UNIVERSITY OF TWENTE.

**Faculty of Electrical Engineering,
Mathematics & Computer Science**

Designing an interactive energy data representation to raise awareness within the UT community

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B.Sc. Thesis
July 2020

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Abstract

One of the main causes of climate change is energy consumption, of which over one-third derives from buildings. Moreover, the behaviour of users has a considerable impact on building energy consumption. The University of Twente's (UT) objective is to reduce its CO_2 footprint by 49% in 2030 compared to 2018. To raise awareness for energy consumption, the Energy Data Platform was set up by the Campus and Facility Management (CFM). This platform displays the data of electricity, gas, heat, water and cooling that is being consumed by the university. However, the platform has not been successful to increase the UT community's awareness of energy consumption. Therefore, in this project an interactive energy data visualisation was developed that enables the UT community to gain insight in their personal contribution to the UT's energy consumption and provides tips on how energy can be saved. The concept was developed according to the requirements of the different stakeholders using an exploratory design approach through several idea generation methods. Research has been done into effective characteristics of energy data representations and applying the Transtheoretical Model of behavioural change. From user testing, it was concluded that the interactive energy data visualisation was found to be appealing, easy to use, understandable by the UT community, and raised awareness for energy consumption at the University of Twente.

Acknowledgements

First of all, I would like to thank my supervisors Richard Bults and Kasia Zalewska for guiding and supporting me throughout this bachelor project; they have helped me think critically and exploratory and helped me stay on the right track. Secondly, I would like to thank the representatives Brechje Marechal and Henk Hobbelink from CFM for their time, enthusiasm, feedback and involvement in this project. On top of that, I would like to thank the participants for taking their precious time to evaluate the prototype. To my family: thank you for always providing your support, honest opinions, and enthusiasm during my bachelor studies at the University of Twente.

Contents

List of Figures

List of Tables

List of acronyms

CFM Campus and Facility Management

EEP Energy Efficiency Plan

LTA Long-Term Agreements

TTM Transtheoretical Model

UT University of Twente

1 Introduction

The main focus of this thesis is to design an energy data representation aimed at raising awareness of energy consumption among the University of Twente community. This representation will be developed for the Campus and Facility Management (CFM), the client of this project. This introduction chapter will firstly provide the context of the problem, then define the challenges of the project and the research question with relative sub-questions, and lastly present an outline of the thesis.

1.1 Context

There is no doubt that climate change is caused by human activity. The scientific consensus that human activity causes global warming has passed 99% [1]. One of the main causes of climate change is energy consumption. From the Global Energy and CO_2 Status Report 2019 [2] was concluded that due to the increasing energy demand, global energy-related CO_2 emissions rose to a record high. As buildings are responsible for over one-third of global energy consumption and nearly 40% of total direct and indirect CO_2 emission, many approaches have been introduced to improve energy efficiency of buildings.

The University of Twente (UT) is committed to sustainability by agreeing to the Long-Term Agreements (LTA) on energy efficiency in the Netherlands. The LTA is a voluntary agreement that is aimed at promoting energy savings in the Netherlands [3]. The UT's objective is to reduce its carbon footprint by 49% in 2030 compared to 2018 and 95% by 2050 [4]. As part of the LTA, every four years an Energy Efficiency Plan (EEP) is formulated. In the EEP, the energetic situation and the savings options of the university are provided. These measures are taken by regulating processes more efficiently by for example using intelligent software when planning transport routes, implementing energy-saving measures like LED lamps and improving work processes such as stimulating video conferences so less travel is required [4].

The behaviour of users has an considerable impact on building energy consumption [5]–[7]. Therefore, the Campus & Facility Management (CFM), which is responsible for managing the sustainability, energy and environmental performance at the UT, has set up an *Energy Data Platform* [8] to give the UT community insight into the amount of energy that is consumed (see figure 1.1). This platform displays the data of electricity, gas, heat, water and cooling that is being consumed by the university. Data can be compared between individual buildings and the time range can be selected. However, the platform has not been successful to increase the community's awareness, raising frustrations at CFM. The community, which involves students, employees, campus residents and visitors, did not know about the existence of the Energy Data Platform, or were not convinced enough by the representation of this data to start thinking more about sustainability and reduce their energy consumption.

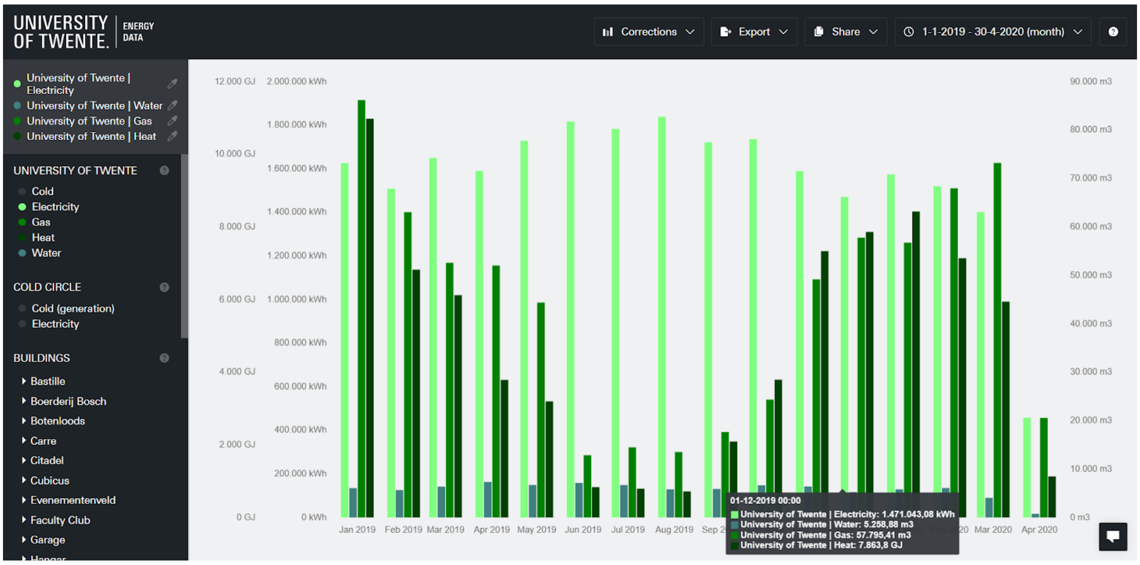


Figure 1.1: Energy Data Platform

1.2 Challenge

The main challenge of this project is to realise an energy data representation such, that it raises awareness within the UT community concerning energy consumption. It should also act as a tool that can be used to motivate users to act more sustainable. This could either be achieved in the form of a data physicalisation or visualisation. Lastly, the data representation should make impact and let the UT community identify with their energy consumption at the university.

The Transtheoretical Model of behavioural change (TTM), which is developed by Prochaska and DiClemente [9] will be applied to this project. This model was originally developed for changing behaviour related to health, but is applicable to this project because it provides a guideline for changing behaviour. With the help of this model, the project is constraint to change the behaviour of the target group to a certain stage of change of the TTM. This will help maintain focus throughout the process of the development of the project.

1.3 Research question

The main research question for this thesis is:

How to represent the University of Twente's energy data to enable UT community identification with the UT's energy consumption?

In order to answer the above question, the following sub-questions will also be answered:

- *How can an energy data representation make impact?*
- *How to apply the Transtheoretical Model to an energy data representation?*

1.4 Outline

Chapter 1 introduces the context and goal of this paper. Chapter 2 provides a background research including a literature review and an overview of the state of the art related to this project. Chapter 3 describes the applied design process as well as the methods and techniques that will be used throughout this design process. In chapter 4 the ideation process is described and in chapter 5, the chosen concept is further specified so the realisation phase can be entered in chapter 6. Finally, the evaluation of the prototype is described in chapter 7 and a conclusion and future recommendations are provided in chapter 8.

2 Background Research

In this chapter, the theory and background information needed for the completion of the thesis will be outlined. This includes a literature review and an exploration of existing work. The sub-questions proposed in section 1.3 are being addressed in this chapter.

2.1 Literature Review

The main goals of this literature review is giving insight into how an energy data representation in combination with the application of the Transtheoretical Model, can be utilised to raise awareness for energy consumption.

One of the approaches in combining data visualisation and sustainability, is the interdisciplinary topic of eco-visualisation. Therefore, this type of data visualisation is being examined as it relates to the aim of this project. First, the term eco-visualisation will be defined. Second, an overview of characteristics of an effective eco-visualisation will be provided. Subsequently, The first three phases of the Transtheoretical Model of change (TTM) are explained and strategies to apply this model to an eco-visualisation will be given that aim to target individual motivations at these stages of behavioural change. Lastly, a conclusion is drawn on how these different characteristics of an eco-visualisation in combination with the implementation of the TTM, can contribute to the effectiveness of a representation of the UT's energy data.

2.1.1 Defining eco-visualisation

To know how an eco-visualisation can be applied to this project, it first needs to be defined. *Eco-visualisation* is a type of data visualisation that focuses on representing energy data in a way to promote sustainable behaviours. *Eco-visualisation* which is described by Holmes [10] as "any kind of interactive device targeted at revealing energy use in order to promote more sustainable behaviours or foster positive attitudes towards sustainable practices" is a relatively new approach to visualise energy data. In another paper by Löfström and Svanaes [11] *eco-visualisation* was described as "the dynamic means of revealing the consequences of resource use in order to promote sustainable behaviour, decision making and/or attitudes." Hidden information becomes visible to the user by combining both artistic and scientific information. Therefore, an eco-visualisation can assist encouraging reducing energy consumption.

A wide range of such eco-visualisations have been proposed and developed. For this literature review, eco-visualisation characteristics have been investigated and the ones that were found most effective and applicable for a representation of the energy data of the University of Twente are described below.

2.1.2 Effective eco-visualisation characteristics

Comparison

In the design of eco-visualisations, a type of comparison is often used to give the users the opportunity to see how their energy behaviour is. Two frequent used types of comparison are historical comparison and normative comparison. Historical comparison is often seen as a necessary component for designing an effective eco-visualisation [12], [13]. When users have the ability to view their previous energy consumption, they can compare it to their current consumption and gain insight into the amount of energy that they have consumed. Moreover, it can provide users with a personal baseline as to what a normal or desirable consumption is [13]. Nevertheless, it was noted that historical comparisons become less effective when the user's performance improves over time [5].

In a survey of 44 papers studying eco-feedback technology in the field of Human-Computer Interaction and twelve papers within environmental psychology [14], was concluded that comparison between others e.g. buildings, households, or individuals is also effective in motivating action. This type of comparison is also known as normative or social comparison. Chen, Lin, Hsieh, *et al.* [15] tested an eco-visualisation represented by a virtual aquarium in a university. According to the energy behaviour of the users, this digital ecosystem would interact by adjusting its visual condition towards a 'good' or 'bad' state. The better the behaviour of the participants, the healthier the aquarium. The visualisation was set up in two neighbouring graduate student offices in order to allow the students to compare their results with each other. From the study was reported that energy consumption had reduced by 10%. Nevertheless, Fischer [5] claims that although normative comparison may stimulate users with a high energy consumption to conserve, it also suggests users with a lower energy consumption that they are performing above average and that they may upgrade a bit. Consequently, these effects are likely to cancel each other out, making normative comparison less effective.

Thus, regarding these papers, both historical and normative comparison could be used to visualise the energy data of the UT by showing previous data and giving up-to-date feedback, and letting users compare with each other. However, to make sure these components are effective, it must be kept in mind that the users attitude towards energy consumption will change when actions are taken. This highly influences the success of the eco-visualisation.

Real-time feedback

Eco-visualisations are also characterised as dynamic data representations. Real-time feedback often concurs with historic comparison and enables the users to anticipate the impact of their energy consumption. In a model set up by Fischer [5] was stated that the more directly after an action feedback is given, the more effective it is. In addition, feedback is most adequate when it is given frequently and over a long period of time because this way, the feedback establishes a direct link between the actions of individuals and their consequences. However, it must be considered that the feedback frequency is bound to system limitations [16]. For example, when the designer wants to provide historical comparison on a daily basis, the system limits the data frequency that can be provided when it is only measured per week.

To conclude, real-time feedback is an important component in the field of eco-visualisation. Without real-time feedback, the user is not reminded frequently enough of his behaviour in order to undertake action. Therefore, feedback must be given frequently, but is also up to the designer's intentions on how frequent this feedback is given.

Measurement units

Energy data can be represented by various units. Displaying direct energy units have proven not to be effective for reducing energy consumption. To illustrate, a frequent used unit for representing energy use, is the kilowatt-hours (kWh). However many people have difficulty understanding scientific units [17]. Moreover, Jain, Taylor, and Culligan [18] examined the effectiveness of direct energy (kWh) feedback versus feedback represented by environmental units (numbers of trees needed to offset CO_2 emissions). Results showed that feedback that was represented by "trees" was more effective, as participants that received this feedback saved more energy than participants that received feedback through kWh. Karjalainen [12] adds that presenting the data by environmental units is more valuable to let users understand the environmental effects of their energy consumption. It was also suggested that it should be presented along with some kind of comparative data to give insight into the relative emission levels.

Thus, in the design of an eco-visualisation, using direct energy units is least preferable. A different measurement unit, such as the number of trees needed to offset CO_2 emissions can be considered to give a better understanding of the data and thus, increasing the effectiveness of the eco-visualisation.

Reward

A reward can be used when a certain goal-setting is being achieved. In an eco-visualisation this is for example a reduction in energy use. This can either be a goal that is determined by a bigger instance, or a goal that arises from the users themselves. Two types of reward that are often mentioned to be effective components for eco-visualisations are monetary and emotional rewards. Monetary rewards include for example displaying the amount of money saved, or direct payments like a coupon. Emotional rewards can be visual rewards, such as a digital aquarium becoming more lively and colourful [15], or social rewards [19] like leaderboards that display energy saving achievements against other users.

Including a type of reward can be utilised to motivate users to change their behaviour, although there is little research evidence that rewards motivate long-term energy savings.

Besides, Wood and Newborough [20] state that it must be ensured that the reward is not the main component and motivational factor that causes a reduction of energy consumption.

Therefore, there is not much proof that a reward could be applicable to stimulate the UT community to reduce their energy consumption, however utilising it in combination with other components is not inconceivable. Furthermore a goal-setting is recommendable to motivate users by showing them what they can improve on.

Aesthetics

The aesthetic appeal of a data visualisation has much influence on the way the audience perceives it. While aesthetics affects usability, it is an important aspect to pay attention to. If an eco-visualisation is not attractive, it limits the interaction, reducing the possibility of receiving feedback on the energy consumption [21]. Elements of the aesthetics of a visualisation include the use of colour, shapes, and the kind of presentation (abstract or artistic). These elements were investigated.

In a large scale visualisation study, 2,070 single-panel visualisations were analysed to determine which visualisation types and attributes are most effective [22]. It was concluded that attributes such as colour and the use of human recognisable objects such as pictograms, enhanced the memorability of a visualisation. In addition, the use of data representatives like circles and round edges, were found to be more effective as people's perceive visualisations much easier when they appear to be more 'natural'. Chart junk, which is a term for unnecessary or confusing visual elements, should be avoided as it can distract the audience from the relevant aspects of the data. Common graphs like bar charts and line graphs were found to be less effective as they did not draw the attention of the audience and were not found to be 'natural'.

Visualisations using colour-coding have been found to be easily understandable and appreciated. An eco-feedback study conducted by Bonino, Corno, and De Russis [17] found that colour-coded eco-feedback provides the optimal information representation, as approximately 72% of the participants responded that this helped them understand how much energy the building consumed. To note, the eco-feedback utilised a traffic-light colour system; red would represent a 'bad' and green 'good' energy consumption status (see figure 2.1). Besides, through this colour-coded information representation, there was an increased engagement and motivation to make changes concerning the participants' energy behaviour.

Figure 2.1: Colour-coded layout of energy visualisation

In a comparative study for designing persuasive systems [23], an iconic and an indexical representation of the amount of idle computer time were developed. The iconic representation displayed the health status of coral reefs and fish (see figure 2.2a). The indexical representation consisted of a bar graph that displayed the daily idle time versus the total up time (see figure 2.2b). Results showed that the iconic representation triggered more awareness and motivation through triggering emotions, and the numerical approach had more an informative and retrospective purpose.

(a) Coralog: an iconic representation

(b) Timelog: an indexical representation

Figure 2.2: Two different representations of daily idle computer time

Therefore, in designing an eco-visualisation for the University of Twente, appropriate use of colour and type of representation should be taken into account. The eco-visualisation should appeal to the users. This can be done by making for example use of a suitable colour-coding system and preferably representing the data in an appealing way such as an iconic representation.

2.1.3 The Transtheoretical Model

As introduced in Chapter 1, the Transtheoretical Model of behavioural change (TTM) developed by Prochaska and DiClemente [9] will be applied to this project. The TTM defines six stages of change that individuals move through: precontemplation, contemplation, preparation, action, maintenance, and termination. The challenge of this project is focused on raising awareness and motivating users to behavioural change towards energy consumption. Therefore, this model can be utilised to direct the users through the precontemplation, contemplation and preparation stage. These are defined the following:

precontemplation
The stage in which people are not (yet) aware of the problem and are not intending to take action in the foreseeable future.

contemplation
The stage in which people are intending to change in the next 6 months. They are more aware of the positive, but also negative effects of changing.

preparation
The stage in which people are intending to take action in the immediate future, usually measured as the next month. Often they have taken some significant action in the past. These people have a plan of action.

2.1.4 Applying the Transtheoretical Model

To change energy behaviour, not only must be focused at the eco-visualisation itself, the target group must be considered as well. While eco-visualisations can be effective, they are limited to a “one-size-fits-all” solution. As He, Greenberg, and Huang [24] claim ”they provide the same feedback to differently motivated individuals, at different stages of readiness, willingness and ableness to change”. Therefore they proposed a motivational framework that addresses individual motivations at different stages of behavioural change in the TTM. For each stage, the motivational goal, and recommendation(s) for how technologies may reach these goals were described.

Precontemplation

In the paper was stated that for individuals who are in the precontemplation stage of change, information should be presented in such way that it ”plants the seed” to make them acknowledge their current energy behaviour is problematic [24]. Through a lack of knowledge of the effect of their behaviour, or willingness to do something about it, precontemplators, as mentioned in the paper, do not consider change. Therefore, three recommendations were given [24]:

1. Show both positive and negative effects of the individual’s current (non-sustainable) energy behaviour. These should be presented in relation to what the individual

values, in a non-biased way. Negative effects can for example be the costs of energy usage or the amount of CO_2 emissions. Positive effects are more engaged with life comfort such as using heating when it is cold, or power to watch television.

2. Refer to a social norm regarding sustainable energy behaviour. Hereby a kind of comparison such as normative comparison can be of use.

3. Provide personalised feedback of various small actions that may help improve the individual's energy behaviour. These come in the form of tips such as unplugging unused appliances, or turning down the heat a little.

A last suggestion is to present the information in moderation as more intensity will often result in a smaller effect in this group [24].

Contemplation

Individuals that are in the contemplation stage of change, have acknowledged the problem but are not yet ready to take action. Therefore, the designer should "tip the balance" in favour of change [24]. In order to achieve this, the designer can [24]:

1. Provide personalised feedback on positive effects of sustainable behaviour and negative effects of non-sustainable behaviour. The positive effects highlight the improvements to the individual's quality of life and the negative effects represent the loss in relation to what the individual values.

2. Remind individuals of their more sustainable attitude by informing them about the expected behaviour corresponding to this attitude and encouraging them to change from an attitude, to a change in sustainable behaviour.

3. Provide encouragement for small actions to encourage larger actions in the future to consume less energy.

4. Set up a community (website) to give the opportunity to read about the experiences of sustainable individuals in their community. Consequently, a social norm is provided that the individual will strive for.

Preparation

Individuals that are in the contemplation stage of change, are ready to take action and often have a plan. In this stage it is important to [24]:

1. Support individuals to set their own goals and ensure that these goals are achievable.

2. Support individuals to develop various methods to achieve these goals. For example providing ways in which water consumption can be reduced like shower a minute less or installing a rainwater tank.

3. Within the community, give individuals the opportunity to connect with people who are in the action or maintenance stage of the TTM to as they are more likely to copy the behaviour of others who have successfully adopted energy actions.

2.1.5 Conclusion

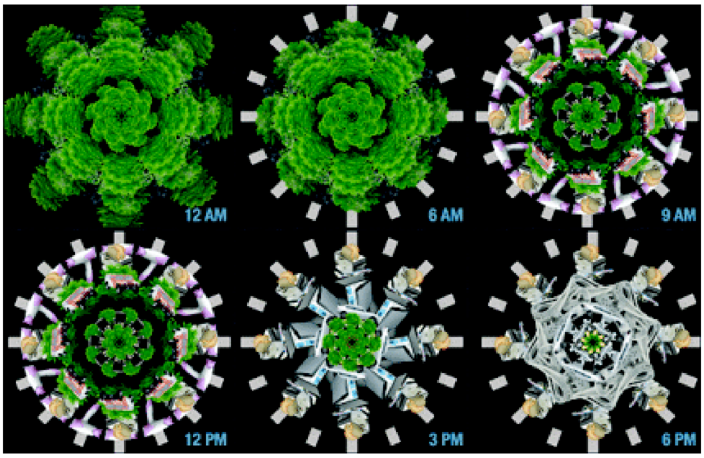
An eco-visualisation in combination with the application of the Transtheoretical Model, can be utilised to raise awareness for energy consumption at the University of Twente. When designing an eco-visualisation, there are different characteristics that can contribute to its effectiveness. Both historical and normative comparison can be used to visualise energy data by showing previous data and letting users compare with each other. Real-time feedback is an important component while users are reminded frequently of their behaviour in order to undertake action. Using direct energy units is not recommended, Using a type of reward is possible, however, it should not be the determining factor. A goal-setting can help as a motivating source to reduce energy consumption. Lastly, appropriate use of colour and type of representation should be taken into account as aesthetics highly influence the usability of the visualisation.

The core of creating an effective eco-visualisation is to integrate these characteristic such that it maximises effectiveness. In combination with the recommendations followed from the motivational framework by He, Greenberg, and Huang [24], it is possible to use these characteristics in such way, that it addresses individuals in different stages of behavioural change. Recommendations that are common for both the precontemplation, contemplation and preparation stage, are that positive and negative effects of the individual's current non-sustainable energy behaviour may be shown, a social norm is involved and tips for small actions regarding energy consumption are given.

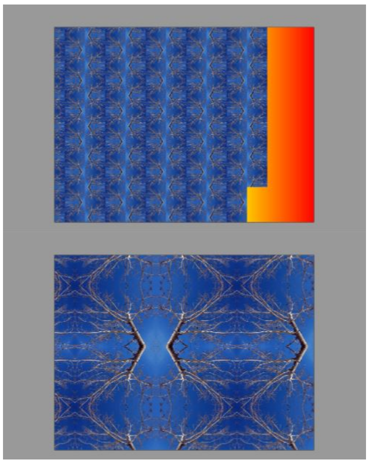
2.2 State of the art

In this section, an analysis in the field of eco-visualisations is provided to give an overview of successful existing work regarding this topic.

One of the first examples of eco-visualisations is *7000 Oaks and Counting* [10], a public artwork that combines art and technology to display an animation of the estimated number of trees needed to offset the CO_2 emitted from the energy consumption process in a university building at NCSA in Urbana, Illinois (USA). Figure 2.3a shows that when the carbon load is high, a greater number of tress is displayed. When the carbon load is low, treas are larger and more detail is visible (see figure 2.3b). The installation encourages people to consider paying an organisation to plant a tree or taking other actions that will help reduce their carbon footprint. The artwork also integrated a subtle sound element. The building's audio was recorded and appeared when there were higher carbon loads. Lower loads replaced the building sounds with bird songs.



(a) Tree animations depending on carbon load



(b) More details visible with lower carbon loads

Figure 2.3: Tree animations of 7000 Oaks and Counting

The *Power Aware Cord* by Static! [25] is a project that started as a joint project between the Swedish Interactive Institute's POWER and RE:FORM studios with the goal to increase consumer awareness of energy usage and promote pro-environmental behaviour. The *Power Aware Cord* is a power cord that makes electricity visible through glowing pulses, flow and intensity of light (see figure 2.4). From an initial user study [26], it was proven that the *Power-Aware Cord* was found to be an intuitive and intriguing tool with an overall positive response from the participants. However, this project mainly aims at creating awareness and does not motivate users to reduce their energy consumption. To illustrate, an increase of glowing effects when more power is consumed, might stimulate users to consume even more energy. Therefore, as the project was still in a prototype phase, the actual usage of the cord is something that is not guaranteed to reduce energy consumption. Nevertheless, recently a Swedish company named *Power Aware Company* further developed the idea and at the moment, it is for sale online [27].

Figure 2.4: Power Aware Cord

Mentioned earlier in section 2.1.2 *Coralog* [23] is an eco-visualisation that displays the amount of idle computer time by means of a digital aquarium with coral reefs and fish. Energy usage was chosen to be represented by coral reefs as they are being destroyed by the rapid increase of the amount of CO_2 dissolved in the ocean and increased sea temperatures. The health conditions of the coral reefs and fish would alter according to the amount of idle computer time of the user (see figure 2.5). The coral reef would become more vibrant and the amount of fish increased when the amount of idle computer time reduced. As this eco-visualisation established an emotional connection between the users and the coral reefs and fish, users had become more aware of their energy consumption and felt motivated to change their behaviour.

