KTH Industrial Engineering
and Management

Big data insights into energy and resource usage in the Live-in Lab apartments

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Bachelor of Science Thesis

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KTH Industrial Engineering and Management	**Bachelor of Science Thesis EGI-2016** **Big data insights into energy and resource usage in the Live-in Lab apartments** Elisabeth Danielsson Amanda Koskinen	
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Abstract

This report aims to find ways of getting insights into energy and resource usage in a home with big data, based on the project Live-in Lab. Live-in Lab is a project that aims to increase the innovation pace in the building and construction sector when developing environmental technology. This is done by conducting implementation and research at the same time in a living lab that will be the home of about 300 students. The main objectives of this report is to find out what is possible to measure in the apartments that is related to energy, with what technologies and how the data can be analyzed to generate maximal insight and utility. The methodology used originates from the field of product realization.

A literature study was carried out to learn more about energy usage in a home, big data and state of the art of similar projects as well as available technologies that can be used to collect data with. The technologies were investigated in four different levels; Social data and IoT, Infrastructure mediated systems, Direct environment components and Wearable devices.

The result comprises eleven purposed solutions that get insights in patterns of water consumption, ventilation, light, movements inside and outside the apartment, consumption patterns among others. To be able to get maximal insights and utility it was studied how the purposed solutions could be combined.

At the end, aspects of ethics were discussed as well as what data and information that possibly could be shared with a third party. Since the collected data might contain sensitive information about the residents the aspects of ethics and security is important.

The solutions and the report was discussed with one of the stakeholders, Schneider Electric. They were able to share some additional perspective of big data in living labs, such as what third parties that might be interested in Live-in Lab, what solutions that are possible to combine, the importance of having a simple system of technology and the importance of maximising the insights from the collected data instead of collecting a lot of separate data.

Sammanfattning

Syftet med den här rapporten är att med hjälp av big data få inblick i energi- och resursanvändning i hemmet, baserat på projektet Live-in Lab. Live-in Lab är ett projekt med syftet att påskynda innovationstakten i byggnadssektorn vid utveckling av miljötekniska produkter och tjänster. Detta görs genom att implementera och forska samtidigt i ett living lab som kommer innefatta lägenheter åt cirka 300 studenter. Huvudmålet med den här rapporten är att ta reda på vad som är möjligt att mäta i lägenheterna som är relaterat till energi, vilka tekniker kan användas och hur datan kan analyseras för att generera maximal inblick och användbarhet. Metoden som används för det här projektet har sitt ursprung från projektutvecklings metodik.

Rapporten börjar med en litteraturstudie för att ge en bredare bild av energianvändning i hemmet, big data, state of the art samt aktuella tekniker som kan användas för att samla data. Tekniken undersöktes i fyra olika nivåer, Social data och IoT, Infrastructure mediated systems, Direct environment components samt Wearable devices.

Rapporten resulterade i elva förslag till lösningar som ger inblick i beteenden kring vattenkonsumtion, ventilation, vädring, ljus, rörelsemönster inomhus och utomhus, konsumtionsvanor med mera. För att ge maximal inblick undersöktes även hur de framtagna lösningarna går att kombinera.

Slutligen diskuteras aspekten kring etik när man samlar in och behandlar stora mängder data, samt vilken data som skulle vara av intresse för en tredje part. Eftersom de förslagna lösningarna eventuellt kommer att innehålla känslig och personlig information om de boende i Live-in Lab är etik och säkerhet viktiga aspekter att ta i beaktning.

Lösningarna och rapporten i sin helhet diskuterades med en av intressenterna till Live-in Lab, Schneider Electric. De delade med sig av ytterligare aspekter kring big data i living labs; vilka ytterligare berörda parter skulle tänkas vara intresserade, vilka av lösningarna går att kombinera, vikten av att ha ett enkelt välfungerande system samt vikten av att maximera nyttan av insamlad data istället för att enskilt samla in olika sorters information.

Acknowledgements

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Last but not least we would like to thank our supervisor Omar Shafqat for being patient, guiding us through this whole process, providing new approaches, but also for reviewing this report.

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Nomenclature

Abbreviations

Abbreviation	Description
SEK	Swedish kronor
RFID	Radio Frequency Identification
WSN	Wireless Sensor Network
HSB	Hyresgästernas Sparkasse- och Byggnadsförening
SMS	Short Message Service
KTH	Kungliga Tekniska Högskolan
GPS	Global Positioning System
USA	United States of America
MIT	Massachusetts Institute of Technology
IoT	Internet of Things
IFTTT	"If this, then that"
SWOT	"Strengths", "Weaknesses", "Opportunities" and "Threats"
DDDM	Data Driven Decision Management
LED	Light Emitting Diode
CCTV	Closed-Circuit Television
ICT	Information and communications technology
TV	Television

Chapter 1

Introduction

This chapter introduces the background, objective, method, limitations and assumptions of the project.

1.1 Background

Residential and commercial buildings use a big part, 39%, of the total amount of energy produced in Sweden. Of those 39% about 60% goes to hot water and heating respectively, and the rest is for electricity usage [SP Sveriges Tekniska Forskningsinstitut, 2011], [Energimyndigheten, 2016] [Kungl. Ingenjörsvetenskapsakademien, 2008]. Therefor, decreasing the amount of energy used by this sector would have an significant impact on the energy usage in Sweden. To find new ways of reducing the energy usage new technologies need to be developed. Another issue is that the energy demand is concentrated to specific times of the day. These peaks of energy usage makes the renewable energy sources insufficient, which makes the fossil fuels play an important part of the energy supply. Since this is not desirable the energy usage in homes need to be distributed more evenly during the day. Therefore, technologies need to be implemented in the homes so that the renewable energy sources can meet the demands at a higher rate. Today the innovation pace in the construction and building sector is too slow, to be able to reach set energy goals [Sandra Backlund, et.al., 2012], [EU-upplysningen, 2016], [Kungl. Ingenjörsvetenskapsakademien, 2008]. The research project Live-in Lab aims to increase the innovation pace. This is made by doing both research and implementation at the same time, in a living lab. The Live-in Lab project is partly the effect of a study [Jonas Anund Vogel, Per Lundqvist, Jaime Arias, 2015] that found several barriers that exists when implementing new technologies in new apartment blocks and when renovating old ones, some of these barriers are listed in the next chapter. The lab will be the home to 300 students that will contribute to research just by living their ordinary life at home. The behaviour and habits of the residents will be studied with big data analysis. A quotation from the mathematical physicist and engineer William Thomson is appropriate here, “If you cannot measure it, you cannot improve it."

1.2 Objective

This project aims to study the energy usage in residences with the help of big data analysis. What is possible to measure and with what technologies can it be measured? How can data be analyzed to generate maximal insight and utility?

Additional objectives

- What can we learn from former or ongoing similar projects?
- How often should data be collected?
- Should some data be made available for third parties?
- Are there any concern for privacy and data security?
- In addition to "traditional energy data" what other types of data can add value to the data sets to bring more insight into energy behaviours.

1.3 Methodology

The methodology used originates from the field of product realization discussed by Ullman [David. G Ullman, 2009] where several steps are carried out to come up with new products and services. This project was a iterative process as shown in Figure 1.1. The first step is about identifying the needs and then investigating them. In this project the needs from both the residents, the ones involved in Live-in Lab and the researchers were identified and investigated. This was made by studying the energy system and usage in homes and collecting insight in what Live-in Lab aims to achieve. A literature study was carried out to gather relevant information, learn about the available technology in relevant areas and identifying the needs of reducing the energy and recourse usage. Information was found in research reports, articles and at agencies' websites among others. After this concepts and models were developed. This was done by a brainstorming, followed by evaluations and refining of the solutions. By using insights from the literature study several aspects of the solutions were developed such as; technologies, analysis and aspects of security and ethics. To be able to get maximal insight and utility the purposed solutions were combined and analysed. Through out the process meetings within the Live-in Lab project were attended, and interviews and study visits were done continuously to keep up with current research and to receive inspiration and a greater perspective.

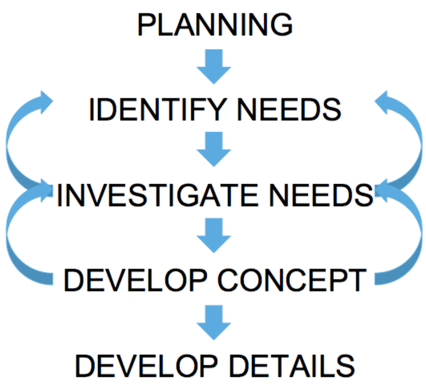


Figure 1.1. A product development process

1.4 Limitations

The most significant limitation is that this Live-in Lab system is not existing, which makes it difficult to know about all the circumstances. No concerns are taken to the back end such as how the big data is stored or the business aspect such as how the cost for suggested solutions are justified. Security aspects when collecting and analysing data are not considered during all phases, but is discussed. The main focus regarding security is the aspects of the privacy of the residents.

1.5 Assumptions

This report does not take into account what legal issues there might be when collecting big amounts of private data from peoples everyday life. There is also an assumption that there are no limitations in accessing social data.

Chapter 2

Literature study

This chapter introduces the theory behind the thesis project; relevant technologies, identifies the needs of reducing the energy and recourse usage and presents similar projects that have been done before.

2.1 Live-in Lab

Live-in Lab is a collaboration between KTH and Einar Mattsson, among others, and will produce about 300 student homes at Campus Valhallavägen at KTH. The aim with the project is to shorten the lead time from research to implementation and increase the innovation pace in the construction and building industry, and by doing that find new ways to decrease the consumption of resources in our current and future homes. The Live-in Lab enable research in several fields connected to construction, energy and living, and the researchers are able to execute their work in a real environment. Live-in Lab origins from the result of a report, [Jonas Anund Vogel, Per Lundqvist, Jaime Arias, 2015], that found several barriers, at three different levels, that stands in the way when implementing new technologies when constructing and renovating apartment buildings. Some of the found barriers were:

Institutional framework for the two following levels.
- Different incentives for the involved actors.
- Not enough contact between energy user and energy producer.

Building industry
- Unsatisfied methods of giving and receiving feedback.
- Deficient communication between the actors such as companies, organizations, and academia.
- Research and development only at company levels limit possibilities of progress.

Singular building projects
- Poor knowledge and low interest in energy related topics.
- Lack of transparency which block development in the system.
- Fear of having increased operation costs and risks when new technology is intro-

duced.

Live-in Lab aims to integrate several actors such as the industry, academia and society to an open and neutral environment without competition. The hope is to distribute and reduce risks, uncertainties and costs. Products and services can be tested and verified. Norms and regulations can be stretched, questioned and changed. All with the object of increasing the innovation pace and finding new products and services. The Live-in Lab project will consist of an active part with 4-6 apartments that can be rebuilt according to the current research work. The rest of the apartments are passive apartments. In the passive area the focus is to collect data and measure consumption of resources, living behaviour or other information that can be used to transform future construction work and increase the energy efficiency. This study will focus on the passive part of the Live-in Lab.

2.2 Energy usage

The end usage of energy in homes vary depending on unit type and building age, but on the average apartment the energy is distributed as in Figure 2.1 below. Since Live-in Lab is aiming to develop products and services for the building and construction industry it is interesting to investigate where energy is used in a home. The most energy goes to heat losses through the ventilation and envelope of the building, and the third biggest energy user is domestic hot water. [Hossein Shahrokni, Fabian Levihn, Nils Brandt, 2014] The water tank stores hot water, at least 60°C, in the tank around the clock even if it is mostly used during the mornings and evenings. It is the light, freezer, fridge and cooking that consumes most electricity in the average home, but the electronic devices is steadily increasing its consumption.

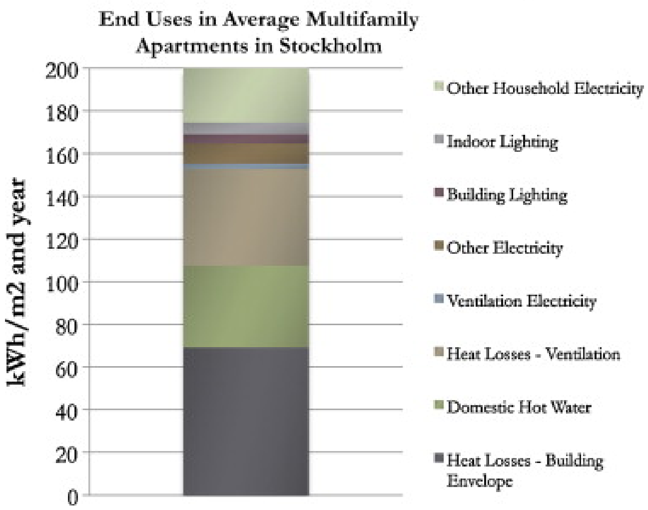


Figure 2.1. The distribution of energy in the average apartment in Stockholm.

Commercial and residential buildings use about 39% of the total amount of energy produced in Sweden. [Energimyndigheten, 2016] Currently this sector is responsible for about 15% of Sweden's total greenhouse gas emissions. Therefor Sweden is to decrease these emissions with 17% before 2020 and with 50% before 2050 (compared to the levels of 2005). [EU-upplysningen, 2016] To reach these goals buildings need to be more energy efficient. The goal, set by the Swedish government, is to be 20% more energy efficient by 2020 compared to 2008. [Regeringen, 2016] A general estimation is that energy usage in residences can be reduced by 20% by changing behaviours and habits [SP Sveriges Tekniska Forskningsinstitut, 2011].

