Gemeente Enschede

Climate measurements in public spaces

By: Laura Kester

Date: 12-07-2018

Final version

Supervisor: Hans Scholten

Critical observer: Richard Bults

A Creative technology graduation project

image by Tom Rossiter Photography via CTBUH

Abstract

The urban heat island effect is responsible for higher temperatures in urban areas than in rural areas nearby. With most of the worlds population living in urban areas the high temperatures in these areas are a concern for public health. The municipality of Enschede is concerned of this issue and therefore interested in the magnitude of the urban heat island in Enschede. At the end of last year, the concept of monitoring the urban heat island effect with autonomous sensor nodes was proven to be effective. The goal of this project was to improve the design of the sensor node, so it would be able to give a better image of the urban heat island effect of Enschede.

To achieve this goal the phenomenon of the urban heat island and its drivers were researched and with the help of the stakeholders, requirements were setup. A system to meet these requirements was designed using an adapted version of the cyclic design model. Three generations of prototypes were building to evaluate the functionality and accuracy of the design. The results from these prototypes were analysed using data from one of the weather stations of the faculty ITC and used to improve the next prototype. This resulted in a sensor node which measures air temperature, humidity and wind speed with an accuracy relevant for gaining information about the magnitude of the urban heat island effect in Enschede and which can withstand the climatological conditions in Enschede. This node is autonomous as it generates its own power and sends data wirelessly over the LoRaWAN network. This gives a huge freedom of placement as it does not need any infrastructural changes before it can be placed. Next to this, the sensor node is relatively cheap and easy to manufacture. Allowing for a flexible system which can be adapted and expanded with relative ease.

Acknowledgements

This report is the result of half a year of hard work and I am very proud of the result. But I could not have done this project on my own. First, I would like to thank my supervisor Hans Scholten and my critical observer Richard Bults for discussing my ideas with me, pushing me to know what I was talking about and helping me in the right direction. Their feedback has made a real difference in getting this project at the level it is now.

Next, I would like to thank my stakeholders. Hendrik-Jan Teekens, the contact at the municipality, Hendrik-Jan has supported the project greatly and provided valuable information for the goal and requirements of this project. I would like to thank Wim Timmermans from the ITC for our insightful conversations about the urban heat island and for giving me, together with Murat Ucer, the opportunity to compare my sensor data with the data from the weather station on top of the ITC hotel.

Last, I would like to thank some of my fellow students. Adam Bako for sharing his ideas with me and for the teamwork during the first part of this project. Dennis Vinke for helping me debug and for reducing my stress when I was completely stuck after many hours of programming. And Jonathan Juursema for programming the back-end of the system which makes communication with the server possible.

Table of Contents

Table of figures

Chapter 1: Introduction

1.1 Problem statement

Urban areas have been growing steadily over the last 50 years. According to data from the world health organisation in 2020, 56,22% of the world population will live in urban areas. In Europe this percentage is ever higher with 74% in 2017 [1]. This urbanisation gives rise to a new set of problems and challenges. One of them is controlling the climate in these areas. It is known that the average temperature in urban areas is higher than in the surrounding rural areas. This is called the urban heat island effect later referred to as UHI. The larger the city, the extremer the urban heat island effect [2] [3]. This effect causes an increase of air pollutants due to increased use of electricity [4] [5]. The combination of the extreme heat and pollution leads to an unhealthy living climate [3] and an increase in mortality rate [6] [4]. The urban heat island effect is caused by several drivers. These drivers interact in a complex system and can greatly influence each other. The expression of the UHI differs greatly per city and climate, but in general five main differences can be seen between cities and rural areas in relation to the UHI:

- Decreased evapotranspiration
- Increased anthropogenic heat release
- Low albedo of surfaces
- Increased amount of greenhouse gasses
- Lack of airflow

For some of these definitions the meaning is clear. Some need a bit more explanation. Starting with evapotranspiration. This is the evaporation of water which is contained in all kinds of sources. This can be water contained in vegetation, concrete, soil etc. Anthropogenic heat release is also an uncommon term. It means the heat that is released by human activity. This includes sources like industry, air-conditioning, traffic and even livestock. Albedo is also a term that might be unfamiliar to some readers. Albedo of a surface is a value from 0 to 1 that specifies how much incoming solar radiation is reflected. For example, asphalt has an albedo between 0.1 and 0.2. This means that 10-20% of the incoming sunlight will be reflected. The rest will be absorbed and converted to heat. The higher the albedo the more radiation will be reflected.

The municipality of Enschede

The first stakeholder in this project is the municipality of Enschede. Enschede is a medium size city in the east of the Netherlands. The municipality of this city counts more then 150.000 citizens, of which a great majority live in the city itself. The urban heat island has been a known phenomenon for many years but is most apparent in large cities. In the inner city, citizens experience extreme temperatures in the summer, with city centre squares reaching 37.8 degrees in the shade and up to 60 degrees in the sun during heat waves [7]. Now, the urban heat island effect is also on the political agenda of the municipality. That is why they want to get a better understanding of the problem. It is not clear for the municipality what the size of the issue is, if the problems are caused by the urban heat island effect and which locations are affected most. Their goal is to get informed about the urban heat island effect in Enschede by getting a more detailed view on the scale and urgency of the urban heat island effect in Enschede. This can help them assessing the severity of the problem and, if necessary, take precautions.

Faculty ITC

The second stakeholder is the faculty ITC of the University of Twente represented by Wim Timmermans. The faculty ITC is the Faculty of Geo-Information Science and Earth Observation. Wim Timmermans is a researcher at the faculty ITC and has extensive knowledge on gathering weather data. Currently he is working on a model which, with input from the measurements taken by the faculty ITC and a network of private weather stations, can predict the temperature of specific locations in the city of Enschede. The current model has a resolution of 60m x 60m. Wim aims to improve this resolution and make his model more precise by using the data gathered by the sensor nodes from this project as reference.

The municipality of Enschede and University of Twente faculty ITC are working together on the project 'heat measurement in public spaces'. The past half Year, six heat measurement sensors were developed and distributed through Enschede. The goal of this project is to improve the existing sensor network. This will be done by making improvements on the current design guided by the findings of Tom Onderwater's research [8], expand the size of the sensor network and include new sensors to measure parameters which have a strong correlation with extreme temperatures in cities due to the urban heat island effect. To reach this goal it is important to first, understand the system of drivers causing the heat island effect. Then, evaluate measuring which parameters could contribute to a better insight in the urban heat island effect, and design the new sensor in such a way that measurements of these parameters can be collected.

1.2 Statement of research questions

To achieve the goal of this project, the following research question need to be answered:

How to develop an outdoor sensor system that measures dominant variables linked to the drivers causing an Urban Heath Island effect in the city of Enschede?

To answer this question, first a set of sub questions need to be answered. Before anything can be build is important to determine which of the variables involved in the urban heat island effect are dominant in a medium size, moderate land climate city like Enschede's. The first sub question is therefore as follows:

Which variables are dominant in gaining insight in the drivers behind the urban heat island effect?

Second, it is crucial to find out how these variables can be measured with a relevant accuracy, so that the data generated can be used for gaining a better understanding of the heat island effect in Enschede. Therefore, the next sub question is:

How measure these variables with relevant accuracy?

Last, the sensor nodes still need to be self-contained without the need of an external power supply, so the power supply should still be able to power the node regardless of added sensors. Because of this, the following question needs to be answered:

How to implement the extra sensors and power supply in such a way that sensor nodes can be stand-alone for at least a year?

Chapter 2: State of the art

Measuring environmental factors and using sensor networks to monitor cities has been done before. To get an idea of what technologies are already out there, state of the art research was performed using both scientific and non-scientific sources. This chapter summarises the results of this research in 5 parts. First the urban heat island effect will be explained further, followed by a description of the previous project and its results. Additionally, an overview of other IOT[1] based networks collecting climate data will be given. Next, a literature research into relevant parameters to measure will give more insight in which parameters are important to measure. The outcome of this literature review is then strengthened by the expert opinion of Wim Timmermans[2].

2.1 Understanding the urban heat island effect

In the introduction the five main drivers behind the urban heat island effect were introduced shortly. To get a better understanding why these drivers are so important and how they interact a literature review was done. The findings of this review are documented in this paragraph.

Five main drivers of the UHI effect can be identified from literature. First of all reduction in evapotranspiration is described as an important driver, but not all sources agree on the causes of this phenomenon [9] [10] [11] [12] [5]. This is caused by a scarcity of soil water [9] [10]. Most water in cities is directly carried away through the sewers and does not penetrate the surface, so there is no water left in the ground surface to evaporate and cool down the city. In ward et al. [9] Jiachuan et. al [11] and Nuruzzaman [5] it is explained that evapotranspiration can also be inhibited by large soil sealing, but different reasons for a large soil sealing are given. Most sources give pavement as most important reason. Rehan [9] argues that large grassy areas also play an important role but does not elaborate on the climate conditions in which this effect takes place. Other sources explain that grassy areas can act as a mitigation strategy in certain climate conditions, further weakening the claim made by Rehan [3] [2].