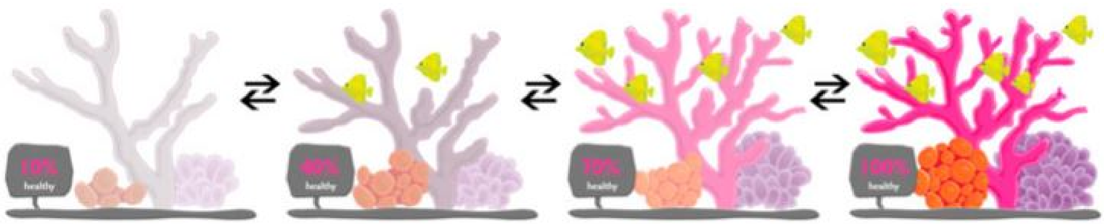


Figure 2.5: Gradual change of health status coral reefs and fish according to the amount of idle computer time

The ECOS project was developed for a large public space in a building at Queensland University of Technology [28]. It visualises the energy usage of the university that before was invisible to the users. By adding playful elements, this eco-visualisation aims at encouraging users to engage and explore energy in a fun way. The different university buildings are displayed across multiple climate zones on a globe as illustrated in figure 2.6. Users are given the ability to change a number of variables such as the internal temperature or humidity of the building and the allocation of sustainable energy sources, and observe the effects of these variables. The visualisation involves gamification as users must successfully balance the use of green technologies with comfortable internal conditions of a single building. Only then the globe will appear clear.

Figure 2.6: Two users interacting with the ECOS project

Inefficiency Machines is an interactive installation created by Royal Arts graduate Meret Vollenweider [29] and is a human-powered installation (see figure 2.7) that makes users aware of the effort necessary to power consumer products, such as a television or hairdryer as they are often taken for granted. For example, one must bounce as fast as possible on a trampoline in order to power a small television. Afterwards, a receipt is printed that states how much energy they generated and is compared to the average energy consumption of the particular device they were attempting to power. By letting users experience how much energy it costs to use daily used products, the designer aimed to make them think twice before leaving a light or television on in a room they are not using.

Figure 2.7: Inefficiency Machines

2.2.1 Analysis

From this state of the art can be concluded that eco-visualisations come in various forms. It may be an interactive installation like the *ECOS project* [28] and *Inefficiency Machines* [29], but can also come in the form of a digital visual representation such as *7000 Oaks and Counting* [10] and *Coralog* [23]. In addition it may come in the form of a product design such as the *Power Aware Cord* [25]. Therefore, there are many possibilities in creating a data representation to make people aware of energy consumption at the University of Twente. The success of these eco-visualisations can be derived from presence of effective characteristics that were analysed in the literature review. To illustrate, all examples have an aesthetically appealing element. To mention a few, *7000 Oaks and Counting* displays a pattern of trees, the *Power Aware Cord* shows a glowing pulse of light and *Coralog* becomes more vibrant when there is a reduction of energy consumption.

Another aspect that makes these state of the art examples effective, is the fact that they are interactive. Information is communicated real-time between the user and the visualisation. Consequently, users will start identifying themselves with the data that is being presented, making it an effective component to enable behavioural change. As the visualisations change over time, users are given the opportunity to compare previous data or data from peers to their current data, making them aware of how much energy they consume and how they are doing compared to the norm that is set. Thus, it may be argued that interaction is consistent with the aforementioned eco-visualisation characteristics, making it an effective component to make people aware of energy consumption.

Lastly, these state of the art works have (unintentionally) implemented some of the recommendations that were provided by He, Greenberg, and Huang [24]. All provide a way of personalised feedback. For example, the *ECOS project* specifically displays the buildings of the university that it is located at. Due to this, users are confronted with the data that is derived from their close surroundings, creating more impact as they will feel more engaged with this data. Another example that brings the data to an even more personal level is *Inefficiency Machines*. The installation directly shows the impact of individual user behaviour. By printing a receipt, users receive a personalised data set that can be used to compare with others and makes them realise what the impact of their behaviour is on energy consumption. However, some of the recommendations that address individual motivations at different stages of behavioural change in the TTM, were absent. To illustrate, in table 2.1 it can be seen that none of the eco-visualisations address the preparation stage. Only the *ECOS project* and *Inefficiency Machines* were found to be addressing users who are in the precontemplation as well as in the contemplation stage in the TTM, as they give users insights into what actions can be taken to reduce energy consumption such as installing solar panels, turning down the heat or leaving the lights off in a room that people are not using.

	Precontemplation	*Contemplation*	*Preparation*
7000 Oaks and Counting	X		
Power Aware Cord	X		
Coralog	X		
ECOS Project	X	X	
Inefficiency Machines	X	X	

Table 2.1: Addressed stages of behavioural change in the TTM

Therefore, there is an opportunity in this project to cover more phases of the TTM than present in most of the state of the art. The state of the art demonstrate effective ways to represent energy data which can act as a source of inspiration, however, applying the TTM in a successful way to this project is the challenge to overcome to raise awareness on energy consumption and influence users to act more sustainable.

3 Methods and Techniques

In this chapter the methods and techniques that will be applied throughout this project are defined. First, the design process is explained. Subsequently, approaches to generate and evaluate creative ideas are presented.

3.1 Design process

The design process that will be applied to this project is the Creative Technology Design Process, which is a design process widely used in the BSc Creative Technology at the University of Twente. This method was developed by Mader and Eggink [30] and consists of four phases: ideation, specification, realisation and evaluation (see figure 3.1). To understand the process this project will undergo, the phases of this process are outlined respectively. In addition, approaches that are used during the process of this project are outlined according to each phase.

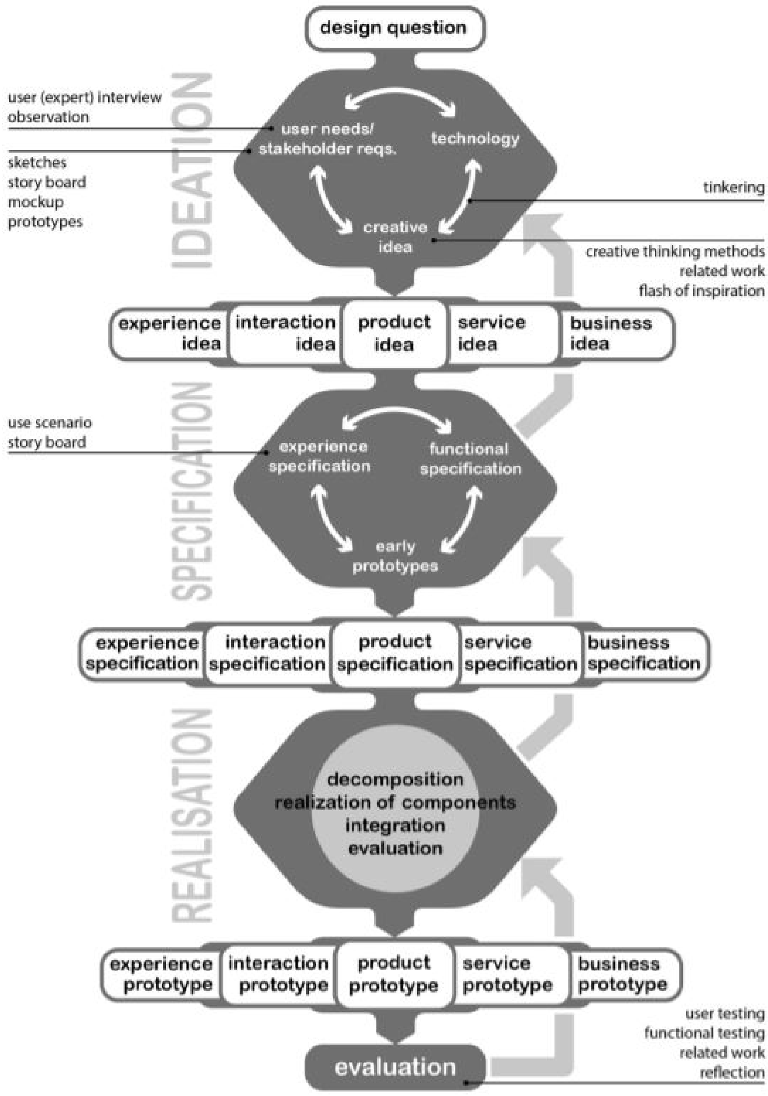


Figure 3.1: Creative Technology design process

3.1.1 Ideation

In the ideation phase, the goal is to generate many creative ideas. To do this, relevant information is collected through literature research, interviews and stakeholder analysis. This information acts as a source of inspiration for brainstorming sessions where ideas are being generated. In addition, the collected information will help set requirements that this project shall meet. First, ideas are generated in the diverging phase. After the process of divergent thinking, ideas are categorised and filtered during the converging phase. With the aid of sketches, storyboards, mock-ups, and/or prototypes, the best ideas can be presented to and discussed with the stakeholders. With the feedback from the stakeholders, a final idea will be chosen and elaborated on in further phases of the design process.

3.1.2 Specification

In the specification phase, one final idea is being developed and the requirements that the project must meet are set up. The chosen idea is being specified through an iterative design process. A final list of requirements is constructed that acts as a guideline during the realisation phase. In the evaluation phase, it will act as a checklist to examine if the final solution aligns with these requirements.

3.1.3 Realisation

Once the latest specifications are gathered, the realisation phase of the project begins. In this phase the actual prototype is built. In this chapter, the different design elements of the prototype are presented and explained.

3.1.4 Evaluation

In the evaluation phase, the prototype will be evaluated through user testing and interviews with the stakeholders. Finally, it is evaluated whether the set requirements in the specification phase have been met.

3.2 Approaches

3.2.1 Stakeholder analysis

To be able to determine the requirements of this project, a stakeholder analysis will be conducted. Stakeholders are individuals or representatives of a group or organisation who are affected by or may affect a certain decision in a project [31]. The stakeholder analysis will be conducted in the ideation phase to estimate what requirements the stakeholders hold, and what they expect from the outcomes of this project. Sharp, Finkelstein, and Galal [31] state that stakeholders can be categorised according to their role in the project. They identify four roles:

1. User: the people, groups or companies who will interact with the product and control it directly.
2. Developer: include analysts, programmers, maintainers, trainers, project managers and so on. While developers should not be considered as stakeholders of the final system, they need to be recognised as stakeholders in the design process.
3. Decision-maker: often managers of the development team, and user and financial managers who are closely involved with the development of the product.
4. Legislator: professional instances such as government agencies, or legal representatives who produce operating guidelines that will affect the development and/or operation of the product.

A stakeholder matrix can help to display the stakeholders alongside a power- and an interest-axis. This way, an overview is given of which stakeholders should be managed closely and which stakeholders should simply be kept up-to-date. This will help to decide on the importance of requirements made by these stakeholders.

3.2.2 Mindmap

There are several ways to organise and document a brainstorm. During an individual brainstorm, a mindmap helps to structure ideas and information and enables the designer to make connections and come up with new ideas. The mindmap may include elements from the research that has been done before as well as new idea elements that arise from this.

3.2.3 Interviews

By conducting interviews, more in-depth knowledge can be gathered from the stakeholders. This can help to get insight into what the stakeholders expect from the outcome of this project and what requirements they set. Interviews can be conducted in three ways [32]:

- Structured: the interviewer asks the interviewee a list of predetermined questions. During the interview, no additional questions are asked.
- Semi-structured: the interviewer has prepared a set of open-ended questions and may ask additional questions inspired by discussions with the interviewee.
- Unstructured: the interviewer has not prepared a specific set of predetermined questions, although the topics that are going to be discussed are thought of beforehand. Therefore, an unstructured interview can be considered more like a spontaneous conversation.

During this project, semi-structured interviews will be conducted. Semi-structured interviews are preferred because the designer wants to discuss specific questions and topics with the interviewee. However, answers to these questions will also provide new insights for further conversation. Therefore, the interviews will be prepared, but the conversation with the interviewee will change according to their answers.

3.2.4 MoSCoW

MoSCoW is a technique used to categorise project requirements [33]. By categorising a set of requirements that a project must, should, could and sometimes won't have, an overview is made of which requirements have priority. Which requirements have priority is based on the positions of the stakeholders. Requirements from stakeholders who are decision-makers for example, have higher priorities than those of stakeholders who are users. In the ideation phase, the MoSCoW method will help to set a first list of preliminary requirements that can help during the converging phase to filter out the ideas that will provide the best solution to the problem. In addition, in the specification phase MoSCoW will be used to generate a specific list of functional- and non-functional requirements of the energy data representation.

Must have
Requirements that are considered must have are prioritised first. These are critical and non-negotiable pieces to let the project function.

Should have
Requirements that are considered should have are important but not crucial for the functioning of the project, but when added, have significant value to the project.

Could have
Requirements that are considered could have are desirable but not necessary.

Won't have
Requirements that are considered won't have will not be implemented in the project. However, they might be of relevance or value in future work, therefore, worth mentioning.

3.2.5 Harris Profile

To make design choices, a Harris Profile can be made to visualise the strengths and weaknesses of design concepts. Per concept a Harris Profile is created which are assessed by several criteria. A simple four-point scale matrix is used -2, -1, +1, and +2. These can be interpreted as: -2 = very bad up until +2 = very good. After assessing each concept, a clear visual overview is given that can quickly be viewed and the design concepts can easily be compared. However, it must be noted that a Harris Profile should not be interpreted as a 'true' representation of the performance of the evaluated design concepts. The assessment of the concepts is typically based on an intuitive prediction of performance, therefore poorly reliable. Nevertheless, a Harris Profile clearly communicates the evaluations that the designer makes and may also help to sharpen the definitions of requirements or improve the chosen design concept.

3.2.6 User scenarios

In the specification phase, a user scenario can help the designer to understand what motivates users when they interact with their product. A user scenario is a short story that shows how a user interacts with the product. It focuses on a user's motivations, and visualises the process by which the user might use a design [34]. By evaluating what experience the energy data representation should offer, new ideas and features can be generated, and requirements can be further refined. Furthermore, a user scenario gives a bit of context to the product that is being developed.

4 Ideation

In this chapter, the ideation process is described. First, due to the involvement of several stakeholders, a stakeholder analysis is performed. By identifying and analysing the stakeholders, more information about the requirements of the energy data representation can be obtained. Second, the divergent and convergent processes of the ideation phases are described. Lastly a description of the preliminary concepts is provided including the process of choosing the final concept.

4.1 Stakeholder identification and analysis

In this project, multiple stakeholders are involved. It is important to identify and analyse these stakeholders since they are necessary to make the project successful. Furthermore, stakeholders determine the functional and non-functional requirements of the energy data representation that is going to be created. In table 4.1 the stakeholders and their roles are identified. In figure 4.1 the stakeholders are positioned in the power-interest matrix.

Stakeholder	**Role**	**Contact**
CFM	decision-maker	Henk Hobbelink & Brechje Marechal
University of Twente	decision-maker	Richard Bults & Kasia Zalewska
UT staff members	user	Stephan Maathuis
UT students	user	Thijn van Weert
UT visitors	user	-
Realised	developer	Diederik Bakker

Table 4.1: Stakeholder identification

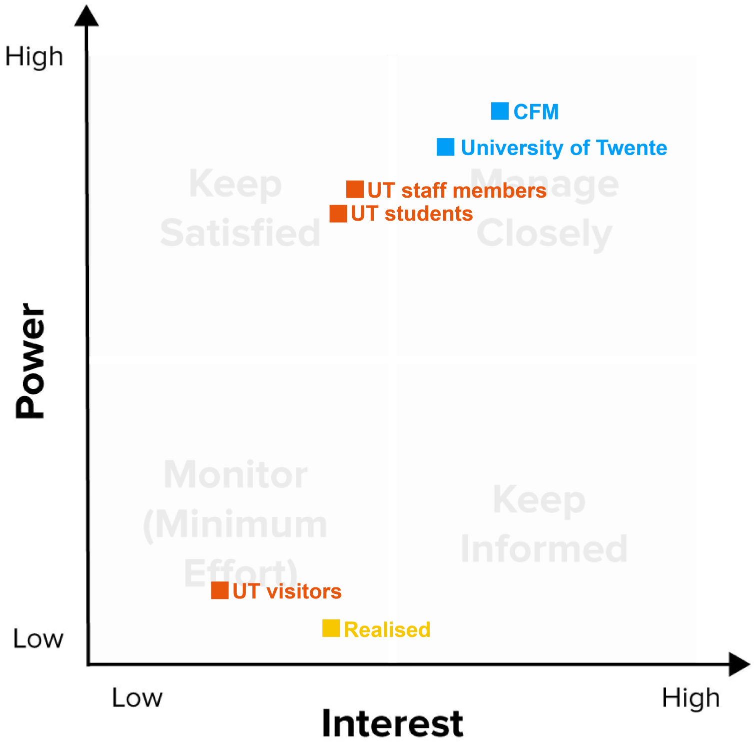


Figure 4.1: Power-interest matrix

4.1.1 CFM

The Campus & Facility Management (CFM) is the client of this project. CFM is represented by Henk Hobbelink, contract manager of CFM, and Brechje Marechal, the policy officer of environment and sustainability at the UT. Since this stakeholder is the client of this project, power and interest are high. Therefore, this stakeholder should be managed closely.

4.1.2 University of Twente

The University of Twente is represented by Richard Bults and Kasia Zalewska. They are the decision-makers in this project as they also have the role of supervisors of this project. Therefore, the power of this stakeholder is relatively high. However, interest is lower than that of CFM since they do not have the frustration of the current lack of energy consumption awareness at the university. It is therefore important to manage them closely as well.

4.1.3 UT community

The UT community consists of students, staff members, and visitors at the University of Twente. These three types of users have a different power-interest ratio, therefore these are described separately.

Staff members

The staff member's power is relatively high since their experience with the energy data representation is the decisive factor in whether the solution is successful or not. For example, when the energy data representation is not understandable by staff members, it will lose part of its effects of raising awareness for energy consumption. Thus, according to the power-interest matrix, they should be kept satisfied, which can mainly be of aid during the evaluation phase of this project when it is user tested and alterations can be made based on the user experiences.

Students

Just like the UT staff members, UT students spend much of their time at university. Therefore, their power and interest level are quite similar. It may be argued that students are less interested in their energy consumption data since they do not have a fixed working space, but overall, the success of the solution also depends on their experience with the energy data representation.

Visitors

In general, UT visitors are not present as often at the University of Twente as the other stakeholders. Nevertheless, they should be considered since they are part of the UT community. The visitors' power is quite low, but their interest is about the same level as UT staff members and students. The energy data representation might be interesting for them since they see what kind of projects are being carried out and the data that is being represented tells something about the university too.

4.1.4 Realised

Realised is a start-up from the University of Twente that developed the Energy Data Platform. Since the envisioned energy data representation will be based on this platform, this start-up is recognised as a stakeholder because they are involved in the project. In addition, while Realised is specialised in energy-related data visualisation, they can be contacted for advice during the design process. Realised is not involved as much as the other stakeholders. Therefore, their power is low, although they might be interested in further developments upon the Energy Data Platform. Due to their distant involvement, they are monitored.

4.2 Interview

From an interview with the client CFM, it became clear that they do not set strict requirements for this project. Therefore, there is a lot of freedom in the development of this project. According to CFM, the most important aspect is that the energy data is represented in such way a that it is easy to understand by the UT community. Personalising the data is therefore an important characteristic to include into the energy data representation. Furthermore, CFM added that the energy data representation should interact in a fun way with the user. From the interview it also became clear that the energy data set that is available, is not a strict requirement for creating an energy data representation. To explain, Henk Hobbelink explicitly mentioned that the Energy Data Platform that was especially set up for people who want to use the data for research purposes.

4.2.1 Preliminary requirements

From the interview with the client CFM and several meetings with supervisors Richard Bults and Kasia Zalewska, more explicit requirements were collected. In table 4.2, a first list of preliminary requirements is demonstrated. The table also shows whether the requirement is a functional or non-functional requirement, and comments are included to give meaning to the category that the requirement is placed in. With the aid of the preliminary requirements, the ideas that were generated in the divergence phase could be compared and see which weigh up best to these requirements.

Category	**Functional (F)/Non-Functional (NF)**	**Comment**
Must have		
1. Display the UT energy data	F	Input of this project
2. Be applicable in multiple contexts (i.e. campus, university building, employee office)	F	Enables UT community identification on multiple levels
3. Provide data relating to its context	F	Enables UT community identification on multiple levels
4. Include a type of comparison (i.e. between buildings, comparison with other energy consuming entities)	F	Gives the users insight into what the actual data means in a relatable and understandable way
5. Use measurement units different from direct energy units (e.g. kWh)	F	Direct energy units are not comprehensible and do not make impact
6. Display data timely	F	There must be an action-cause relation

7. Raise awareness for energy consumption at the UT	NF	This is the main goal of this project
8. Make UT community identify with UT energy data	NF	Results in awareness of own (UT) behaviour
9. Be appealing	NF	Increases the effectiveness of the project since it draws attention
Should have		
10. Consist of only one artefact	NF	One recognisable object that can be placed in multiple context
Could have		
11. Include a type of reward (visuals, goal-setting)	F	Users are not addressed on changing their behaviour, but goal-setting could be used to show the importance of CO_2 reduction goals.
12. Provide tips for small actions (e.g. turn off the lights, turn down the heat)	F	Possible for future work to promote sustainable behaviour
13. Show positive effects of pro-environmental behaviour and negative effects of energy consumption	F	Only necessary for changing behaviour
14. Provide personalised feedback (individual)	F	more focused on behavioural change
15. Change energy consumption behaviour	NF	Goal of this project is to raise awareness, but project could lead to unintended change of behaviour
Won't have		
16. Focus on changing energy consumption behaviour	NF	Focus is on raising awareness of energy consumption

Table 4.2: Preliminary requirements

4.3 Divergence phase

During the individual brainstorm, several methods and techniques which are described in section 3.2, were used to explore creative ideas. To start, the divergence phase was entered to come up with a wide range of solutions.

4.3.1 Mindmap

To start the ideation process, a mindmap was created to get an overview of all the factors that are involved in this project. In addition, the mindmap helps to generate ideas in a set framework. Figure 4.2 illustrates the mindmap including a summary of earlier research as well as an exploration of interactions inspired by the state of the art review. For example, the dark purple branch gives an overview of effective eco-visualisation characteristics that were investigated in the literature review such as including real-time feedback, a reward, a comparison, and paying attention to aesthetics and the use of measurement units. Furthermore, the yellow branch summarises the recommendations that apply to the first three stages of the TTM. An exploration of interactions can be found within the green branch. Other relevant information that must be kept in mind during the brainstorm are listed as well.

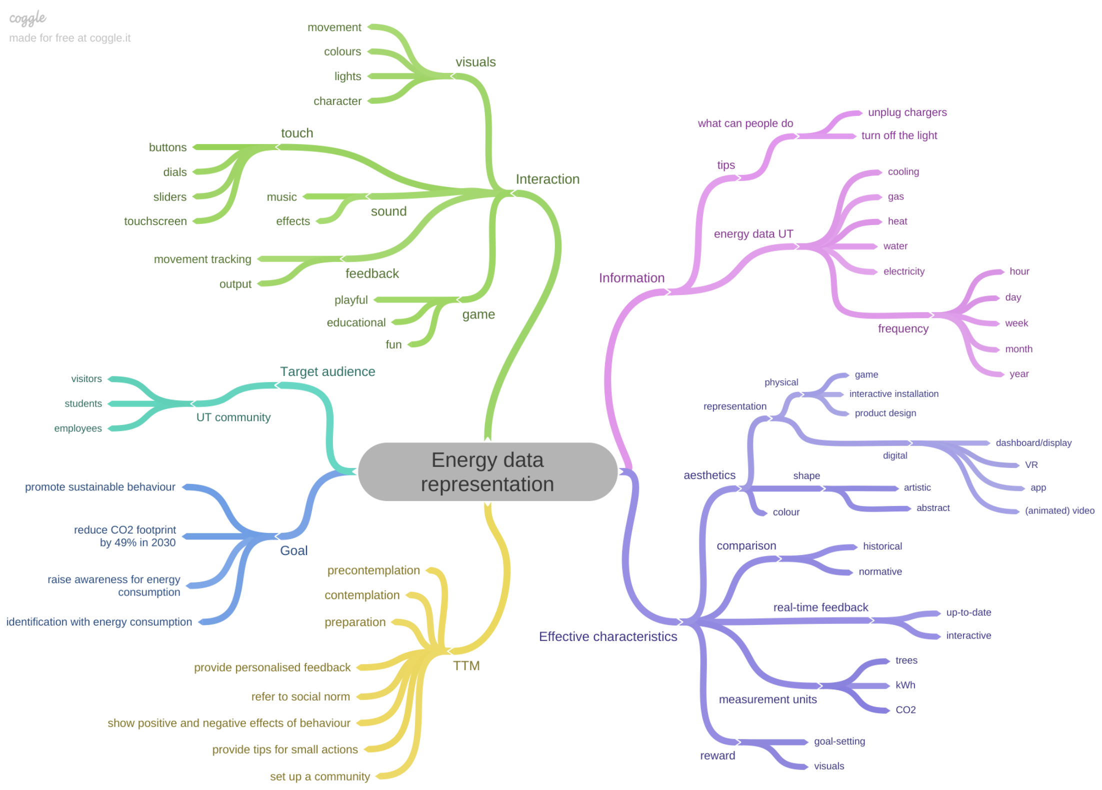


Figure 4.2: Mindmap

4.3.2 Brainstorm

Initially, with inspiration from the mindmap a few ideas were generated. However, to stimulate the creation of more ideas, a table (see table 4.3 was created to explore the different technologies that can be used to realise an energy data representation. Technologies were divided into two categories: physical and digital. Physical technologies are technologies that are tangible such that they physically exist. Digital technologies are technologies that deal with the creation and practical use of digital or computerised devices or systems. Technologies that were explored in this brainstorm are interactive installation, (ambient) art installation, product design, interactive web page, virtual reality, video, game, and app.