On weekdays the demand of electricity, hot water and heating is highest during the mornings and evenings. There are also variations between the seasons. A study [SP Sveriges Tekniska Forskningsinstitut, 2011] found that the total amount of energy produced during January was about three times as high as the amount produced in July. At the same time the emissions in January were 15 times as high as in July, since the seasons when the energy demand is high requires coal as the dominant fuel.

When summing up the total electricity and energy usage of all Swedish residences these variations makes distinct highs and lows. If the consumption were more even the renewable energy source could be used at a higher rate, this is called load shifting, and would make the system more environmentally friendly [SP Sveriges Tekniska Forskningsinstitut, 2011]. When having these peaks of energy demand the fossil fuels gets more important since the renewable sources can not provide the system enough energy during the peaks. Another solution is to make the energy usage follow the energy mix of the renewable sources. This can be made by for example storing energy when it is not needed in batteries or sell the excess energy and for example use batteries when the renewable sources are not meeting the demand.

2.3 Big data

From the beginning data was entered by employers by hand and the volume of data were manageable. When the technology evolved and the world wide web was opened for everyone and the ones using it started to enter data themselves the volume of data increased and also the velocity and variety of the data streams grew. Velocity is the frequency of incoming data that needs to be processed, and variety is the different kinds of data such as SMS messages, Facebook status updates or credit card swipes. The next step in the evolution of data was when machines and sensors et cetera started to collect data and the streams become even more unmanageable. Three V's: volume, velocity and variety were distinguish and the term big data was created. To this one more V has been added, veracity, which refers to the trustworthiness of the data. With many forms of big data, quality and accuracy are less controllable, but the volumes often make up for the lack of quality or accuracy.[Bernard Marr, 2015]

The interesting part of big data is not the large amount of data or the different forms of data but the information that can be found from analyzing the data. By analyzing data in real time together with historical data, patterns can be distinguished and insights and information of what happened and why it happened can be realized.

In the article Big Data Analytics [Deborah Gonzalez, 2014], Oracle stated five approaches when analysing big data to get insight:

Discovery Tools: The user interact with the data, that can be both structured and unstructured and comes from different sources, to understand and display relationships and apply them to issues.
Business Intelligence Tools: Analyze transactional business data to get information about the data. This is a much more technical approach than the previous.
In-Database Analytics: Processing the data in a database to find patterns and how different data relate to each other. This is used to conserve resources.
Hadoop: A programming framework that can be used as a tool when analysing big amounts of data and developing applications.
Data Driven Decision Management (DDDM): Uses self learning, data predictive models, data analysis and business rules to make decisions.

The potential of big data are endless and can be implemented in all kinds of industries. Products can learn, adapt to the environment and to the users needs, service themselves, and operate on their own. Advertising can be personalized and adjusted according to your mood. Additionally, in products variability is expensive since it requires physical parts to be varied. The software in smart, connected products makes variability cheaper since digital user interfaces can replace buttons and physical applications, making it easy and less expensive to change, repair or personalize a product. [Michael E. Porter and James E. Heppelmann, 2015]

When gathering this large amounts of data the security becomes an issue. Where should the data be stored and who should get access to it? Maribel Lopes, Mobile Market Strategist, [Deborah Gonzalez, 2014] mentions three components of data regarding security. Data in creation, data at rest and data in transit. During all of these phases there are problems that need to be considered regarding for example coding, encryption, storing data, destroying data et cetera. There are also security and integrity aspects such as the protection needed when personal information or data of business value is getting collected. Since the data in this report is collected and stored, for Live-in Lab, the main security issue regards what is acceptable to measure from a peoples personal life. Data can be classified depending on what the needed level of security is. Can the data be made public, is it for internal use only, is it company confidential or is it even highly confidential. By classifying data like this it is for example easier to decide who should have access to the data. [Deborah Gonzalez, 2014] What data can be made into business, what can be displayed for the residents and what should only be available for the researchers in Live-in Lab? This report does not discuss the security and privacy in a detailed way except for discussions about security and privacy regarding the purposed solutions for Live-in Lab.

2.3.1 Social big data

Social big data is another aspect of big data. Today we live in a connected world and social big data is a term that includes information we share on social networks, social media data. Facebook, LinkedIn, Twitter and Instagram are a few examples of applications that generate a stream of information daily. About 400 millions tweets are published on Twitter every day and social media data can be used as "listening platforms" to understand the motives behind actions [Camacho, Bello-Orgaz and Jung, 2015]. University of Cambridge and Stanford University published a study in 2015 about how Facebook knows you better then your friends and family [Clifton B. Parker, 2015] . Everywhere we go we leave digital traces with information that not only include place and time. When registering the public transport pass, performing a Google search, shopping online, streaming TV, using a GPS, are on the phone et cetera. Owing to the information you share, Facebook and other technologies are able to analyse you, your mood and your patterns better than people close to you. With this information they can predict future actions and offer personalized services. Today there are many companies offering services that analyze social media. For example MyBuys uses over 200 million consumer profiles and 100 terabytes of data to deliver real-time product recommendations. Social big data can be used to for example analyze the moods or needs of the residents in Live-in Lab. If "the home" can understand its habitats it can communicate with or adapt to them.

2.3.2 Internet of Things

IoT, Internet of Things, is an other aspect of big data and is an interesting perspective of this report. IoT means connecting an object to Internet and generates big data. With the broadband becoming a part of every city's basic services and with the decreasing cost of technology and connecting devices IoT becomes a bigger part of our lives. IoT can be implemented in our coffee maker as well as in an jet engine of an airplane. With this you can start the coffee maker from the bed with your smartphone or get an alert from the jet engine when it is in need of reparation. Or your car can have access to your calendar and know the best route to get to a meeting.

Studies indicates that by year 2020 50 billion devices will be connected to the Internet [Dave Evans, 2011] . The development of objects connected to the Internet is shown in Figure 2.2

In the Live-in Lab project IoT plays an important role in order to obtain control and be aware of the energy usage or resource consumption.

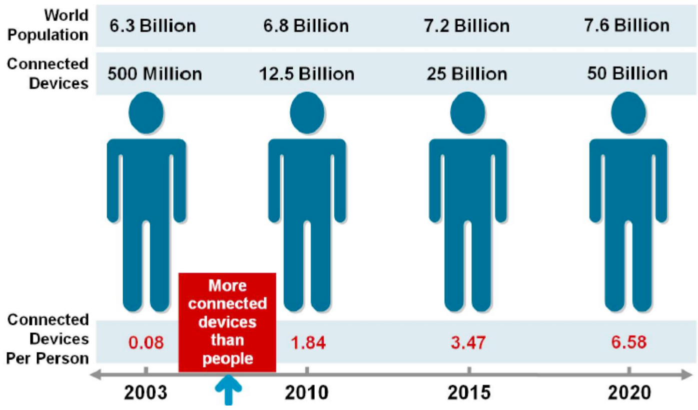


Figure 2.2. The development of Internet of Things.

2.4 Devices to collect data with and systems that use big data in a home

This report is discussing three ways of detecting the activities regarding human activity and energy usage in a home. A fourth one include social data and IoT and can be used to find patterns outside the home. The hierarchy of the different ways of collecting data is visualised in Figure 2.3

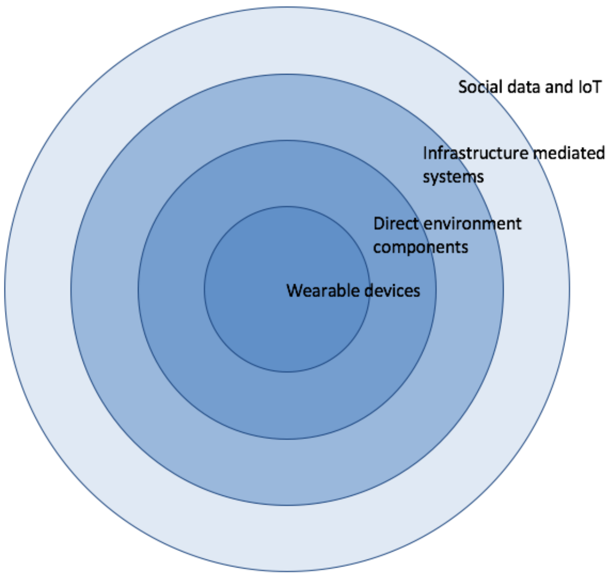


Figure 2.3. The hierarchy of ways to collect data.

Wearable devices: Sensors can be attached to objects or objects that humans wear to detect for example movement. This can be done with RFID tags and read-

ers. Motion detectors can be used to sense the presence of people in a home or room and their location, and switches can be used to detect the state of a door or window.
Direct environment components: This category consists of systems that are integrated in the home. Sensors are distributed in the home and interact with each other. The sensors are part of a network and the collected information is used to be able to optimize the energy usage in the home and is often displayed to the user. A smart meter measures energy, water or natural gas consumption of a building or home, and is connected to the Internet. Traditional meters only measure the total consumption, but a smart meters detects when and how much of a resource is consumed and display the information on a in-home display. A smart energy monitor connects home appliances and electronic devices to the Wi-Fi network and allows the user to make schedules, program notifications and change their status from anywhere. Smart thermostats can adjust inside temperature with the help of sensors in all rooms, access to the outside temperature and then make the right adjustments for optimal comfort and energy conservation.
Infrastructure mediated systems: The usage of electricity and water, among others, can be detected by installing sensors into the existing infrastructure in a home, e.g. plumbing.
Social data and IoT: Social data and the use of IoT can give valuable information about for example consumption patterns of the residents. This is more about developing algorithms and not specific devices, therefore it is not discussed in this section.

2.4.1 Wearable devices

Radio frequency identification and wireless sensor networks

To be able to track applications or to collect environmental data, wireless sensor networks, WSN, can be implemented in active radio frequency identification, RFID, tags. RFID tags make it possible to track and identify objects and send that information to its readers. WSN can gather and store information such as the measurement of temperature, humidity, sound intensity, power-line voltage, pollutant levels, etc. To integrate these two with each other can give real time information, alerts and warnings. [Aikaterini Mitrokotsa, Christos Douligeris, 2009] [Hai Liu, Miodrag Bolic, Amiya Nayak, Ivan Stojmenović, 2008]

Applications when integrating WSN to RFID

The WSN can detect movement and with the help of RFID it is possible to get information about who or what is moving. With the RFID tags for example the settings of the light in rooms can be customized according to what the different users prefer, since the tags can make a system recognize who is entering a room. If several people is in the same room the settings can adjust to an average. [Sajisd Hussain, Scott Schaffner, Dyllon Moseychuck, 2009] RFID tags integrated to WSN have also been used by the U.S Navy to be able to track the condition of stored aircraft parts. They are using battery powered sensor tags that can communicate and send information between each other. These RFID sensor-tags are able to get information about temperature, humidity, air pressure. Since the security is important the information is sent only when the tags are contacted from a base station, which also has to send a security code. [Hai Liu, Miodrag Bolic, Amiya Nayak, Ivan Stojmenović, 2008]

Applications of RFID

RFID readers can also be used to monitor interaction with tagged objects. This was used in the PlaceLab project which is discussed in the State of the art-section.

The SmartPlug system provides a household to keep track of their electronics by placing a RFID reader on every power outlet on the wall and a RFID tag on every electrical device's plug. When a device is plugged into an outlet the reader reads the tag and sends information to a computer that can identify the applicant and its location. To monitor how electrical devises are used can help the residents to get insight in their use of electronics, as well as send alarms when something unexpected happens. [Dan Ding, Rory A. Cooper, Paul F.Pasquina, Lavinia Fici-Pasquina, 2011]

Switches

Switches can be used to find out the status of for example door or windows, are they opened or closed?

Motion detectors

Motion detectors react to motion. They can be places in for example a doorway to be able to notice when someone is entering a room. This can be used to manage lamps, thermostats or ventilation systems.

Applications of sensors in the home

A sensor system installed in a apartment can monitor how a person behaves, monitor patterns and notice when they are changed. These kinds of data can be used to alert the resident about behaviors that may effect for example its health or efforts to save energy at home. [Healthsense, 2016]

2.4.2 Direct environment components

The range of products offering services to manage the energy usage in homes is constantly growing. Smart meters, smart energy monitors and thermostats comes in many different shapes and below they are discussed in general and some of the available brands on the market are mentioned.

Smart meters

A smart meter measures energy, water or natural gas consumption of a building or home, and is connected to the Internet. Traditional meters only measures the total consumption, but a smart meters detects when and how much of a resource is consumed and displays the information on a in-home display. The traditional smart meters are smart by collecting data more often than the old electricity meters do which gives more detailed information about the electricity consumption. This makes it possible for the utility to set different prices during different times of the day and year. When the demand is high the price might be high. By doing this the customers can be motivated to shift their electricity usage to times when the electricity is cheaper, which will contribute to peak shaving. Since it is connected to the Internet there is no need for the utilities to go home to their customers to be able to read it. The new smart meters also offers a two way communication that offers the utilities to be informed when there is a problem, e.g. a power outage, and information about for example time-of-use pricing can be sent to the home.

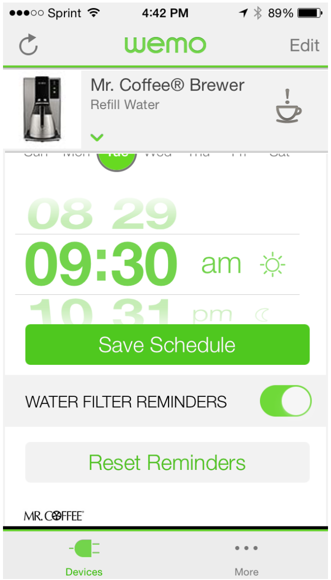
Smart energy monitor

Residents can get insights in their energy usage with a smart energy monitor, which gives real-time feedback on the energy usage and what it is costing. With this system they will know what the utility bill will be before they receive it. [Kaile Zhoua, Chao Fua, Shanlin Yang, 2014]

There are systems that include sensor systems that detect when someone is in the room. This makes it easy to save energy since appliances such as lights only are activated when someone needs them. Some even monitors the carbon dioxide emissions to determine the carbon footprint of the activities in the home. [Efergy, 2016] Apps can be downloaded to a smartphone to be able to turn lights on when entering the house or turn a fan of when leaving the house. With the GPS function in smartphones a smart home system can put the home in "away mode" when the residents are leaving the house to save energy.