Second, anthropogenic heat release has a large effect on the temperature in a city. Climate control systems are a large contributor to anthropogenic heat release [5] [13] [14]. Especially in the summer when the UHI effect is the most extreme and large amounts of heat need to be dissipated from buildings. Rehan [2] and Jabareen [3] suggest the busy traffic in many cities also contributes to the anthropogenic heat release. Although this sounds like a very logical cause for anthropogenic heat release, it in not supported in other sources.

Third, the low albedo of commonly used building materials can add to this effect [5] [15] [12]. Low albedo of asphalt and concrete, building materials which are often used in cities, results in absorption of sun radiation [10] [14] [5] [12]. This process heats up both the ground surface and buildings. This also slows down the cooling process at night as the absorbed radiation is slowly released into the atmosphere.

Forth, Nuruzzaman [5] Mohajerani et. al [10] and Qin [15] elaborate that large amounts of greenhouse gasses in a cities atmosphere can trap heat inside the city, but here is some debate about the main cause of this. The sources state that this is caused by an increased energy use in the summer. Vamos et al. [4] and Jabareen [3] agree on this but add that the amount of traffic in cities is also an important contributor.

Lastly, the lack of airflow through a city increases the effect of all factors above. Heat radiating

[1] Internet of things. See appendix N for more explanation

[2] More information about Wim Timmermans can be found in the introduction under the heading 'faculty ITC'

from pavement or anthropogenic heat release can not be dissipated and gets trapped between high buildings [5] [14] [16]. Thus, increasing the heating effect of the previous four drivers. It seems, some cities are less affected by this effect than others, because it does not come up in other papers. It is unclear why this is.

These five drivers are not stand alone. They interact with each other in multiple ways [17] [14] [11] [18]. These interactions are explained by the diagram below.

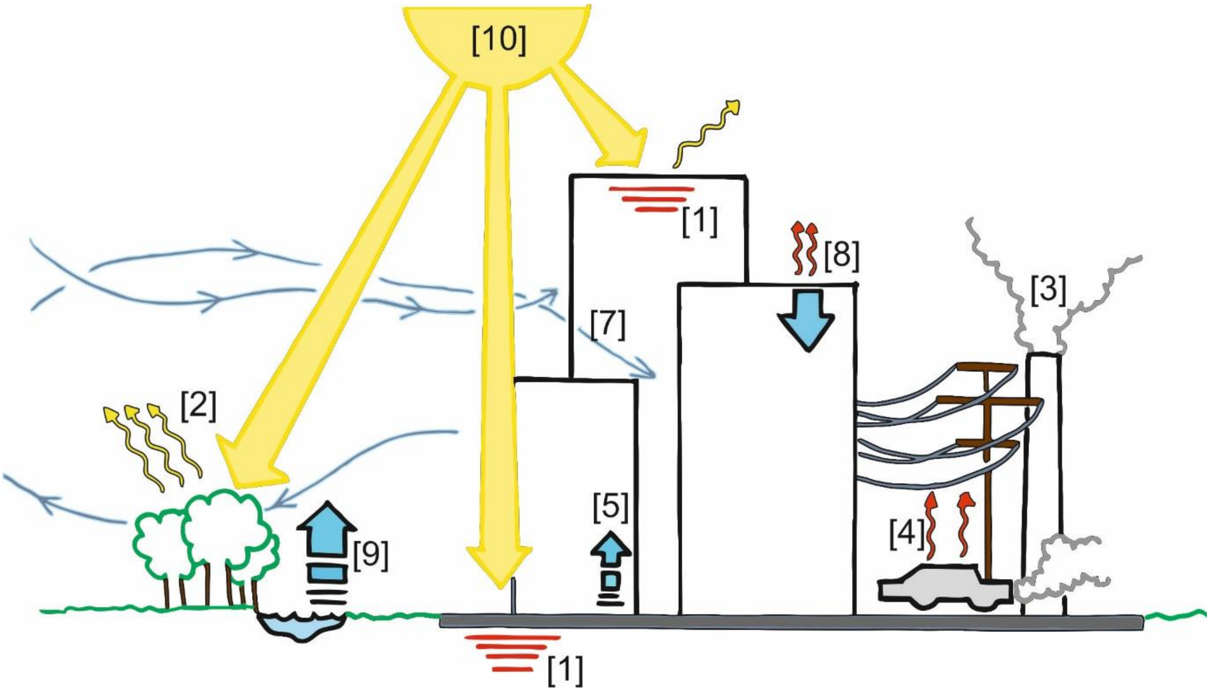


Figure 1: Graphic representation of heat island

The sun radiation hits concrete and pavement (1). Due to its low albedo it does not reflect the radiation but absorbs it. This heats up buildings and ground surface. In rural areas the surface has a higher albedo and more radiation will be reflected (2). In the urban areas large soil sealing and lack of surface water inhibits the ground surface to cool down via evapotranspiration (5). In rural areas evapotranspiration from the surface and ground water cools down the atmosphere (9).

The heated-up buildings are cooled by climate control systems. These systems release their heat in the atmosphere and use a lot of power (8). This increases the total anthropogenic heat release. Increased power use leads to an increase of greenhouse gasses released into the atmosphere by power plants or generators (3). The large amount of traffic in cities also release their heat, adding to the anthropogenic heat release, and exhaust into the atmosphere (4). The greenhouse gasses trap the heat between the tall buildings. Buildings also inhibit airflow, so the heat cannot be dissipated.

2.2 IOT networks collecting climate data

Greenhouse Environment Monitoring System Based on IOT Technology

To make greenhouses more efficient, close monitoring of environmental factors is necessary to make sure the climate is ideal for the crop to grow. In L. Dan et al. [19] a low cost, low power IOT network for monitoring environmental factors is described. The network is based on the CC2530 ZigBee. Nodes measure temperature, CO_2, humidity and light intensity. Data gathered by the network can be used to control climate conditions. The paper concludes that using the network improves operational efficiency and flexibility and reduces manpower costs.

Design of sensor network for urban micro-climate monitoring in Abu Dhabi

The goal of this project [20] was to achieve a more efficient urban infrastructure by developing an appropriate framework for monitoring, modelling and manipulating urban micro-climates. The sensors were designed to be put partially inside a light pole. A big solar panel on top of the light pole charges the battery which powers the large sensor nodes. Because of the capacity of this setup there are few restrictions on power usage, resulting in the sensor being able to function completely autonomous. It measures multiple parameters like: wind speed/direction, infrared, position and temperature at different heights. The data is used to verify satellite data and the model.

IOT based smart system for controlling CO2 emission in India

The project [21] uses a Raspberry pi embedded into a cloud server to monitor and control air pollution in a large city in India. A temperature, humidity and carbon sensor are connected to the Raspberry pi. The pi sends the sensor data to a server. The server collects the information from the different nodes, after which users like local authorities are able to check the atmospheric status. Real time monitoring of particular places enables the government to take more suitable measures and maintain a better air quality.

Array of things: Chicago's wireless sensor network

The Chicago wireless sensor network [22] is one of the most extensive networks in the world. 300 nodes are already distributed through the city streets and collect data on a wide variety of parameters. The nodes measure: temperature, humidity, barometric pressure, light, noise, and vibration. Next to this, the nodes also feature air-quality sensors which will measure the presence and concentration of up to eight different gasses. Activity sensors measure standing water and urban flooding while counting pedestrians, bicycles, cars, trucks, and buses. Once the data is processed it will be used to make sensible improvements on infrastructure and city services. The data is publicly available, so citizens can personally benefit from the data by being able to choose a less busy way to work or avoid asthma triggers. The array of things has partners in 15 different cities who want to place a sensor network in their own city.

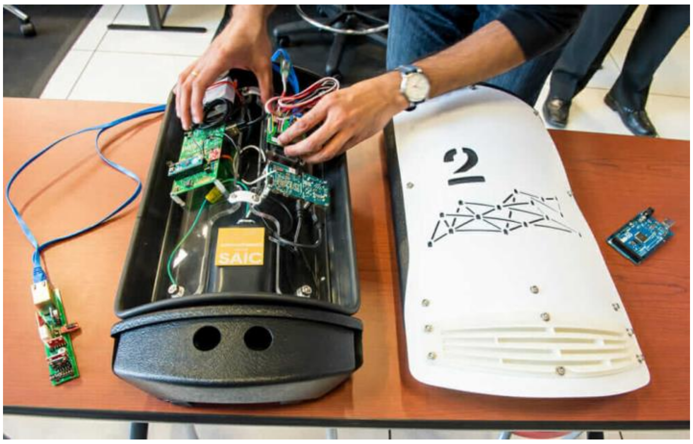


Figure 2: Prototype of an Array of things sensor [22]

Smart City: An urban Internet of Things experimentation

The internet of things network in Padova [23] is a pilot project form the university of Padova and the municipality. The project consists of wireless nodes equipped sensors measuring air pollution, temperature, humidity, noise. Next to this it also monitors the traffic lights. The self-contained nodes are powered by batteries, except one node which has a dc power supply. This is because its benzene sensor, which needs significantly more power. The nodes communicate with a server via the 6LoWPAN protocol which is energy efficient, but still allows for a IPv6 address. Especially the communication protocol in this project is very sophisticated. The system is very energy efficient as batteries only have to be replaced every other year.