Physical technologies			Digital technologies				
Interactive installation	**Art installation (ambient)**	**Product design**	**Interactive web page**	**Virtual Reality (VR)**	**Video**	**Game**	**App**
Inefficiency Machines	*7000 Oaks and Counting*	*Power Aware Cord*	*Coralog*	User needs to perform sustainable actions, see effects on campus environment	Animated video showing UT energy data in a fun way	*ECOS project*	AR, scan buildings with QR code and get overview of building's energy status
Interactive elevator where users are accounted for their behaviour by a virtual character, while also learning about energy consumption	Tree with light bulbs that show how much energy is consumed per building	Device that reminds people to turn off the lights when leaving a room	Quiz about own energy consumption (environment IQ), compare with other users, giving tips on how to improve	Virtual campus, see building efficiency of buildings heat map	Interactive animated video where user can make choices, see impact on university	Make the buildings comfortable to live in but also keep them energy efficient	App where UT community can see energy performances of buildings and get tips to act more sustainable
3D Map of the UT (physical model) showing building energy by LED's	More detailed patterns when energy consumption is low	A desk tree that will change colour according to energy consumption	Animations that show data in an appealing way, interactive by digital sliders, buttons etc			Competition between users, who consumes the least?	App where users can keep track of their energy consumption, have to fill in habits
Users fill in their energy habits, see how they compare to others/building by balls in air	Abstract map with coloured lights	Power strip that has LED ring around to show energy consumption	"Plant your seed" creating a forest of choosing right actions e.g. install led lamps				
Installations in different buildings at UT, competition, see how others perform	Jellyfish aquarium getting more colourful with less energy consumption		Digital aquarium/forest				
Container with balls representing CO2 emissions	Forest that interacts when someone passes by (motion sensor)						
Light spots represent a university building energy consumption, compare by pressing buttons							

Table 4.3: Brainstorm ideas based on different technologies

A number of ideas generated through this table were sketched out as demonstrated in figure 4.3. For example, a couple of lamps hanging from the ceiling that show energy consumption by coloured light. Each university building is represented by one of the ceiling lamps and users can select through a dashboard with buttons which buildings they would like to compare. The light circle that is reflected on the floor, will be bigger or smaller, according to amount of energy consumption.

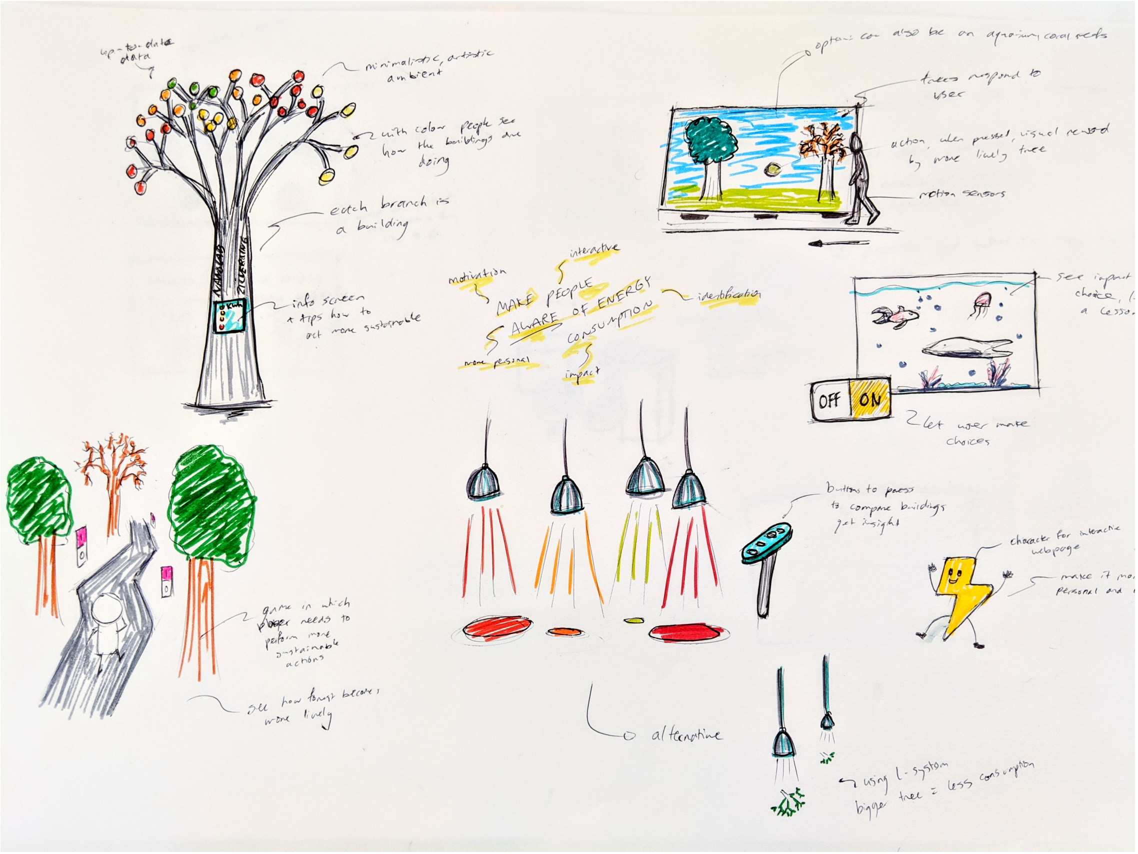
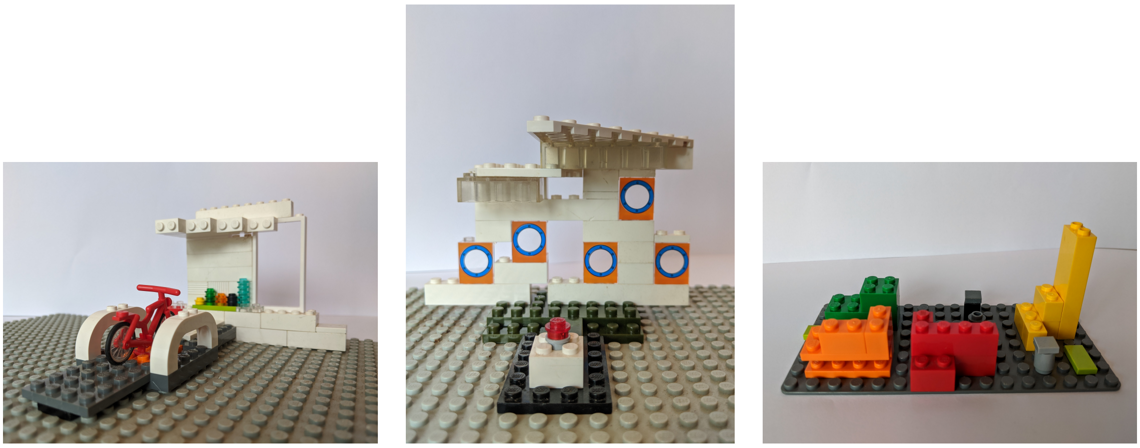


Figure 4.3: Some idea concept sketches

Another concept visible in figure 4.3 is a wall displaying a forest or aquarium that responds when someone passes by. The forest or aquarium will appear colourful and lively when energy consumption levels are low, and dull and deserted when energy consumption levels are higher than average. In addition, an idea for a game was visualised. In the game, players need to reduce energy consumption by for example turning of light switches. A character is running through a forest where more leaves will grow on the trees when energy consumption is reduced.

Lastly, some concepts were explored by using LEGO (see figure 4.4) as a different way of visualisation. In figure 4.4a, a set up for a data physicalisation where users should cycle to see how much energy they generate is shown. This can be compared to the amount of energy that the university consumes. In figure 4.4b, another interactive installation is demonstrated. Users can push a button, or make use of any other input device, and will provide insight into how much electricity the university consumes regarding other appliances such as a phone or hairdryer. Each device would then have its own ”window” as visible in the image, that displays a short animation of these devices. Thirdly, figure 4.4c shows a heat map model of the university campus. By LED’s, users can see how the energy status of each building is compared to the average amount that is being consumed. A possible option could also be that buildings are rated based on whether they align with the UT’s objective to reduce its carbon footprint by 49% in 2030.



(a) Interaction by cycling changes data physicalisation

(b) Possible set up of interactive installation

(c) Heat map model of university campus

Figure 4.4: Idea concepts generated by using LEGO

4.4 Convergence phase

From the divergent ideation session, it can be concluded that this project can be realised in multiple ways using different kinds of technologies and interactions. Since many ideas were generated during the diverging phase, it is necessary to filter out the best ideas of the convergence phase. This way the amount of solutions is narrowed down, and these can be presented to the stakeholders. A way to filter ideas is by setting preliminary requirements. By doing this, the focus is brought back to the main goal of the energy data representation and aids with filtering out ideas that do not suffice these requirements.

4.4.1 Convey a message

In the preliminary list of requirements, as constructed in the divergence phase, most requirements that are engaged with the representation of the data are listed in the *must have* category. Since the data that will be implemented in this energy data representation is an important aspect of this project, it is essential to make a decision on what message is aimed to be conveyed and how the data can be utilised to contribute to this message. After analysing the data on the Energy Data Platform, messages that can be conveyed with the UT's energy data are listed below:

- Show how much energy a building consumes compared to its average to gain insight into consumption patterns.
- Show how much energy the university and its buildings consume compared to daily used appliances to relate the data of buildings to people's daily lives. For example: "At 08:00 the UT consumed as much energy as needed for 84 washes and charging 528 laptops. At 13:00 as many as 142 washes and 938 laptops."

- Show that the number of people that are present at the university has influence on energy consumption to make them aware about the energy consumption at the university. For example, at 07:00 most people are absent, at 13:00 most people are present. The energy consumption shows an increase too.
- Show the effects of energy consumption on the environment with grey electricity to make people aware of. For example, the number of trees that are needed to compensate CO_2, or the contribution to air pollution.
- Show how much CO_2 is consumed per student on average per building per year, to gain insight that over the years, less energy is consumed per student since the number of students increases each year, but the energy consumption more or less remains the same.

4.4.2 Choosing energy data elements

During the divergence phase, ideas were generated by exploring the different technologies that could be utilised in the creation of an energy data representation. However, the data elements that were going to be used were not clearly elaborated on yet. As described above, there are also many possibilities for the message that can be conveyed with the data to raise awareness for energy consumption at the UT. This message strongly depends on the energy data elements that are being used. Therefore, since the process of entering the converging phase was obstructed by the absence of this decision, it was chosen to decide upon these so a set of preliminary concepts could be defined.

The way in which the data is represented on the current Energy Data Platform is assumed to be one of the main problems why it is not successful in raising awareness for energy consumption at the UT. On this platform, the energy data electricity, heat/cooling, and water is represented in kilowatt-hour (kWh), gigajoule (GJ) and cubic metre (m^3), respectively. For analysing and research this is convenient, however, as discovered in the literature research (see section 2.1), it is not the most effective way to make people aware of energy consumption. Thus, the data should be represented in a way that is appealing and easy to understand by members of the UT community.

To simplify the process of defining three preliminary ideas, one energy source was chosen to focus on. This way, the ideas could be elaborated in more detail than when proposing designs that cover all energy sources. It was chosen to only use electricity as an energy source.

Subsequently, regarding the time frequency it was chosen to present the data on an hourly basis per day because the more directly after an action feedback is given, the more effective it is. Figure 4.5 shows a screenshot of the Energy Data Platform displaying the energy consumption (kWh) of commonly used buildings at the UT on 27 February 2020.

Figure 4.5: Electricity consumption (kWh) of various UT buildings on 27 February 2020

The data can be interpreted as a normal distribution curve. This curve corresponds most likely with the amount of UT students, employees, and visitors present during the day. When this time frequency is utilised in the energy data representation, it will enable the UT community better to identify with the data since they are confronted with the data that applies to the time of their presence. As visible in the graph, the amount of energy that is consumed per building differs a lot. For instance, at 16:00 the Horst consumed 985.09 kWh where Ravelijn consumed about 14 times less, 69.87 kWh. This may be due to the size of the buildings as well as the number of occupants and intensity of electricity usage.

4.4.3 Preliminary concepts

After converging several ideas, filtering them based on the preliminary requirements and specifying the energy data elements, the following ideas were generated and are described below.

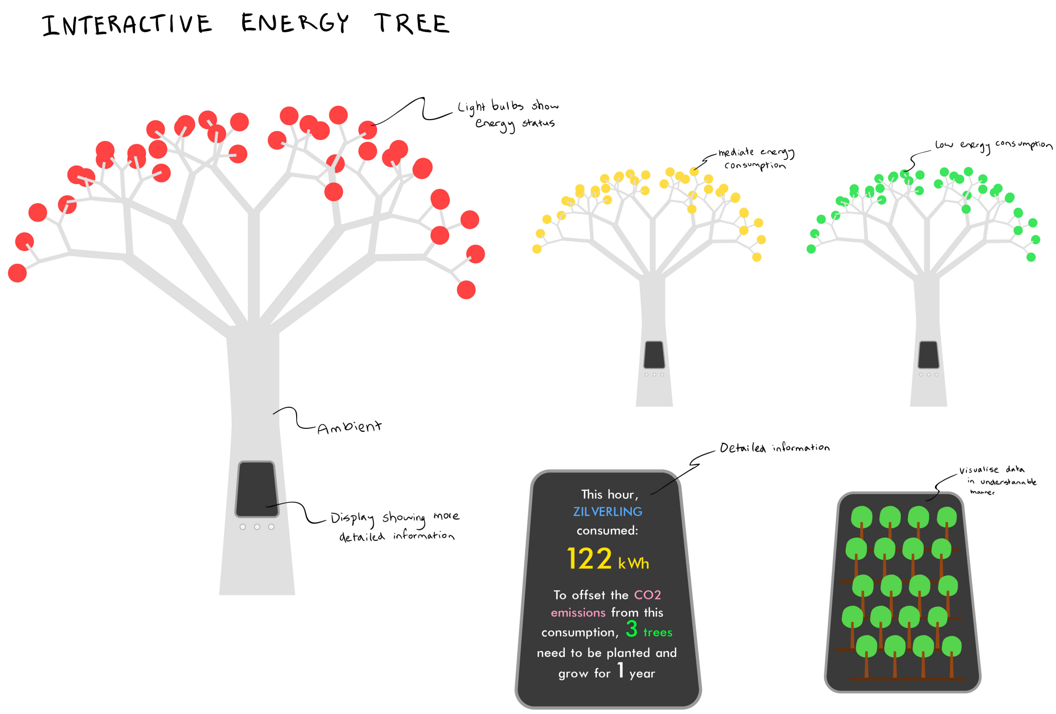


Figure 4.6: Interactive tree

Interactive energy tree

This concept consists of an interactive installation in the form of a physical tree that can be placed in public spaces at the University of Twente as visualised in figure 4.6. Light bulbs are attached to the branches of the tree that show whether energy consumption is high, mediate, or low. When energy consumption is high, the light bulbs will be red. When energy consumption is low, the light bulbs will appear green. When the installation is placed on campus, it may visualise energy data of the whole campus, whereas placed in a university building, the installation may only show data of that building. Consequently, when the installation is placed in an office, it addresses the UT community members on an even more personal level. By using a dashboard, users can interact with the tree by selecting which type of energy data (i.e. electricity, water, heat, etc.) they would like to see represented by the light bulbs and what time period they would like to view.

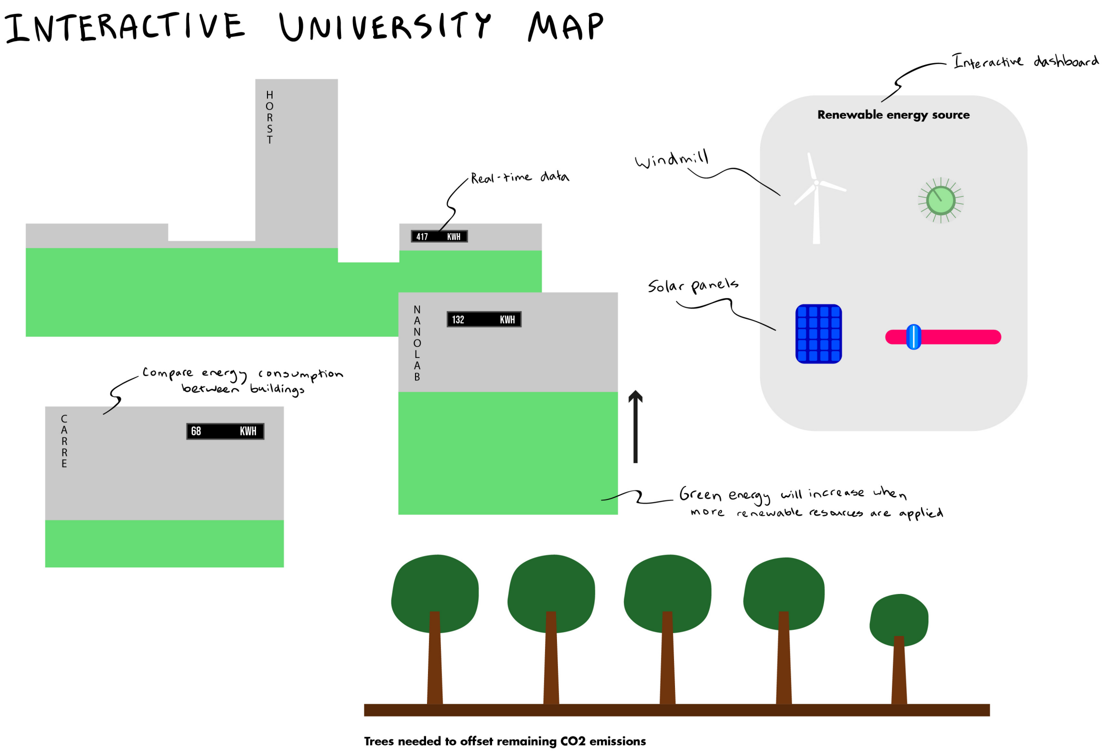


Figure 4.7: Interactive university map

Interactive university map

This concept consists of a tangible scale model of the University of Twente. Each building will have a small display that shows its current energy consumption (electricity in kWh). Figure 4.7 gives an impression of what the concept could look like. Users can interact with the installation by moving sliders and turning knobs to see what influence renewable energy sources such as windmills and solar panels have on the CO_2 footprint of the university. When more renewable energy sources are applied, the buildings will become greener since more LED's in the tangible buildings will turn on. Lastly, the number of trees needed to offset the CO_2 emitted from this grey energy will be displayed as well. With this concept, the UT community will not only get insight in the amount of energy that is consumed, but also how the CO_2 footprint can be reduced, which is one of the goals of the University of Twente. By also giving an estimation of the number of trees needed to offset the CO_2 emissions, it links energy consumption to environmental impact, which may convince people to start thinking about sustainability.

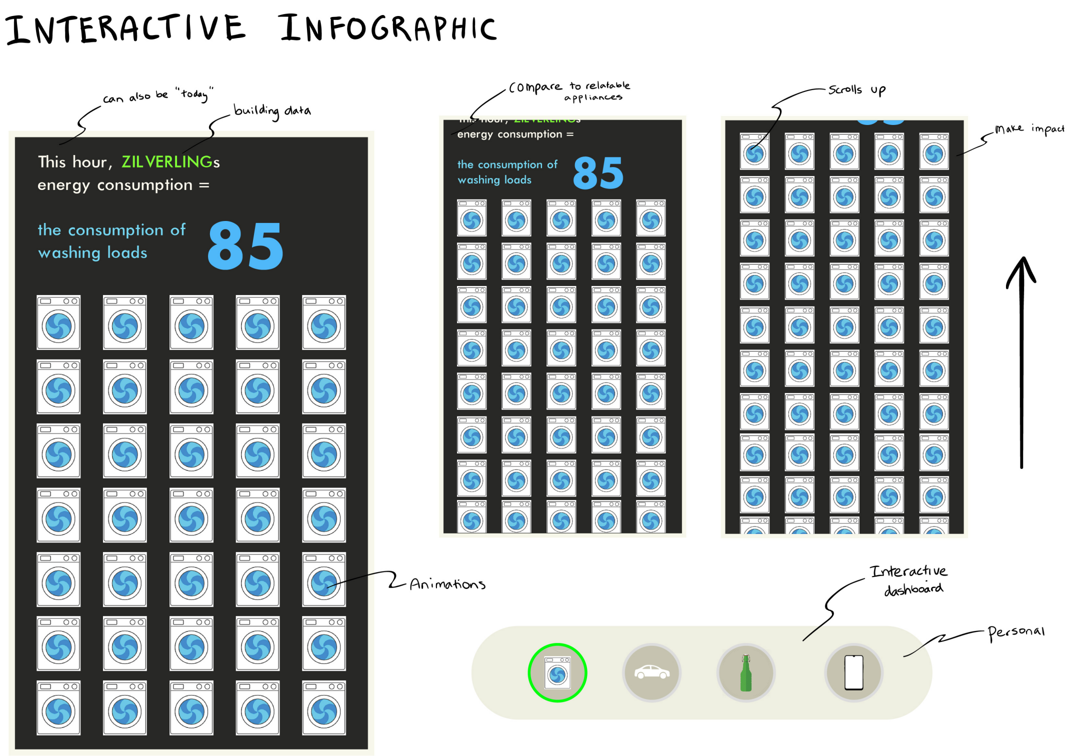


Figure 4.8: Interactive infographic

Interactive infographic

This concept consists of a screen and a dashboard that users can interact with. The interactive infographic is very versatile since it can be placed in many different places and does not take up much space. Users can compare the building's energy consumption with commonly used appliances. Through the dashboard, users can pick an object of their choice. For example, when the user selects the ”washing machine” button, it will display the amount of washing loads that consume the same amount of kWh that are consumed by the building at that time of the day. Due to this, data from buildings is brought to a much more personal level as it brings big data from buildings to the daily lives of people. In figure 4.8 the concept is displayed. By presenting the UT energy data simply in a fun, appealing and relatable way, the UT community can become more aware of energy consumption at the university.

4.5 Harris Profile

To decide on the final concept that will be specified and realised in this project, a Harris Profile, as describe in section 3.2.5 was made of the three preliminary concepts that are described above. Figure 4.9 shows that the three preliminary concepts are assessed on five criteria: appealing (draws attention), context-applicable, easy to understand, personalised data and feasible. As a designer, these criteria were chosen based on the preliminary requirements set in section 4.2.1 and on criteria that the project must meet to be successful and realisable.

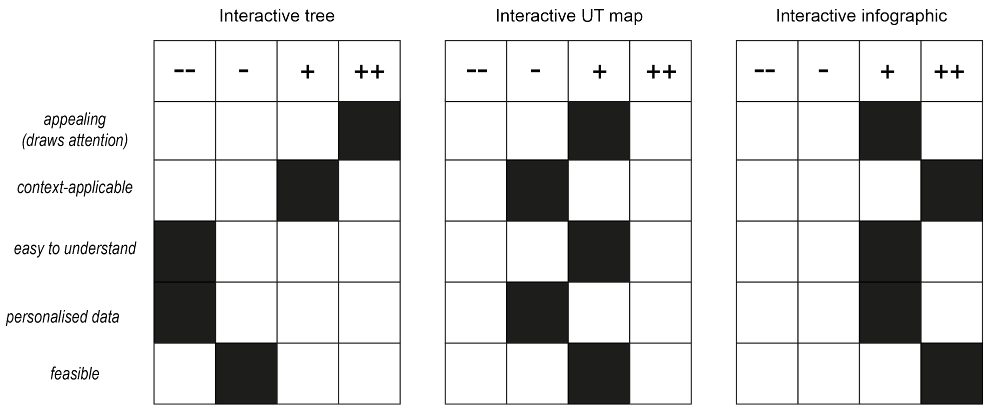


Figure 4.9: Harris Profile of the preliminary concepts

From the Harris Profile, it can be concluded that the interactive infographic is the concept that scored best on the criteria. This concept will be specified, realised, and evaluated. In the following chapters this concept will be referred to as interactive energy data visualisation.

5 Specification

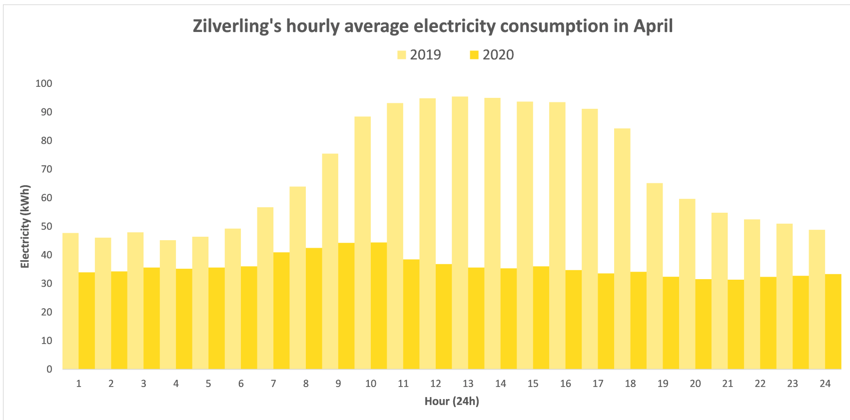
In this chapter, the final design that was chosen in the ideation phase will be further specified. First, the data set that will be utilised in this project is analysed. Then, the iterative design process is described. Lastly, the design and experience specifications of the final design are outlined as well as the final requirements that the interactive energy data visualisation must meet.