A smart energy monitor can help the user to manage the energy usage in several ways. First it monitors the energy usage and gives updates for example every fifth second, so the user instantly can see the effect of turning on for example a light. It displays the daily average so that the user can see when the electricity consumption is higher than normal and see how the average usage reduces as the user change the way he or she does things. [Efergy, 2016] A smart energy monitor can also help distributing the energy usage more evenly during a day or a week since it displays information about the energy usage to the user, instead of having the energy usage peak at specific times. If the consumer gets information about its energy usage patterns and when the energy is cheaper this will encourage to change patterns.[Shafik Ahmad, 2011]

WeMo is a smart energy monitor that connects home appliances and electronic devices to the Wi-Fi network and allows the user to turn them on and off, program



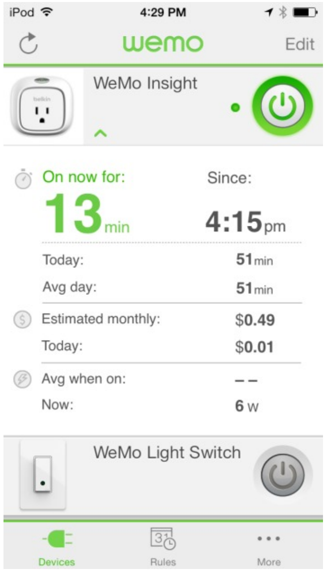


Figure 2.4. Schedule devices with WeMo

Figure 2.5. Status of connected devices

notifications and change their status from anywhere. WeMo monitors the connected devices and displays their electricity consumption for the user. The coffee maker can be schedule, as seen in Figure 2.4, to start at a specific time and the user can find out if the space heater has been left on when leaving the home.

The system motivates the user to keep the electricity bills low by setting schedules, monitor energy usage, as seen in Figure 2.5, and displays which devices that are used most often.

The motion sensors in the WeMo system can make the lamps go on only when someone is in a room. Then the user does not have to remember to turn the lights off. The motion sensors can also be set to only react during specific times of the day to prevent them from being turned on by for example the cat at night. With the integration of "If this, then that" (IFTTT) the user can connect the WeMo to Jawbone UP. By doing this lights can be set according to your habits. They can be turned on when the user wakes up in the morning, or it can be set to turn the lights on after for example 8 hours of sleep. IFTTT can also be used to turn the air conditioner of when the air in the room is at a specific temperature. By installing smart plugs where appliances are plugged in to the wall users can get information, through an app, on how much electric power a specific product consumes and for how long it has been used. [Dario Bonino, Fulvio Corno, Luigi De Russis, 2011]

Ventilation and air quality

There are sensors that senses the condensation, humidity and mold in a room. By implementing these, for example excess humidity can be found. The system that the sensors belong to will be activated and turn on the fan. There are several settings that the user can adjust such as sensor sensitivity, humidity level and set schedules to meet the need of ventilation in that specific room. [Leviton, 2016] Other smart systems measure the indoor air quality and displays to the user if the air is polluted or not. In a smartphone app it can display historical data, pollution peaks, send a notification when crossing a threshold defined by the World Health Organization and send warnings when there are predicted pollution peaks. It detects: Volatile Organic Compounds (including gases such as Formaldehyde, Benzene, Toluene, Ethylene glycol, etc.), Particulate Matter, Carbon Dioxide, Carbon Monoxide, Temperature and Humidity [The Foobot Team, 2016].

Thermostats

Thermostats are useful tools to save energy from heating and cooling systems in a home. Much of the energy used by these systems is used for space conditioning during times when the home is unoccupied or occupants are sleeping, during these times energy can be saved. The temperature at home can be adjusted by thermostats that have sensors in all rooms, access to the outside temperature and then manage the system to put the home at a comfortable temperature and save energy. The sensors also notice if any one is home at all, which rooms that are occupied and adjust the thermostat to that. Many of the available systems are connected to Wi-Fi which makes it possible to control the temperature from your smartphone. [ecobee, 2016] In addition to the traditional manual thermostat there are programmable and self-programmable thermostats. A programmable thermostat gives the user the opportunity to schedule the times the heating or air conditioning are turned on. One example of a self-programmable thermostat is the Nest Learning Thermostat, which displays the current data etc as seen in Figure 2.6.

Figure 2.6. Nest displays the current status

Nest's Auto-Away setting can determine when the home is unoccupied and adjust the temperature in the home to that. The Auto-Schedule feature learns the behaviour of the users when they successive set the thermostat and automatically programs a changeable schedule. The user can also manage the Nest with a smartphone and get a monthly energy report. By doing this the user can see the history of its energy usage.

Two studies [Nest labs, 2015] were carried out in Oregon and Indiana, each independently funded, a third was performed by the Nest in 41 states in USA. In these three studies the participants were Nest users. The study compared energy usage before and after installing Nest Learning Thermostat. The results from the three studies were similar and showed that the homes had been saving energy after the Nest was installed. 10-12% of heating energy was saved and 15% of the electricity used when cooling the homes with central air conditioning was saved. Another study [Carlyn Aarish, Matei Perussi, Andrew Rietz, Dave Korn, 2015] compared the savings between the users of Nest Learning Thermostat and programmable thermostats. The results showed that the homes using Nest saved more when heating their homes as seen in Table 2.1 below.

Table 2.1. Savings of heating by using Nest thermostat

Test group	Savings [%]	Range of savings [%]
Nest	10	8-11
Programmable	2.5	1-4

The study contained 300 households that received a Nest thermostat, 300 households received a standard programmable thermostat and a control group of 3,845 households continued to use a manual thermostat.

Showertime

Showertime allows the user to monitor the amount of water used each shower. It displays the current water usage, as seen in Figure 2.7, and a alarm will go off when the set target amount of water have been used. [Efergy, 2016]

Figure 2.7. The display fills up during the shower so the user can keep track of its water consumption.

2.4.3 Infrastructure sensors

To install sensors in the already existing infrastructure in a home can give interesting information about gross usage and is quite cheap since it only requires a few sensors, but it does not give details of the circumstances regarding the activities that might be interesting. For example a study was conducted on how to detect motion in a home. Pressure sensors were installed in the existing duct work infrastructure of central heating, ventilation and air conditioning systems to sense how people move in a house. By sensing the changes in pressure the system could detect a person walking through a specific doorway or closing or opening a door. This was made by Patel which succeeded to measure this with 75-80% accuracy. [Shwetak N. Patel, Matthew S. Reynolds and Gregory D. Abowd, 2008] When the purpose is to manage systems in the home it is more common to use motion sensors. By installing motion sensors in the home the heat and ventilation can be shut down or regulated depending on if the residents are at home and what rooms they are using. HydroSense is a system that can be installed in for example a utility sink spigot in the existing water infrastructure. The system analyzes the pressure to detect when and how much water that is being used. [Dan Ding, Rory A. Cooper, Paul F.Pasquina, Lavinia Fici-Pasquina, 2011]

2.5 Other smart technologies and services

2.5.1 Geofencing

Thermostats and other smart meters can use geofencing to manage their systems. Geofencing is an invisible boundary around a neighborhood that recognizes when the user crosses it. When the invisible line is crossed, the device communicates with an app in the users smartphone, and act depending on if the user is leaving or coming home. With this technology there is no need of learning patterns or schedule programming. [thecoolist, 2016].

2.5.2 Mesh network

Instead of having sensors that control lights and other devices there are systems that uses bluetooth to form a mesh network. The network is connected to an app and senses where the user is at home to manage for example the lights. A plug is installed in the electrical socket before plugging in the appliance that the user wants to control. This does though require that the residents carry their smartphones when at home, which might not be the case today. On the other hand lights will not be turned on when a pet enters a room [Michael Brown, 2016].

2.5.3 Waste tracking

IoT can be used to optimize waste management and make the process more personalized and simplified for the end user. By using RFID keys the residents can keep track of their individual waste disposal and get information about how to recycle better. The information can be sent to the end user by applications and web. An other important aspect of having RFID keys is that the ones responsible for the collection of the waste can get real time information about for example how much waste is dumped, which times and which materials that is sorted. They can also decide when people will be able to recycle if needed. [Stockholms stad and Envac, 2016]. Furthermore a smart way of using IoT in waste management is as a scale system. By having a scale system to measure the percentage of waste in a container the transportation costs and emissions can be minimized. The responsible for the system will always be aware about the amount of waste in the containers in order to be able to empty them only when they are full, as seen in Figure 2.8 [Stockholms stad, 2015].

Figure 2.8. Efficient waste management

2.5.4 Load forecasting

Load forecasting is one important area when talking about big data in terms of energy. With historical load data, weather data and social factors, et cetera it is possible to forecast the future demand of energy. There are also often similarities in demand between houses in the same area. With this knowledge strategies can be developed to offer personalized energy services, such as help consumers develop their energy saving plans. Load forecasting can help to even out the energy usage with the advantages which were mentioned in the section about Energy usage. [Heiko Hahn, Silja Meyer-Nieberg, Stefan Pickl, 2009]

Time-of-use electricity pricing

Some electricity suppliers offer electricity contracts where the prises vary during the day. To take advantage of this the users can schedule their energy usage to when it is at its cheapest. This will make the electricity demand more even during the day since the the usage will shift from on-peak to off-peak periods when possible. This will make the strain on the electricity system more even, be beneficial for the environment and lower the electricity bills for the users. Another idea is to use energy from batteries when the electricity is more expensive and then re-charge the batteries when the electricity is cheaper. This method has been used at IBM's administrative headquarters and they estimate that the energy costs can be reduced by 3-5%. [IBM, 2013]

2.5.5 Smart windows

Smart windows can be used to decrease the demand of heating and cooling in a home, as well as decrease the use of lamps. The smart windows available today can run automatically and adjust themselves to the current state, or be controlled with a smartphone. By admitting natural daylight and rejecting solar glare, smart windows can lower the energy costs. The window will maximize the use of daylight and minimizing heat and glare.

2.6 State of the art

In this section similar projects are studied as well as smart cities which is an important aspect to get the bigger picture of the word smart smart and IoT.

2.6.1 HSB Living Lab

HSB Living Lab will be the home of students at Chalmers in Gothenburg and is now under construction. It will be finished by June of 2016 and will also be a place where research is taking place during a period of ten years to investigate what our future homes will look like, a living laboratory. The house will be movable and consists of modules that can be assembled in a short amount of time. There is one part of the house that consists of 29 apartments where people can live and one part where there will be office, show room and wash house. Their vision is to investigate what parts of a home that the residents can share, this is to decrease the consumption and material flow. To do this they want to find out how people interact. This project aims to find solutions of how to reduce the usage of energy and resources. They focus on social, economical and ecological sustainability, and hope to find new smart technical solutions that can be used in future homes. Some examples of technical solutions that will be installed from the start is that the inhabitants will be able to get a message if a window is left open, turn some receptacle off with their phones, see how much electricity they use compared to their neighbours and see how much garbage that leaves the house. [HSB Living Lab, 2016]

2.6.2 PlaceLab

A study called PlaceLab [Beth Logan, et.al., 2007] was carried out at MIT where 900 low cost sensor inputs were placed in a apartment to be able to compare the results from different kinds of sensors. Installed sensors were wired reed switches, current and water flow inputs, object and person motion detectors and RFID tags. At the same time everything was filmed to get the absolute truth. The purpose was to evaluate methods of activity recognition.

The study was carried out during ten weeks when a couple was living in the apartment, and during these weeks the residents had no contact with the researchers. Once a week the researchers entered the apartment and placed sensors on new things such as magazines and food. From this, analysis were made and resulted in a list with all activities taking place during these weeks, how often the activities were performed and for how long. They found that 10 infra-red motion detectors outperformed the other sensors. Especially for the activities that were typically carried out at the same location in the apartment. Since they had it all on video they could find the reasons for why the tags were less useful:
- All activities do not involve interactions with objects, e.g. sleeping.
- Some activities (e.g., dish washing) involve objects that could not be tagged since it is metallic.
- Some activities involve objects that were too small to tag.

From this evaluation you can tell that it might would have helped to video tape activities for some time before placing the sensors. To get as realistic data as possible, consider privacy and to make sure that the residents were living as normal as possible the data were never observed in real time, the sensors were also disconnected from the Internet. A computer was sending a signal once every hour to the researchers to make sure the system was working. The participants also had the opportunity to look at the videos and data and delete sensitive parts, before letting the researchers use it.

2.6.3 The active house in the sustainable city

This project [Carin Torstensson, et.al. , 2014] was a living lab where a family lived during a period of time. The aim of the project was to examine solutions that later could be developed and integrated in 170 apartments in Stockholm Royal Seaport. The project included small and big companies as well as research organisations, from different industries. Visualisation tools were installed in the apartment, with these the family was able to see their electricity usage, price and CO2 footprint. In the apartment it was possible to control and make devices interact with each other. A button was installed that could be set as *home, away* or *asleep.* When set at *home* everything was ready to be used. When set at *away* everything except the freezer and refrigerator was switched of. Sensors were installed that could sense if anyone was in the room. The purpose was to save energy by switching off applicants when no one is present. White goods often use the most electricity in a home and therefore the goal was to make them run at times when the price was low or during times of low CO2e-emission, or both if possible. These were not installed in the living lab apartment but run in the Electrolux lab in Porcia, Italy. A schedule algorithm was used to schedule the smart home applicants to run when the electricity is cheap and the CO2 emission as low as possible, or it found some optimal mix of both price and CO2 emission.