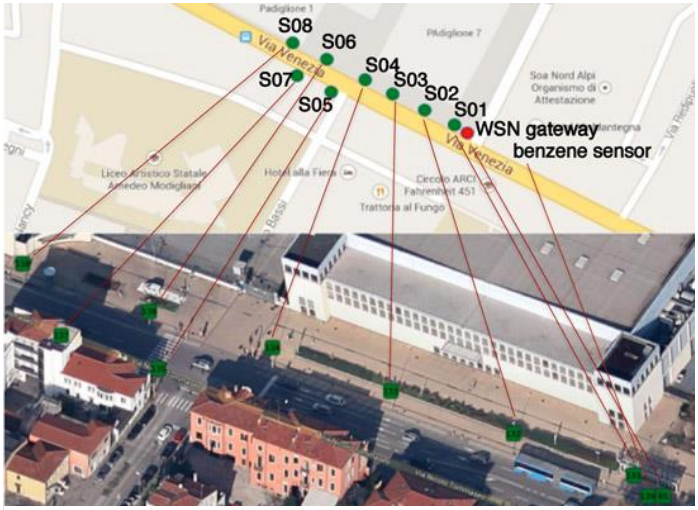


Figure 3: Positioning of sensor nodes in Padova [23]

Busan: smart city

The Busan city network [24] aims to improve city planning and infrastructure, quality of life, public transportation and disaster management. To collect large amounts of environmental and situational data, large amounts of nodes and multiple sensors are needed. This data will be collected by different smart sensor nodes embedded in existing city infrastructure like street lamps, roads and parking lots. The system will also make use of existing urban sensors like CCTV and satellite data. Although the system is not operational yet, the government aims to have it operational in 2023. Parts of the system that are already operational are the CCTV network and the free Wi-Fi access for citizens. Next to this, the ICT infrastructure necessary is already in place.

2.3 Current sensor design

During the previous project an autonomous sensor node was developed by Tom Onderwater. The node consists of three main parts. The hardware, software and communication. The microcontroller is the Sodaq one development board [8]. It is able to use the LoRa protocol for communication and is compatible with the Arduino IDE. The Temperature sensor, DS18B20, is connected to this microcontroller [8]. This is powered by a LiPo battery with a capacity of 1200mAh. The battery gets charged during the day with a 1W solar cell. The entirety is encased in a water-resistant PLA casing. The casing is designed in such a way that the temperature sensor can come into contact with the outdoor air without being exposed to sunlight [8].

The software is designed in such a way that its processes are energy efficient. Because of this the microcontroller is in sleep mode for most of the time. Every five minutes the timer wakes up the sensor. Then, the microcontroller tries to get a fix on its GPS location. If this is not successful it uses the previous location stored. Next, it reads out the temperature sensor and formats the data in such a way that it can be send using the LoRaWAN network and will be understood by the server. After sending the data, the cycle timer is activated and the microcontroller goes back into sleep mode. [8]

As said before, communication of data goes via the LoRaWAN network. This is a low power wide area network which is very suitable for IOT applications. It offers radio coverage over very large areas which is made possible by using a very small transmission band. Because of this, devices cannot send large amounts of data over the LoRa network. Nevertheless, due to the low power and wide range it is still very suitable for this sensor node. The sensor nodes communicate to various public base stations situated all over the city, where the information gets forwarded to a server. [25]

2.3 LoRaWAN

The communication network used in the design of Tom Onderwater [8] is called the things network. This network is an open infrastructure supported by its own members. The communication technology used is LoRaWAN. This is a high range, low bandwidth, low power communication network. The nodes in the network communicate with gateways on the 868Mhz frequency. These gateways are connected to the internet, so data can be forwarded to the database. Due to the long range and low power constraints the LoRaWAN network has a very small bandwidth. Next to this, it has a maximum duty cycle of 1%. The application payload per packed in Europe ranges from 51 to 222 bytes. The protocol always takes up at least 13 bytes of the payload. To make sure the network can be used by as many devices as possible the Things Network (TTN) regulates the amount of data each end device is able send. For now, these regulations do not have to be strictly followed but are guidelines of the fair access policy. This may change in the future when the network will be more widely used. The TTN fair use policy states that an end device can have 30s of uplink time on air per day and at most 10 uplink messages including acknowledgements. If messages need to be send every 5 to 10 minutes, this adds up to a payload of 12 bytes per message [26].

2.5 Parameters for measuring the urban heat island effect

The urban heat island is often measured by differences in temperature, but there are multiple drivers which affect this which are defined in paragraph 2.1. The interaction between these drivers can differ greatly between urban areas, especially when these areas are located in different climates with varying infrastructure. To better understand the urban heat island effect in a certain area, it is important to collect information on these drivers as well. Therefore, the goal of this review is to determine how to collect information about the interaction between the contributing drivers of the urban heat island effect. This will be done by addressing each driver separately and discussing possible measurement methods to collect information on this driver and can be implemented on ground surface.

First of all, the amount of evapotranspiration contributes greatly to the expression of the urban heat island effect, but it is difficult to get quantitative measurements. Differences in evapotranspiration can be found by measuring the gradient humidity [27] [28]. This method is fairly simple but can only measure differences in evapotranspiration instead of a certain amount. Another option would be to measure both the air and surface temperature [27]. These temperatures can be compared and from the temperature difference, information can be deducted. For example, if the surface temperature is close or lower than the air temperature, the amount of evapotranspiration is high. Nevertheless, it is impossible to determine the exact amount, because there are too many other variables involved [27]. There are other, more precise methods for measuring evapotranspiration, but they involve satellite imagery and large installations using electromagnetic waves to determine disturbances in the atmosphere and are therefore outside the scope of this project. Thus, regarding this project, high and low amounts of evapotranspiration can be determined by measuring the gradient humidity or difference between air and surface temperature, but it is not doable to get exact amounts from this data.

The next driver is the anthropogenic heat release, which is difficult to measure, and additional value of these measurements can be questioned. An increase in anthropogenic heat release, increases air and surface temperatures, which then results in more anthropogenic heat release by climate control systems [11]. Measurements of the amount of anthropogenic heat release involve complex models of the cities energy budget [17]. A very rough estimate could be made by looking at temperature and sun radiation [28]. With high temperatures and high solar radiation high anthropogenic heat release is expected. Therefore, air temperature and anthropogenic heat release have an almost direct link. This makes anthropogenic heat release more an enforcing driver in the already existent effect, resulting in higher extremes in temperature, instead of a direct cause of the urban heat island effect.

Furthermore, the effect of low albedo of surfaces can be determined by different effect and is especially important for determining local heat stress. To get information on this knowledge is needed on absorption of solar radiation. This is the most accurate variable in connection to albedo. A possible strategy when sensing on ground surface level is air temperature measurements above the surface combined with solar radiation measurements. If the albedo of a certain area is lower, high sun radiation will lead to a higher temperature above the surface compared to the average air temperature [11] [18]. Furthermore, measurements with light intensity sensors sensing light coming in from the atmosphere and the light reflected by a surface can be used for determining the albedo accurately [20]. Using both strategies, the heat stress increase during sunny and clouded periods can be determined, but this does not give much information on the total share low albedo surfaces have as cause of the urban heat island.

Next, the pollution from greenhouse gasses can be measured by a range of chemical sensors. There are many different types of greenhouse gasses that play a part in the urban heat island effect. Some of which can be sensed pretty straight forward with chemical sensors [29], but there are some challenges as well. Although the sensing process is straightforward, the mechanisms performing the measurements are not. There is a trade-off in most sensors between sensitivity and selectivity. Also, low durability of chemical sensors due to corrosion or other sources of decreasing sensitivity is an issue that is mentioned multiple times [29] [11].

Lastly, the airflow through a city can be monitored quite easily with a combination of wind speed and direction sensors scattered through a city and the sensors are placed in different layers in the urban canopy[3]. This is important because the airflow can differ per layer caused by the tall roughness elements (buildings) that make up the urban canopy [18]. The wind direction measured by the sensor nodes can be combined in a grid to give information about how the airflow moves through the city. Some sources note that it is necessary to combine this information with a simulation to get more valuable results [28] [17]. Thus, data on wind speed and direction are relevant regarding airflow, but more accurate results could be generated if the data is used in a simulation of airflow through the city.

In this survey six parameters could be defined which give information on the different drivers behind the urban heat island effect. These are humidity, solar radiation, wind speed, wind direction, chemical make up of the air and surface temperature. Comparing parameters from different sensor nodes or reviewing different values from one sensor node can give at least some information on all the different drivers. Some comparisons or measurements are more valuable than others in getting a better understanding of the different drivers and their role in a cities unique urban heat island effect.

[3] Urban canopy: The assemblage of buildings, trees, and other objects composing a town or city and the spaces between them.

Expert opinion

To get more practical information on measurements of variables related to the urban heat island effect, an interview was conducted with Dr. Wim Timmermans. Adam, another student doing a related bachelor assignment, was with me during the interview. Some of the questions mainly concerned my project and some where more focussed on his part of the project.