5.1 Data analysis

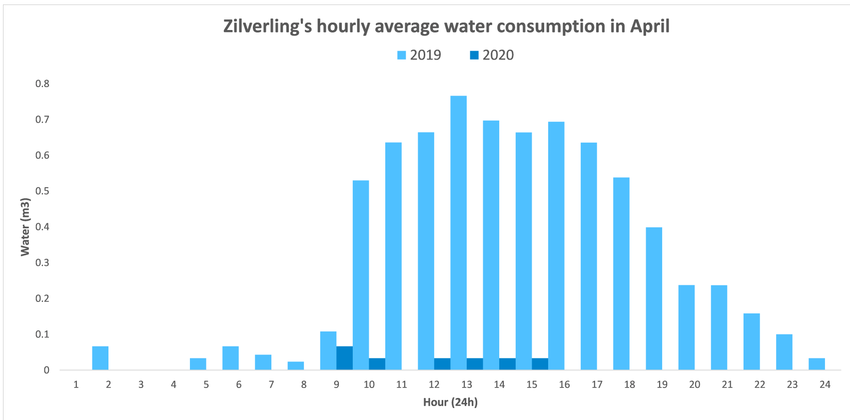
Before the concept itself can be further specified, the data set that is being used must be analysed. The data set that will be used is obtained from the Energy Data platform [8]. As described in section 4.4.1, there are various messages that can be conveyed with the data that is available. The message that the concept will convey is showing how much energy the university and its buildings consume compared to a personal energy consumption context by the means of daily used appliances. Based on the preliminary requirements, the product must be able to let the UT community identify with the UT energy data. This can be done by bringing the data to a more personal level. In this data analysis is examined how much influence the UT community has on the energy consumption of a building. Subsequently, it is investigated how this energy data can be personalised by calculating how much energy an average student and staff member consume in one day while being on campus. In this data analysis, the Zilverling building was chosen as a starting point, but the analysis and calculations may be applied to other UT buildings too.

5.1.1 COVID-19 intelligent lockdown

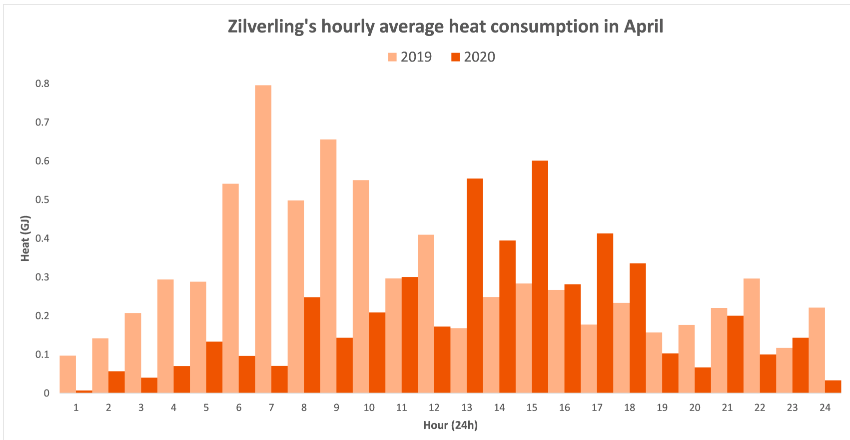
Due to the coronavirus (COVID-19), the University of Twente was closed at 18 March 2020 [35]. As an effect, the UT community, with a few exceptions, was not present at the university. This is clearly visible in the energy consumption of the buildings. The month April was selected to compare the data from 2019 to 2020. Due to this extraordinary situation, an estimation can be made how much influence the UT community has on the energy consumption of buildings. In figure 5.1, the Zilverling's energy consumption (electricity, water and heat) in April was compared between the year 2019 and 2020.



(a) Electricity



(b) Water

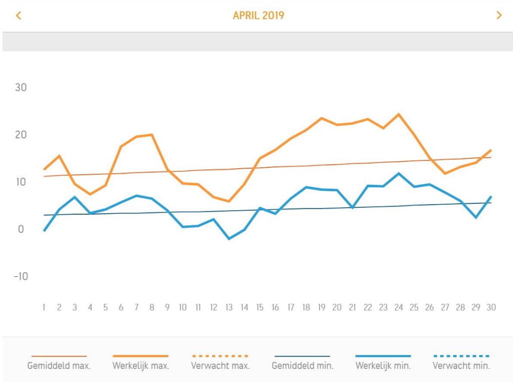


(c) Heat

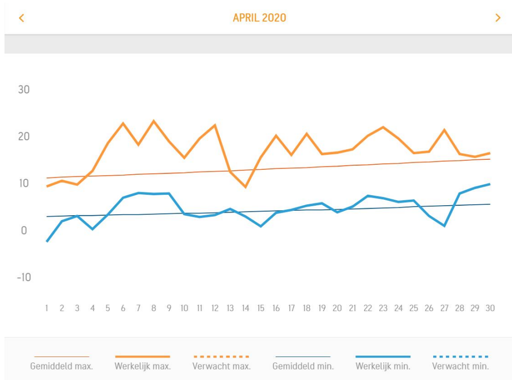
Figure 5.1: Average energy consumption of the Zilverling per hour of April 2020 compared to April 2019

As depicted in figure 5.1a, the amount of electricity consumption in April 2020 was 47.5% lower than in 2019. Moreover, the bar graph clearly shows that in April 2019 consumption rates increase at approximately 06:00 and decrease around 18:00. Most students and staff at the UT have working hours from 08:45 until 17:30, so the increase of electricity consumption can be explained by this. That the increase starts around 06:00 might be due to the heating (and cooling) systems starting up, as wells as cleaning staff that starts working then. In contrast to April 2019, this normal curve is not visible in April 2020. Here, the amount of electricity consumption stays roughly the same throughout the day. Only between 06:00 and 09:00 there is a small increase.

Figure 5.1b displays the Zilverling's average water consumption in April per hour. The amount of water that is consumed in April 2020 is tremendously less than the year before, namely 96.8%. Besides, the graph of April 2019 shows a similar pattern to that of the graph of electricity consumption in April 2019. This again, shows that indeed the UT community influence the amount of energy that is being consumed by the buildings at the UT. However, when looking at figure 5.1c, which displays the Zilverling's average heat consumption in April per hour, we do not see such a big difference. The amount of heat consumption fluctuates a lot throughout the day in 2019, as well as in 2020, but less strongly. This can be explained by the fluctuations in temperature as depicted in figure 5.2. Nevertheless, this figure also shows that the average maximum and minimum of the month April in 2019 and 2020 are roughly the same. Therefore, to have some sort of indication of energy consumption by the UT community, we assume that the heat energy consumption is also affected by the presence of UT community members.



(a) Temperature in April 2019



(b) Temperature in April 2020

Figure 5.2: Temperature in Enschede (Accuweather)

5.2 Personalising data

To enable the UT community to identify with the UT energy data, the data can be presented on a more personal level than on the scale of a building. To do this, first it must be determined how much influence UT community members in the Zilverling have on the energy consumption in the Zilverling building. Second, specifications about the Zilverling building are provided. Lastly, it is calculated how much energy UT students and staff members consume on average in the Zilverling building, which can then be calculated per person.

5.2.1 UT community influence on building energy consumption

The amount of influence the UT community members in the Zilverling have on the energy consumption in the Zilverling building can be determined by subtracting the average amount of energy consumed in April 2020 from April 2019, because in April 2020, we may assume that the building's energy consumption was not affected by UT community members due to COVID-19 as explained before. In table 5.1 the calculated amount of energy that the UT community consumes based on these assumptions is presented. It must be noted that these numbers are based on the month April 2019 only, and do not represent the average energy consumption of a full year.

Zilverling	**Amount of energy consumption**
Electricity	778.95 kWh
Water	7.10 m^3
Heat	2.58 GJ

Table 5.1: Average energy consumption per day by UT community members in the Zilverling building

5.2.2 Building specifications

Since the data of all university buildings cannot be analysed in the time given, it was decided to choose the Zilverling building as a starting point. The Zilverling is mainly used by people within the Faculty of Electrical Engineering, Mathematics and Computer Science (EEMCS). Michel ten Bulte, facilities manager at the Zilverling, provided more specific information about the Zilverling building. The Zilverling building mainly consists of office space. In total, office space in the Zilverling add up to 4116 m^2. Educational space consisting of the SmartXp, W-Zaal, and Educafé add up to 1110 m^2.

5.2.3 Calculations

Average amount of students and staff members present

In this model, the average amount of students and staff members present in the Zilverling building per day was calculated. These calculations are based on:

1. The amount of staff members and students making use of the Zilverling building.
2. The occupancy rate of offices as well as educational spaces in the Zilverling building.

According to Michel ten Bulte, The Zilverling is occupied with 480 staff members. He estimated that the occupancy rate of staff members in the Zilverling is about 60%, therefore approximately 288 staff members are present per day in the Zilverling building. Since the total number of EEMCS students is 2710. Since students do not have a fixed workplace, it was assumed that on average 7% is present in the Zilverling building per day, which is 190 students. The occupancy rate must be considered as well. According to

Richard Bults, the SmartXp and W-Zaal together have a maximum capacity of 200 students. With an occupancy rate of 60%, this comes down to 114 students. In addition, it was estimated that approximately 40 students are present in the Educafé per day. Thus, in total, there are approximately 154 students present per day in the Zilverling building.

Energy consumption by the average student and staff member

To calculate how much energy an average student and staff member consumes in the Zilverling per day, two factors are involved:

1. The average number of students and staff members present in the Zilverling per day.
2. The amount of office space occupied by staff members and amount of educational space used by students.

If available, the actual number of students and staff members present in the Zilverling per day may substitute the estimated average number of students and staff members. Moreover, if known, the (average) amount of hours students and staff members are present in the building may be considered as a third factor to give a more accurate estimation of the energy consumption per student and staff member.

The UT community does not only consist of students and staff members, visitors are also part of the UT community. However, these are not taken into account in the calculations since they are not present in the university buildings as often as students and staff members, and therefore it is also not possible to make an estimation of their influence on the energy consumption levels. In table 5.2 an overview is given of the calculations of the two factors that determine the energy consumption of students and staff members.

Zilverling	**Students**	**Staff members**
Amount present per day	154	288
Amount of space occupied (m^2)	1110	4116

Table 5.2: Ratio student/staff member data

For each of the energy sources, an estimation can be made what share students have and what share employees have regarding the consumption of energy in the Zilverling building.

Electricity consumption

Since electricity is present everywhere throughout the building, it was assumed that the consumption is similar in each room in the Zilverling. Hence, the electricity consumption by UT staff members and students may be computed the same way. Therefore, the average electricity consumption by students is calculated by:

$$\text{TotalElectricity}_{\text{students}} = \frac{\text{Space}_{\text{students}}}{\text{Space}_{\text{total}}} * \text{Electricity}_{\text{total}} \quad \text{kWh}$$

$$\text{ElectricityPerStudent} = \frac{\text{TotalElectricity}_{\text{students}}}{\text{Amount}_{\text{student}}} \quad \text{kWh}$$

By staff members this is:

$$\text{TotalElectricity}_{\text{staff}} = \frac{\text{Space}_{\text{staff}}}{\text{Space}_{\text{total}}} * \text{Electricity}_{\text{total}} \quad \text{kWh}$$

$$\text{ElectricityPerStaff} = \frac{\text{TotalElectricity}_{\text{staff}}}{\text{Amount}_{\text{staff}}} \quad \text{kWh}$$

Where $\text{Space}_{\text{student}}$, $\text{Space}_{\text{staff}}$ and $\text{Space}_{\text{total}}$ are measured in m^2, $\text{Electricity}_{\text{total}}$ is measured in kWh, and $\text{Amount}_{\text{student}}$ and $\text{Amount}_{\text{staff}}$ represent the number of students and staff members present in the building per day.

Water consumption

Since everyone in a building utilises the same spaces when consuming water, the average water consumption by students and staff members is not bound to the share of space occupied by these two groups. Therefore, the average water consumption by students and staff members is equivalent and is calculated by:

$$\text{WaterPerPerson} = \frac{\text{Water}_{\text{total}}}{\text{Amount}_{\text{student}} + \text{Amount}_{\text{staff}}} \quad m^3$$

Where $\text{Water}_{\text{total}}$ is measured in m^3 and $\text{Amount}_{\text{student}}$ and $\text{Amount}_{\text{staff}}$ represent the number of students and staff members present in the building per day.

Heat consumption

The amount of heat energy needed to heat a room depends on the total area volume of that room. Therefore, the average number of students and staff members present in the Zilverling per day as well as the amount of space occupied by staff members space used by students were taken into account. The average heat energy consumption by students is calculated by:

$$\text{TotalHeat}_{\text{students}} = \frac{\text{Space}_{\text{students}}}{\text{Space}_{\text{total}}} * \text{Heat}_{\text{total}} \quad \text{GJ}$$

$$\text{HeatPerStudent} = \frac{\text{TotalHeat}_{\text{students}}}{\text{Amount}_{\text{student}}} \quad \text{GJ}$$

By staff members this is:

$$\text{TotalHeat}_{\text{staff}} = \frac{\text{Space}_{\text{staff}}}{\text{Space}_{\text{total}}} * \text{Heat}_{\text{total}} \quad \text{GJ}$$

$$\text{HeatPerStaff} = \frac{\text{TotalHeat}_{\text{staff}}}{\text{Amount}_{\text{staff}}} \quad \text{GJ}$$

Where $\text{Space}_{\text{student}}$, $\text{Space}_{\text{staff}}$ and $\text{Space}_{\text{total}}$ are measured in m^2, $\text{Heat}_{\text{total}}$ is measured in GJ, and $\text{Amount}_{\text{student}}$ and $\text{Amount}_{\text{staff}}$ represent the number of students and staff members present in the building per day.

With the aid of these formulas, an estimation can be made of how much energy an average student and staff member consumes per day. In table 5.3 the data calculated with the aid of the aforementioned formulas, is presented.

Average energy consumption per day by	Student	Staff member
Electricity	1.07 kWh	2.13 kWh
Water	0.0141 m^3	0.0141 m^3
Heat	0.00356 GJ	0.00705 GJ

Table 5.3: Average energy consumption per day per individual student and staff member

As indicated in table 5.3, the numbers for water and heat are very small. In the interactive energy data visualisation, this will not make impact. Therefore, it was chosen to convert the amount of water in cubic metres (m^3) to litres (L), and the amount of heat energy from gigajoule (GJ) to megajoule (MJ). In table 5.4 this conversion was applied. Now, these data can be implemented into the concept.

Average energy consumption per day by	Students	Staff members
Electricity	1.07 kWh	2.13 kWh
Water	14.1 L	14.1 L
Heat	3.56 MJ	7.05 MJ

Table 5.4: Average energy consumption per day per individual student and staff member with conversions

5.3 Iterative design process

The design of the interactive energy data representation went through several iterations before the final design was specified. In this section, the iterative design process is elaborated.

5.3.1 First prototype

Having taken into account the list of requirements and building upon the chosen concept introduced in the ideation phase, a first prototype was devised. In figure 5.3 the functional layout of the first prototype of the envisioned interactive energy data visualisation is visualised. The layout shows a start screen (left) and three screens representing the energy sources that can be selected. The start screen acts as an overview of the total energy consumption of a building. In this case, the electricity consumption is displayed, but it circulates automatically to water and heat energy consumption as well. The building name, as well as time and date are indicated in the header of the screen. In the footer, two buttons are present that can be pressed to see the energy consumption of either UT students or staff members. When a user presses either the student or staff button, the amount of energy consumption will be presented in a personal energy consumption context by the means of relatable appliances, so it allows the users to gain knowledge and insight about their energy consumption. Elements in between < ... > mean that they are dynamic elements. Based on the energy source and UT community member that are selected, the value of these elements will change accordingly. Figure 5.3 demonstrates what the layout of the screens would be like if the staff button was pressed. Lastly, in the left bottom of the body, the direct energy unit is displayed to give the user a reference point of the data being presented.

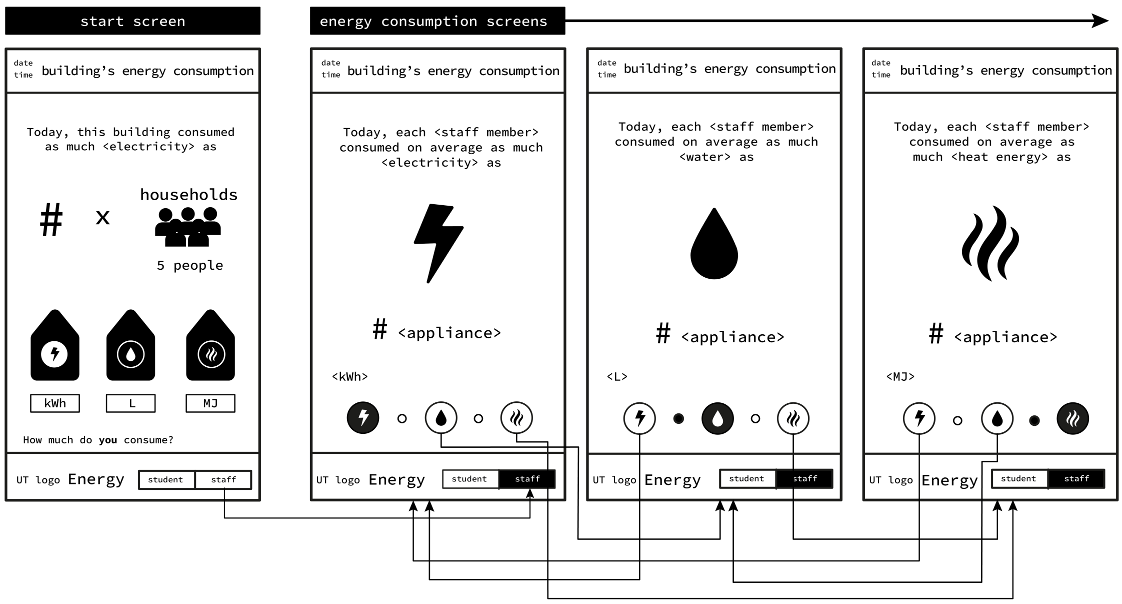


Figure 5.3: First functional design layout of the interface

5.3.2 First iteration

For the first iteration, a small-scale user test was set up. The prototype was distributed to a small number of students. From this user test was concluded that:

- All participants found that the data was presented in a meaningful way.
- The start screen was found appealing, but the green background colour was not appreciated.
- The data was easier to understand represented by households and appliances instead of direct units.
- In general, the screens showing electricity, water and heat consumption gave the participants insight into how much energy they consume in the Zilverling building.

However, it was recommended to compare the energy data to appliances that would show a larger value. For instance, instead of showing one laundry load, show it by the amount of phone charges, which is much bigger.
- After seeing the saving screens, the majority of the participants thought they could help the UT reduce energy consumption.

In addition, the prototype was sent to the supervisors Richard Bults and Kasia Zalewska. Their feedback on the first prototype was:

- Move the UT logo from the footer to the header.
- The building name should be located at the centre of the header.
- Change text suggestion “How much do you consume?” to “How much energy do you consume?”.
- Centralise the student/staff button.
- The purpose of the two grey dots in between the electricity, water and heat is not clear, these can be removed.
- Change the layout and style of the start screen to match the screens showing energy consumption and saving options.
- Change the household size from five people to four people since a household of four is more common.
- Include a menu showing that different buildings can be selected.

The remarks from both the small-scale user test, as well as the feedback of the supervisors, were taken into account in the first iteration of the prototype. In figure 5.4 the functional layout of the first iteration of the prototype is visualised. Moreover, it shows some more detail about the saving option screen which was not connected to the first prototype yet. Therefore, in the right bottom of the screen, a button with a leaf was added that represents the option to go to the saving option screen. In this figure, electricity was chosen as energy source, however, it must be noted that this layout also applies to the other energy sources (water and heat energy). With the first iteration, it was attempted to simplify the design. Therefore, the amount of text was reduced and superfluous visual elements were removed.

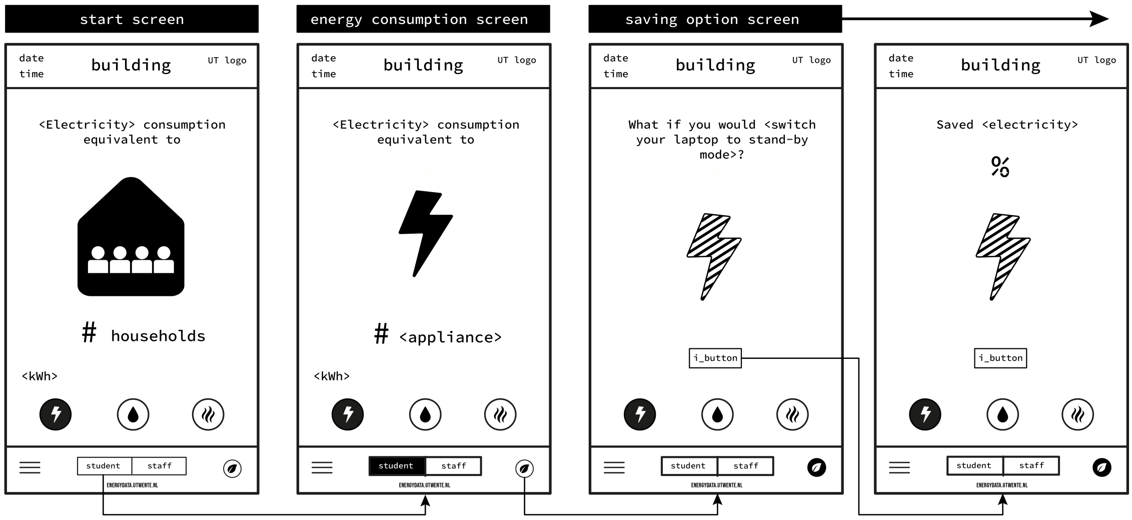


Figure 5.4: First iteration on the functional layout of the interface

5.3.3 Second iteration

After the first iteration on the prototype, Brechje Marechal was interviewed so the design of the concept could be refined more. From the interview was concluded that overall, the design was appreciated and would fit the style of the UT. The data was found to be represented in a meaningful and fun way. Nevertheless, navigation was still a bit unclear. For example, there was no option to go back to the start screen.

In figure 5.5 the functional layout of the second and last iteration of the prototype is visualised. Regarding the start and energy consumption screen, the texts were changed again, since after the first iteration, the text was found to be too long and distracting. Furthermore, the layout of the saving option screen was altered. The element showing the amount of saved energy in percentages was positioned just above the interactive button (see figure 5.5) to match the style of the rest of the prototype better. Lastly, the menu that was suggested by the supervisors has been implemented. This menu will also act as a way to go back to the start screen again.

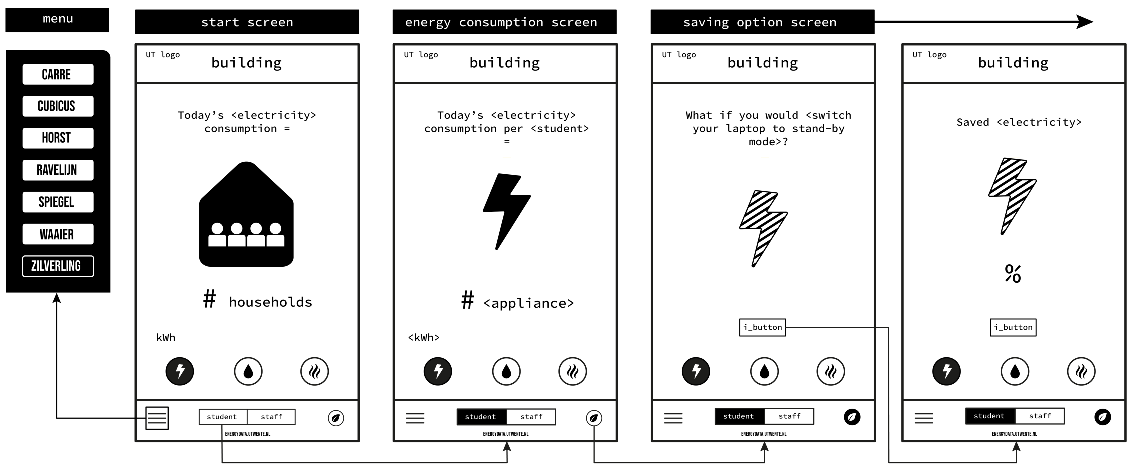


Figure 5.5: Second iteration on the functional layout of the interface

5.3.4 Appliances

After the second and last iteration, the specification of the appliances that the energy data can be compared to is outlined. As stated earlier, to present the data in a way that can be understood by the UT community, it was chosen to compare the data to several appliances. This will provide users insight into how much energy they consume and will make more impact and be memorised better than when the data is presented in direct energy units. Table 5.5 gives an overview of the proportion of the appliances regarding the energy sources. These proportions are based on various sources on the internet. It must be noted that these sources were used to get an approximation of the energy consumption of appliances, but these numbers may deviate from the mean.

Energy source	**Appliance**	**Amount**
Electricity (1 kWh =)	Phone charges (amount) [36]	276
	Laptop (hours)[37]	20
	Washing machine (loads) [38]	1
	E-bike (kilometers) [38]	50
Water (1 L =)	Shower (minutes) [39]	6
	Running tap (seconds) [40]	6
	Grolsch beugels (amount)	2.2
	Coffee cups (amount)	4
	Toilet big button (flushes) [41], [42]	0.17
	Toilet small button (flushes) [41], [42]	0.33
Heat (1 kWh=)	Preparing tosti (amount) [43]	33
1 MJ = 0,278 kWh	Hairdryer (minutes) [44]	2

Table 5.5: Appliances conversions

For the start screens, the total electricity and water consumption are compared to the amount of four-person households. For electricity, this comes down to an average of 10.8 kWh per day per four-person household. For water, a four-person household consumes on average 450 litres of water per day. While heat energy depends on the area volume of a room, the total consumption of this energy source is compared to the amount of terraced houses. One terraced house consumes on average per day 110 megajoule [45].