2.6.4 Smart cities

To get a bigger picture of the word smart in this context and why research and implementations of big data is integrated in the Live-in Lab project this part of the text focus on smart cities and an user-led approach. A study visit to Ericsson Studio at Ericsson's Headquarter was done to get a greater perspective of IoT, Smart cities and ICT.

A smart city is about integrating ICT, in the city and using data to optimize the city. Some examples of things that can be improved: optimize traffic flow, improve health care and minimize energy usage. According to Microsoft's project Sway, five aspects need to be considered when building a smart city: digitization, IoT, citizen's experience, a data-led approach to safer cities and digital equality.[Microsoft, 2016].

Digitization is obvious the core of building a smart city and by transforming information to a digital structure.

IoT is one of the keys to a smart city and is a part of many future solutions, for example by implementing IoT in cars, traffic management can be optimized. Time and fuel can be saved by using IoT as well as accidents can decrease and the comfort for the inhabitants increase.

Citizens and visitors experience is another improvement that should be implemented, the well-being is crucial in a smart city. A society lives on its inhabitants and visitors, therefore it is important to meet the people's needs. To attract people the city has to be safe, clean and easy to get around in.

Safer cities by prevent, detect, and minimize criminal and terrorist activity by using ICT is another important aspect of a smart a city. Even emergency services could be improved this way. By analyzing digital information from sensors, videos and mobile technology this can be accomplished.

Additionally digital equality is important. It is crucial for a city to adjust to its citizens and be aware of individual variation and work for combining social harmony and urban development to ensure cultural and environmental sustainability.

2.6.5 Stockholm Royal Seaport

An example of a smart city is Stockholm Royal Seaport. Stockholm Royal Seaport is a urban development project located in Stockholm and it is a part of the city's vision of a world-class Stockholm by 2030 and the plan is to build 10 000 new homes and make 30 000 new jobs. The objectives for the project are environmental, physical space, economic and social [Stockholms stad, 2012]. Below are some examples of how Stockholm Royal Seaport work with smart technology to minimise energy and resource use.

Smart electricity grid

An intelligent electricity grid, automated heating and ventilation systems that will run when electricity and energy usage are low will be used [Stockholms stad, 2016b]. By visualizing and making the users aware of their energy usage it is estimated that a family can theoretically save up to 30% [Interactive Institute Eskilstuna, 2016].

Smart waste management

Stockholm Royal seaport is planning a well developed strategy for handling waste. A vacuum waste collecting system reduces the amount of transportation when sorting and managing the waste. Along with personnel access connected to Internet to keep track of each apartment's usage, by using an electronic key with RFID. The information is analyzed and feedback is given back to encourage people to sort the waste more. Furthermore food waste contributes to the production of biogas [Stockholms stad, 2015].

Smart City SRS

Smart City SRS is a part of the project Stockholm Royal Seaport and the core of the project is a common and shared ICT infrastructure. A shared ICT structure enables the full potential of IoT, and there is a need for a common structure. A shared ICT structure also enable cost savings and encourage innovation growth [Stockholms stad, 2014]. An other important part of a well functioning ICT system is information to the user. Communication and feedback to the end user to enable a understanding for the system consequences of decisions and providing greater insight to the impact of every day habits and actions. The aim for Smart City SRS is to enable smart decisions by using real time data [Stockholms stad, 2016a].

Chapter 3

Development of concepts

This chapter presents the development of concepts and solutions.

3.1 Methodology

The development of concepts was a partly iterative process where solutions were found during a divergent session of brainstorming. This was followed by a convergent process where the purposed solutions were evaluated to eliminate solutions that were not technologically possible or did not contribute to energy related insights into the Live-in Lab. This was followed by a divergent process where the remaining solutions were developed and refined to maximise their contribution to the Live-in Lab. Documentation was made by making a table, Appendix A, to make sure that all parts of all solutions were developed. The solutions that were about the same device or system in the home were put together. This is demonstrated by giving them the same colour in Appendix A. The method, Figure 3.1, is common when developing concepts and is described in The Mechanical Design Process [David. G Ullman, 2009].

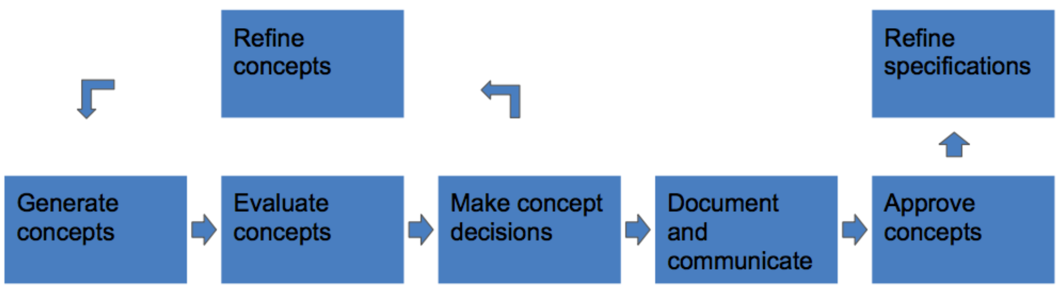


Figure 3.1. The process of developing concepts.

3.2 Brainstorming

During the brainstorming all ideas were welcomed and there were no limitations. The brainstorming began with a mind-map where different areas were defined and evaluated to find where big data could be implemented, Figure 3.2. This resulted in about 50 solutions or attempt to solutions which can be seen in Appendix A.

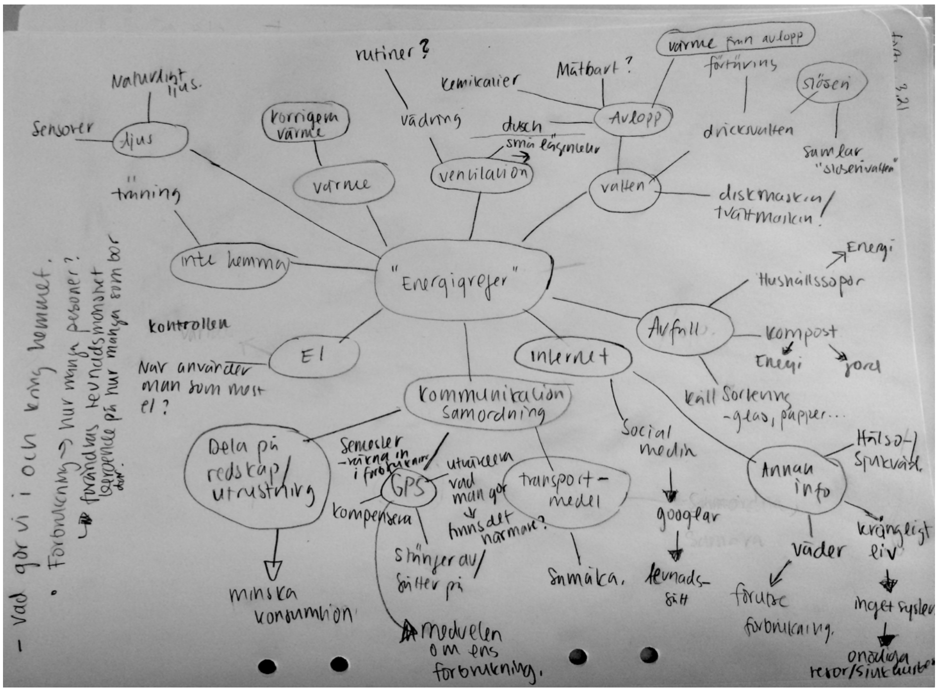


Figure 3.2. A mind map was made to distinguish areas where big data could be implemented.

These solutions were evaluated based on the limitations and the objects of the project and compared to the existing products on the market to be able to pick out the solutions that were most unique or useful for this report. The purposed solutions were ranked according to the criteria below and the ranking can be seen in Appendix B and the total score is presented in Figure 3.3. The solutions are listed below and in the next chapter the highest ranked solutions are described in detail, the rest can be found in Appendix C. It is described what is measured and how often. The background of the solution is described, the technology used to collect the data, some possible analysis and some thoughts regarding security and privacy. At the end each solution is evaluated with a SWOT analysis, discussed and the ranking is motivated.

3.3 Solutions

1. Water consumption: Patterns of water consumption are studied.
2. Ventilation: The quality of the air indoors is measured, to be able to adjust the ventilation and to find correlations between the air quality and for example architecture.
3. Ventilation through windows: The aim is to track the energy loss when windows are opened and find patterns of how windows are used.
4. Light: Lux is measured to be able to adjust architecture and lamps to the natural light.
5. Flushing the toilet: The aim is to investigate how much water that is wasted when flushing the toilet.
6. Fridge and freezer: Patterns of electricity consumption and usage of the fridge and freezer is studied.
7. Unnecessary usage of electricity: The aim with this solution is to decrease the electricity consumption from standby products.
8. Movement inside the apartment: By collecting information about how people move in the apartment infrastructure systems and the architecture can be adjusted.
9. Movement outside the apartment: By collecting data about how people move in the common areas infrastructure systems, the architecture, recycling stations among others can be adjusted. Furthermore data from movements outside the residence can also be collected to find the transportation habits to draw conclusions regarding the energy usage outside the home.
10. Consumption: By gathering data from the credit card and chart the consumption, divide the information into categories and present the consumption patterns for the user, the user could become aware of unnecessary consumption.
11. Social data: With social data health, moods and interests could be charted. With this data for example social communities in a building or block could be developed.

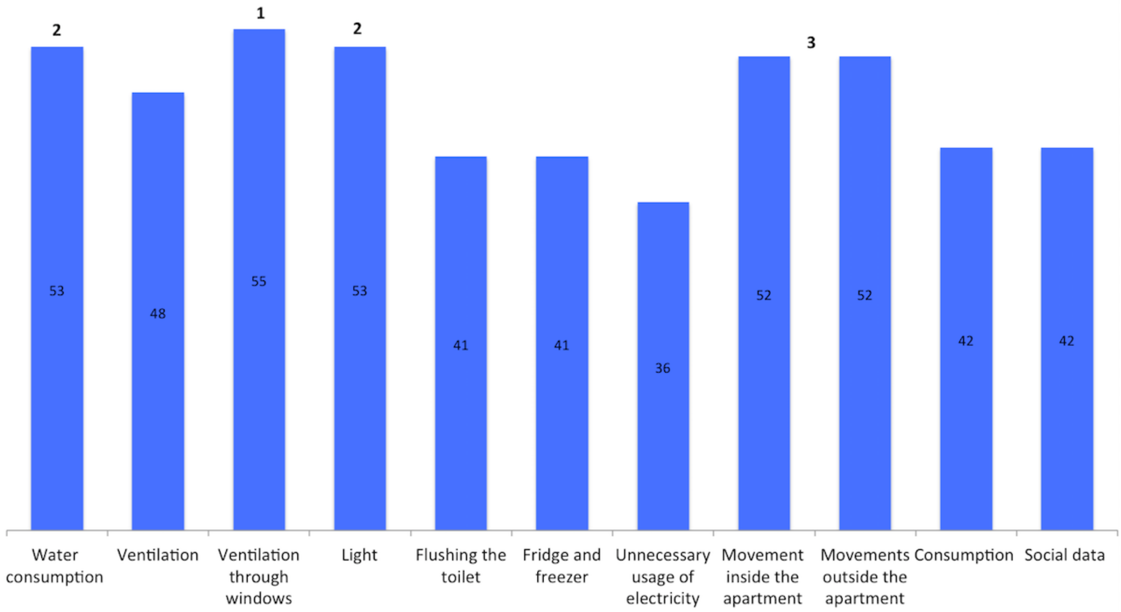


Figure 3.3. Diagram that shows the ranking of the solutions

3.4 Evaluation and aspects of security and privacy

Criteria

Criteria were developed to be able to see the strengths and weaknesses of the solutions, and also to be able to screen them. The criteria were chosen according to what have been the focus during the development of the solutions. The ranking is motivated in the *Criteria* part of each solution.
Reliability Will this data collect what is needed, or will it be affected by sources of error? Ranking: 2
Flexibility Can this data possible give insights in different areas or is it limited to just one? Ranking: 1
Independency Can this data give insights independently or does it depend on some other source of data? Ranking: 1
Energy savings potential How much energy does this solution save in relation to the amount of energy used in a home? Ranking: 3
Innovative Are there any similar products on the market? Ranking: 3
Technological potential Is this solution possible to carry through. Are there technologies available? Is it easy to implement in the existing applicants? Ranking: 3

Ranking of the criteria

The different criteria were ranked from 1 to 3 according to how important they are to this report. This report focuses of finding new ways of getting insights into energy usage in a home with big data. Therefore it is of high importance that the solutions gives possibilities of saving energy, are innovative and have technological potential. The technological potential is related to the reliability of the data which because of that also becomes important. Least important is the flexibility and independency which are criteria that are not that important for the solution itself, but are criteria that can separate the better solutions from the ones that are less useful.

SWOT analysis

All solutions were evaluated with a SWOT analysis where four aspects of each solution were studied. Strengths, Weaknesses, Opportunities and Threats. This method of evaluating the solutions is useful to be able to compare the different solutions with each other. It also puts the purposed solutions in several perspectives by asking these questions about strengths, weaknesses, opportunities and threats, the answers can be used for further discussions and identifies requirements of future work.