First, Wim was asked multiple questions on the feasibility and usefulness of measuring different variables regarding the urban heat island effect. He told us the usefulness of measuring variables depends on what you want to measure. Because Wim is coming from an agricultural climate measurements background, the field of urban climate measurements is relatively new to him. According to Wim, if you want to map the UHI, obviously you need to measure the heat. However, if you want to model the urban heat island effect, you need to know what the driving factors are. For that you could measure incoming radiation, solar radiation, and wind speed. In principle these factors are more or less sufficient. However, if you also want to map the problem which citizens are experiencing, it is different. There are days the temperature is 25 degrees, sometimes it's pleasant, sometimes it's not. In this case humidity is a factor as well. You can also think of additional factors as anthropogenic influences, exhaust caused by traffic etc. Then air quality becomes an issue as well. But then you go towards mapping something which is like a comfort index or something that's different from the UHI. If you want to add sensors: humidity, solar radiation and wind speed are good starting points to implement. For gaining more knowledge about air quality the CO2 level is a good indicator. This is done by ITC as well. Wim notes that this could be rather complicated to implement.

Next, Wim was asked about the frequency and accuracy of the data his project would require. He would like to have as much data as possible. But, he would be okay with continuous data every half hour. Here the continuity is important. If the sensor nodes manage to send data successfully 100% of the time this would be okay, but that is not the case. Another solution would be to receive data more often, so he might average it out. Then gaps in the data are not a big problem because there is still data available somewhere in the period of half an hour. The current accuracy of the temperature data (±0.5 degrees) is sufficient for him, but more accuracy would always be better. See appendix A for transcript

2.6 Conclusion state of the art

There are multiple things which came forward from the state of the art research. First of all, the five main drivers behind the urban heat island where determined. For all of these drivers at least one measurable variable was determined, which could provide information about how this driver expresses itself in the urban heat island of the city of Enschede: humidity, solar radiation, wind speed, wind direction, chemical make up of the air and surface temperature. These parameters can give some information on all the different drivers. Further selection of these variables will be done in later chapters.Furthermore, the existing sensor node from the previous project, its functionalities, hardware and software were explored and reported on. Comparing this to the six other IOT networks collecting climate data yields some interesting similarities and differences. Most important of which is that all but one of the similar projects found use existing infrastructure as power source. This limits freedom in placement of the sensors. Additionally, almost all the existing projects feature a large array of different sensors leading to a quite complicated and often expensive hardware design. Partially due to the power constraints, the hardware design in this project will be as simple as possible. This most likely makes the node easier and cheaper to produce. These two things make this project novel in its field.

Chapter 3: Methods and techniques

3.1 Design method

A design method that also seemed to fit this project was the iterative design process. The iterative design process in general is a design process in which, after determining preliminary requirements, a prototype was made. This prototype was evaluated with the requirements in mind. This evaluation was then used to determine the effectiveness of solutions, identify shortcomings and update requirements accordingly. A new and improved prototype was made keeping the findings from the previous evaluations in mind. This cyclic process is known to weed out unexpected inconsistencies among requirements and implementation, encourages more involvement of stakeholders during evaluation and puts focus on the most critical issues of a project without too many distractions. To determine which version of the iterative design process fits this graduation project the best two design methods were looked into further.

Design process for creative technology

The design process for creative technology [30] is a mix of principles from different design processes from engineering, software design and industrial design. It consists of four phases; ideation, specification, realisation and evaluation. The setup of this process is such that it allows for plenty of evaluation during the process and is very suited for a multidisciplinary project where stakeholders are involved. The phases are elaborated on below. A visual representation of the model can be found in appendix B

Ideation phase

During the ideation phase ideas are generated. during this phase the user starts with gathering information on requirements and studying related work. This is the time for observations and interviews with expert or client. Ideas are quickly documented in sketches and mock-ups. The goal of this phase is to generate a few clear ideas, which can be used in the specification phase

Specification phase

In the specification phase the ideas from the ideation phase are further developed. Early prototypes are used for feedback on experience and functionalities. This feedback is than used to further specify the idea, so the functional requirements become more and more defined. At the end of the specification phase, the requirements for the product are defined and the product idea is specified.

Realisation phase

These requirements and design are used to build a functional prototype. The product idea is decomposed in the smallest possible functional parts. These components are realized after which they are integrated one by one until the prototype is complete. Functional testing is done to make sure the functional requirements are met.

Evaluation Phase

This phase addresses the evaluation of the requirements identified in the ideation phase. This can be done by user tests. Often the stakeholders will be involved. The product can now be placed in the context of the related work.

The spiral model

The spiral model of Boehm [31] is a very suitable design method for this project. More about this model can be found in appendix B. This specific model was chosen because it has some fitting advantages next to the general advantages of iterative design. First of all, it is a good model when the stakeholders are unsure of their exact needs. This is the case in this project because the municipality of Enschede and the ITC both have a goal in mind for the data the sensor nodes will gather, but they have no clear vision on the requirements and design of the sensor node. This method allows for requirements analysis with stakeholders and redefining requirements, so the prototype will continue to meet the stakeholder's expectation. Furthermore, the model allows for significant changes in the design. This is a very positive point because during hardware design happens that a solution which worked great in theory does not work out in practice because of some unexpected effects. The extensive risk analysis is used to identify these problems and in the new prototype a completely new solution might be implemented.

There are also some downsides to the spiral model. Most important of which is the fact that the effectiveness of the model is highly dependent on the quality of the analysis. If he analysis is done sloppy, the new iteration will not address critical issues. Because of this, it is very important that the analysis plan is prepared carefully, and the analysis is done precisely. This downside leads to another. Because the risk analysis must be done carefully the model can be very costly to use timewise. Therefore, a detailed and realistic planning is crucial when using the spiral model. Furthermore, there is not much room for analyses of the process itself and it it very focussed on releasing a final product onto the market, which is not the goal of this project.

Hybrid design method

The Spiral model was chosen to use in this graduation project due to it's advantages, but some adaptions were made to make sure it fit the goal of a graduation project. These changes were made with the design process for creative technology in mind, because this model suits the academic nature of a graduation project better than the spiral model.

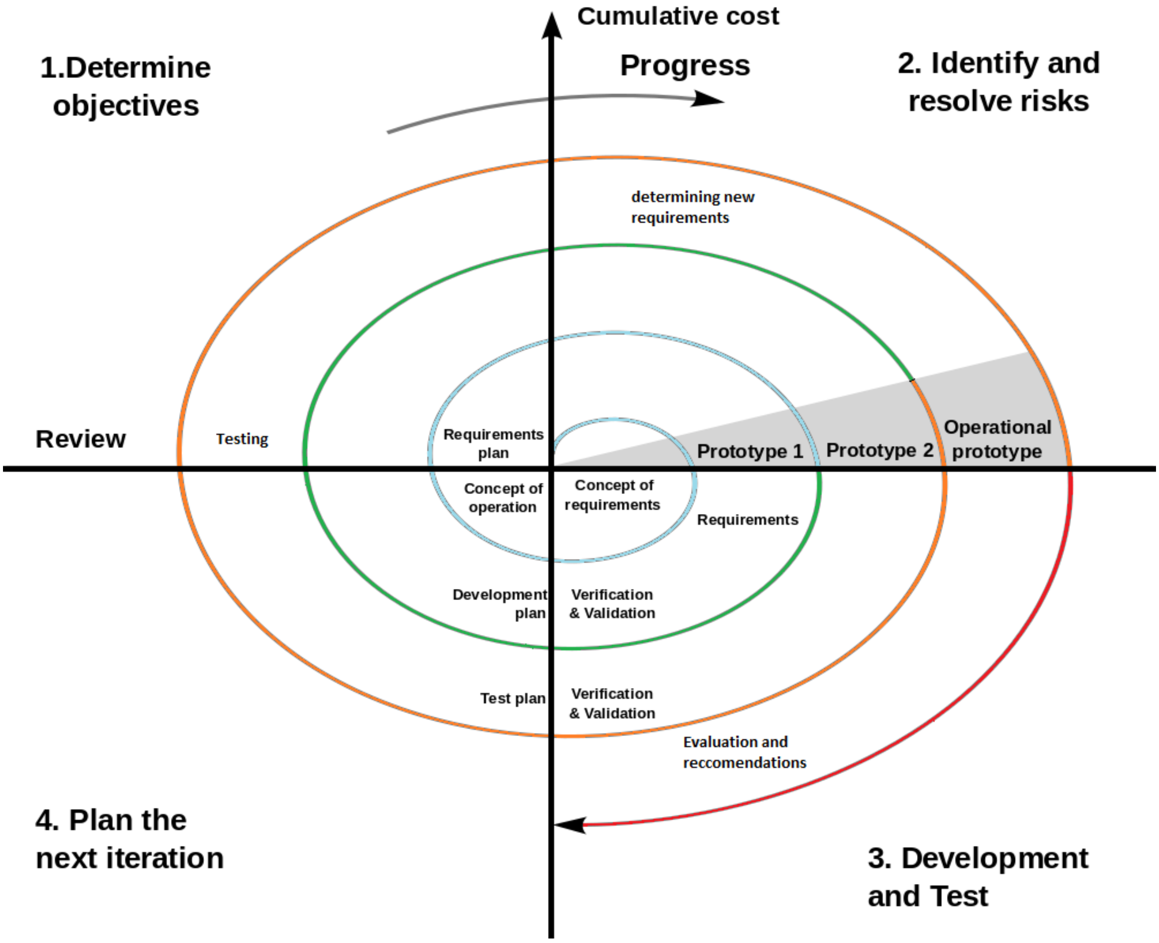


Figure 4: Spiral model adapted to the tree phases of the graduation process

The first phase is the ideation phase. This includes concept requirements and operation, the plan to acquire requirements from the stakeholders and the initial iteration in the form of sketches etc. After which the specification phase starts in green which includes determining requirements, validate them and plan the development of the physical prototype. The realisation phase start with building this prototype, after which this prototype is tested according to a test plan. The results of these tests are incorporated in the design of the second prototype. The last phase is the evaluation phase in which the results will be evaluated and recommendations for future research will be made.