5.3.5 Saving options

For each of the saving option screens, one example was provided per energy source on how energy consumption can be reduced. For electricity, switching a laptop to stand-by mode saves 33% [37]. To reduce water consumption, the example of a toilet was chosen. Each toilet may have a different volume of rinse water, but for this project, in the case of a dual-flush toilet, the volume of rinse water when pressing the big button is 6 litres, and for the small button this is 3 litres [41], [42]. When always pressing the small button compared to always pressing the big button, this would save 50% water. When it comes to heat energy, when the thermostat is turned down by one decrease, 7% heat energy is saved [46]–[48]. These examples were chosen since they are applicable at the university and the UT community can actually change their energy consumption behaviour.

5.4 Final requirements

In the ideation phase, a set of preliminary requirements was devised that acted as a filter to narrow the amount of ideas down to three preliminary concepts. After deciding on the concept and analysing the data set, this set of preliminary requirements was refined to a list of final requirements for the envisioned interactive energy data visualisation. This final list of requirements not only helps to specify the design elements of this interactive energy data visualisation, but will also be used to evaluate the final prototype.

Functional requirements
Must have
1. Display the UT electricity, water and heat data
2. Display the building's total energy consumption per day
3. Option to choose between the energy sources electricity, water and heat
4. Option to choose to view energy consumption of student and staff member
5. Include a start screen showing the total electricity,water and heat consumption of the building
6. Include direct energy units as reference, but should not be the main component
7. Compare the data to relevant and meaningful appliances that the UT community can relate to (e.g. shower, washing machine, hairdryer)
Should have
8. Include animations to make the data visualisation more appealing
Could have
9, Option to select a different building
10. Option to select different time periods (e.g. per week, month or year)
11. Option to select appliance to compare data with
12. Include a screen that shows how energy can be saved
13. Include a type of reward
14. Show positive effects of pro-environmental behaviour and negative effects of energy consumption
15. Display data real-time
16. Provide personalised feedback (individual)

Non-functional requirements
Must have
17. Raise awareness for energy consumption at the UT
18. Make the UT community identify with the UT energy data
19. Be appealing
Should have
20. Consist of one artefact
Could have
21. Change energy consumption behaviour
Won't have
22. Focus on changing energy consumption behaviour

Table 5.6: Final functional and non-functional requirements

5.5 User experience

To get a sense of what interactions with the energy data visualisation are expected, the user experience was specified. This was done by creating a set of personas and introducing scenarios where these personas interact with the envisioned interactive energy data visualisation.

5.5.1 Personas

Personas can help to better understand the user group. In addition, personas can be used in a user scenario so the designer has a set of particular characters in mind to empathise and imagine them in the scenarios related to the product. The UT community consists of three types of users namely: students, staff members and visitors. Therefore, for each of these, one persona was introduced.

Student

Simon is a 20 year old Creative Technology student at the University of Twente. He lives on the university campus and in his spare time he likes to play online games as well as drinking beers with his housemates. During weekdays he can often be found in the SmartXp, which is located in the Zilverling building. On a daily basis, Simon is not concerned with thinking about sustainability.

Staff member

Marije is 46 years old and is a lecturer at the University of Twente for the study Creative Technology. She works for approximately 32 hours a week. For a long time Marije has been interested in sustainability. At home, she has a smart lighting system and solar panels installed on her roof. In her spare time she likes to read and play tennis. At the University of Twente, she shares her office with her colleague Bas, who often argues that it is too cold in their office, especially in the winter. That annoys her because she wants to reduce her environmental footprint, but she cannot seem to convince her colleague that she likes to keep the temperature a bit lower to save energy.

Visitor

Bram is 18 years old and is in his senior year of VWO. He visits the University of Twente during the Open Days because he would like to study Electrical Engineering. For his school research project he is investigating rainwater harvesting systems. Besides school, Bram likes to skate and play football with his friends.

5.5.2 User scenarios

User scenarios help to specify what user experiences and scenarios are expected. The introduced scenarios below include the aforementioned personas and illustrate how these users interact with the envisioned interactive energy data visualisation.

Student

Figure 5.6 demonstrates how Simon interacts with the interactive energy data visualisation. Simon just came back from the toilet and walks through the hallway in the Zilverling to get to the SmartXp. He notices the interactive energy data visualisation. Simon is interested in how much electricity he consumes as a student in the Zilverling, so he selects to view the average electricity consumption by students. Simon is surprised how much electricity is consumed in only one day, it is as much as two laundry loads. Simon is also interested in the amount of water an average student in the Zilverling consumes in one day. Fourteen litres, that is showering for two and a half minutes. He did not know that so much water was consumed when showering. After a long day of studying and project meetings, Simon has to do his laundry. He thinks back to the interactive energy data visualisation he saw that day. He realises that he spent just as much energy at the university as this one washing load. This gave Simon insight into how much energy he consumes on a day at the the university and he is thinking more often about his energy consumption.

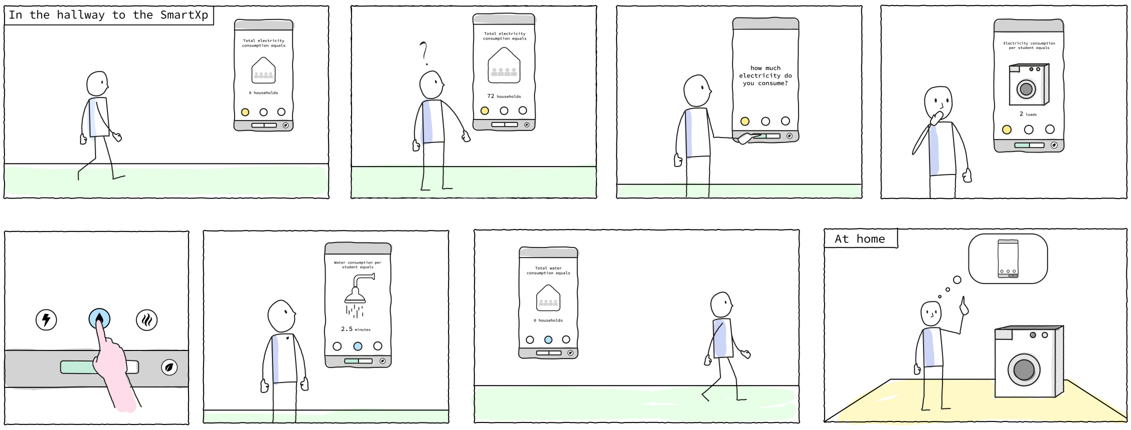


Figure 5.6: User scenario student

Staff member

Marije is in the office with her colleague Bas. During their lunch break, they decide to go for a walk. In the hallway to the SmartXp, they come across the interactive energy data visualisation. Marije explains to Bas that it shows how much energy is consumed in the Zilverling building. When they arrive, the heat consumption screen of the Zilverling is visible. Marije selects the ”staff” button since Bas is often complaining about the temperature in their office. Marije suggests him to also have a look at the saving option for heat energy. Bas sees that 7% heat energy can be saved when the temperature is turned down by one degree. He did not realise that this could make that big of a difference. Especially since he saw that an average staff member in the Zilverling consumed as much heat energy in one day as using a blow dryer for 235 minutes. After the lunch break, Marije and Bas return to their office. Marije asks if it is okay to turn down the heat a little bit since it would reduce their heat energy consumption. Now Bas knows how much his energy consumption is, he agrees with Marije. When he is cold, he will just put on an extra sweater.

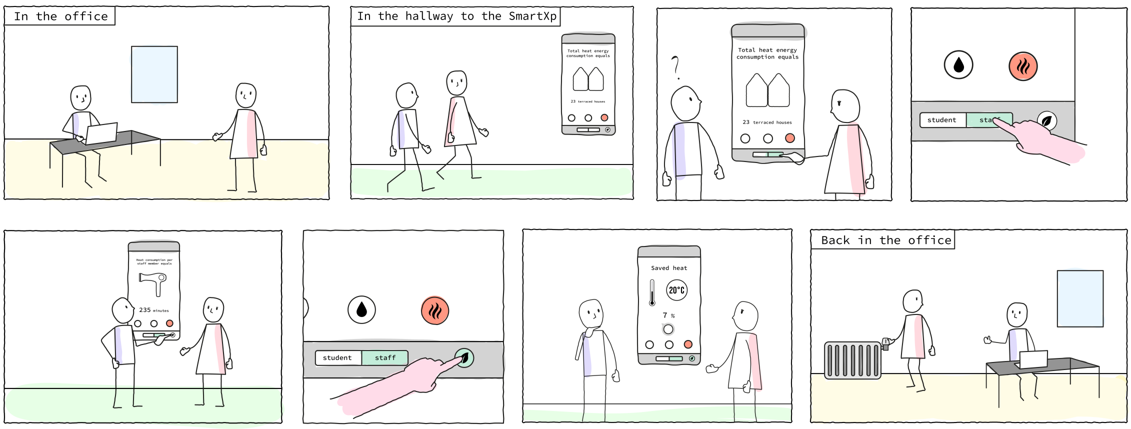


Figure 5.7: User scenario staff member

Visitor

During a tour through the university buildings, Bram walks across the interactive energy data visualisation in the hallway to the SmartXp. Since he is doing his school research project about rainwater harvesting systems, he is interested in the water consumption of the university. He notices that in the building he is currently in, daily water consumption is about as much as consumed by 14 households of four people. Bram is surprised. He is also curious about the water consumption of a student and how water can be saved. Bram is inspired by the interactive energy data visualisation. Maybe the rainwater harvesting systems could be a solution to decrease the amount of drinking water that is being consumed even better.

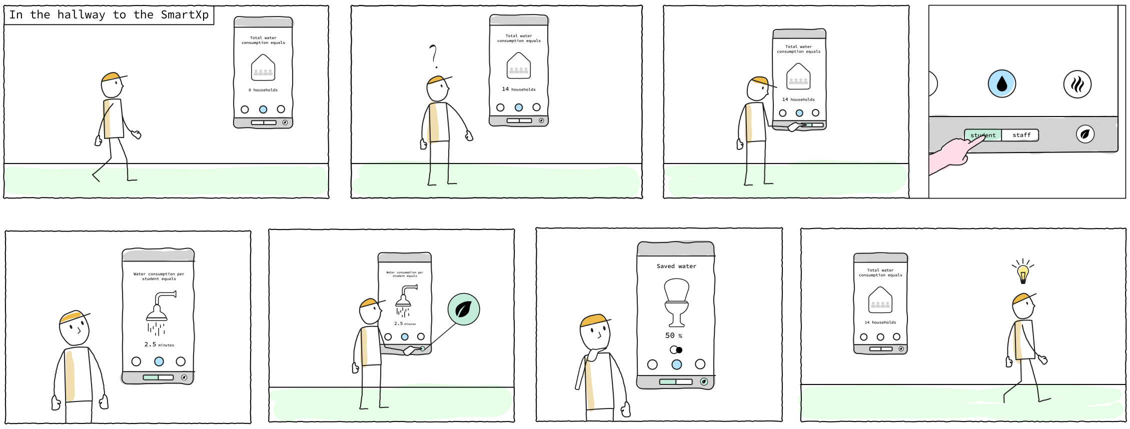


Figure 5.8: User scenario visitor

6 Realisation

In this chapter, the envisioned interactive energy data visualisation as described in the specification chapter will be realised.

6.1 Tool

To create an interactive prototype, the tool Adobe XD was used. Adobe XD is a vector-based user experience design tool that is often used to design web and mobile applications [49]. In Adobe XD, it is also possible to create simple animations. Since Adobe XD is part of the Adobe Creative Cloud, it seamlessly works together with Adobe Illustrator, which will especially be used to create the designs of the appliances. However, Adobe XD also has its disadvantages. Real-time data cannot be implemented and when exporting the application, the extension that Adobe XD exports cannot be further developed or built upon. Moreover, the extension can only be opened in a browser, which may result in different experiences depending on the hardware that the participant is using when doing user testing.

6.2 Illustrations

The process of realisation started with designing the appliances that will be used to compare the energy data with. Later, these illustrations are implemented in the user interface.

6.2.1 Appliances

For staff members, it was chosen to compare electricity to the amount of washing machine loads, water to the number of seconds running tap water, and heat to the number of minutes using a hairdryer. These examples were chosen since they can generally relate to the user's everyday life. In figure 6.1 the illustrations of these appliances are shown.

Figure 6.1: Illustrations of the appliances for electricity, water and heat consumption when staff is selected

For students, it was chosen to compare electricity to the amount of phone charges, water to the number of minutes showering, and heat to the amount of tosti's[1] that can be prepared. It was determined to show different examples compared to the examples given for the staff members since this would create more possibilities to relate to the appliances. In figure 6.1 the illustrations of these appliances are shown.

Figure 6.2: Illustrations of the appliances for electricity, water and heat consumption when student is selected

6.2.2 Start screen comparisons

For the start screens a different approach was taken. As described in section 5.3.4 the building's daily electricity and water consumption are compared to the amount of four-person households. The building's daily heat energy consumption is compared to the amount of terraced houses. In figure 6.3 the four-person households and terraced houses are visualised.

[1]At the University of Twente, with a tosti is understood a grilled cheese sandwich

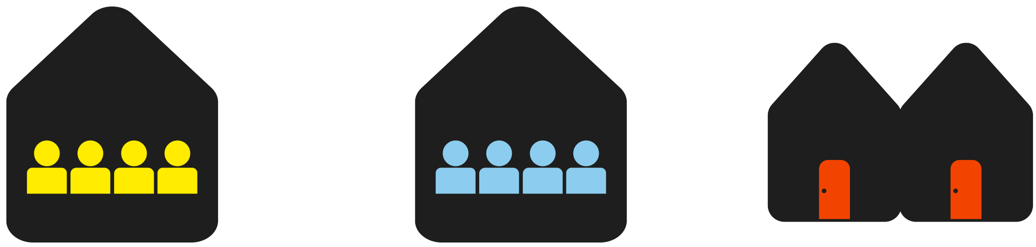


Figure 6.3: Illustrations to compare to households and terraced houses for electricity, water and heat consumption in the start screens

6.2.3 Saving options

The illustrations for the saving option screens are visualised in figure 6.4. As described in section 5.3.5, switching a laptop to stand-by mode is introduced as a way to save electricity. To save water, the example of pressing the small button instead of the big button when using the toilet is presented. For heat energy, turning the temperature down by one degree was provided as saving option. In figure 6.4 the design of the interactive buttons to see how energy can be saved, are shown as well.

Figure 6.4: Illustrations for the saving option screens for electricity, water and heat consumption

6.3 User interface

The user interface consists of multiple parts. First, there are the screens themselves including the start screens, energy consumption screens, saving option screens and the menu pop-up. Second, there are the animations and navigation flows in the application. These will be elaborated below.

6.3.1 Screens

Start screens

The start screens represent the building's total energy consumption. The application will automatically switch from one energy source to another so that a loop is created. This way, when the interactive energy data visualisation is placed in the university buildings and nobody is interacting with the energy data visualisation, it will still show information in a dynamic way and draws attention of people passing by. In figure 6.5 the start screens are shown. Note that for the background of the body, images from the University of Twente campus were inserted to fit the context the concept will be placed in, and to create a bit more depth in the visualisation. These images were applied to all screens in the interactive energy data visualisation.

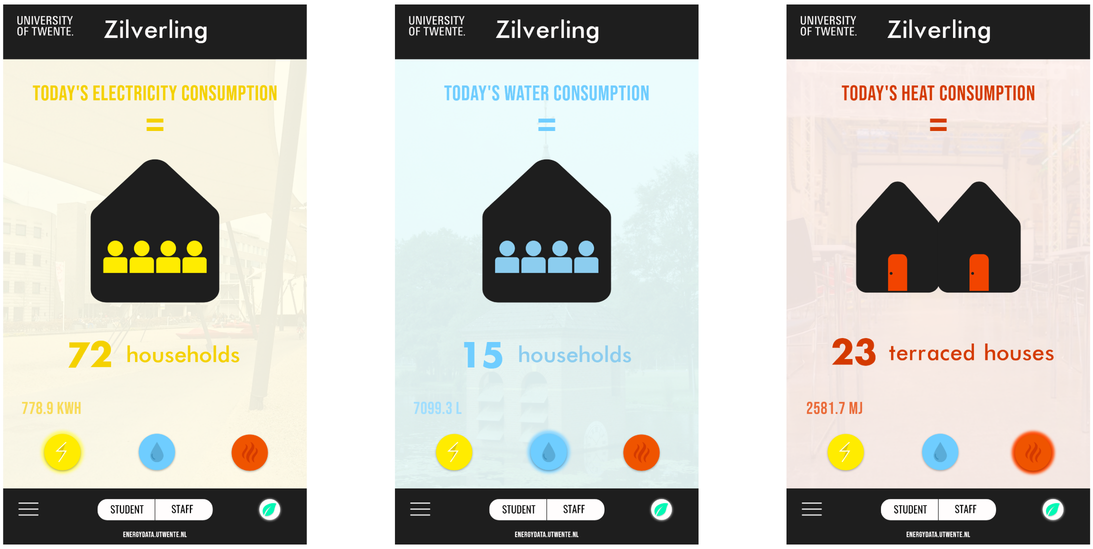


Figure 6.5: Start screens

Energy consumption screens

With the energy consumption screens, daily energy consumption per staff member and student are visualised and compared to relatable appliances. The purpose of these screens is to approach the UT community in a more personal way. By showing how much a UT staff member or student consumes in a particular building, the building energy data from the Energy Data Platform, which on the smallest scale shows energy consumption per building, is brought to a more personal level. In figure 6.6 the energy consumption screens are shown. The top row represents the energy consumption screens when selecting staff member. The bottom row represents the energy consumption screens when selecting student.

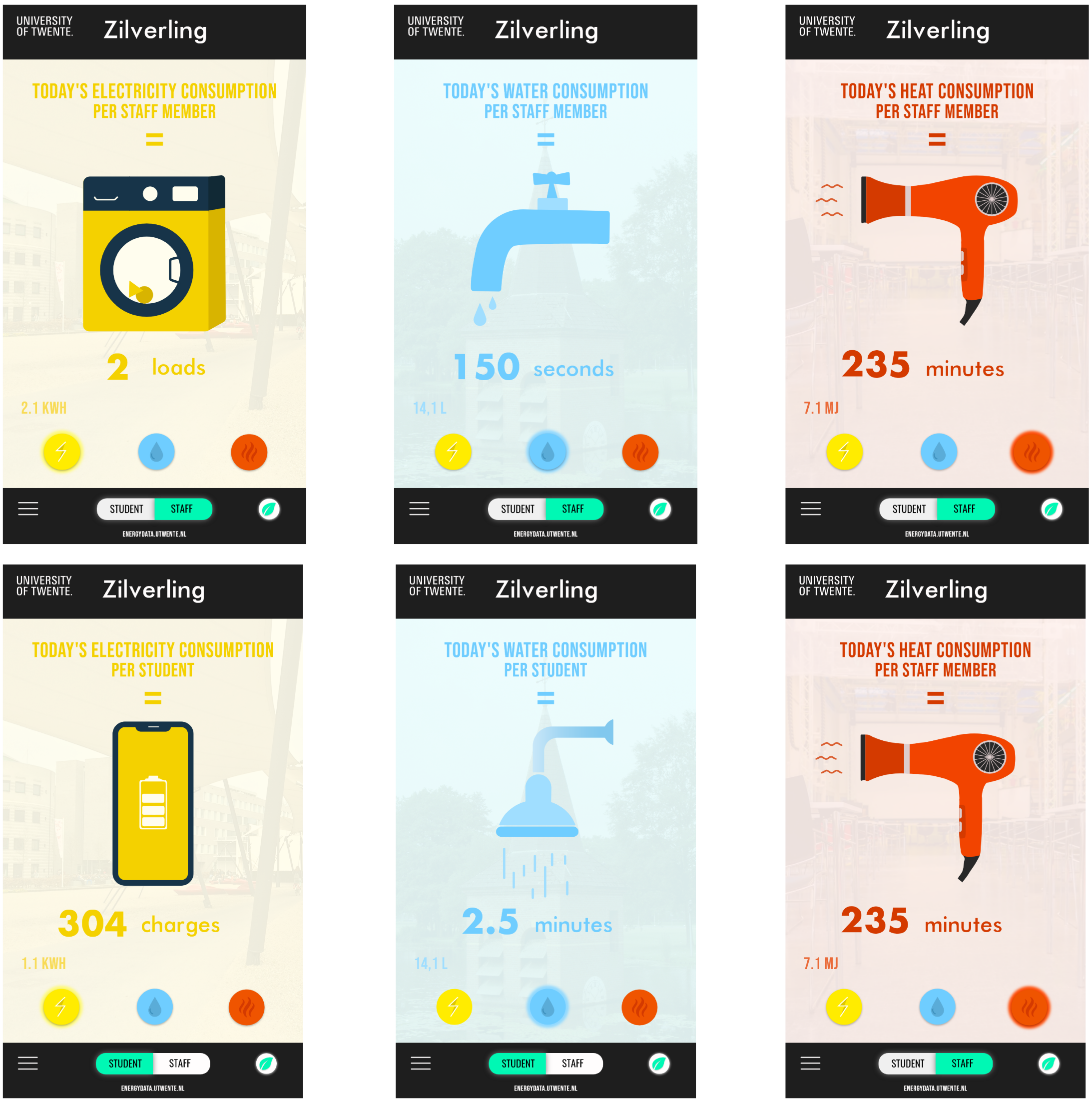
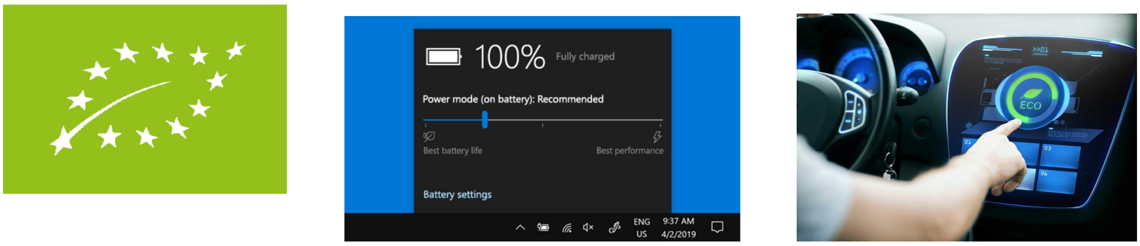


Figure 6.6: Energy consumption screens

Saving option screens

The saving option screens can be accessed when the user presses the button with the green leaf on the bottom right. The saving option screens can always be accessed and enable the user to gain insight into how small actions can help to reduce energy consumption. A leaf was chosen as an indication to navigate to the saving options, since it may refer to sustainability. To illustrate, on some products, a leaf is used to refer to eco-mode and/or making environmental-friendly choices. In figure 6.7 some examples are given. The colour green was chosen because this colour is widely used to promote sustainability [50].



(a) EU Biolabel (b) Battery saving option in Windows 10 (c) Eco-mode in a Toyota car

Figure 6.7: Examples of using a leaf as an indication for sustainability

In figure 6.8 the saving screens including the screen transition when interacting are shown. The top row shows what the screens look like before interaction. By proposing a question at the top of the body of the screen, the intention is to invite the user to see what happens when pressing the switch (electricity), button (water) or knob (heat).

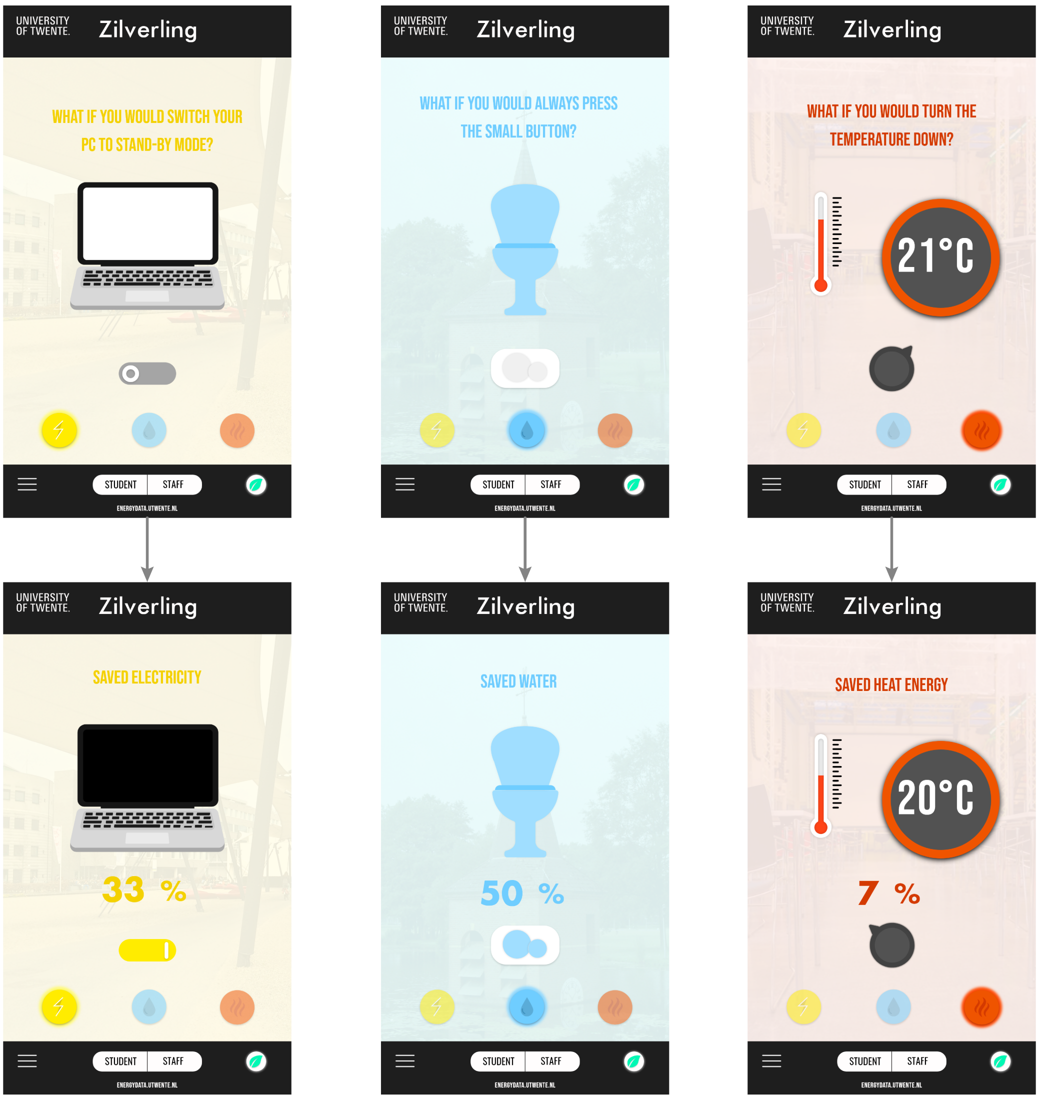


Figure 6.8: Saving option screens, before and after interacting

Menu pop-up

The menu pop-up is an element that shows that different buildings can be selected. This is a feature that anticipates to future work since in this prototype only the Zilverling building can be selected. Therefore, in the prototype it will serve as a way to go back to the start screen again. Whenever a user presses the menu icon, the menu will pop-up and when selecting the Zilverling, it will take the user back to the start screen. In figure 6.9 is demonstrated how the menu pop-up appears on the screen when the menu icon on the bottom left has been pressed.