Security and privacy

The security and privacy aspects of each purposed solution is discussed. What is important to take in account regarding the security aspect when collecting these data? Can the collected data somehow invade the integrity of the resident? Is it possible that the data can be used and analyzed in away that will invade the integrity? The residents are well aware of that they are contributing to research by just living their ordinary life. It is important though that the information is used carefully with respect to the resident, so that they do not feel supervised.

Chapter 4

Concepts for analyzing energy and resource usage with big data in Live-in Lab

Purposed solutions for the Live-in Lab are listed in this section, followed by some discussions and evaluation of each solution.

4.1 Water consumption

What is measured?
The temperature and volume of water consumption, and the temperature and volume of the unused, wasted, water. As well as when it is used. The time for the water to adjust to the desired temperature is also measured.
Background
Water consumption is one of the big consumers of energy in a residence, especially hot water. Therefore, it is interesting to investigate how the water is used, how much is wasted and to find correlations between water consumption and other types of energy usage and behaviour in a home. When using hot water there is energy lost in form of heat in the water that is unused and goes back to the drain. There is also a lot of water wasted when opening the tap and waiting for the water to adjust to the desired temperature, this is clean water that goes directly from the tap to the drain.
Technology
The total water consumption can be measured with a water flow meter where data is gathered every second. For this application, it is necessary to gather data as often as possible to be able to find patterns of how people use water. If they turn the water on and off during a short period of time, or if it is left on for a longer period of time. With thermometers and algorithms the time for the water to adjust to the desired temperature can be found. One idea of how to measure the unused water that goes directly from the tap to the drain is to install a motion detector in the

tap.

Analysis

From the patterns of water consumption there is a possibility of identifying the activities that uses and wastes water. Total water usage can be compared to the volume of unused water. The water that goes directly from the tap to the drain can be taken care of in some way, it can be sent to for example the toilet to flush with. The infrastructure could be complemented with a second pipe for this unused and clean water. The tap could close if it has been opened for a longer period of time with water of a constant temperature and with no motion, which indicates that the water is wasted. The temperature and volume of wasted water is interesting to know to be able to decide if it is profitable to take advantage of this, now wasted, energy stored in the water. It can be used to heat up the apartments or the tanks with hot water.

The time for the water to adjust to the desired temperature is interesting to be able to examine if it is desirably to find ways of developing the technologies of the water infrastructure in apartment buildings. If the patterns of water usage were studied the infrastructure could also be designed to have hot water ready when it is needed. The data can for example give insights in if the circulation of the water in the water infrastructure is sufficient. When comparing these data between apartments with different placement in relation to the water tanks the data can be used to get insights in how many and where the hot water tanks should be placed.

Security and privacy

This data will not give any sensitive information regarding security directly, but it can for example reveal when the residents usually are away from home. It will also reveal personal information about other habits and patterns regarding the everyday life of the residents.

Discussion and motivations of the ranking of the criteria

According to the evaluation table in Appendix B these suggested solutions are good ways of getting insights into energy usage with reliable data since the water system is delimited. The water comes in a tap and goes away into the drain which makes it easy to measure. There is potential of saving energy in several ways since water is a resource that is used often and during many of the daily activities in a home, both volume and energy can be taken care of, and systems can be developed that optimize the energy usage. The data is therefore also flexible and can be used to find several correlations. The technologies used are simple sensors and conventional water meters, which are well developed. A SWOT analysis of the solutions is shown in Figure 4.1.

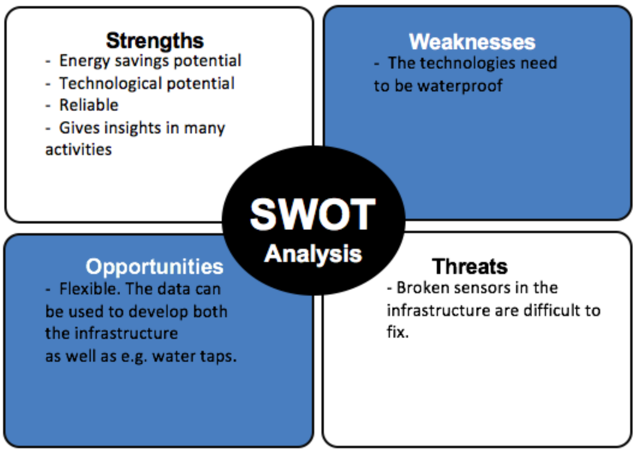


Figure 4.1. SWOT-analysis for Water consumption

4.2 Ventilation

What is measured?
The air quality, humidity, condensation, CO2 emission, mold, temperature among others.

Background
Many of today's ventilation systems are not adjusted to people's presence or the quality of the air. By measuring the air quality in instead of area of the apartment, the ventilation system could be adjusted and be more energy efficient. Furthermore by collecting data correlations can be found between air quality, temperature and architecture or placement of electronics.

Technology
The technology to be used is sensors that measure the air quality. WSN placed in the apartment to chart for example the CO2 emission and temperature. The measurements can be collected about every ten minutes.

Analysis
By analyzing the air quality, ventilation systems could be adjusted as well as warnings could be given from real time data if something is out of the ordinary, if it is too much CO2 or mold or something else out of ordinary. By logging data and find information about patterns, comparisons could be made with information from other sources such as architecture or placement of electronics and future homes can be designed and constructed differently if needed. Together with the data from the opened windows systems can be developed to adjust the ventilation when windows are opened. Moreover alarms can be given if something out of the ordinary happens.

Security and privacy
The information about air quality would not give any sensitive information about the people living in the apartments. No security aspects need to be considered regarding the stored data.

Discussion and motivations of the ranking of the criteria
The independency is high because the information alone could give great insights. The possibility to measure different aspects of air quality open up to a high grading in flexibility, as well as the possibilities of developing both the architecture and ventilation system. Since the ventilation is used everyday in every apartment the possibilities of saving energy when optimizing this system is good. There are technologies available to do these measurements. A SWOT analysis of the solutions is shown in Figure 4.2.

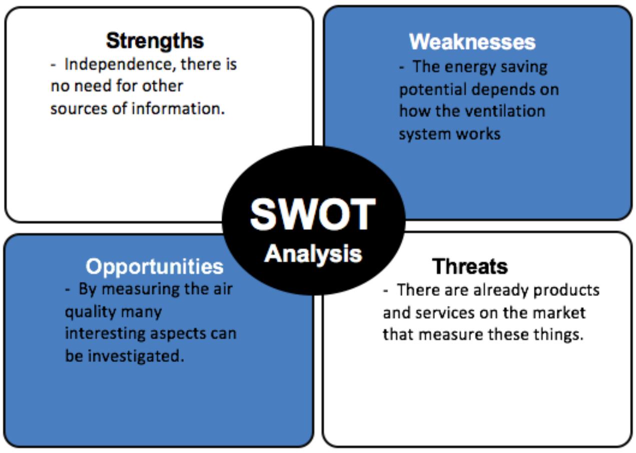


Figure 4.2. SWOT-analysis for Ventilation

4.3 Ventilation through windows

What is measured?
Temperature difference between indoor and outdoor air, the time windows are opened, the size of the window and how much they are opened. Humidity and air quality is measured indoors and outdoors.
Background
Today energy is lost due to opened windows and they are often opened more than necessary. Heat is lost and the heaters operates unnecessarily and energy and money is lost. Furthermore the ventilation and heating system is not working correctly if it is disturbed by opened windows. The aim is to track the energy loss when windows are opened and investigate how windows are used.
Technology
On/off switches to measure the time between a window is opened and closed. Thermometer to measure the temperature outside and inside as well as sensor measuring the humidity and air quality.
Analysis

By measuring the difference between the outdoor and the indoor temperature together with the time the window is opened, the total amount of lost energy can be calculated. This information compared with information about how often the windows are opened as well as information about the air quality, how the windows are opened during the year can be compared with how much the ventilation is working and how much energy is lost due to this unnecessary behavior. Algorithms can be made so that the windows could close automatically. By measuring temperature and air quality differences in the whole apartment it could be calculated how the opened windows affect the conditions, where the window should be placed and how big they should be. By measuring other aspects of the air, as humidity or pollution, this solution could be combined with the ventilation system and the windows could be opened and closed according to other aspects than temperature. The real time aspect could be used as well and the sensor could be connected to the heating system and ventilation system, which can be turned off when the windows are opened to save energy. This technology could be placed between rooms and register differences between the rooms as well as how often the doors are opened and for how long. This information can be used to evaluate the architecture and give insights in how the heat and ventilation system works.

Security and privacy

This data could not alone reveal any sensitive information. Information about residents habits of opened window together with real time information about movement inside or outside the apartment could reveal when no one is at home.

Discussion and motivations of the ranking of the criteria

The independency is high because the information alone can give great insights in how much energy is lost. The flexibility is high due to together with other types of collected data even more conclusions can be made. The energy savings potential differ during the year. If you open a window during the winter more heat is lost. Similar products could be obtained that connect window sensors to the heating system but is not used in large scale. Furthermore this data can be analyzed which have not have been made. The technology exist so it is easy to install in Live-in lab. A SWOT analysis of the solutions is shown in Figure 4.3.

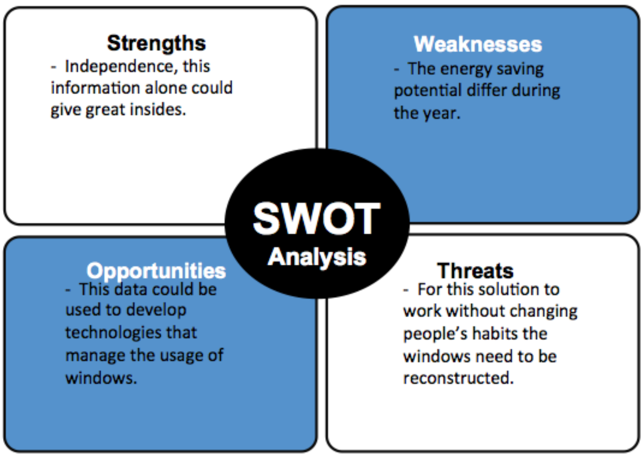


Figure 4.3. SWOT-analysis for Ventilation through windows

4.4 Light

What is measured?
Lux is measured where a lamp is placed. It is registered when the lamps are turned on by movement or when they are on in general. Lux is also measured all around the apartment.
Background
Lamps consumes 26% [Energirådgivningen, 2015] of the electricity used in a home. Therefore it is desirable to reduce the usage of lamps. It is a common way to manage lamps by movement sensors in smart homes but this does not take in mind if the lamp is needed regarding the natural light. If the solution also sensed the lux the lamps would only be turned on when someone is in the room and the light is needed.
Technology
A sensor that detects the surrounding light is needed, which can activate the lamp when it is to dark and someone is in the room. This data should make the lamp react in realtime. The data of how the light is in different places of the apartment is interesting to store less often, about every 10 minutes, since it refers to measure the natural light which do not change fast.
Analysis
If the lux is measured where the lamp is placed this can be compared to when the lamp is turned on by movement. This can be used to analyse how often lamps are used when they are not needed, how lamps should be placed in a home. The data can also give insights into how the architecture can be developed to make use of the natural light and design the home so that the natural light is present where it is most needed, as for example by the desk.
Security and privacy
This data will not give any sensitive information regarding security or privacy.

Discussion and motivations of the ranking of the criteria
The used technology is just a simple light sensor which makes this data quite reliable and independent. It is a quite flexible solution since it can contribute to development of lamps as well as the architecture. Since lamps consumes 26% of the electricity a decrease of this electricity usage would have a meaningful impact on the total usage. This solution contributes to the development of lamps with a new point of view. A SWOT analysis of the solutions is shown in Figure 4.4.

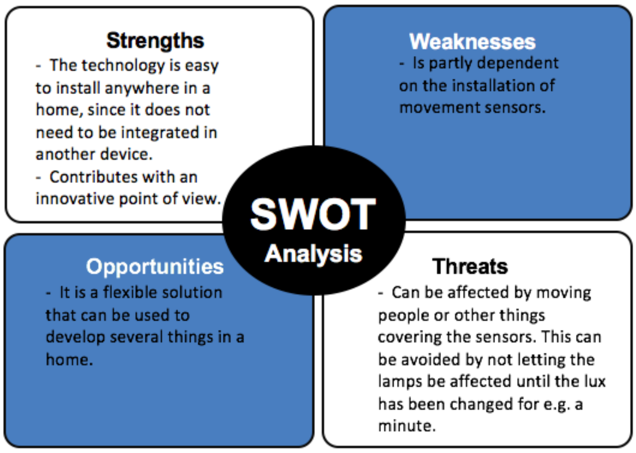


Figure 4.4. SWOT-analysis for Light

4.5 Movement inside the apartment

What is measured?
The inhabitants' movements in the apartment. The movement detectors will detect whenever people is moving and evaluate how often and for how long there are people in the supervised area. Another way of collecting this information is to use wristbands or face recognition to track how people move as well as who is moving.
Background
Energy related measurements are not the only way of detecting patterns of energy and resource usage. By collecting information about how people move in the apartment infrastructure systems and the architecture can be adjusted.
Technology
To record each person's movement technologies it is important to separate each inhabitants patterns. Therefore technologies that can handle this must be used such as movement sensors with algorithms that can separate people, wristbands, face recognition, or other family database technology.
Analysis
By using sensors to detect how people move in the apartment and what they do,

the behavior of the residents can be analyzed. Knowledge of which areas is used the most and what people do in the apartment can be obtained. By using that knowledge homes can be designed after activity, optimize usage of natural light and optimize the living area. If it is known when people are at home and when they perform specific activities such as cooking or sleeping, for example systems for load forecasting can be improved. The information about when activities are taking place can be used to develop systems of sharing for example home devices. Another aspect is the real-time data that can go back to the residents and products in the home. Ventilation and heat can be adjusted after the amount of people in the room and sleeping patterns can be studied as a part of health analysis.