Application of spiral model

To reach the final goal of developing an outdoor sensor system that measures dominant variables linked to the drivers causing an Urban Heath Island effect in the city of Enschede, sub-goals are set for every iteration. These sub-goals allow to evaluate every iteration specifically to see if this goal was reached and give a clear direction for the features to focus on during an iteration. The evaluation of each iteration was used to further specify goals for the next iteration.

Iteration	goal	phase
first	Determining and prioritizing user requirements and functional requirements	Ideation/Specification
Second	Realizing first prototype to test functional requirements	Realisation
third	Realizing second prototype with improvements on first where functional requirements were not met	Realisation

Table 1: Sub-goals of iterations spiral model

The complete planning in included in appendix C

First iteration

The first iteration consists of a set of design sketches with a description of what the system functionalities are included. The goal of this iteration is to generate specific and prioritized requirements for the functionalities the system is going to have. The first iteration falls in the ideation and specification phase.

Second iteration

In the second iteration the goal is to create a first prototype. The evaluation of the requirements in the first iteration will form the basis for determining the functional requirements for this prototype. Then, the hardware and software design need to be made to meet these requirements. Finally, the first prototype needs to be build. A functional requirement analysis will determine what improvements still need to be made to meet these requirements. This iteration falls partly in the specification phase and in the realisation phase.

Third Iteration

In the third iteration the second prototype is constructed. The evaluation of the functional requirements of the first prototype will show which improvements still need to be made to meet the functional requirements. The second prototype will be evaluated on both the functional requirements and the user requirements. The last of which will be done with the stakeholders. This iteration falls into the realisation phase.

3.2 Stakeholder analysis

The stakeholder analysis was done according to some of the principles explained in Sharp et al. [32]. To make sure doing the analysis was not too time consuming, the focus of this analysis was on the design of the system and the stakeholders in this process. The method described in this paper is to look at one stakeholder and identify its role regarding the system. Next, the supplier and client stakeholders regarding this initial stakeholder are identified. A client stakeholder requires information or resources from the initial stakeholder, a supplier stakeholder supplies information and resources to the initial stakeholder. Last, the satellite stakeholders are identified. These are stakeholders who interact with the initial stakeholder, but do not supply or request anything that can have great impact on the initial stakeholder. This process is repeated for every stakeholder that is identified. This all combines to a web of relationships between stakeholders. This analysis gives a clear image of the existing stakeholders, their relationships and what impact they can have during the process.

3.3 Requirements analysis

There are many types of requirements. Still, a distinction can be made between two categories of requirements [33]. The functional requirements, which are concerned with what the functionalities of the system are. And the non-functional requirements, which describe how the system should behave or look when performing a certain function. The requirement analysis for this system will consist of gathering user requirements which will be translated to system requirements. Then the requirements are categorised in functional and non-functional.

MoSCoW requirements analysis

The requirements were also categorized on importance. This was done with the MoSCoW analysis. The MoSCoW analysis is a method for prioritizing requirements which is used in many different fields like business analysis of software engineering. Using this prioritization method allows to focus on the most crucial requirements with the greatest benefits first, before spending too much resources on the other requirements. The categories used in this method respectively must, should, could and won't generally gives a better understanding about the set priority then terms like high and low. The Requirements and in which categories they fit are determined in consultation with the stakeholders.

Must have

This category has the highest priority. The requirements in this category are considered crucial to be included for the final product to be a success. If these requirements are not included the product can be considered as a failure.

Should have

The requirements in this category are still important and may be as important as the requirements in the 'must have' category. But, they are not necessary to implement in the current time space. These requirements can be met in another way or they can be held back for future implementation in another time space.

Could have

Requirements in this category are desirable to implement but not necessary. They are not crucial for the functionality of the product but can improve the user satisfaction. Most of the time these requirements will be met if the resources allow.

Won’t have

This is the least critical category. They are determined to be the lowest payback and least appropriate requirements. The requirements in this category are not planned into any time schedule and are often dropped further along the project.

3.4 Interview

There are many types of interviews [34]. All have their own strengths and weaknesses and require a different degree of skill from the interviewer. Inportant variations between these different methods are the degree of structure, qualitative or quantitative data gathering and the expertise of participants. The techniques used during this graduation project are elaborated on below.

Semi-structured qualitative interview

This technique requires an interview guide which lists topics that has to be covered in a specific order. The interviewer can follow this guide, but when he/she deems it appropriate can also diverge from this guide to follow up on new insights gained during the conversation. It requires intermediate skills from the interviewer, because he/she needs to be able to follow interesting leads while not losing sight of the goal of the interview and topics that still need to be discussed. The goal of this interview is to gather qualitative data on the topic. Therefore, the interviewee needs to have a certain degree of knowledge about the subject to be able to answer the specific questions.

Unstructured interview

This technique does not require an interview guide, only a defined goal the interviewer wants to reach. It resembles a guided discussion. It lest the interviewee express themselves and is very low pressure. This technique requires more skill from the interviewer. He/she must constantly direct the discussion, so it will eventually allow them to get the information he/she wants from the interview.

3.5 Functional architecture diagram and software design

To determine the actions and functionalities the system should have, the system needs to be broken up in the smallest parts possible. Interaction between these parts is specified. The final product is called a functional architecture diagram. There are several methods for making a functional architecture diagram. The method that was chosen for this project is a method from the book ‘software engineering’ [35]. This method allows a modular decomposition of the product and uses a simple notation which leads to a comprehensive model, and so capture the fundamental organisation of the system. Different diagrams are made for the hardware and software design. The stages of this method are described below.

Determining the scope

To determine the scope, the operational modules of the system and interactions with other systems need to be determined. This can be defined in the product context diagram. In this diagram the functionalities of the product are identified and put inside the scope of the product. All external products the product has to interact with are identified and put outside the scope, but inside the usage environment of the product.

Define request feedback flows

In this phase the functional interactions between the modules of the system and between external products and the system are identified. These interactions often appear in a pair of a request and return arrow but can also be one way. Hereby the focus lies on the interaction with external parties.

Model the operational module flow

The operational models stand for the main functionalities of the product. These modules also consist of multiple processes. The aim in this phase is to split up the operational modules in input, processes within the module and output. The information flow between these processes also needs to be identified here. At the end of this phase all modules are split up into the smallest possible processes.

Add control and monitoring modules

The operational model flow is often controlled by control modules. Control modules control the timing and actions of an operational module and are in turn controlled by timing modules. The interaction between a control module and operational module is a request feedback loop.

Specify external to/from internal interactions

This step is needed to do additional analysis of the interactions between internal and external modules and to identify which modules need to be interfaced with external modules for each request feedback flow. If needed, new modules need can be added in this stage and previous steps can be repeated.

3.6 Tools

In this paragraph the tools for creating and documenting the sensor node are described. Every tool is described shortly and the reasoning behind using the specific tool is described.

Corel draw

Corel draw is a program that allows the user to make graphic designs and features many options for efficient designing. Next to this, it can export files in a format that is recognized by laser cutting software. Corel draw was used to make illustrations for this report and to design laser cuts for the sensor node. The choice to use this tool was made because of the familiarity with the tool and its features for digitalising manually drawn pictures and editing them.

Arduino IDE

The Arduino IDE is open-source software used for programming microcontrollers. The Java environment is based on processing. Included libraries make programming a microcontroller simpler and faster. The editor features one-click mechanisms to upload and compile and basic text-editing functionalities like pasting and searching text. Its special code structure using the functions setup () and loop () separates the code which is only run once and the code which is executed repeatedly. It supports the languages C and C++. This IDE was chosen because of its ease of use and the compatibility with the Sodaq ONE.

Fusion 360

Fusion 360 is a cloud-based CAD program that allows the user to create 3D models in a relatively intuitive way. Fusion has the functionalities of a standard CAD program with a more understandable user interface. This was one of the main reasons why this tool was chosen. Next to that, the software is free to use for students under a student license. This makes the tool more accessible than most CAD programs. Fusion was used to design the 3D models for the housing and export them to a 3D printer.

Smart draw

To document electrical circuits smart draw was used. His is an online tool to draw all kinds of diagrams including electrical diagrams. The tool was chosen because of their library of electrical components. Where other programs fall short because some components are just not included, this tools component library is overcomplete. A drawback is that in only has a 7-day free licence, so if changes to the diagram need to be made this might not be possible. For the purpose of this project the advantage of the overcomplete library was chosen over the drawback of the limited licence.