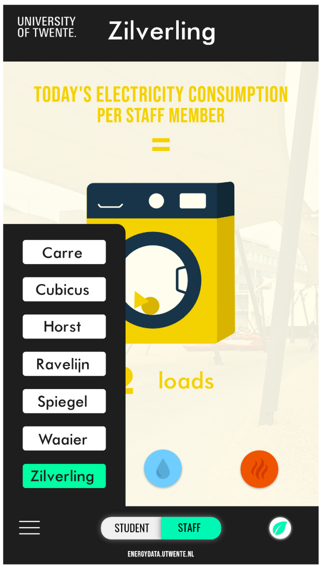


Figure 6.9: Menu pop-up on an electricity consumption by staff members screen

6.3.2 Navigation flow

The aesthetic appeal of a product highly influences the way the audience perceives it. While aesthetics affects usability, it is an important aspect to pay attention to. Hence, the layout was aimed to be as simple and intuitive as possible so navigating through the prototype is easy to understand. In figure 6.10 the navigation flow between screens from the electricity consumption by students screen is demonstrated. This navigation flow also applies to the other energy consumption screens.

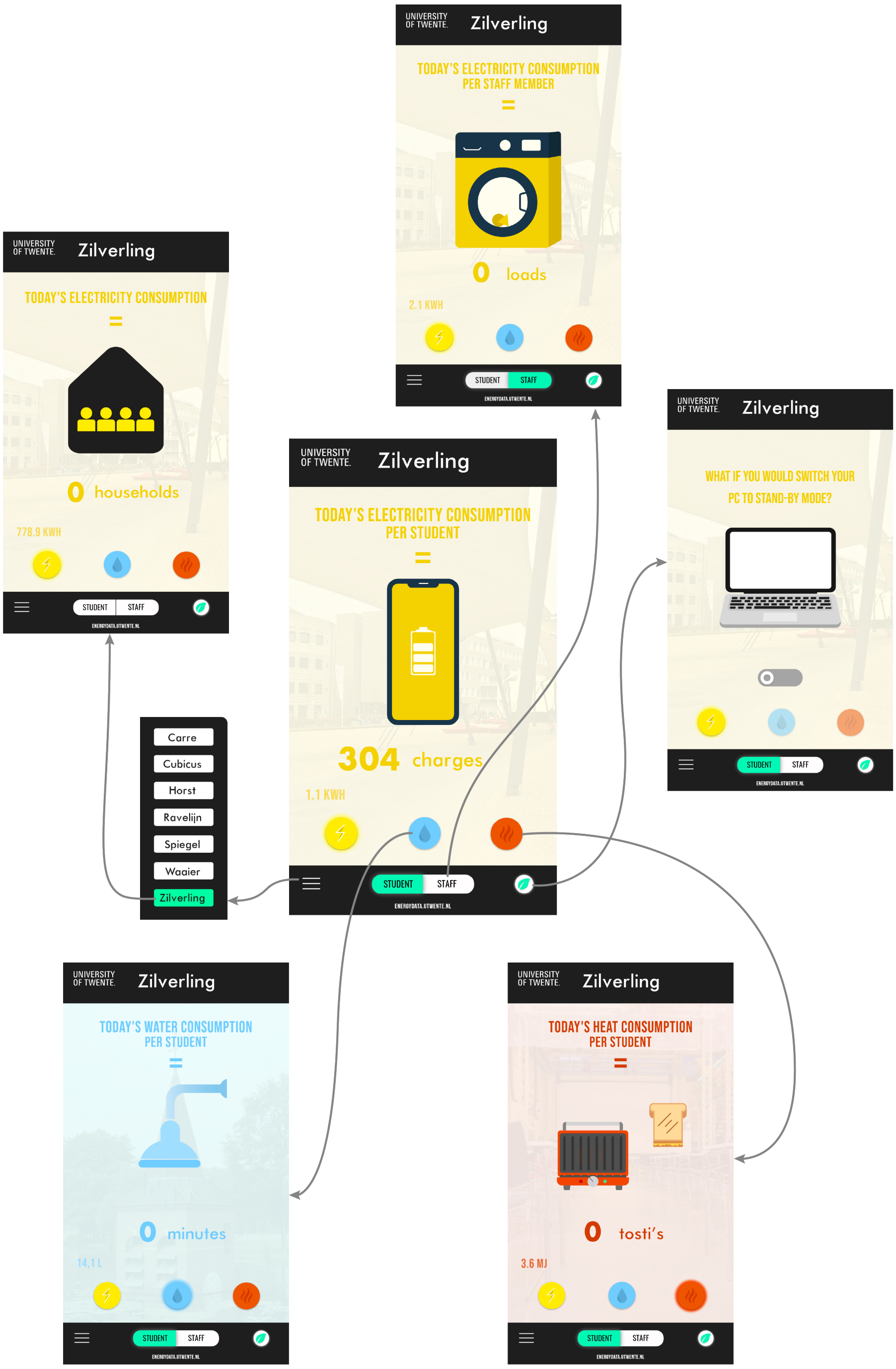


Figure 6.10: Navigation between screens from the electricity consumption by students screen

6.3.3 Animation flow

To make the interactive energy data visualisation dynamic and appealing, animations were added. These animations include number counters and simple animations of the appliances in the energy consumption and saving option screens, such as the washing machine spinning or water flowing out of the shower head. In addition, suggestions to navigate through the application were included. In figure 6.11, the animation flow of such suggestion is demonstrated. This animation shows the pop-up of a suggestion to click on the staff or student button. The goal of these suggestions is to make the application more teasing to interact with and to make the navigation more understandable. During the pop-up a suggestion, the buttons to see the consumption of other energy sources is disabled. This was decided to make sure the buttons would have a static feeling and cannot be used when moved to a different place on the screen.

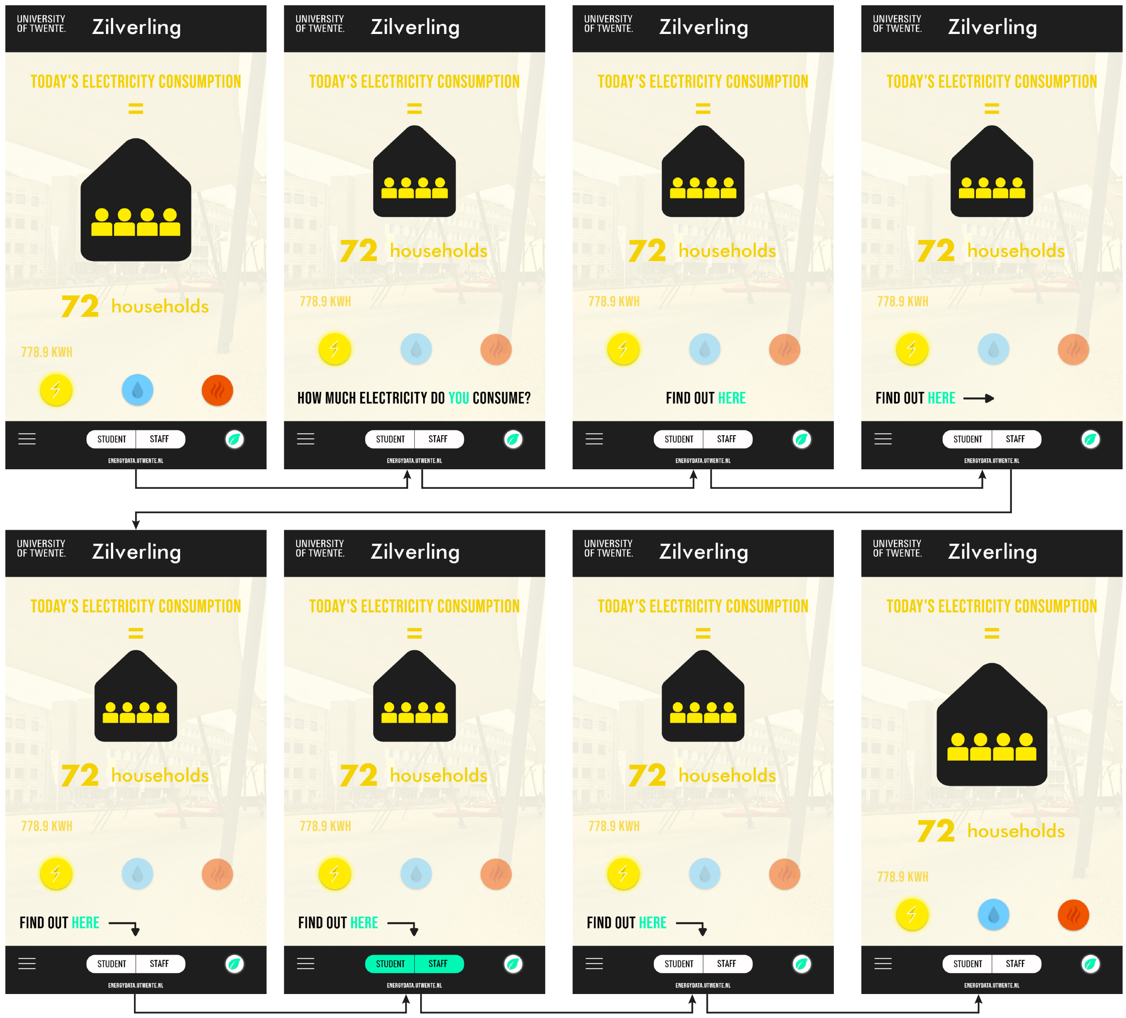
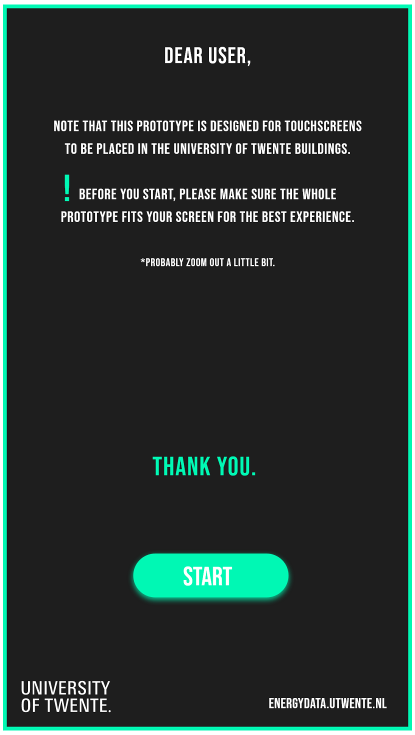
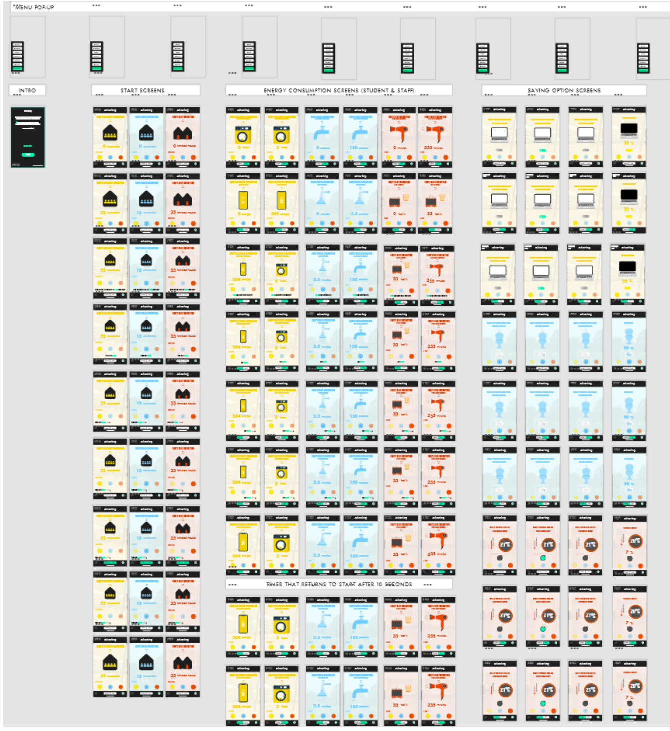


Figure 6.11: Animation flow of a suggestion in the electricity start screen

In figure 6.12b an overview of all the screen that were created in Adobe XD is given. As shown in figure 6.11, more complex animations require more screens. Therefore, the total amount of screens of this application is quite large, namely 127 screens. Consequently, this caused some problems with the menu pop-up since almost all the screens were connected to a single menu pop-up screen. Therefore, it was decided to create duplicates of the menu pop-up screen so the amount of screens connected to it was distributed. Lastly, for the user testing a screen (see figure 6.12a) was added that the participants would see first to make sure the prototype would fit the size of the device they would be testing it on.



(a) Introduction screen to notify participants



(b) Overview of all screens in Adobe XD

Figure 6.12: Introduction screen and overview screenshot

6.4 Mock-up

The interactive energy data visualisation is designed to be displayed on touchscreens that are located in the buildings of the University of Twente. To get an impression of the context that the interactive energy data visualisation will be placed in, a mock-up was created. This mock-up is shown in figure 6.13 and gives a sense of the size of the concept in its context.

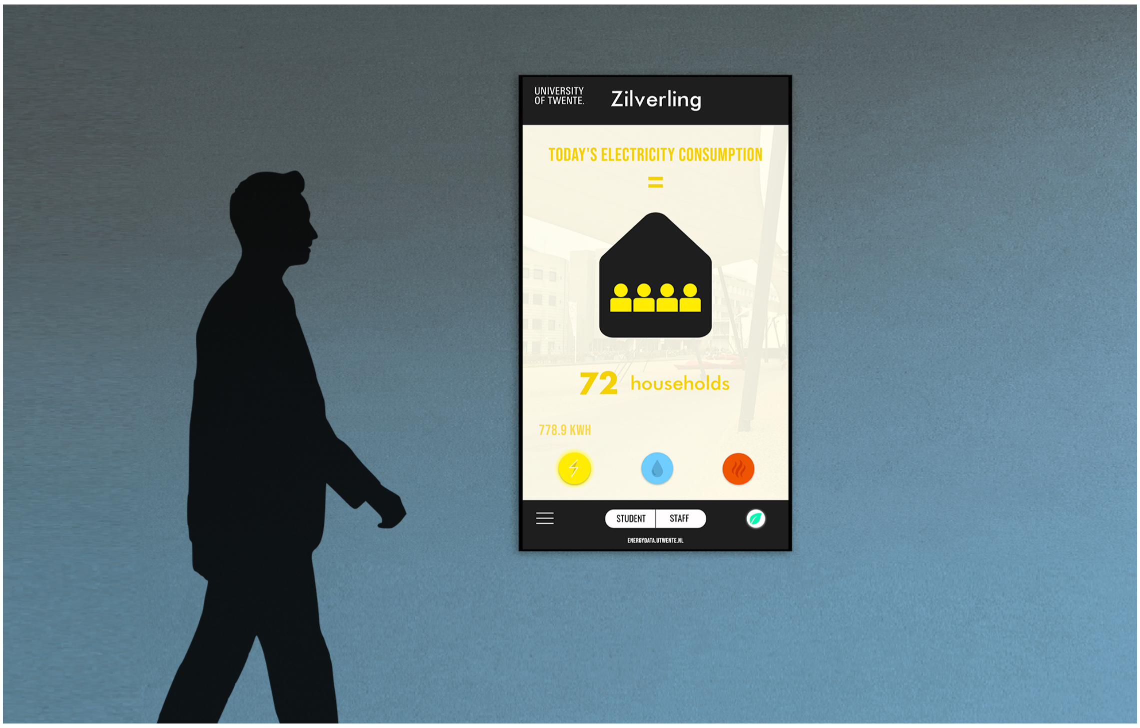


Figure 6.13: Mock-up of the interactive energy data visualisation

7 Evaluation

In this chapter, the prototype that has been designed in the realisation phase will be evaluated. The evaluation is designed to test the user experience and whether the functional and non-functional requirements that were set in the specification phase, are met.

7.1 Survey

To evaluate the prototype, a survey was sent to Creative Technology students and UT members that have their office located in the Zilverling. In total, thirteen students and five staff members participated in the research. In the survey, participants were first asked to assess the prototype. Second, they were asked to compare it to the Energy Data Platform.

7.1.1 Results

In figure 7.1 the results of the interactive energy data visualisation are shown. The figure shows how the concept scored on aesthetics, usability, comprehensibility and whether it made the participants more aware of their energy consumption at the University of Twente.

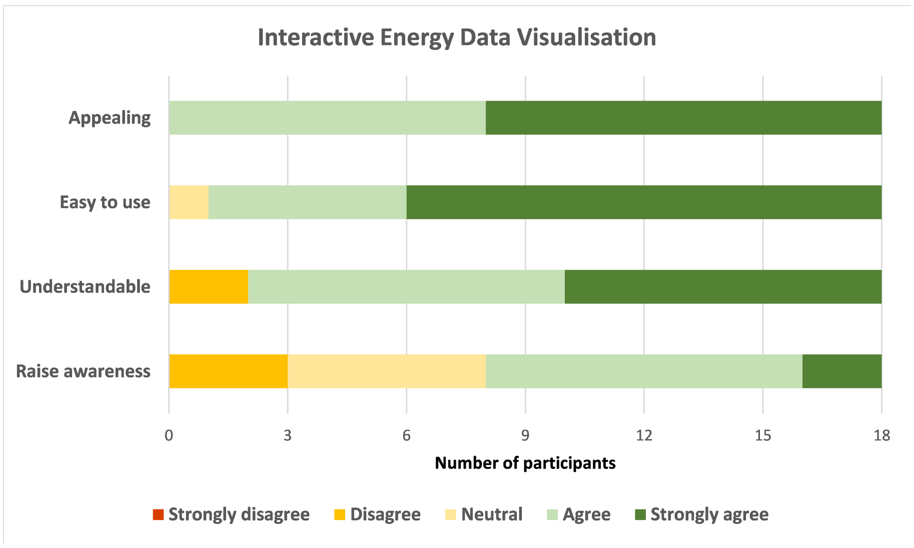
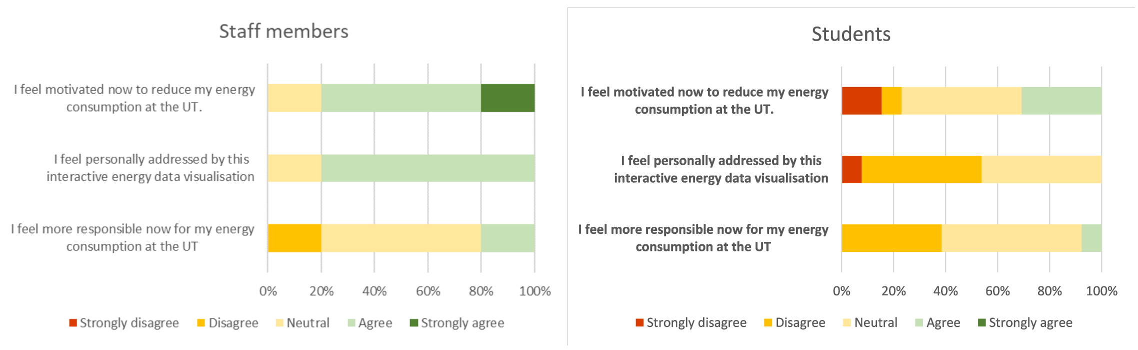


Figure 7.1: Results of the interactive energy data visualisation

Regarding the aesthetics, the interactive energy data visualisation was found appealing and easy to use, and was described as nice, inviting, fun, stylish and polished. What was liked about the design were the minimalist and simplistic look, the colour scheme, and the use of icons and visual cues. Moreover, people enjoyed the animations, although it was frequently mentioned that these were found to be too slow. Another feedback on the design was that the different appliances between student and staff member made it confusing and a little chaotic when switching between those.

In general, people thought that the data was represented in an understandable way. However, two of the eighteen participants disagreed. For example, one of the participants mentioned that for the electricity consumption by students screen, he/she did not understand what the 304 charges meant: "I did not charge my phone 304 times?". This shows that the goal of comparing the energy data with appliances was not interpreted in the intended way by everyone. To make this goal clearer, it was advised to display the same appliance for each of the energy sources.

The biggest objective of this interactive energy data visualisation is to raise awareness of energy consumption within the UT community. The results of the user test show that after seeing the interactive energy data presentation, the majority of the participants agreed that they had become more aware of their energy consumption at the University of Twente. However, this did not mean their feeling of responsibility increased. Of all participants, only 11.1% felt more responsible for their energy consumption at the university. When asked if the participants felt personally addressed by the interactive energy data visualisation, opinions differed widely. Most participants did not necessarily feel personally addressed. However, when analysing the results of students and staff members separately, as shown in figure 7.2, it can be concluded that most staff members did feel personally addressed by the interactive energy data visualisation, whereas most students did not.



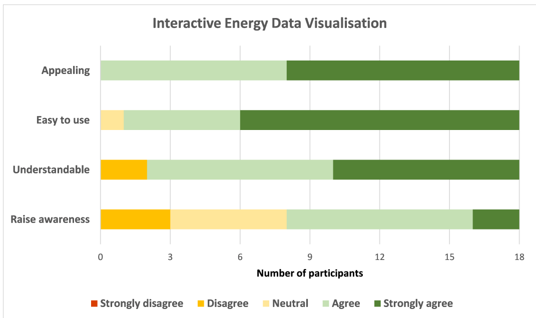
(a) Staff member responses (b) Student responses

Figure 7.2: Responses from staff members and students

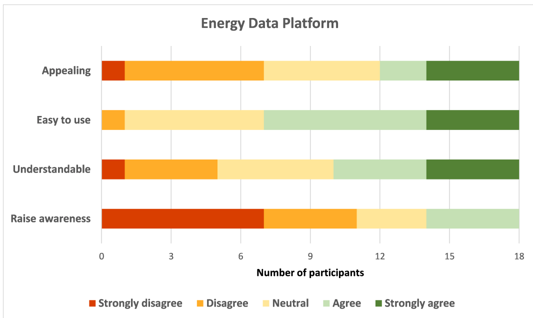
When asked whether the participants felt motivated to reduce their energy consumption at the UT, 80% of the staff members felt motivated. Of the student responses, 30.8% felt motivated to reduce their energy consumption at the UT. Some of the students responded that they did not feel like they contribute much to the energy consumption of the university, or found it hard to place it in perspective while the last couple of months, they have not been at university due to the COVID-19 intelligent lockdown. Others felt discouraged because they felt like their individual contribution would not make a difference and would have liked to see what the consequences of reducing their energy consumption are. Why staff members felt more motivated than students may not only be due to the aforementioned reasons, but also to the fact that staff members utilise the UT buildings in a different way than students. Most staff members have a fixed working area and have control over room temperature and lightning, whereas this is often automated for students, who also switch between varying buildings during the day.

7.1.2 Comparison

After assessing the prototype, the participants were asked to have a look at the current bar graph-based Energy Data Platform of CFM. In figure 7.3b the results of the Energy Data Platform are shown.



(a) Results of the interactive energy data visualisation



(b) Results of the Energy data Platform

Figure 7.3: Comparison of the interactive energy data visualisation and the Energy Data Platform

The figure shows how the Energy Data Platform, just like the interactive energy data visualisation, scored on aesthetics, usability, comprehensibility and whether it made the participants more aware of their energy consumption at the University of Twente. Compared to the interactive energy data visualisation, as shown in figure 7.3, the Energy Data Platform scored worse in these areas, but opinions differed amongst participants. Some found the Energy Data Platform clear, intuitive, and liked the fact that more detailed analysis is possible, whereas others were overwhelmed by the large amount of data and thought this energy data visualisation was not very engaging, instantly understandable, nor easy to interpret. Regarding aesthetics, only 33.3% found the Energy Data Platform appealing compared to the interactive energy data visualisation, where all participants found the design appealing. When it comes to usability, most participants thought the Energy Data Platform was easy to use, but not as much as the interactive energy data visualisation, 61.1% compared to 94.4% respectively. The data was also represented in a less comprehensible way, 44.4% versus 88.9%. When asked if this energy data representation raised the participants' awareness of the of energy consumption at the University of Twente, the majority of the participants disagreed, namely 61%.