Security and privacy

This kind of data can give insights in how a person choose to live hers or his life, which can be a security risk if the information gets in the wrong hands. It can reveal when the resident is at home, what she/he is doing, sleeping patterns and so on. This information can be used for marketing purpose and to track patterns and behaviours. Moreover people can feel a invasion of privacy.

Discussion and motivations of the ranking of the criteria

The independence is high due to there are no need for other information to be able to draw conclusions. The flexibility is high since the data can be used to analyse many different aspects of energy usage, behaviors and habits. Furthermore the real-time data can be used directly to adjust lights, ventilation or heat. There is technology at the market but the information is now analyzed in a new thinking way which can give new conclusions. A SWOT analysis of the solutions is shown in Figure 4.5.

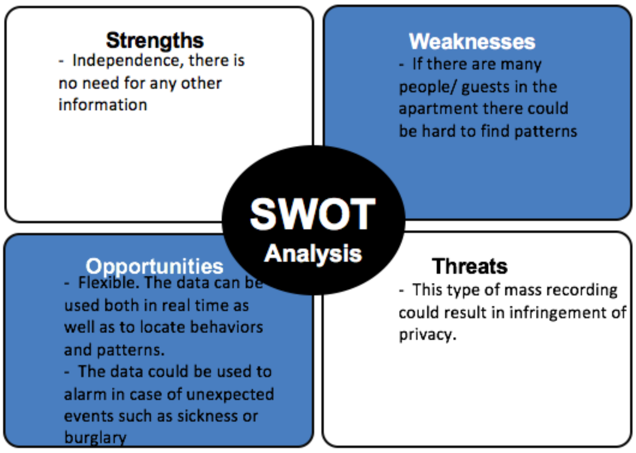


Figure 4.5. SWOT-analysis for Movement inside the apartment.

4.6 Movements outside the apartment

What is measured?
The movements and habits outside the apartment, both in the common areas of the building and outside the building. Who is using the common areas? When are they used and what activities are taking place? How and when does the residents travel to and from work?
Background
Energy related measurements are not the only way of detecting patterns of energy and resource usage. By collecting information about how people move in the common areas infrastructure systems, the architecture, recycling stations among others can be adjusted. Systems for sharing cars and other equipment can be developed by analyzing how people move outside the building, for example to school, work or people go for grocery shopping.
Technology
Movement sensors together with data from booking systems (laundry room). RFID keys or face recognition. GPS data from the residents' smartphones.
Analysis
By collecting data about how people move in the common areas insights can be given in habits, how people use the laundry room, bicycle rooms, recycle or other common areas as well as who is using it. By collecting data from the recycle room insights can be given in people's habits regarding waste. RFID keys and weight system can give information about recycling habits. By collecting this information patterns can be found and ways to avoid wastefulness can be developed. The information about how much and when the residents do their laundry can be used to develop systems that manage this usage to make the electricity usage more even, or people could be encourage to use the laundry room during hours when the electricity demand is lower. The GPS function in the smartphone can collect information about the residents traveling patterns. With the data from the residents GPS similar patterns from the residents could be found. If people for example work or study in the same area or go for shopping at different times common cars, carpooling, could be used. Furthermore movements outside the residence can also be collected to find the transportation habits to draw conclusions regarding the energy usage outside the home.
Security and privacy
This information can be use for targeted marketing or other services that requires your location. The data can also be saved and reveal information about habits i the everyday life. What stores you usually go to, when you are away from home, who you visit and so on. This can lead to serious consequences if the data gets in the wrong hands. This information could be categorised as an invasion of privacy.
Discussion and motivations of the ranking of the criteria
The independency from this data depends on the technology, but in whole the information alone could give great insight in behaviors in many different areas. The information alone do not generates a decrease in energy usage but this source of

information could encourage people to save more energy unknowingly. A SWOT analysis of the solutions is shown in Figure 4.6

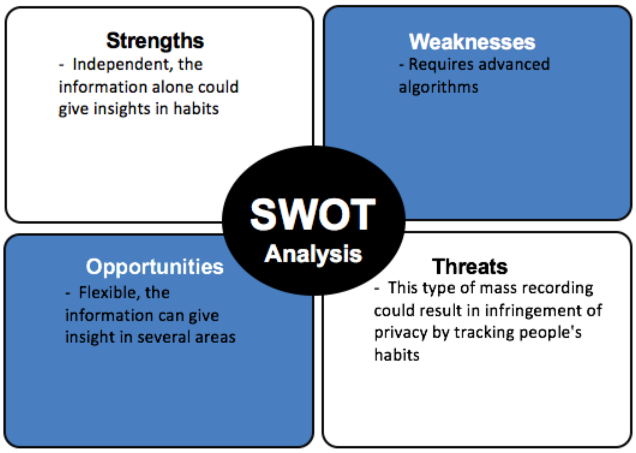


Figure 4.6. SWOT-analysis for Movement outside the apartment.

4.7 Consumption

What is measured?
Information from credit card swipes is stored every time you swipe your card when buying something. Not exactly what you buy, but how often you use the card and where you use it.

Background
By collecting data of what your consumption behaviors look like, unnecessary consumption could be found. Excessive consumption of food, cloths and products over all leads to unnecessary use of resources and CO2 emission. Overconsumption must decrease to meet the future challenges of a sustainable society and one way of doing this is to make the users aware of their behavior.

Technology
Algorithms that categorize purchases, stories among others.

Analysis
By gathering this data and chart the consumption, divide the information into categories and present the consumption patterns for the user, the user could become aware of unnecessary consumption. The data could be compared with waste data to compare patterns over a longer period of time. As well as compare the consumption patterns between different households to meet set consumption goals. These data could be used together with standardized grocery shopping lists to minimize unnecessary consumption and expenses.

Security and privacy

This data could give great insights in people's habits and consumption habits and be used for target marketing and other services.

Discussion and motivations of the ranking of the criteria

The data alone could be used to track consumption behaviors which leads to a high independency but other data sources could be used to get the bigger picture. The flexibility of this data is low because the information could only be used to track behaviors linked to consumption. The energy savings potential is rather high but mostly in a long term context, since it requires behaviours to change. There are similar applications and banking services on the market that categorize purchases but from a household economy perspective. A SWOT analysis of the solutions is shown in Figure 4.7

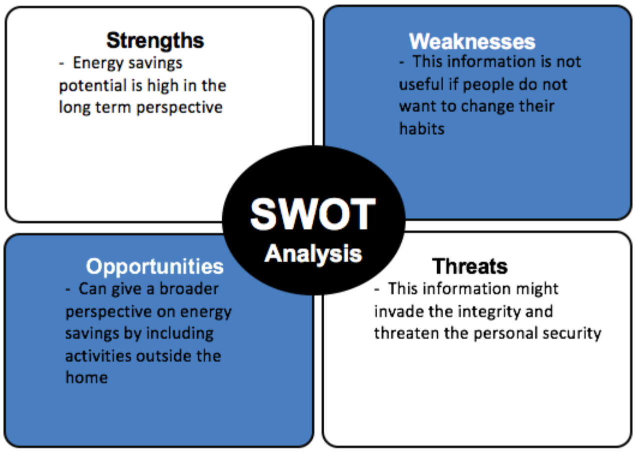


Figure 4.7. SWOT-analysis for Consumption.

4.8 Social data

What is measured?

Social big data is gathered from Google searches, Facebook and instagram likes and updates, Tweets, Spotify usage, YouTube et cetera. Codewords are found that the user use that are connected to behaviors.

Background

As mentioned earlier in the report Facebook knows you better than your friends and family. By collecting and analyzing social data health, moods and interests could be charted.

Technology

There are several tools for analysing social data.

Analysis

By collecting social big data the behavior and habits of the residents could be analyzed and conclusions of what people like and like to do could be found. With this data social communities in a building or block could be developed. Social communities and networks increase social health, collaboration which facilitates carpooling, shared tools and appliances. These applications could decrease unnecessary consumption and emissions of CO2. When people feel like they are a part of a bigger context it might be easier to see that efforts of saving energy will have an effect. Analyzes of this data can be one part of health analysis and alarms could be given if something seems to be wrong.

Security and privacy

By tracking a persons social media habits great insights in people's lives could be given. Emotions, habits, relations, among others could be charted and which would invade the integrity.

Discussion and motivations of the ranking of the criteria

Analysis from this data alone could give insights in social behavior which leads to a high ranking in independency. Furthermore the data could be compared together with other information such as consumption patterns to give an other picture. The information could only be used to track behaviors and indirectly decrease unnecessary consumption or emissions. A SWOT analysis of the solutions is shown in Figure 4.8

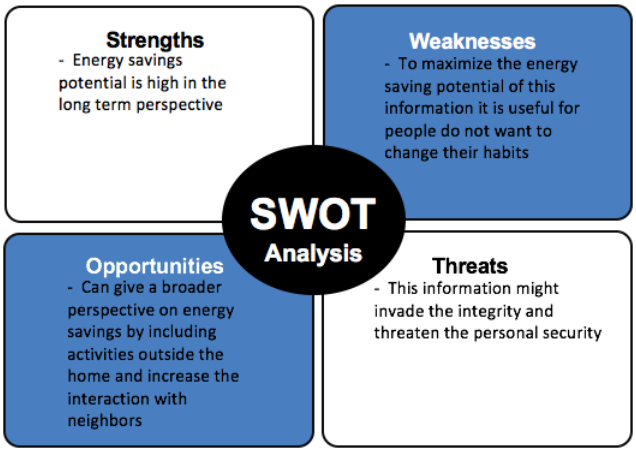


Figure 4.8. SWOT-analysis for Social data.

4.9 Summary and further analysis

The purposed solutions for getting insights into energy and resource usage in the Live-in Lab include big data from single applicants, the infrastructure in a apartment and from the everyday life of the residents. Some of these solutions can be combined, as seen in Figure 4.9, to generate even more insight. Examples of insights that can be found are listed below.

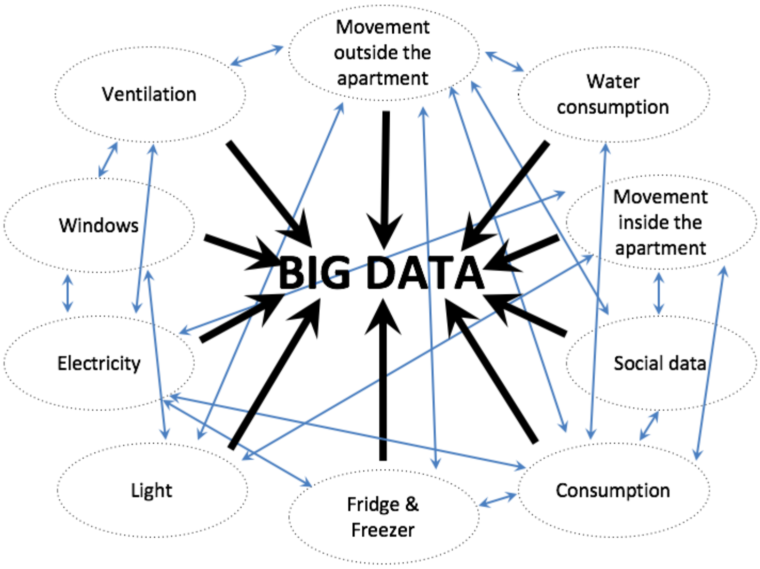


Figure 4.9. Relations between different solutions which can lead to further insights.

Patterns between electricity consumption and ventilation usage can be used to find relations between how for example the heat generated by electronic devices makes the ventilation system work harder to get rid of the heat.

Patterns between the total water consumption and consumption patterns related to for example restaurant visits et cetera can be used to inform the resident about their total water consumption. Just because the the total water consumption has decreased in the home does not indicate that the resident has decreased its total water consumption in life. To make the residents aware of their behaviour in life will increase the awareness of their ecological footprint. The same relations can be found by studying the patterns between electricity consumption and consumption. This is interesting to investigate to find the total ecological footprint of the resident.

How will open windows affect the electricity consumption, ventilation and heat systems. Compare the patterns. Open windows will make the ventilation and heat system work less effective. Open windows will affect the indoor temperature which will have an impact on the freezer and fridge, this might increase their electricity consumption.

Movements outside the apartment can manage the ventilation and light. If the GPS function in the resident's smartphone is used, algorithms can make the ventilation and light turn on when the resident is on her or his way home, and turn them off when the resident is leaving home. This can also adjust the heating of water, it is unnecessary to have hot water ready in the tank if no one is at home using it. The data that shows the patterns of the residents habits can be stored to set schedules.

Patterns of movements inside the apartment can be used to design future homes to where activities are taking place in the home and where we spend most of our time. The natural light can be used as much as possible by studying the patterns of when and where lamps are turned on and by placing the windows where people spend most of their time. It can also be used to study where the ventilation is needed the most.

By analyzing the consumptions patterns and chart the purchases these can be combined with information of the status of the fridge and freezer. The data of the purchases and data of the fridge and freezer can together be analyzed and you can be alerted if you are out of daily groceries.

Patterns of movements outside the apartment together with data from social data and consumption can be used to locate where you do your grocery shopping, work, go to school and perform other activities. This information can be used to arrange shared transportation, as bikes and carpooling.

If the windows are smart there is important for the windows to communicate with the heat system and the lamps to get a comfortable temperature and level of light without using too much energy.

Real time data from movement sensors and movement patterns can be used together with data from unused electricity to turn of appliances and stand-by to minimize electricity usage. For example the TV do not need to be on if no one is watching or the stand by do not need to be on if no one is home.