3.7 Testing procedures

Testing basic functionalities first prototype

The most vital functionalities of the sensor node are tested with the first prototype. This is to avoid unnecessary complications when the node is put in a more demanding testing environment. These tests are conducted outside the SmartXp[4]. The basic functionalities the first prototype is tested for are: the quality of the housing, the transmission of data and the functionality of the sensors. First, the voltage of the full battery is measured before testing. Next, the sensor node is activated and attached to a pole. It will remain there for a week. During this time the data sent by the node is monitored 3 times for periods of at least 6 hours. This data is used to see if the transmission of data is stable. Every hour the payload in last received message is translated from hexadecimal to ascii to inspect the data collected by the sensors. If the sensors output values within a reasonable range from the values measured at the KNMI weather station it is assumed that the sensors function correctly. The judgement of what is a reasonable range is made on site with the help of a smartphone, because it allows for judgement of the conditions under which the measurements are taken when a real weather station is available. The housing is tested in water resistance by continuously pouring water over it from all sides for at least a minute. After 10 minutes the sensor node and power module are screwed open to check for water inside. If there is no water inside the housing is sufficiently water resistant. Any problems will be reported and resolved if necessary for continuing testing. After a week the node is opened and checked on inconsistencies and damage. During this procedure the voltage of the battery is measured to see if the power module is experiencing any problems.

Functional requirements testing second prototype

Testing the functional requirements is done to determine if the system has all the functionalities necessary according to the requirement analysis. Every ‘must have’ requirement requires a different testing procedure. The testing procedures are, with one exception, designed to be conducted when the sensor is placed on top of the ITC building in the centre of Enschede. This building features a large weather station that outputs reliable data. This data is used to test the accuracy of the data gathered by the prototype. Testing procedures for every must have functional requirement are listed below.

Measure accuracy of temperature humidity and wind speed

First, setup the sensor node next to a reference temperature, humidity and wind speed sensor which are at least twice as accurate as the required accuracy. Next, get two hours of readings from all sensors at the same time. Now, compare the readings from the sensor node with the reference sensors. For each measured parameter the test is considered a success if 90% of readings from the sensor node differ less than or exactly the required accuracy with the reference sensor. These accuracy tests can also be executed separately per parameter if convenient.

[4] Classroom A138 in the Zilverling building, University of Twente

Get a fix on GPS coordinates with an accuracy of 20m

First, place sensor on position with known GPS coordinates. Now, try to get a fix on the GPS coordinates for 30s. Do this at least 5 times. Repeat this for 2 other locations. Compare these GPS readings with the actual location. If 90% out of the measured GPS readings do not differ more than 20m, a deviation of more that 0.3 seconds[5] in longitude or latitude, from the original position it is assumed that the requirement is met. For the calculations behind this threshold of 0.3 seconds see appendix K.

Generate sufficient power to function on a cloudy day with 8 hours of sunlight.

This test cannot be performed when the sensor node is on top of the ITC building. First, measure the voltage of the battery. Now, place the sensor outside om a cloudy day for 8 hours. Keep it in a dark place for the rest of the day. Measure the battery again after 24 hours. If the voltage did not drop more than 3.5v, which is equal to 70% discharge [36], the test is success.

Transmit data successfully at least every half hour

Let the sensor send data every 10 minutes for at least 4 hours and collect this. Check how much of the send data was received. Now the number of messages lost can be calculated. If this number of successful messages is above 60% and there was no instance where there were no messages for half an hour, it is assumed that the requirement is met.

Send all packages within a 1% duty cycle

Set up the sensor node and collect meta-data of each message. This metadata contains information about the time of the up-link. Do this for at least 3 hours. Calculate the average time of up-link per message. Now, the duty cycle can be calculated with the following formula: $D = \frac{PW}{T} * 100\%$ where PW = pulse width and T is total period of the signal. If the duty cycle is calculated to be 1% or lower, the requirement is met.

Functional and non-functional requirement testing third prototype

The third prototype is the final prototype. First of all, the functionality of the entire system needs to be tested. This will be done by letting the system generate data for a week and checking the data for inconsistencies. Next, some requirements were already met in the second prototype. Nevertheless, changes were made to calibrate the sensors. Therefore, the sensor accuracy will be tested with the same procedures as the second prototype with one difference. Instead of collecting data from the node for two hours, data is gathered for five hours. Last, the non-functional requirements will be reviewed on being met or not by assessing the third prototype on the feature specified in the requirement. All this information is used to draw conclusions on the results of the entire project.

[5] In GPS coordinates a second is 1/3600 of a degree. See appendix N for more explanation

Chapter 4: Ideation phase

4.1 Generating ideas

From the state of the art in chapter 2 it is clear that the concept of monitoring the urban climate with many dispersed sensor nodes has been done before. Therefore, the idea generation focussed on the autonomy of the node while aiming to include measurement systems for more variables. To decide which variables to measure the stakeholders were consulted and presented with ideas for the next generation sensor node. These ideas were generated through making multiple quick sketches. These can be found in appendix D. The sketches were used as a brainstorming tool.

4.2 Stakeholder identification

A better understanding of what the stakeholders expect from this project is crucial for gathering requirements. To gather the information for the initial requirements the stakeholders need to give their opinion and express their expectations of the project. Both stakeholders differ in their background knowledge and the goal they hope to achieve with this project. Because of this, the method of gathering the required information also differs. Below, the gathering of information from the stakeholders is described.

ITC – Wim Timmermans

To get a better idea about the needs of Wim Timmermans and gather information to formulate requirements, a semi-structured qualitative interview [34] was conducted. This method was chosen because Wim has an extensive knowledge in the field of climate sensing and can therefore give clear answers on specific questions regarding the project. The transcript of this interview can be found in appendix A.

This is the second part of one interview. The first part is described in paragraph 2.4. This first part of the interview shows that the variables Wim found most valuable from a scientific standpoint were solar radiation, wind speed and the difference in temperature over a day. Other variables he also mentioned as relevant in a scientific context were sky view factor, the percentage of sky visible above the sensor location, and the vegetation fraction of the area. Skyview factor is a variable tied to the incoming solar radiation. The solar radiation does not necessarily need to be measured for every sensor but can be modelled using the sky view factor[6]. The vegetation factor[7] is linked to the evapotranspiration as well as the albedo. Wim also mentions that although these last two variables could be important, they also do not vary once determined for a certain location. These variables might be interesting to include as metadata for a sensor position, but he does not think it is necessary to include measurement systems for these variables in the sensor nodes. Next to the scientific context, Wim notes that it is also possible to look at the urban heat island effect from a human comfort point of view. In the human comfort context, the variable humidity also becomes important. The same temperature with a high humidity instead of a low humidity is perceived as very uncomfortable. The variable CO2 could also be interesting according to Wim, but he understands that due to power restrains this is probably out of the scope of this project[8]. Other variables have a correlation with the urban heat island effect but are in Wim's opinion not very interesting to measure at this point in the project. For Wim's own purposes he would like to see both solar radiation and wind speed/direction

[6] Fraction of open sky visible. See appendix N for more information.
[7] Fraction of ground surface covered in vegetation. See appendix N for more information.
[8] This was not discussed during the interview but in the update on the findings from the state of the art and can therefore not be found in the transcript.

implemented.

Finally, Wim was asked if he knew of any external sources where data on these variables can be found. Wim says that in principle, data on all the variables can be gathered from external sources. The only issue is that these measurements are not detailed enough or, in case of surface temperature, too old and infrequent to be useful for the goal if measuring the urban heat island effect.

Municipality of Enschede – Hendrik-Jan Teekens

Hendrik-Jan, the representative from the municipality of Enschede, does have a certain goal in mind for the project, but he does not have much knowledge within the field of climate monitoring. Therefore, asking him direct questions about what functionalities the system should have, will not work. To gather information about requirements from Hendrik- Jan Teekens a different method was needed. A presentation followed by an unstructured interview was chosen to inform him before giving his opinion. To get his opinion on requirements the project should meet he was presented with the advantages and disadvantages of measuring certain variables and two initial design possibilities where shown. This way he was informed about the possibilities before giving his opinion. The presentation used to inform Hendrik-Jan of the project until now and the pros and cons of including measurement systems for different variables into the sensor node can be found in appendix E.

During the presentation Hendrik-Jan asked a few questions about terms he did not understand and concepts that where a bit unclear. After the presentation the impression was that he had a much better understanding of the project so far and the possibilities of gathering data on additional variables. Hendrik-Jan was asked to choose the variables that he would prefer to be measured by the next generation of the sensor node. He narrowed the six possibilities presented down to three. These where solar radiation, humidity, temperature and wind speed/direction. Due to the time constraints of this graduation project he was asked to choose two 'must have' requirements which are definitely going to be implemented. Hendrik-Jan was quite certain about the necessity of measuring solar radiation. Because the municipality is also interested in the human comfort approach of the urban heat island effect humidity was preferred over wind speed/direction.