7.1.3 Suggestions for improvement

Lastly, participants were asked what the interactive energy data visualisation could improve on. Some valuable comments for future work were:

- Give more examples on how to reduce energy consumption.
- Use the same examples for both students and teachers.
- Being able to see energy consumption over time.
- Allow for it to be used on different devices.
- Show more information about the impact of energy consumption and reduction.

7.2 Interviews

To evaluate the prototype, not only a user test was performed. Stakeholders were interviewed as well to poll their opinions and evaluate whether the interactive energy data visualisation fulfilled their expectations.

7.2.1 Interview CFM: Henk Hobbelink

The frustration that the Energy Data Platform did not manage to raise awareness for energy consumption, mainly originated from Henk Hobbelink, contract manager of CFM. Therefore, as being the client of this project, he was interviewed to evaluate his point of view on the developed concept.

Henk Hobbelink was rather positive and surprised by the interactive energy data visualisations. He mentioned that it exceeded his expectations. Hobbelink thought the prototype looked playful, was dynamic, and liked that there was a lot of interaction. He especially appreciated the saving option screens and commented that it gives a good image of what you can do yourself to save energy at the university. Furthermore, Hobbelink believes that the majority of the UT community that is not interested in energy consumption (yet), will be drawn to and persuaded by this interactive energy data visualisation.

Henk Hobbelink also had some comments on the design of the prototype. He recommended to add a pop-up that explains more about what a kilowatt-hour or gigajoule means. Besides, he suggested to show how much a building consumer per m2 so university buildings can easily be compared with each other. Lastly, he would like the prototype to include real-time data and be implemented in more buildings at the UT since he was curious what effect this would have on the UT community's awareness of energy consumption and whether it would decrease the energy consumption at the university.

7.2.2 Interview Realised

Realised is a start-up from the University of Twente that designed the Energy Data Platform commissioned by CFM. During the process of this project, Realised was not a stakeholder however, since they are specialised in energy-related data visualisation, they were contacted a couple of times to ask for advice.

After the prototype was finished, an interview was held to ask about Realised's opinions. The developers from Realised were enthusiastic about the interactive energy data visualisation. They liked the simplistic design and were impressed by the way the UT building energy data was personalised to the average student and staff member. They also had a few recommendations for future work:

- The button with the leaf to navigate to the saving options could have been bigger.
- The comparison of the heat energy to the amount of terraced houses could be changed into the amount of households to keep the start screens consistent.
- An addition may be an overview screen of the building's energy consumption before entering the individual screens representing each energy source. This way, data between buildings can easily be compared and people can have a quick look at the energy data.
- When implementing real-time data and programming the interactive energy data visualisation, it may be more difficult to include animations in the application. They recommended Lottie, which is an an iOS, Android, and React Native library that renders After Effects animations in real time, allowing applications to use animations with ease [51].

7.3 Requirements evaluation

Finally, the list of requirements that was set in the specification phase were evaluated. In table 7.1 the functional and non-functional requirements are listed as well as whether these were met, partially met or not met.

Functional requirements	Met
Must have	
1. Display the UT electricity, water and heat data	✓
2. Display the building's total energy consumption per day	✓
3. Option to choose between the energy sources electricity, water and heat	✓
4. Option to choose to view energy consumption of student and staff member	✓
5. Include a start screen showing the total electricity,water and heat consumption of the building	✓
6. Include direct energy units as reference, but should not be the main component	✓
7. Compare the data to relevant and meaningful appliances that the UT community can relate to (e.g. shower, washing machine, hairdryer)	✓
Should have	
8. Include animations to make the data visualisation more appealing	✓
Could have	
9. Option to select a different building	(✓)
10. Option to select different time periods (e.g. per week, month or year)	X
11. Option to select appliance to compare data with	X
12. Include a screen that shows how energy can be saved	✓
13. Include a type of reward	X
14. Show positive effects of pro-environmental behaviour and negative effects of energy consumption	X
15. Display data real-time	X
16. Provide personalised feedback (individual)	(✓)

Non-functional requirements	Met
Must have	
17. Raise awareness for energy consumption at the UT	✓
18. Make the UT community identify with the UT energy data	(✓)
19. Be appealing	✓
Should have	
20. Consist of one artefact	✓
Could have	
21. Change energy consumption behaviour	X
Won't have	X
22. Focus on changing energy consumption behaviour	

Table 7.1: Evaluated functional and non-functional requirements

7.3.1 Partially met requirements

Based on the user test results and interviews with the stakeholders, it can be concluded that the interactive energy data visualisation has been evaluated positively. Some requirements were evaluated as partially met (✓). These are further elaborated:

9. Option to select a different building, was executed partly. In the prototype, a menu was created that shows that different buildings can be selected, however, these buildings cannot be selected to see the energy data of these buildings.

16. Provide personalised feedback (individual) was fulfilled to a certain extend. An estimation was made of staff member's and student's individual energy consumption in the Zilverling building, however, to truly personalise feedback, more sensors are required that measure energy consumption on a more personal level.

18. Make the UT community identify with the UT energy data, was also partly met. To identify with means to think of as being very closely associated with something. In this user evaluation, this was examined by asking if participants felt more responsible for their energy consumption at the TU and felt personally addressed by the interactive energy data visualisation. Regarding responsibility, only 11.1% of all participants felt more responsible for their energy consumption at the university and concerning personally addressing the users, there was not significant evidence, although the majority of the staff members did feel personally addressed.

8 Conclusion

Having developed an interactive visualisation based on the UT's energy data, the conclusion serves as a reflection of the conducted work, assessing whether it can answer the research question which has been set in the introduction of this thesis. Therefore, the key findings of this research will be described as an answer to the research question:

"How to represent the University of Twente's energy data to enable UT community identification with the UT's energy consumption?"'

with the aid of answering the sub-questions:

- *"How can an energy data representation make impact?"*
- *"How to apply the Transtheoretical Model to an energy data representation?"*

Besides describing the key findings to these question, this chapter will list recommendations for future work.

8.1 Key findings

8.1.1 How can an energy data representation make impact?

An energy data representation can make impact by a various number of factors. From the literature review, characteristics of energy data representations, more specifically of eco-visualisations, that are effective were investigated. These characteristics include using a type of comparison, either historical or normative, real-time feedback, measurement units other than direct energy units, goal-setting and providing good visual aesthetics. During the design process of the project, these were taken into account and were aimed to be incorporated as much as possible.

Besides, personalised feedback was added. The interactive energy data visualisation is based on energy data of buildings. By also calculating the personal contribution of a UT's community member to the building's energy consumption, the interactive energy data visualisation's impact was increased. When aiming for user identification with energy data, it is important that users receive personal feedback. This way they feel more personally addressed and feel more responsible for their energy consumption. In addition, by converting big numbers of building energy data to an individual footprint, data is brought to a level that is much easier to understand since users can better relate it to their personal life.

8.1.2 How to apply the Transtheoretical Model to an energy data representation?

The Transtheoretical Model can be applied to an energy data representation by acknowledging differently motivated users within the target group and providing feedback corresponding to these different motivations to behavioural change. This project was focused on the first three phases of the TTM, namely precontemplation, contemplation and preparation. A paper by He, Greenberg, and Huang [24] provides a framework on how to apply the Transtheoretical Model to energy data representations. From this paper was obtained that by providing personalised feedback on the positive effects of sustainable behaviour and negative effects of non-sustainable behaviour, referring to a social norm regarding sustainable energy behaviour, and providing encouragement for small actions to consume less energy, these three phases of the TTM can be addressed in an energy data representation.

In this project, these recommendations were used as a guideline. The energy data was presented on a more personal level by calculating how much energy an average student and staff member consume in a building, and tips were provided on how energy can be saved, such as switching a laptop to stand-by mode or turning the temperature down. Furthermore, users had the opportunity to compare themselves with others, namely staff members against students. Additionally, by comparing the energy data to daily used appliances, a norm is set that users can compare themselves with. For example, when a user showers for fifteen minutes per day, and the visualisation shows that the average water consumption is as much energy as showering for eight minutes per day, then this person will consume more energy than the average and may start to wonder if he/she should reduce his/her water consumption. The user gains insight about his/her own energy consumption and has the ability to view how to change his/her behaviour.

To better implement the Transtheoretical Model, the designer must aim to step away as much from a one-size-fits-all solution. When an energy data representation provides feedback that corresponds to users different stages of readiness, willingness and ableness to change their energy consumption behaviour, the chance that this behaviour will change increases. Furthermore, to enable behavioural change, more phases within the TTM should be addressed by the energy data representation to guide the users through behavioural change.

8.1.3 How to represent the University of Twente's energy data to enable UT community identification with the UT's energy consumption?

This graduation project presents the development of an interactive energy data visualisation based on the UT's energy data that is designed to be placed on touchscreens throughout the University of Twente's buildings. The interactive energy data visualisation provides a solution to raise awareness of energy consumption at the UT by turning a bar graph-based energy data visualisation into an interactive visualisation that provides data more personal, is appealing, easy to use and understandable by the UT community. In addition, by applying effective eco-visualisation characteristics and following guidelines of applying the TTM during the design process of this project, a representation of the University of Twente's energy data to enable UT community identification with the UT's energy consumption, has been achieved. The interactive energy data visualisation was especially effective for UT staff members. They felt more personally addressed by the visualisation, more responsible for their energy consumption in the building, and felt more motivated to reduce their energy consumption at the UT than the student respondents did. However, in general the interactive energy data visualisation shows to be a great improvement over CFM's current Energy Data Platform and the goal to raise awareness for energy consumption has been reached. What effect the interactive energy data visualisation has on UT visitors remains to be investigated.

8.2 Future recommendations

The development of this interactive energy data visualisation is a first step to raising awareness at the University of Twente for energy consumption and enabling UT community identification with the UT's energy data. To further develop the interactive energy data visualisation, several future recommendations are given.

8.2.1 Additional functionality

First of all, regarding the interactive energy data visualisation itself, an overview screen could be developed that displays all the energy consumption data including the total energy consumption by the building, as well as the energy consumption by students and staff members. This will make it possible to compare buildings quickly and have a brief glance of the energy consumption in a university building without the involvement of interaction. In addition, an option to select different time ranges can be implemented, so users can compare the data and see whether they themselves and the university are improving. Another recommendation for future work is to do more research into which appliances that the energy data is compared to, will appeal best to the user group. This will contribute to better identification of the energy data and providing more personal feedback.

8.2.2 Increase effectiveness

From the evaluation was concluded that the interactive energy data visualisation was less effective for UT students than UT staff members. To increase the effectiveness of the interactive energy data visualisation for the whole UT community, the concept needs to be turned into a real solution, so it can be researched if the energy data visualisation has more impact when the UT community gets confronted with their energy consumption at the university more often, since the energy data visualisation is intended to be placed in every UT building. Another recommendation to increase the interactive energy data visualisation's impact, is to place more sensors in the university buildings. When data is measured more accurately, more personal feedback of the energy data can be provided. An option is to start placing energy measuring sensors in staff member offices and study association rooms. A competitive element can be included as well. For example, a competition between which study association consumes the least amount of energy in one week, will win a price. Another option to provide energy feedback more personally is to directly give feedback on actions that involve energy consumption, such as measuring if someone pressed the big or small button after a toilet visit, and addressing that person on his/her behaviour immediately.

8.2.3 Calculate personal data

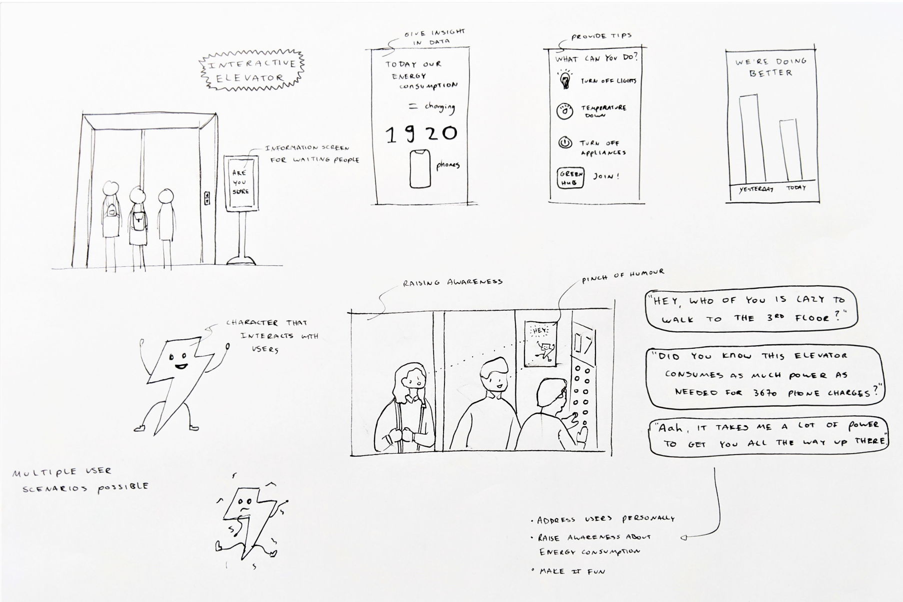
To calculate the average energy consumption per person in a building more accurately, sensors can be placed at the entrances of buildings. This way the occupation rate can be calculated and more precise numbers of the amount of energy that is being consumed can be provided. To truly make the UT's energy data more personal, it is necessary to measure energy consumption on a more individual level. A good example that shows developments in this area is the Technohal building (TechMed Centre), where energy consumption can be measured per floor.

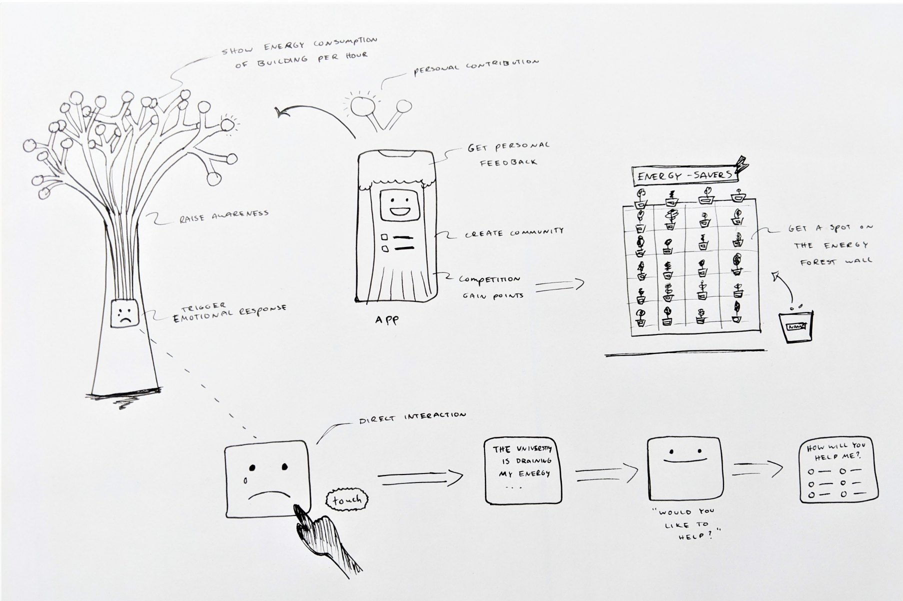
8.2.4 Conclusion

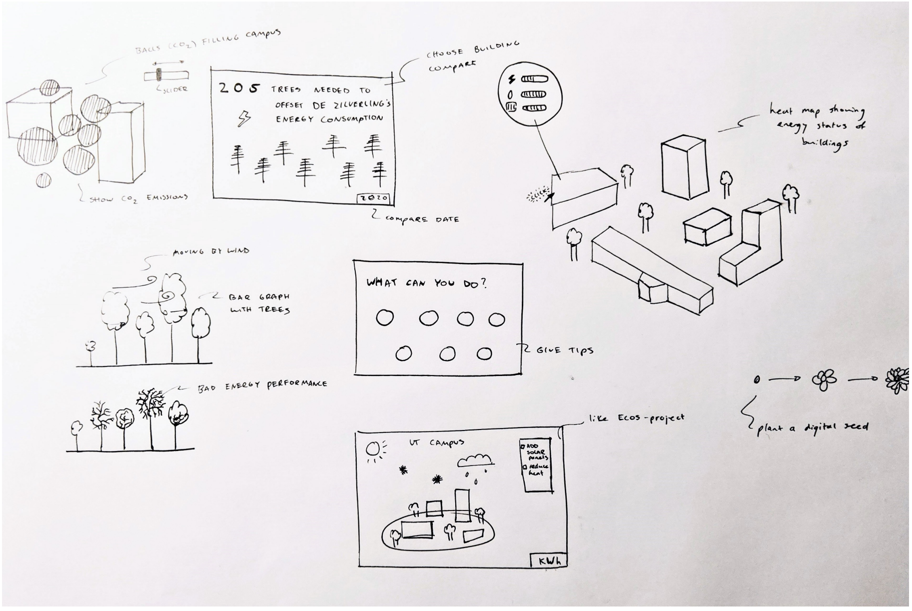
To conclude, there is a lot of potential in raising awareness for energy consumption by the means of an interactive energy data visualisation, but more research on the effects of such energy data representation is required to better understand energy consumption behaviour driven by feedback. To better test if the interactive energy data visualisation can make impact on the University of Twente's energy consumption, it needs to be turned into a working solution that provides real-time feedback and is integrated in multiple UT buildings. Besides the interactive energy data visualisation, other energy feedback strategies could be investigated to find the most effective method to raise awareness for energy consumption and enable UT community identification with the UT's energy data.

A Sketches

A.1 Additional brainstorm sketches






BALLS (CO_2) FILLING CAMPUS
SLIDER
SHOW CO_2 EMISSIONS
205 TREES NEEDED TO OFFSET DE ZILVERLING'S ENERGY CONSUMPTION
2020
CHOOSE BUILDING COMPARE
COMPARE DATE
CLICK
heat map showing energy status of buildings
MOVING BY WIND
BAR GRAPH WITH TREES
BAD ENERGY PERFORMANCE
WHAT CAN YOU DO?
GIVE TIPS
plant a digital seed
like Ecos-project
UT CAMPUS
ADD SOLAR PANELS
reduce heat
KWh

B Interview questions

B.1 Semi-structured interview questions: Brechje Marechal

Wat is uw algemene mening over het ontwerp?
What is your general opinion about the design?

Vindt u dat de data op een begrijpelijke manier is gepresenteerd?
Do you think the data is presented in an understandable way?

Waarom vindt u dat?
Why do you think that?

Hoe is het prototype in gebruik?
How is the prototype in use?

Is de manier waarop je door het scherm navigeert duidelijk?
Is the way you navigate throught the screens clear?

Wat is er duidelijk/onduidelijk?
What is clear/unclear?

Denkt u dat dit project de UT gemeenschap kan laten identificeren met de energie data van de UT?
Do you think that this project enables the UT community to identify with the energy data of the UT

Denkt u dat de UT gemeenschap door dit project meer bewust gaat worden over hun energieverbruik? Waarom denkt u dat?
Do you think that this project will make the UT community more aware of their energy consumption? Why do you think that?

Gebaseerd op eerdere gesprekken die ik met u, Henk Hobbelink en mijn begeleiders had, heb ik een lijst met eisen opgesteld waaraan de interactieve energie data visual-

isatie moet voldoen. Deze zullen in de uiteindelijke testing Heeft u nog toevoegingen aan deze lijst?
Based on previous conversations that I had with you, Henk Hobbelink and my supervisors, I have drawn up a list of requirements that the interactive energy data visualization must meet. These will be included in the final testing. Do you have any additions to this list?

Wat zijn de beste / slechtste aspecten van het prototype?
What are the best / worst aspects of the prototype?

Op welke vlakken kan het prototype nog verbeteren?
In what areas can the prototype improve?

B.2 Semi-structured interview questions: Henk Hobbelink

Wat is uw eerste indruk van het ontwerp?
What is your first impression of the design?

Voldoet het prototype aan uw verwachtingen?
Does the prototype meet your expectations?

Denk je dat dit project de UT gemeenschap zich kan laten identificeren met de energie data van de UT?
Do you think that this project enables the UT community to identify with the energy data of the UT

Denkt u dat de UT gemeenschap zich door dit concept meer bewust van energieverbruik op de UT wordt?
Do you think that this project will make the UT community more aware of their energy consumption? Why do you think that?

Op welke vlakken kan het prototype nog verbeteren?
What areas can the prototype improve on?

Welke toekomst zie je in dit project? *What future do you see in this project?*

B.3 Semi-structured interview questions: Realised

Wat is je eerste indruk van het ontwerp?
What is your first impression of the design?

Hoe is het prototype in gebruik?
How is the prototype in use?

Denk je dat dit project de UT gemeenschap zich kan laten identificeren met de energie data van de UT?
Do you think that this project enables the UT community to identify with the energy data of the UT

Denken jullie dat er potentie in zit?
Do you think it has potential?

Denken jullie dat jullie hier iets mee kunnen? Het concept uitbreiden of verder uitwerken?
Do you think you can do something with this? Expand or further develop the concept?

Wat zou er denk je nog kunnen verbeteren?
What do you think could improve?

Welke toekomst zie je in dit project?
What future do you see in this project?

C Information brochure

Dear reader,

Thank you for your interest in participating in this research. With this information brochure, I would like to give you some more information about the research.

Purpose
This study is part of my graduation project for the BSc Creative Technology titled: Designing an energy data representation to raise awareness within the UT community. The goal of this user study is to get an understanding of the user experience and to evaluate the concept.

Procedure
In this research you will be asked to assess a prototype. This prototype is an interactive interface designed to be placed on touchscreens in the Zilverling building, University of Twente (UT). The purpose of this prototype is to make the UT community (students, employees and visitors) aware of the energy consumption at the UT. With this prototype you can choose which energy source you would like to view and get insight in the amount of energy that is consumed by the Zilverling. In addition, it will show what influence you, as a UT member, have on the energy consumption in the building.

Important
Some important notes before you start:

- You must be a member of the University of Twente and 18 years or older to participate in this questionnaire, and be able to give informed consent.
- This questionnaire is completely anonymous and no sensitive or personal data will be collected.
- Participation in this questionnaire is voluntary, you can stop whenever you want without a reason.
- Participation in this questionnaire should last no more than 15 minutes.

Finally, I want to thank you for your participation in this questionnaire. By participating you are helping me to complete my graduation project successfully.

For any questions or remarks you may contact me:
Sanne Theresia Huberdina Metten, Creative Technology at the University of Twente
s.t.h.metten@student.utwente.nl

Or my supervisors:
Ir. ing. R.G.A. Bults
Coordinator graduation projects Creative Technology & SmartXp supervisor at the University of Twente
r.g.a.bults@utwente.nl

Dr. K. Zalewska
Programme coordinator/lecturer at Creative Technology at the University of Twente
k.zalewska-kurek@utwente.nl

If you have any complaints about this research, please direct them to the secretary of the Ethics Committee of the Faculty of Electrical Engineering, Mathematics and Computer Science at the University of Twente, P.O. Box 217, 7500 AE Enschede (NL), email: ethics-commewi@ utwente.nl)

D Consent form

Dear participant,

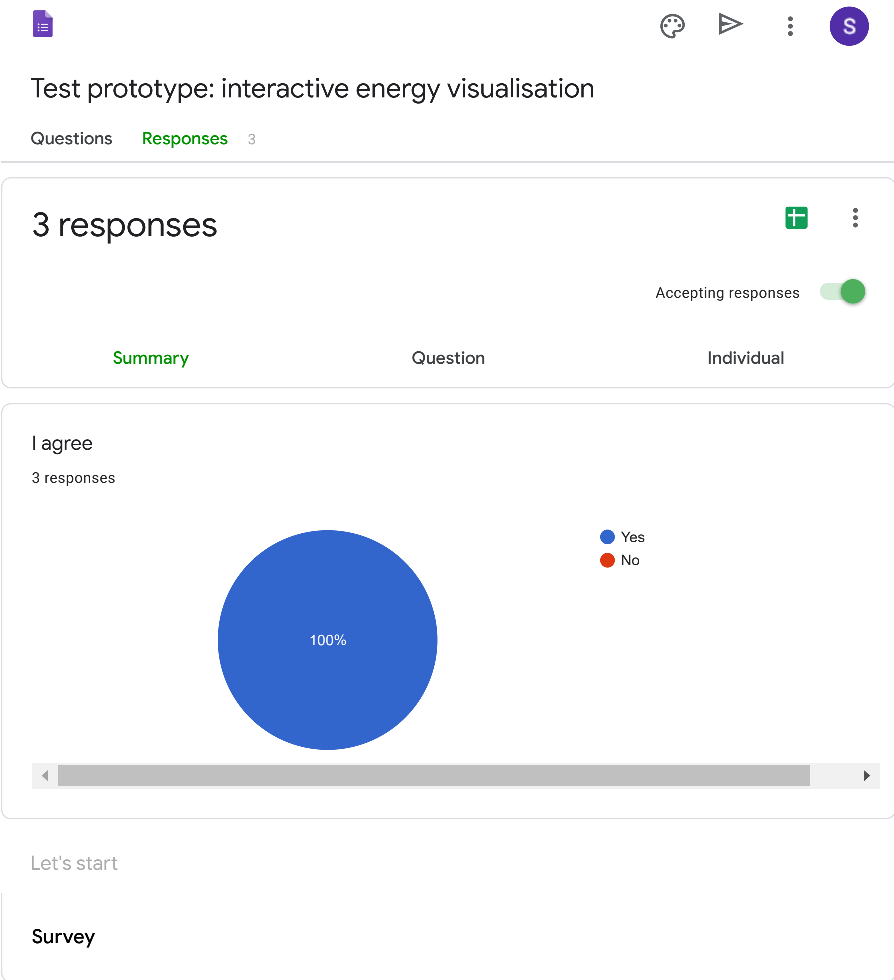
In this research you will be asked to assess a prototype. This prototype is an interactive interface designed to be placed on touchscreens in the Zilverling, University of Twente (UT). The purpose of this prototype is to make the UT community (students, staff members and visitors) aware of the energy consumption at the UT. With this prototype you can choose which energy source you want to view and get insight in the amount of energy that is consumed in the Zilverling. This online questionnaire should take no longer than 15 minutes.

