measures	Laws, regulations etc.	Comment
	Field Measurements	Karoline Dahl Fosby				

NTNU		Risk assessment	Prepared by	Number	Date
⊙ HSE/KS			HSE section	HMSRV2603E	04.02.2011
			Approved by	Replaces	
			The Rector		01.12.2006

Unit: Department of Energy and Process Engineering   **Date:** 25.01.2018

Line manager: Terese Løvås

Participants in the identification process (including their function): Student Karoline Dahl Fosby, Co-supervisor Jakub Wladyslaw Dziedzic

Short description of the main activity/main process: Master project for student Karoline Dahl Fosby. Occupant behaviour in buildings - electricity consumption in residential buildings.

Signatures: *Responsible supervisor:* [signature]   *Student:* [signature] Karoline Dahl Fosby

Activity from the identification process form	Potential undesirable incident/strain	Likelihood: Likelihood (1-5)	Consequence: Human (A-E)	Environment (A-E)	Economy/ material (A-E)	Risk Value (human)	Comments/status Suggested measures
Field Measurements	electricshock	2	A	A	A	A2	Obey health and safety regulations of usage of the electronic devices

Likelihood, e.g.:
1. Minimal
2. Low
3. Medium
4. High
5. Very high

Consequence, e.g.:
A. Safe
B. Relatively safe
C. Dangerous
D. Critical
E. Very critical

Risk value (each one to be estimated separately):
Human = Likelihood x Human Consequence
Environmental = Likelihood x Environmental consequence
Financial/material = Likelihood x Consequence for Economy/materiel

Potential undesirable incident/strain

Identify possible incidents and conditions that may lead to situations that pose a hazard to people, the environment and any materiel/equipment involved.

Criteria for the assessment of likelihood and consequence in relation to fieldwork

Each activity is assessed according to a worst-case scenario. Likelihood and consequence are to be assessed separately for each potential undesirable incident. Before starting on the quantification, the participants should agree what they understand by the assessment criteria:

Likelihood

Minimal 1	Low 2	Medium 3	High 4	Very high 5
Once every 50 years or less	Once every 10 years or less	Once a year or less	Once a month or less	Once a week

Consequence

Grading	Human	Environment	Financial/material
E Very critical	May produce fatality/ies	Very prolonged, non-reversible damage	Shutdown of work >1 year.
D Critical	Permanent injury, may produce serious serious health damage/sickness	Prolonged damage. Long recovery time.	Shutdown of work 0.5-1 year.
C Dangerous	Serious personal injury	Minor damage. Long recovery time	Shutdown of work < 1 month
B Relatively safe	Injury that requires medical treatment	Minor damage. Short recovery time	Shutdown of work < 1week
A Safe	Injury that requires first aid	Insignificant damage. Short recovery time	Shutdown of work < 1day

The unit makes its own decision as to whether opting to fill in or not consequences for economy/materiel, for example if the unit is going to use particularly valuable equipment. It is up to the individual unit to choose the assessment criteria for this column.

Risk = Likelihood x Consequence

Please calculate the risk value for "Human", "Environment" and, if chosen, "Economy/materiel", separately.

About the column "Comments/status, suggested preventative and corrective measures":

Measures can impact on both likelihood and consequences. Prioritise measures that can prevent the incident from occurring; in other words, likelihood-reducing measures are to be prioritised above greater emergency preparedness, i.e. consequence-reducing measures.

MATRIX FOR RISK ASSESSMENTS at NTNU

CONSEQUENCE					
Extremely serious	E1	E2	E3	E4	E5
Serious	D1	D2	D3	D4	D5
Moderate	C1	C2	C3	C4	C5
Minor	B1	B2	B3	B4	B5
Not significant	A1	A2	A3	A4	A5
	Very low	Low	Medium	High	Very high
			LIKELIHOOD		

Principle for acceptance criteria. Explanation of the colours used in the risk matrix.

Colour	Description
Red	Unacceptable risk. Measures must be taken to reduce the risk.
Yellow	Assessment range. Measures must be considered.
Green	Acceptable risk Measures can be considered based on other considerations.