Chapter 5

Discussion and Conclusions

This chapter discuss the solutions as well as some further subjects that is related to getting insights into energy and resource usage with big data. Furthermore the conclusions are presented.

5.1 Ethics

With technology constantly surrounding us people are used to live under surveillance with sensors and CCTV cameras in public areas to name a few, but to be controlled at home is something else. With a world led by statistics and algorithms that now is moving into our private sphere questions about ethics arise. What happens if something goes wrong, who is the person in charge and what is the limit of interference you can make with big data, is it OK to combine all kinds of data streams to find what you look for? With big data from several sources, and the constant development of algorithms and technology, the limit of what information that is possible to find constantly stretches. It can for example be possible to identify someone, find someones location and get insight in real time or near real time. [Mandy Chessell, 2014]. When collecting big data there is a ethical awareness framework that can be used which was developed by the UK and Ireland Technical Consultancy Group (TCG), some examples are mentioned below.

Context – What was the original object for collecting the data? Is it used for some other purpose now?
Consent & Choice – What choices are given to the residents? Are they aware of that they are making a choice?
Reasonable – Are the found relationships between different kinds of data reasonable for the application it is used for?
Owned – Who is the owner of the information that is the result of the collected data? What are the owners responsible for?
Considered – What consequences comes with the collection of data and the analysis?

Accountable – What happens in case of a mistake? How are the mistakes found and repaired?[Mandy Chessell, 2014]

Laws and regulations guide and defines what data that is acceptable to collect and what is not. But with the constant developing technology the gap between what is possible to do and what is legally to do is constantly getting bigger. Information that are sensitive and personal must be handled carefully. When collecting information of great range an estimation is done and aspects as intention, context, the risk for the information to be spread to a third part as well as what the information is going to be used for should be considered [Datainspektionen, 2013]. It is important to remember that there are humans that ask the questions, interpret the answers and results can be found that meet what they are looking for and be adjusted to their criteria.

In Live-in Lab the context and the conditions are a bit different and some difficult questions are already answered. The project is a research project and the collected data and information is owned by KTH but otherwise ownership of information is an important question. Is the information own by the resident, the property owner or the company collecting the data to name a few. Regardless of who is owning the data it is always important to be reminded of what the residents in this case signed up for. Under what terms did they agree on sharing data from their life? What could happen along the way that could violate these agreements?

5.2 Sharing data with a third party

With all the data collected great value can be made. By sharing this data research can be done and services and products can be developed. Utility companies might be interested in getting information about how people use the electricity to be able to develop services that can for example make the energy demand more even during the day.

The data that comes from separate devices such as the toilet, fridge and freezer can be used to develop these. Data from the infrastructure can be used to develop the design of buildings and apartments, but it can also be used to develop specific products. Water consumption data can be used to get better insight in how a shower or tap is used. It can also be used to study how the plumbing system could be developed. With all the collected data an application can be developed that informs the user of the total ecological footprint, by summing up the resources and energy used in the home, consumption and transportation. The data about how people travel in their everyday life can be turned into information about suitable carpooling communities in a neighborhood. When deciding what data that should be collected and shared there is an option to connect the collected data to personal information about the resident, e.g. gender, age, ethnicity et cetera. This makes the data more sensitive. The other way of doing it is to just collect the data from the activity without any personal information, or to anonymize the data before sharing it.

5.3 Discussion of solutions

In this part of the report some general subjects are discussed and important aspects are considered. How could this collected data contribute to a more efficient home and which data is the most interesting to develop and integrate into future homes? Furthermore, which data could contribute to a more energy and resource efficient construction of buildings. Discussion of each solution can be found in chapter 4.

One of the set goals for this report was to discuss the work with one of the stakeholders of Live-in Lab. For this Schneider Electric was chosen to give a wider perspective of the research of big data in Live-in Lab. Three main aspects were discussed during the meeting:
- Stakeholders and possible third parties interested in Live-in Lab
- What solutions that are possible to combine
- Functioning systems

It is important to make sure that the system of technology is as uniform as possible, as well as separate what is *nice to have* versus *need to have*. If the system is optimized and the analysis of the collected data are made sure to give maximal insight the system can contain less sensors and data streams, and therefor be easier to maintain, store, and so on. To have a simple system of technology will also facilitate in case there is some problem or if something is broken. As the preconditions look like today only the resident have access to the apartment. What happens if something goes wrong? Should the operating manager or property owner have access to the apartments and the measurement tools? The costs of maintaining the system need to be considered since they are proportional to the size and number of subsystems.

One of the objectives of this report was to decide how often measurements are supposed to be collected. For a researcher it is desired to collect as much data as possible while the one responsible for the costs need to consider the costs of storing the data. If every apartment contains several subsystems of sensors that will collect the data every other second or minute the amounts of data will be huge. It would therefore be optimal to make the sensors make the measurements only when something has changed, e.g the temperature of the water.

Before making decisions of what to measure it would be interesting to know more about what analysis that have potential of saving most energy, or what would make the home run as automatically as possible. The future work should aim to find solutions that make the behaviour of the resident be as unimportant as possible. Even if the resident waste energy it would be desired to make that not matter, by for example re-using energy.

This report has resulted in eleven solutions of what could be measured in a home. Already existing solutions have not been considered and the innovative aspect has been prioritized. As discussed earlier the important thing to have in mind is how to combine a few solutions to obtain maximal insights. With that in mind a grading system was conducted and the solutions were weighted. The result can be seen in Figure 3.3. As this figure shows the best solutions to measure are;
- Ventilation through windows
- Water consumption
- Light
- Movements inside and outside the apartment

These solutions are according to the ranking the most useful data to collect in a home, and as mentioned in section 2.2 it has been estimated that the energy usage in residences can be reduced by 20% by changing behaviours and habits. If these five solutions are combined the sensors and data streams could be minimized as well as the efficiency could be maximized. Systems of products and services can be developed that will make a great impact on the energy usage of the residents since these solutions cover such a big area. In Figure 4.9 ways of combining data can be found.

The radar chart seen in Figure 5.1 shows the four highest ranked solutions named before and the other high ranked as well as the criteria for each solution. It makes it easier to compare the qualities of the highest ranked solutions and gives an overview. The different criteria are not weighted in this diagram. Movements outside the apartment is not visible since it has the same ranking as Movements inside the apartment. The same regards Consumption and Social data.

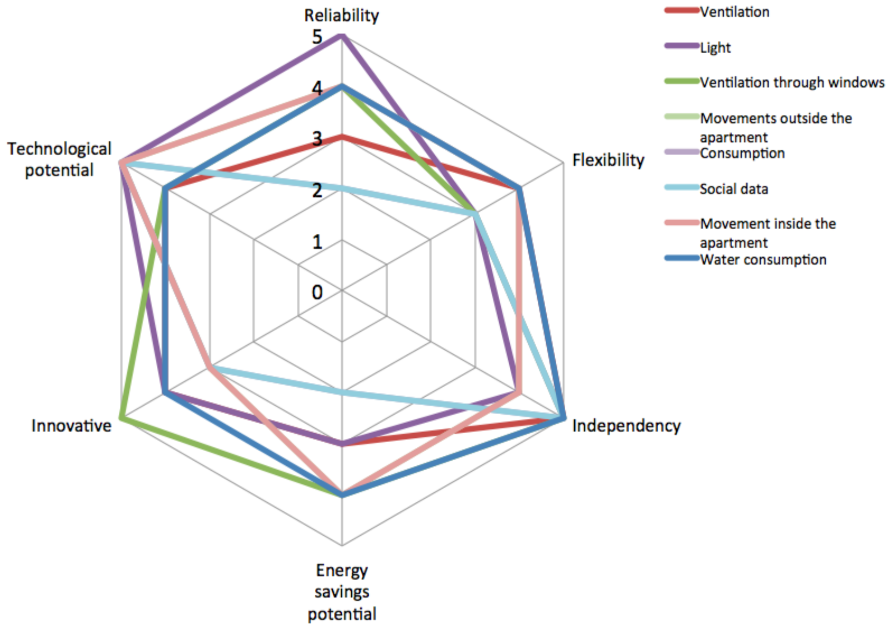


Figure 5.1. Diagram of top rated solutions

The presented solutions are from different kind of levels, some are applicable to products and others to infrastructure. Whether the data should be given back to the end user or not depend on the information. Water consumption, Ventilation, Ventilation through windows, and Flushing the toilet are solutions that are more important to be efficient without any involvement of the resident. These functions that are measured should save energy and resources by them selves without changing the residents behavior.

Information from Movement inside the apartment and Movements outside the apartment are not interesting without any other sources of data or without charting long-term habits. Furthermore, this information is in general not interesting to giveback to the end user without any additional information from an energy perspective. Additional information could be information from the ventilation system or the level of light in the room.

Information from Consumption and Social data should be given back to the end user to change habits. This could be helped by facilitate change of habits but unlike most of the other solutions the responsibility lies with the residents and not the construction of the infrastructure or building.

5.4 Conclusions

The different parts of big data and energy usage in the home have been investigated, such as IoT, social data, Smart cities, living labs and different technologies that can be used to collect data with or that are now used in homes. The purposed solutions will give insights in the energy and resource usage in a home at several levels, and they use other types of data than "traditional enegry data" that will add value. Big data from Water consumption, Ventilation, Movements inside the apartment and Light can be analyzed and give insights in how the infrastructure and design of the home can be developed. The data from Flushing the toilet, Ventilation through windows, Water consumption and Fridge and freezer can be used to develop these specific products. Movements outside the apartment, Consumption and Social data can be used to analyse how the residents use energy and resources outside the home and give valuable information about e.g how neighbors can share cars or make use of similar habits. When people feel like they are a part of a bigger context it might be easier to see that efforts of saving energy will have an effect. When analysing combinations of solutions the utility and insight is maximized.

It would be desired to find a system of solutions that are easy to combine to get maximal insight, instead of having a lot of isolated solutions. This report present eleven possible solution but highlight four solutions that would make home more energy and resource efficient. By using and combining fewer solutions the maintaining costs will be kept low and the system would be optimized.

The data can be useful for several third parties. Utilities, product developers, architects, carpool-organisations and app developers. When sharing the data it is important to consider ethics and security. Some of the data might only be suitable to share if it is anonymized.

5.5 Future work

The SWOT-analysis of every solution can be used to find out what needs to be developed. The strengths and opportunities need to be retained, while the threats and weaknesses need to be analyzed to find possible solutions. All solutions have been ranked, the ones with the highest score are suitable to start developing, the solutions with lower scores need more work or will not contribute enough to the Live-in Lab. Figure 5.1 can be used to compare the qualities of the different solutions, it can be helpful to make sure that the purposed solutions have a variety of qualities. It would be interesting to know more about what analysis that will save the most energy. There are a lot of available living labs that can be investigated to be able to learn from and to find inspiration.

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Appendix A

Solutions draft 1

Nr	Where/ What	Product	What is measured	Resource usage	Technology	Aim/ background	Analysis / Solutions	How often should data be collected?
1	Bathroom	Toilet				health analysis		
2	Bathroom	Toilet	Weight or volume		Scale sensor	The big button is most often used to flush the toilet, even when it is not needed	How can the toilet adjust the water consumption itself to minimize water consumption	
3	Bathroom	Toilet	Chemicals			Measure amount of chemicals in the wastewater	How does a home contribute to the contamination of nature.	
4	Decision making						By analyzing historical data decisions can be made after earlier behaivor	
5	General electricity usage			Electricity	Smart meter		Chart the electricity usage by sec and find correlations between historical data of air quality/ amount of people at home/ activity/ movement..., to find patterns and behaviors	
6	General water consumption			Water	Sensor		Chart the water usage by sec and find correlations between electricity/ air quality/ electricity usage/ amount of people at home/ activity to find patterns and behaviors.	
7	Kitchen	Food	Connected products/ standard placement of products		Sensor/recognition technology	What's left concerning food	Develop services that provide standard products at regular basis/create lists for grocery shopping/prevent food from getting old/connect to calendar	
8	Kitchen	Fridge/freezer	Electricity consumption	Electricity	Electricity meter	Measure electricity consumption	Find correlations between how often the door is open/how full the fridge is and electricity consumption	
9	Kitchen	Fridge/freezer	Time		On/off switches	How long/often is the fridge/freezer door opened	Find correlations between how often/long time the door is open and electricity consumption	Every 0.5 s when the door is opened
10	Kitchen	Fridge/freezer	Temperature difference between inside and outside the fridge/freezer		Thermometer	Energy is lost when the door is opened. Depending on the temperature difference.	Find correlations between the freezer's electricity consumption and the temperature difference	Once a day.
11	Kitchen	Fridge/freezer	How full the fridge is		Sensor	Full freezer/fridge consumes less electricity	Find correlations between electricity usage and how full the fridge/freezer is	
12	Kitchen	Fridge	Dust	Electricity		Make sure the fridge/freezer is effective	How often does it need cleaning	Every other week.
13	General water consumption	Sink	Temperature of water consumption	Heat	WSN	Energy is lost	Can this energy go back and be used	
14	Kitchen	Stove	Temperature, air humidity		WSN	The stove is set at max even if the water is cooking etc. Self regulated, detects when the food is done	Find correlations between the temperature of the food/ air around and the cooked food so the stove does not need to be on for to long and electricity consumption could decrease	
15	Kitchen	Kitchen fan	Humidity		Humidity sensor, WSN	The fan is often set at max even when not needed	Find correlations between air quality and fan usage. Is the fan used more than needed and letting heat out?	Every two second when the fan is used.