Database – Joeri Planting

Joeri Planting is a create student who is also working on his graduation project. His project involves making the database for the sensor nodes developed in this project. That is why he is also a stakeholder in this project. To gather information about what he expects from him an unstructured interview was conducted. The goal during this interview was to determine how the database will communicate with the sensor node and what data format Joeri expects. There is no transcript of this interview because it was not recorded, but notes were made during the interview. Adam Bako was also present during the interview.

Joeri does not have a specific preference according to the format of the data. As long as it is clear what the pieces of the data represent. If the exact format of the data is communicated to him, he will be able to implement it. As for the communication with the database, it can retrieve data directly from the sensor nodes. By using the key, the nodes are registered under, the nodes can be accessed through The Things Network. His part will be covered by Joeri and is therefore outside the scope of this project.

4.3 Stakeholders

Knowing who the stakeholders are in a project is crucial to be able to satisfy their needs. The stakeholder analysis is performed according to the method documented in paragraph 3.2. Figure 5 shows how stakeholders interact with each other. Big arrows stand for the direction of the supply of information and decision making. The small arrows stand for interaction between stakeholders. This diagram was made with the design of the system in mind. Therefore, the stakeholders that have a minimal effect on the design of the prototype like the manufacturer of sensors are excluded.

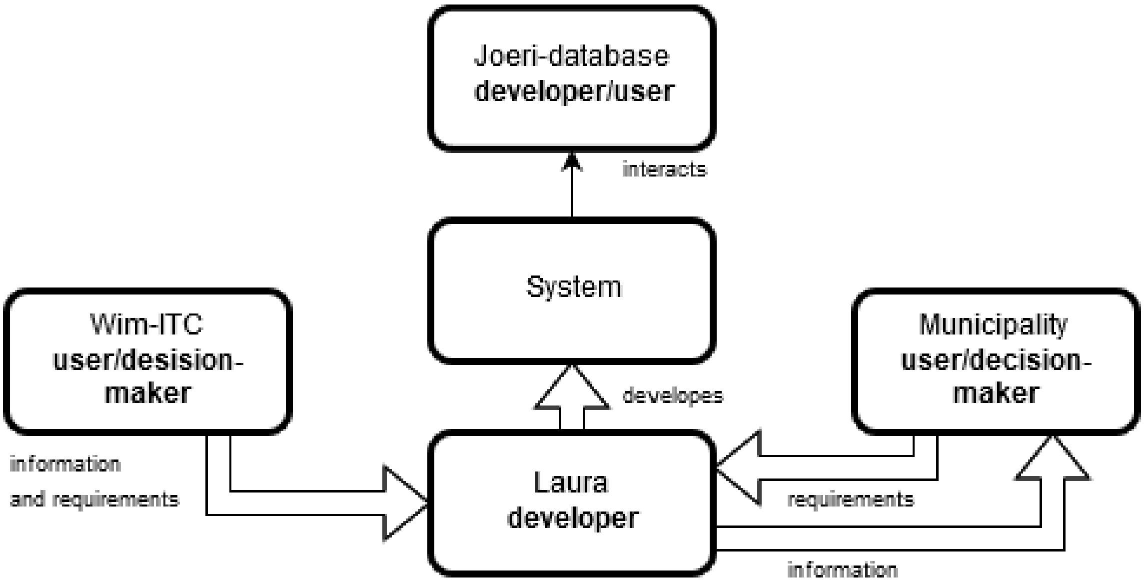


Figure 5: Interaction between stakeholders

4.5 Environmental factors

The sensor nodes will be placed outside in the city of Enschede and measure climatological variables. To explore the context the sensor nodes will be operating in the climate in the city of Enschede was researched using a dataset from the KNMI [37]. The dataset used ranges from 15-05-2017 until 15-05-2018.

Enschede is situated in a temperate sea climate. This climate has a moderate temperature without extremes in temperature due to the proximity of the North Sea. Winters are soft, and summers are relatively cool. On average the yearly precipitation in the area of Enschede is 750mm. The weather depends strongly on the composition of the air and the wind direction and is prone to change constantly.

The sensor nodes will be placed in different microclimates. The average temperatures in Enschede range between -1°C during winter and 22°C during summer. Minimum and maximum temperatures, which are measured with a sensor that is shielded from direct solar radiation, Range from 20°C to 36°C on a hot summer day. During the coldest day of the year the minimum and maximum temperatures measured where -16.5°C to -7.5°C, but temperatures are often above 0°C. During winter there is a bit less than 8 hours of daylight. In summer there is a maximum of 17 hours of sunlight. Humidity constantly changes, but in the last ten years relative humidity has not dropped below 20%. Enschede is situated further inland than most Dutch cities, therefore the average wind speeds are relatively low. Nevertheless, wind speeds can grow up to 37m/sec. at a height of 2 meters. On top of high buildings these speeds are even higher.

4.6 Conclusion ideation

In the ideation phase the stakeholders in the design of the system and their interconnections were identified. Furthermore, the possibilities within the design possibilities of an autonomous sensor node and the area and environment in which it will operate were explored. The most promising of these ideas were presented to the stakeholders. Discussion about these ideas and interviewing them about their needs lead to a final concept. The final concept is a sensor node that can be stand alone for an extended period of time and measures wind speed, temperature and humidity. The sensors measures these values with an accuracy that is relevant for gathering information on the urban heat island effect. The sensor node communicates the measured values and its location over the LoRaWAN network. The image below gives a visual representation of the final concept.

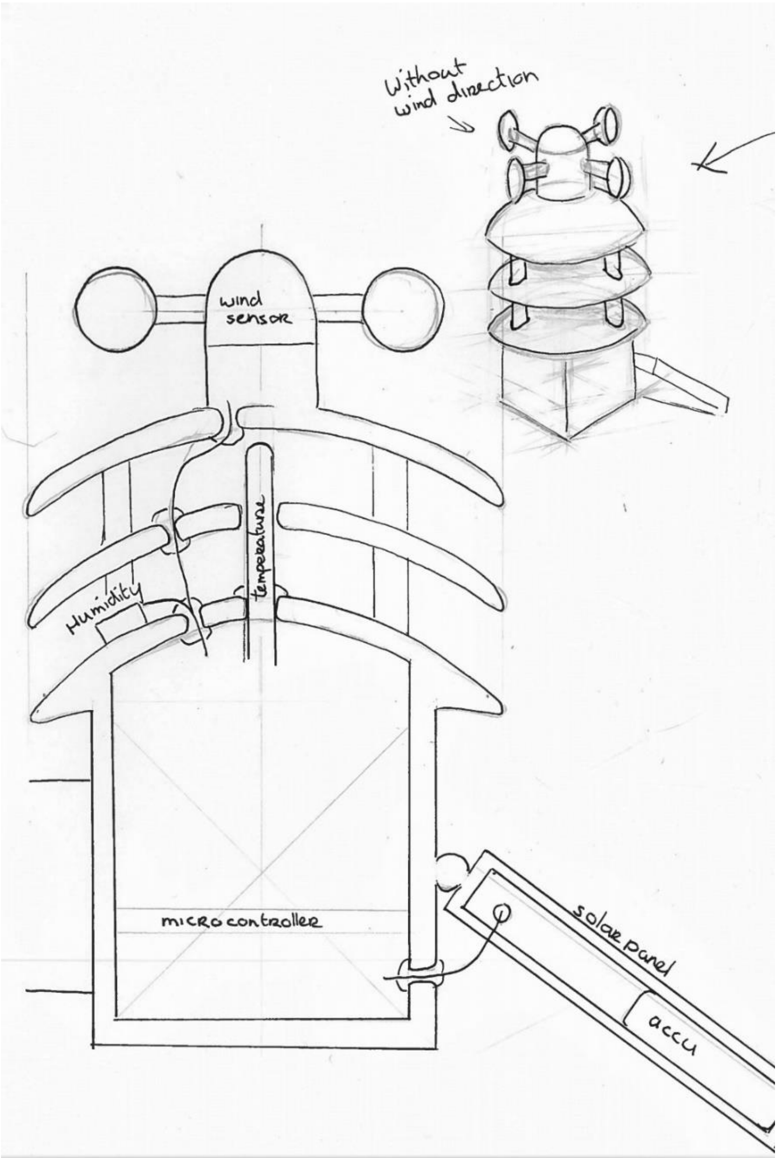


Figure 6: final concept sensor node

Chapter 5: Specification

In the specification chapter the functionalities of the system were specified. With the global requirements gathered in the ideation phase functional requirements can be set up. These requirements than were analysed. Furthermore, an object analysis was made to create a detailed conceptual model of the design.