Before you start, I ask you to agree to the statements below. I hereby declare that:

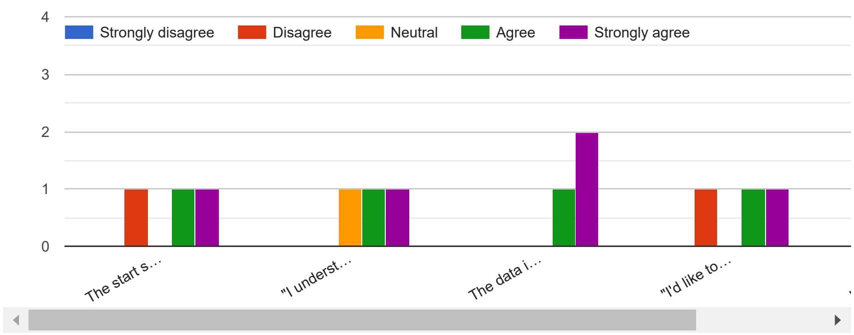
- I know that I have the right to withdraw this consent without giving any reason and I am aware that I can withdraw from the study at any time.
- I know that if my research results are used in scientific publications or otherwise made public, they will be made completely anonymous.
- I am aware that my personal data will not be provided to third parties without my express permission.
- I know that if I want more information about the research now or in the future, I can contact Sanne Metten (tel: +31 (6) 58 98 19 88, e-mail: s.t.h.metten@student.utwente.nl)
- I know that if I have complaints about this research I can address it to the secretary of the Ethics Committee of the Faculty of Electrical Engineering, Mathematics and Computer Science at University of Twente, P.O. Box 217, 7500 AE Enschede (NL), e-mail: ethics-comm-ewi@utwente.nl).
- I voluntarily agree to participate in this study.

E Survey results

E.1 First user test



Start screen



What could the start screen improve on?

3 responses

I would use a different green for the background, a less blueish green

the colors match ugly,
took a while before i saw the persons in a household
student and staff option in the middle

Maybe an option to check the energy consumption on a weekly or yearly basis.

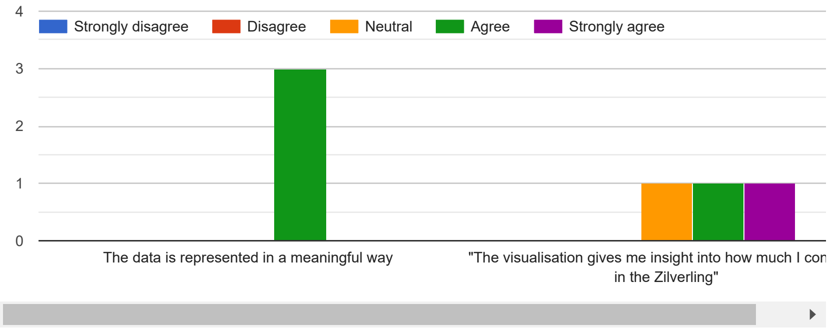
Other remarks

1 response

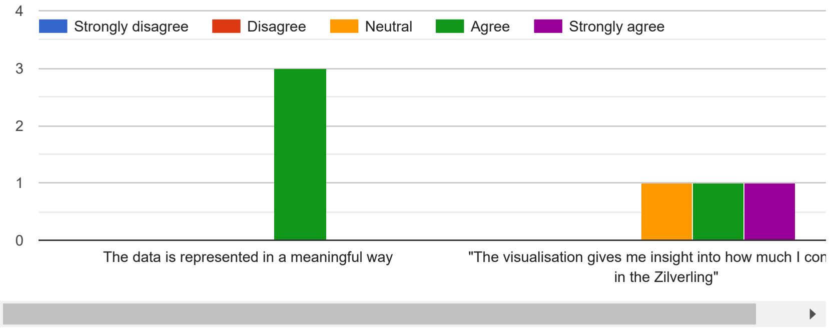
I think all the animations look really nice!

Own energy consumption

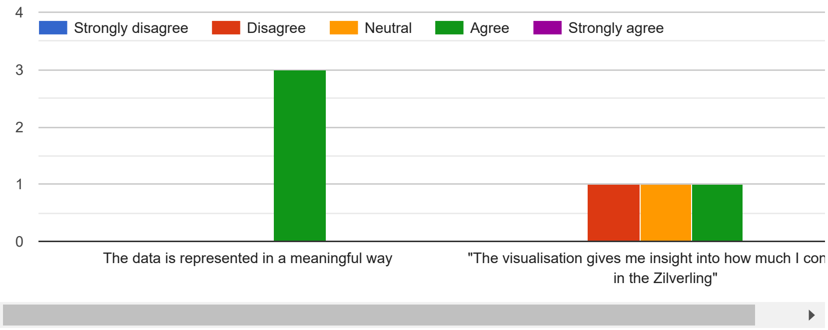
Electricity screen



Water screen



Heat screen



What could these screens improve on?

3 responses

Sometimes when a had a really good look at the screen it went back to the main screen too soon, so maybe make it 10 seconds in stead of 5

1 laundry isn't much in my head, maybe add something like: 18 times charging your phone because 18 is higher than 1 it is directly more in my head

Displaying the heat energy in the amount of tosti's that can be prepared does not really give a good picture/comparison of the amount.

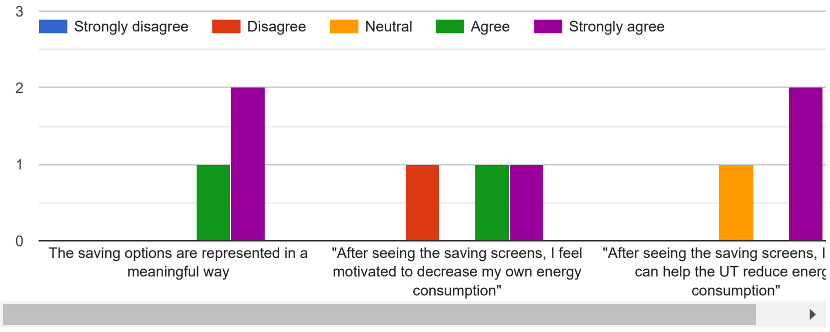
Other remarks

0 responses

No responses yet for this question.

Save energy

Saving screens



What could these screens improve on?

3 responses

In the second one (the toilet one) it was a bit hard to see the white toilet on the light blue background

higher the amount of, so you get suprised by the huge amount, also for things like 1kwh make that 1000wh than it sounds more
more matching colors

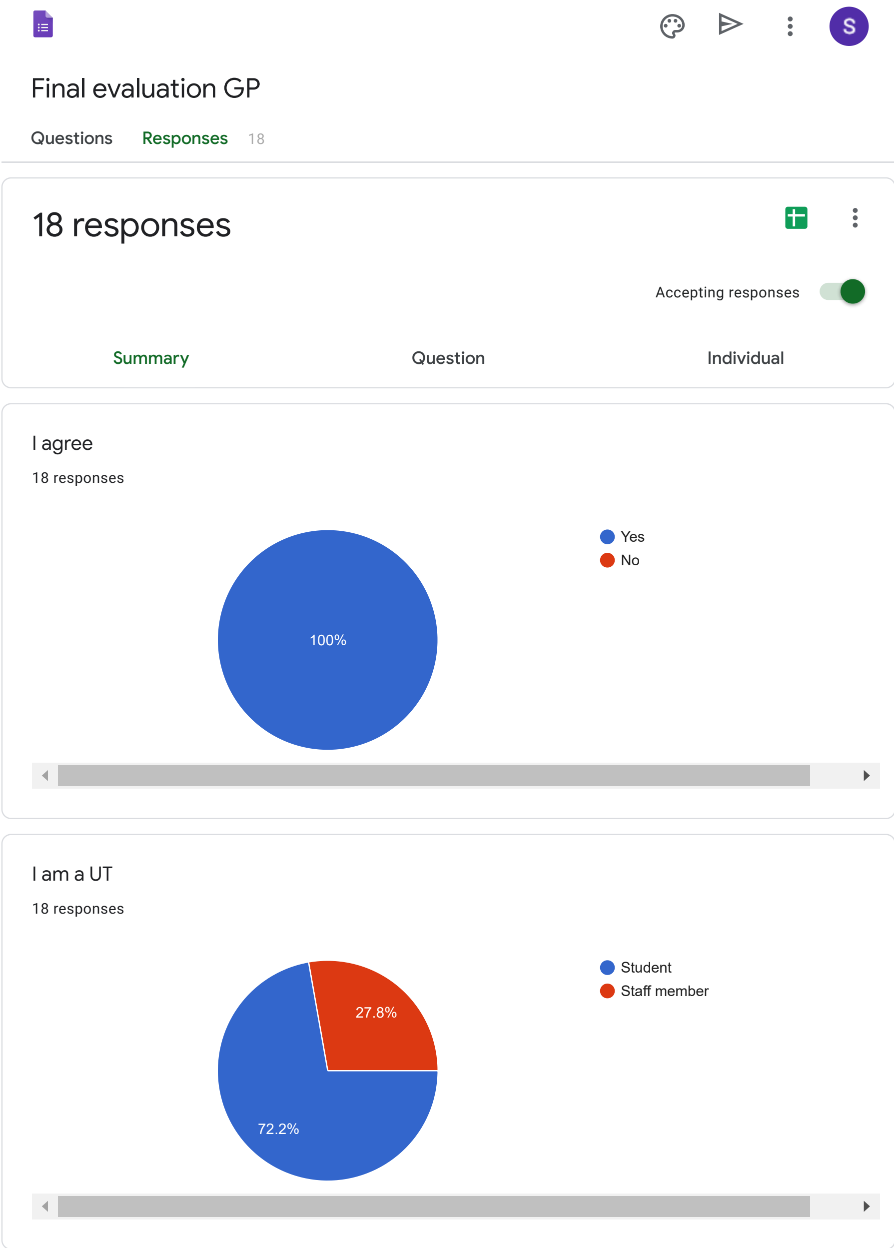
More suggestions ;) I really like this because it shows you how the little steps could reach big goals if the isers change their behaviour

Other remarks

1 response

In between the three round buttons at the bottom of the screen there are two dots in the middle, but i don't see what they are for? And the student/staff buttons still turn green when you hover over it but you cant click on them. And i was wondering how you go from the information screens to the saving screens, or will they be displayed on two different screens in the installation?

E.2 Final evaluation survey



What is your first impression of the interactive energy data visualisation?

18 responses

Nice and stylish

Looks appealing and pleasant, pretty clear where the buttons are and the fact that there are few buttons makes it very easy to navigate

Calm, inviting, want to explore

Looks really clean, super nice animations.
The animations are a bit slow though as it takes them a while to pop-up and for the values to get to their final value. The rest is nice!

It looks nice and understandable, all text is readable and I enjoy the auto-animations

Looks cool, though I'd prefer to also be able to view it in landscape mode

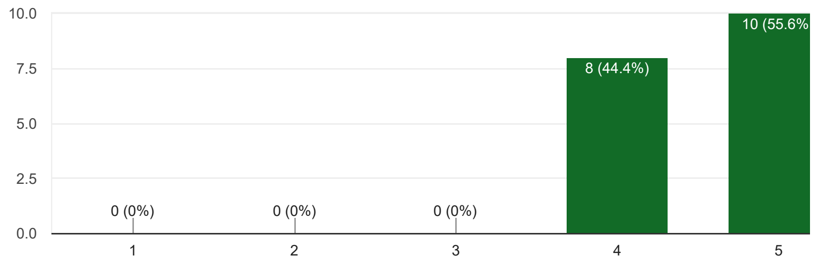
Looks really good, the animations are really nice and look professional

It gives a clear overview

What is your opinion on the following statements?

The interactive energy data visualisation is appealing

18 responses



What is it that you like about the design?

18 responses

Clean and easy to understand, style is consistent. Colors make sense

animation, icons, colors

Simple, good overview

The playfulness of the experience, fun icons, images and animation

It is clear and understandable, the instand change just from the switch of one toggle e.g. the animations, also the use of icons

Its consistency and how everything matches (colors of water, fire & electricity)

It’s very simple and clean

The colours are appealing. The animations are nice.

Recognizable and simple shapes, visual clues rather than text

What is it that you dislike about the design?

18 responses

The yellow letters are hard to read

nothing really

With some colours (yellow, aquamarijn) it is not clear what is displayed inside (on my computer). No title? How can you relate the energy consumption of all people in a building to your individual contribution? I find the link not that strong (yet)

If you want to click things fast and see things fast, it's not really possible

The colors could have been combined better and I would remove the background image of the uni

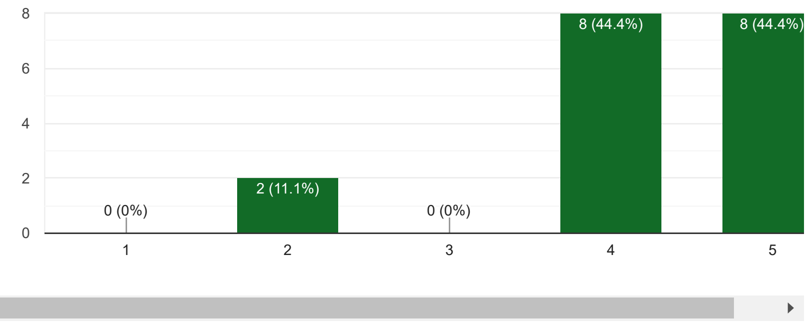
That it seems to only be available in portrait mode

Nothing, I think it’s a nice and well thought out looking design

I dont understand how water consumption per student is displayed as a shower with minutes and for staff with a faucet. Moreover, in electricity for student it says that today's electricity

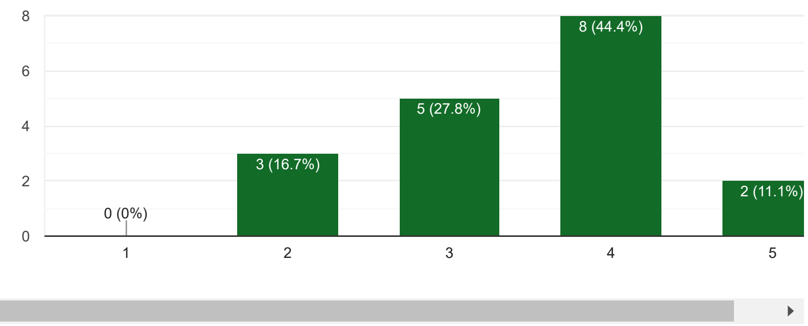
The data is presented in an understandable way

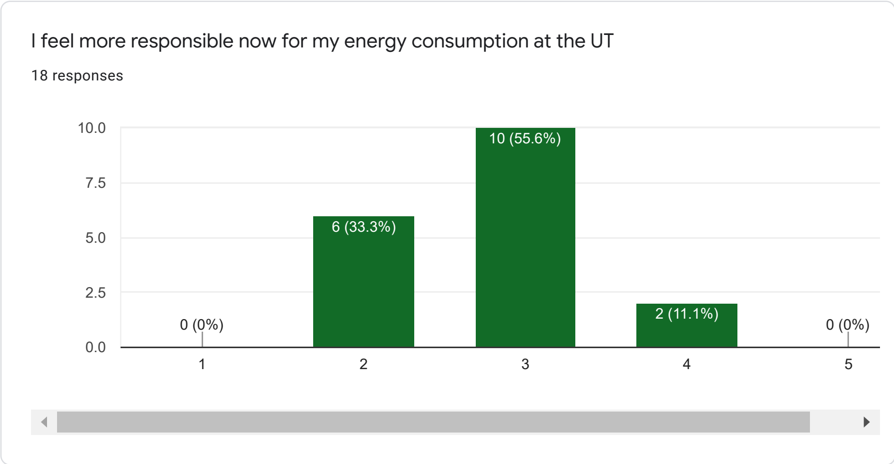
18 responses

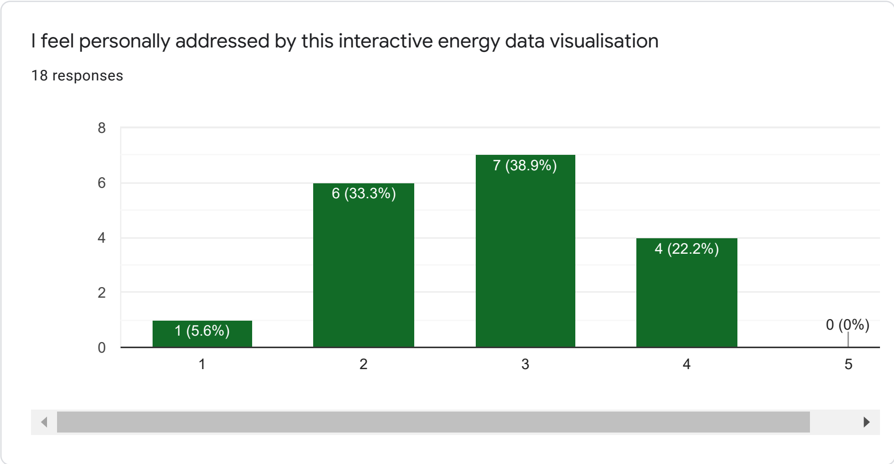


I became more aware of my energy consumption at the UT

18 responses

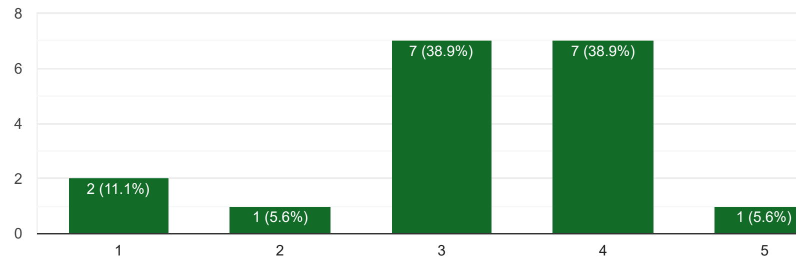



I feel more responsible now for my energy consumption at the UT
18 responses
10.0
7.5
5.0
2.5
0.0
0 (0%)
6 (33.3%)
10 (55.6%)
2 (11.1%)
0 (0%)
1
2
3
4
5


I feel personally addressed by this interactive energy data visualisation
18 responses
8
6
4
2
0
1 (5.6%)
6 (33.3%)
7 (38.9%)
4 (22.2%)
0 (0%)
1
2
3
4
5

I feel motivated now to reduce my energy consumption at the UT.

18 responses



Why?

15 responses

It is hard to place this in perspective right now :), but I think if this is in the buildings and is moving it could very well work

Intrinsic motivation, the number are hard to pinpoint as there is no comparison data or score which tells if energy consumption is moderate, excessive or something else

I usually don't use much energy at the UT. Also, when I saw the numbers, I was like: "Hmm that's not that much" it didn't really feel like it was a lot. Also in general I'm the type of person that doesn't see the point in changing things if it doesn't have any impact, my energy decisions won't change anything, only if everyone does it it will..

I guess no shocking emotional content was provided or no consequences of me reducing my impact, it was just visualized information and all of us are super used to this nowadays, I believe it needs to be more emotionally engagging

I don't feel like I contribute much to the consumption of the university (especially now with corona), but also because I charge most of my devices at home and use most of the water there for example. And I cannot really do anything about the lighting and heating of the uni (I think)

What was unclear about the suggestions?

6 responses

The little button with the leaf in it was hard to identify (on my computer). In the example with the toilet and two buttons I could not see the two buttons

Suggestions were clear! No problem there. The button however is very small. Colors correspond with the suggestion, but color is also confusing as it is the same for student/staff button.

Nothing, really nice

What to expect when pressing a certain button

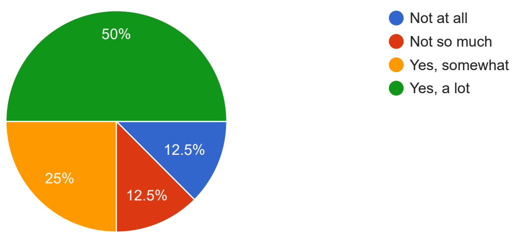
nothing

nothing, but the previous time I didn't fill in an answer the questionaire did not properly fuction anymore

Have a look at the prototype once more and wait for a few seconds before pressing on a button to see the suggestions pop up.

Did this make the interactive energy data visualisation easier to use?

8 responses



Comparing to the Energy Data Platform

What is your first impression of this energy data visualisation?

18 responses

Nice, lots of data

hard to understand and navigate, boring visualizations

Much text, which makes it not so inviting. Looks very technical. You can do more detailed analysis than the other prototype (for instance select time window) but it gives impression of being meant for techy people

A bit basic, boring. But functional and maybe better if you want raw data.

It is just graphs, definitely not so engaging or instantly understandable

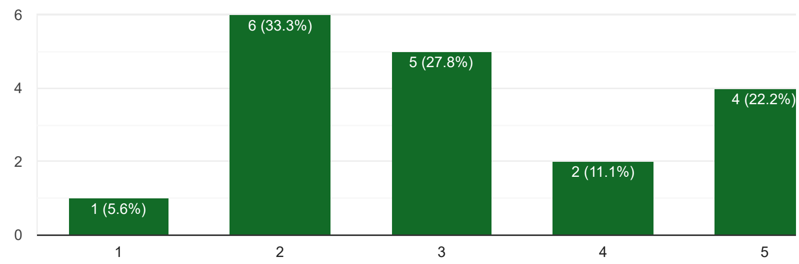
Very detailed

Too many things to choose from and hard to interpret

Clear overviews

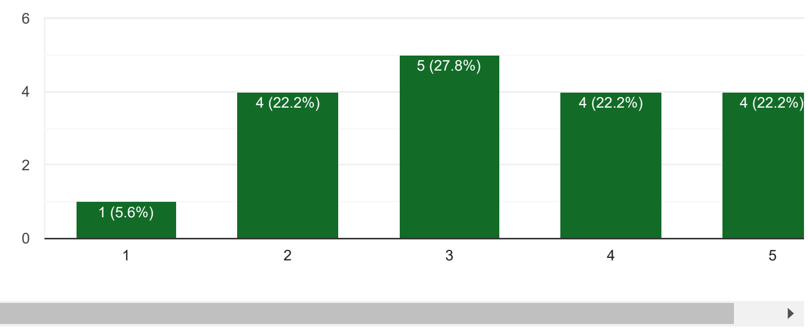
The Energy Data Platform is appealing

18 responses



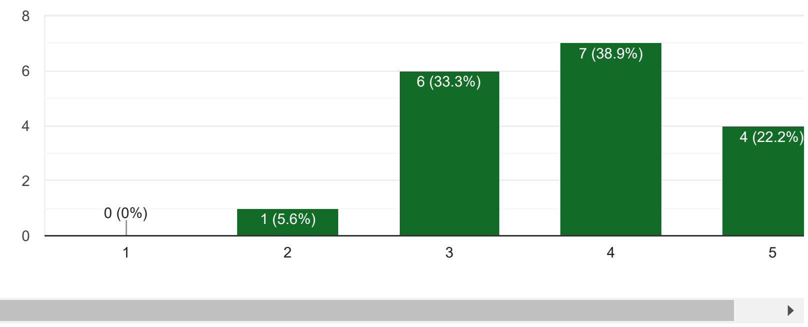
The data is presented in an understandable way

18 responses



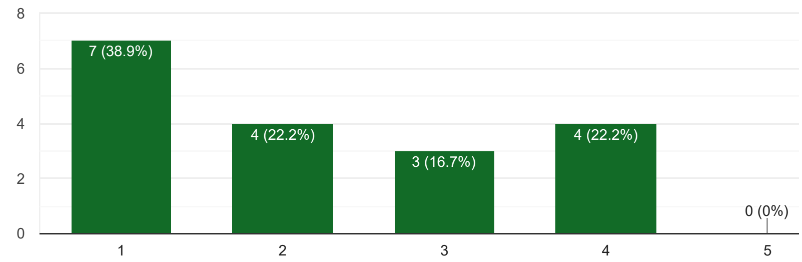
The Energy Data Platform is easy to use

18 responses



The Energy Data Platform makes me aware of my energy consumption at the UT

18 responses



Remarks

What could the prototype you have tested earlier improve on?

15 responses

In functionality, right now it is very one way: you can only click one thing and have to end a cycle before switching to the next one. Overal visual style is very appealing

in some visualization the amount is only written and not graphically represented, like in water consumption visualization... maybe you could find a way to represented visually too, by filling a bucket or something like that

Incorporate a benchmark to put the energy consumption in perspective and compare it with other buildings, certain targeted energy consumption etc.

Being able to see energy consumption over time (do we improve or do we do worse?)

Show actual numbers as well as "how many phone charges" etc.
Faster animations
Maybe go back in time option(graph)

Emotional content

Other remarks

9 responses

Looks good ;)

Good initiative; good first prototype. Good luck with your GP!

Nope, haven't got any

I really like the look and interaction

Good job on providing just enough information in each section!

Overall I am impressed

suggestion in it use: for it to be effective in terms of impact on persons to possible change would need it to pop up on led screens once in a while - as reminder to people & especially at those times when usage is very high.
might also be nice to see in one page a comparison how on is doing in terms of energy use in one building versus another (to possibly increase motivation amongst persons to do better).

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