Nr	Where/ What	Product	What is measured	Resource usage	Technology	Aim/ background	Analysis / Solutions	How often should data be collected?
16	Kitchen	Dishwasher		Electricity, water	Smart plug, water meter		Compare water consumption with the ones who does not have dishwasher	
17	Kitchen	Microwave		Electricity	Smart plug		Find correlations between electricity usage between the ones who uses the microwave or stove more than the other	
18	Kitchen	Kettle		Electricity	Smart plug		Compare with the ones who cook water on the stove	
19	Kitchen	Coffeemaker		Electricity	Smart plug			
20	Light		Movements		Sensors	Light that turn on after movements, synchronized with level of light (lux)	The light is controlled by movement sensors and by light sensors and only turned on if people is in the room or if the light is lower than the set limit	
21	Light		Movements		Impact sensors	Collect information about how people move	By using movement to detect how people move in the apartment and what they do, homes can be designed after activity and optimize usage of natural light	
22	Living area		Unused electricity	Electricity	RFID/plug	Standby consumes unused electricity	How much is standby? Find ways to shut down standby	
23	Living area	TV	Movements in front of the TV		Motion sensor	How often is the TV on when no one is watching	How much electricity is wasted	
24	Other	Movements	People's movement		Wristband, UPnP, face recognition, intelligent human-machine interface, and family database technologies	People move differently --> who is who --> habits	Adjust ventilation/light/heat, log patterns of consumption/usage. Set schemes/standards for water use in shower, toilet	
25	Other		Movements/When/how long is the apartment unoccupied		Impact sensors	During unoccupied times the apartment can save energy and electricity	During these times there is no/less need of ventilation/heat/hot water	
26	Other		Sound		WSN	The amount of construction material can might be reduced and reorganized. Where is it the most noise --> Design homes	By collecting data of the noise in the apartment, homes can be designed to optimize a good level of noise	
27	Other		Touch					
28	Other		Movements in the common area in the building			who is using the facilities and when, how much	Who is washing, how much, how oftern	
29	Other			Electricity	RFID/plug	Measure electricity used by every device, When is electricity used		
30	Other	Sleep	Register sleep patterns, record when the people go to sleep and wakes up			The heating and lamps are not needed as much		
31	Other	Purchases	Register card swipes, how much, when and where			Decrease consumption		
32	Ventelation		Condensation, humidity and mold		Sensor	Air quality	Measure this in different parts of the home to find correlations between air quality and architecture or placement of electronics	

Nr	Where/ What	Product	What is measured	Resource usage	Technology	Aim/ background	Analysis / Solutions	How often should data be collected?
33	Other		Temperature in several places		Thermometer/WSN	Find out if the temperature differ i different parts of the home	Find correlations between temperature and architecture or placement of electronics	
34	Other	Callendar					By collecting data from your callender, both historical and present, your patterns can be detected and the home can adjust itself after your schedule (heath, food, ventilation..)	
35	Other	Transportation	Location				By collecting data from traffic, such as how full the bus is and traffic situations and compare them to your callendar or usall behaivor	
36	Transportation		Movements outside the home		GPS, 5G	Shared transport	By tracking peoples movement and habits outside, not only public transportation can evolve but also possible solutions for shared cars/ bikes	
37	Ventilation	Ventilation	Air quality		Air/humidity sensor/WSN	Compared to the amount of people/ temperature	Are the ventilation used more then needed.	
38	Ventilation	Window	Time		On/off switches	How long/ when/ where are the windows opened	Set schemes so they close automatically	
39	Ventilation	Window	Temperature difference indoor outdoor		Temperature sensor	How much energy is lost	How much energy is lost. How is the heating affected.	
40	Warnings					Warn when something unexpected happened, ex water leak, opened window, stove is on		
41	Waste	recycling	How much waste, when, who, what..		RFID keys, weight system			
42	Water	Water tap/Shower nozzle	Water consumption	Water		Total consumption	Find correlations between total consumption and unused water	
43	Water	Water	Water consumption	Water	Temperature sensor	How long/how much before the water has adjusted to the desired temperature	How much water is unused	
44	Water	Water tap	Time of connected sensors	Water	Sensor	Measure amount of unused water (=time of unconnected sensors)	How much water is unused	
45	Weather	Weather data	Correlations between weather and heat usage			Correlations between weather and heat usage		
46	Weather		Wind, humidity, rain, radiation					

Appendix B

Ranking

Solution:		1	2	3	4	5	6	7	8	9	10	11	Ideal:
		Water consu	Ventilation	Ventilation through windows	Light	Flushing the toilet	Fridge and freezer	Unnecessary usage of electricity	Movement inside the apartment	Movements outside the apartment	Consumptio	Social data	
Criteria	**Rank**												
Reliability	2	4	3	4	5	2	4	4	4	4	2	2	5
Flexibility	1	4	4	3	3	5	2	2	4	4	3	3	5
Independency	1	5	5	5	4	5	4	5	4	4	5	5	5
Energy savings potenti	3	4	3	4	3	2	2	2	4	4	2	2	5
Innovative	3	4	4	5	4	5	3	3	3	3	3	3	5
Technological potential	3	4	4	4	5	2	4	2	5	5	5	5	5
	Tot:	53	48	55	53	41	41	36	52	52	42	42	65
		2		1	2				3	3			

Rank:
1 = Not so important
2 = Important
3 = Very important

Grade:
1 = Bad
2 =
3 = Good
4 =
5 = Excellent

The ranking is motivated in the Criteria part of every solution.

Appendix C

Solution 4-6

Flushing the toilet

What is measured?
The volume changes of the water in the toilet when someone is using it and which button that is used, these data is then stored.

Background
This solution aims to find out if more water than needed is used when flushing the toilet. Maybe the big button is most often used to flush the toilet, even when it is not needed.

Technology
A water level logger can be used to measure the change of the water level and send the data to adjust the amount of water used to flush. For this it is necessary to store the data of the total volume change from every flush session. A switch is used to sense which button that is used every time.

Analysis
The aim is to investigate how much water that is wasted when flushing the toilet. This is made possible by comparing the volume change of the water to the amount of water that is used depending on which button that is used. If the toilet can know how much water that is needed to flush it can adjust the water consumption itself to minimize water consumption. If storing this data it can be used as one of several parts when analyzing the health of the residents, since the change of volume tells what the resident is doing in the toilet.

Motivations of the ranking of the criterias
This solution will not contribute to any dramatic savings of energy, partly because the water used is cold, but it is an innovative idea that will save some water in total since there is a toilet in every home. The data can be stored to develop toilets to be more smart, or it can be used to analyze the health. This gives the solution some flexibility aspects. The measuring is not technologically advanced but the unclear amount of paper can make it more difficult to estimate the amount of water needed to flush, since the paper does not sink into the water that quickly, this can make the data unreliable. Another barrier is that it is difficult to install technology in a toilet since it is such a standardized applicant. The technology used is simple. A SWOT-analysis of the solutions is shown in Figure a

Security and privacy
This data will not give any sensitive information regarding security. It will give personal information about habits and patterns regarding the everyday life of the residents. It might invade the integrity and should only be used for research.

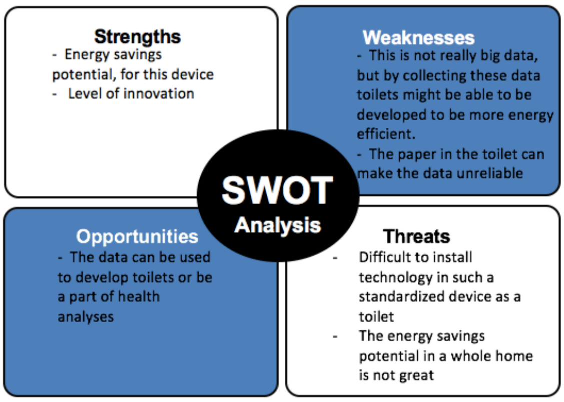


Figure a. SWOT-analysis for Flushing the toilet.

Fridge and freezer

What is measured?
Electricity consumption of the freezer and fridge is measured. For how long the doors are open and how often, when picking out groceries. The temperature difference between inside and outside the device. How full the freezer and fridge is and patterns of where food is placed.

Background
Every time the door to the freezer or fridge opens warm air is let in making the device to work harder and therefore consume more electricity. In addition a full fridge and freezer keeps a more stable temperature since there are less air that can be let out when the door is open.

Technology
The electricity consumption can be measured with a smart plug, and be transmitted every 30 second, according to the available technology. The data can then be sent to a central, for example a smart phone, where the history of the usage is stored and patterns can be studied.

The temperature can be measured and stored with a smart thermometer, the data can be saved in the same way as for the smart plug. The temperature is interesting to measure as often as possible when the door is opened and some time after closing the door. The temperature outside the device is interesting to measure less often, every 10 minutes, since it does not change fast.
The patterns of how the door are opened can be charted by using switches on the doors. These recognize which state the door is in, closed or opened.

To recognize patterns of where and how much food is placed in the fridge is a technological barrier.

Analysis
If the total amount of used electricity is stored it can be compared to the patterns of how full the device is and how the doors are opened. Samsung [Samsung] is doing their best to for example increase the times the doors are open by installing cameras inside which shows what groceries you have. The measurement of how the freezer or fridge is affected by where food is placed and how much, the architecture of the devices can be investigated. It might be possible to find ways of adapting the device to the amount of groceries stored in it, so that

when it is not full the design inside is changed so that there are not to much energy that can be wasted in shape of warm air getting in. By finding out if and how the electricity consumption is affected by the temperature of the surrounding air, for example the placement of these devices can be evaluated, or technologies can be developed to protect the device from the surrounding air.

Security and privacy
This data will not give any sensitive information regarding security. It will give personal information about habits and patterns regarding the everyday life of the residents.

Motivations of the ranking of the criterias
There is a technological obstacle to find the patterns for how food is placed, but the other technology is simple, reliable and easy to install. The flexibility is not to good since these data is quite limited to only give insights in the usage of the freezer and fridge. This system is a closed one and is not in need of any other data to be able to make conclusions, the solution is independent. The energy saving potential is quite high since these the fridge and freezer is on all day the year around and consumes about 22% [Energiradgivningen, 2015] of the total electricity. A SWOT-analysis of the solutions is shown in Figure b.

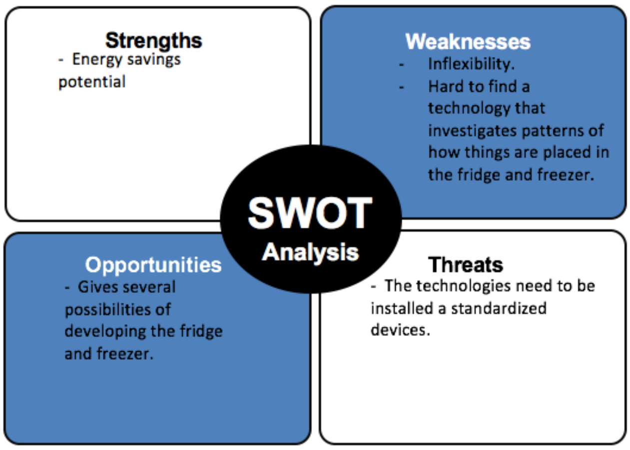


Figure b. SWOT-analysis for Fridge and freezer

Unnecessary usage of electricity

What is measured?
The electricity usage from appliance that are turned off is measured. How much the devices are consuming and when they are on.

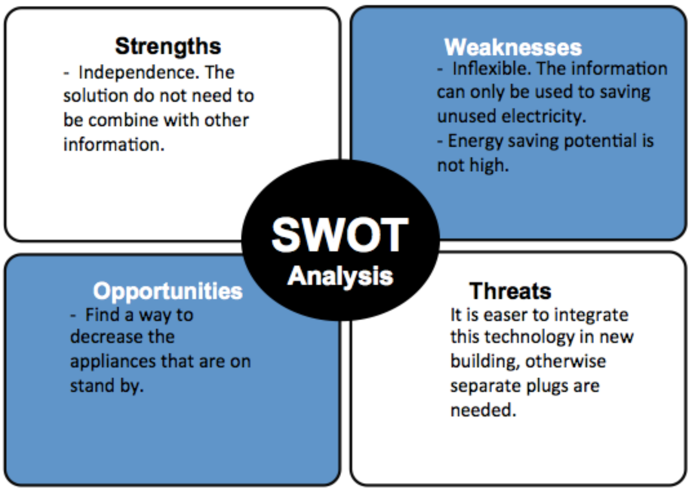
Background
Stand by products as well as cell phone chargers among others increase the total electricity consumption in a home with 10% [John Schueler] The aim with this solution is to decrease the electricity consumption from standby products, by measuring each products consumption of electricity continuously.

Technology
By installing smart plugs where appliances are plugged in to the wall users can get information, through an app, on how much electric power a specific product consumes and for how long it has been on, data can be collected every 30 second.

Analysis
The data can be analyzed to track when appliance are on or on standby, as well as chargers, and ways can be find to decrease unnecessary usage of electricity. The solution can also be used to obtain information of the inhabitants habits linked to use of products as the TV, computers and other devices. Furthermore, the meter can predict if something is out of the ordinary by measure highs and lows and track the common behavior.

Motivations of the ranking of the criterias
The independency is high because it is no need for other information to draw conclusions The flexibility is medium. The solution can be used to turn off products on standby but also track the overall power consumption as well as find out if something is wrong. The savings potential is rather low but steady.
There are similar technologies at the market but in this solution the technology is integrated in each outlet to track the total power intake of the apartments. A SWOT-analysis of the solutions is shown in Figure c.

Security and privacy
This data will not give any sensitive information of regarding security or privacy. The information that can be given is information about how much the inhabitants use different applicants in the home.



Figur c. SWOT-analysis for Unnecessary usage of electricity.

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