5.1 Requirements

Requirements can be determined from the interviews held with stakeholders, the specification of the LoRaWAN network, the environmental factors in Enschede and the design possibilities considered during the ideation phase. From the interviews it was determined that both Wim Timmermans and Hendrik-Jan Teekens agree on the importance of measuring the variable solar radiation. Wim Timmermans notes that a sensor for solar radiation does not necessarily need to be included in the sensor node but can be derived from the sky view factor in combination with the sensor data from the ITC. Hendrik-Jan would prefer more information about the human comfort within the city and thus wants a humidity sensor to be included in the sensor node. Wim prefers the variable wind speed, because it gives him more valuable information to improve his model of the climate in the city of Enschede. During the interview with Wim Timmermans the accuracy of the measurements needed to make the data useful for improving his model was also discussed. For temperature Wim says the needed accuracy is around 0.5 degrees. The previous model designed by Tom [8] already meets this requirement. According to Wim the wind speed data needs an accuracy of 0.1 M/sec. Solar radiation, if measured in W/ m², needs to at least have an accuracy of 10W/m². These are all lower limits. Joeri only mentioned one requirement. The data must be sent in an understandable and stable format. From the environmental factors in Enschede temperature, wind speed and daytime were used to see what the sensor must face when placed outside. The Specifications of the LoRaWAN network give some hard boundaries for the data transmission and some guidelines of fair use. Both can be found in paragraph 2.5. All these factors were used to setup the requirements. In the table below, these can be found. A division was made between functional and non-functional requirements After which they were rated on importance with the MoSCoW analysis. The source of each requirement is denoted with a number. The meaning of these numbers can be found at the bottom of the tables.

Functional requirements	Source
The system MUST	
Measure temperature with an accuracy of 0.5°C	1-2
Measure humidity with an accuracy of 3%	1-2
Measure wind speed with an accuracy of 1m/sec	1
Get a fix on GPS coordinates with an accuracy of 20m	1
Generate sufficient power to function on a cloudy day with 8 hours of sunlight.	4
Send all packages within a 1% duty cycle	6
Transmit data successfully every half hour	1
Measure relative humidity between 20% and 90%	4
Measure wind speed within the range of 2m/s to 40m/s	4
Measure temperature within the range of -20°C to 50°C	4
The system SHOULD	
Be able to withstand precipitation of 100mm/hour	4
Be able to withstand wind speeds up to 133km/hour	4
Fit all data transmission within 12 bytes of payload per package	6
Be able to function with a 3.3V power supply and current limit of 1A	5

Be able to function for 12 hours with a temperature of 36°C	4
Be able to function for 12 hours with a temperature of -15°C	4
The system COULD	
Have adaptive update rates	5
Have accurate prediction of solar radiation at position using data from ITC	2
The system WON'T	
Measure solar radiation with an accuracy of 1W/m	1
Measure surface temperature	2
Measure air quality	2
Allow for over the air software updates	5

Table 2: analysed functional requirements

Non-functional requirements	Source
The system MUST	
Be attachable to medium sized pole	5
Have a humidity sensor in contact with outside air	5
Have a wind speed sensor on the outside of the housing	5
Have a temperature sensor shielded from direct solar radiation	1-5
Have a colour with a high albedo value	4
Send comprehensible data packages in a stable format	3
Generate enough power to function continuously	2-5
Have a button to activate sending of GPS location	2-5
Be able to save data in a database	3
The system SHOULD	
Be associated with a sky view factor in percentages	1
The system COULD	
Have a non-obstructive design for deployment in urban areas	5
The system WON'T	
Be housed in a type of plastic that is more durable that PLA	5
Have a wind direction sensor on the outside of the housing	2

Table 3: analysed non-functional requirements

Legend: 1=Wim Timmermans - 2=Hendrik-Jan Teekens - 3=Joeri Planting - 4=environmental factors - 5=ideas and sketches - 6=LoRaWAN boundaries

5.2 Wind speed measurement

There are a few different ways to measure wind speed. All of them have different properties regarding for example: power usage, accuracy durability etc. This paragraph lists sensors which are often used in both private and professional weather stations including their strengths and weaknesses. [38] [39]

Stationary coil

This sensor works with a small magnet embedded in the rotating part of the anemometer which rotates past one or several stationary coils [38] [39]. When the magnet moves past a coil, the magnetic field create a flux in the coil which can be measured as a voltage over the coil. By counting the peaks in voltage, the amount of rotations over time can be determined. An advantage of this sensor is that once calibrated on amount of rotations at a certain wind speed its behaviour is very stable over time. Next to this, this sensor has almost no friction which increases its sensitivity. Furthermore, it does not require power to operate. A disadvantage is that it has limited precision, especially with high speeds.

Reverse electromotor

The electromotor works similarly to the stationary coil, but instead of the magnet moving past the coils to generate a certain flux over the different coils, here the magnet is stationary while the conducting loop turns trough this field. The faster the wind, the faster the loop turns. Brushes transfer the generated flux into a current [40]. A higher wind speed results in a larger current. The advantage of this sensor is that sensor values have an almost linear relation to the wind speed, so it is very easy to calibrate. Next to this, it also works without an external power supply. The biggest disadvantage is that the brushes in the electromotor have large friction. Therefore, it is not suited for measuring low wind speeds. It is also prone to errors due to the large amount of moving parts.

Mechanical and optical pulsed contact closure

This sensor works with a contact closure switch to measure the amount of rotations over time. This is often a reed switch closed by a small magnet passing by, but it could also be an infrared beam interrupted by a reflector. The reed switch is by far the simplest method. A small magnet sits in the rotating part of the senor, while a reed switch is embedded in the static part. Every time the magnet passes, a full rotation has been made and the switch closes allowing a small current to pass [40]. The pulses of current are picked up and counted by a datalogger or micro-controller. The amount of rotations over time is used to calculate the wind speed. The advantage if this sensor is that it is reasonably precise at both high and low speeds. It is also not very prone to breakage due to the simplicity of the sensor. The biggest disadvantage is that the sensor needs an external power source.

Sonic sensors

Sonic sensors measure disturbances in the atmosphere by sending sonic waves from one point to another. By inspecting changes in the received sonic waves both wins speed and direction can be calculated [41]. The sensor is very reliable in extreme weather and can be extremely precise. The downside is that these sensors are extremely expensive and require a lot of power to operate.

Pressure sensors

The wind speed can be measured with a pressure sensor. A typical pressure sensor measures pressure in pound force per square (psi). This can be translated to a wind speed using the following formula [42]: $wind\ speed = \sqrt{\frac{P}{D*S*\frac{1}{2}}}$

Where wind speed is measured in m/s, P = pressure in N/m², D = density of air = 1,23kg/m³ and S = the shape factor of the sensor. A cylinder shape has the typical shape factor of 1.15. To measure wind speeds of 1m/s, according to the formula a minimal accuracy of 0,718N/m² is needed which is equal to $2 * 10^{-5}$psi[9]. The upside of this type of sensor is that it does not include any moving parts. The downside is that the measurements from this sensor need a lot of post processing to be valuable for this project.

Not all wind speed measurement sensor types meet the requirements specified in paragraph 5.1. Sonic sensors can be dismissed because of the power constraints. The reverse electromotor principle is not suitable for the project because of its high minimum required wind speed. Such a sensor will not be able to take measurements in the lower boundaries of the required range. Opposite to this, he stationary coil type is not precise enough near the higher boundaries to take accurate measurements. The pressure sensor type would suit perfectly, except for the fact that sensors of this type that have the required accuracy all require at least require 7V power supply [43]. Therefore, the sensor type that

[9] Measure of pressure. See appendix N for explanation

fits the requirements best is the pulsed contact closure. This is the only one able to meet both accuracy and range requirements.

5.3 Humidity measurements

There are many types of hygrometers. Both analogue sensors and electronic sensors. Because this project's aim is to develop a sensor node based on a microcontroller, the focus in finding measurements techniques for measuring humidity will lie on electronic sensors.

Capacitive sensors

Capacitive humidity sensors consist of a hygroscopic dielectric material sandwiched between a pair of electrodes forming a small capacitor. Often a polymer is used as dielectric material When there is no moisture present the capacitor has a certain capacitance. The plates absorb small amounts of water vapor present until the absorbed vapor is in equilibrium with the ambient air. With a constant temperature and a growing humidity, the dielectric constant between the plates grows, because the dielectric constant of water is higher than the dielectric constant of the plates. The dielectric constant of water changes when the temperature changes Relative humidity can be calculated from the ambient temperature and sensor capacitance. Power consumption of this type of sensor commercially available ranges between 28µA and 2mA and have a maximum range between 0% and 100%. This type of sensor also features a minimal drift over time. Downside of this sensor is that, due to its low capacitance it needs to be placed a reasonable distance away from circuitry. [44] [43]

Resistive sensors

The resistive humidity sensor measures humidity by the change in impedance of a hydroscopic medium. This medium is often a conductive polymer of sorts. This impedance changes in an inverse exponential relationship. The impedance range of typically used resistive elements vary from 1kΩ to 100MΩ. A upside of this sensor is that its lifespan is higher than 5 years in a normal outside atmosphere. To deploy this type of sensor in an environment with fluctuating temperature, temperature compensation must be done. This is often incorporated in the sensor. A drawback for using this sensor is that values tend to drift when salt is used as coating instead of a polymer. [44] [43]

Both the resistive and capacitive sensor types can achieve the accuracy and range requirements specified in paragraph 5.1. Next to this, there are no inevitable downsides to using one of the types Therefore, either of the types suits the project.

5.4 Functional architecture diagram

The functional architecture diagram was split in tree parts. The first diagram describes the hardware functional architecture diagram. The thick arrows represent streams of data and the thin arrows represent streams of electricity. The scope of this diagram is all hardware in the project. Outside the scope the communications with external parties are included.

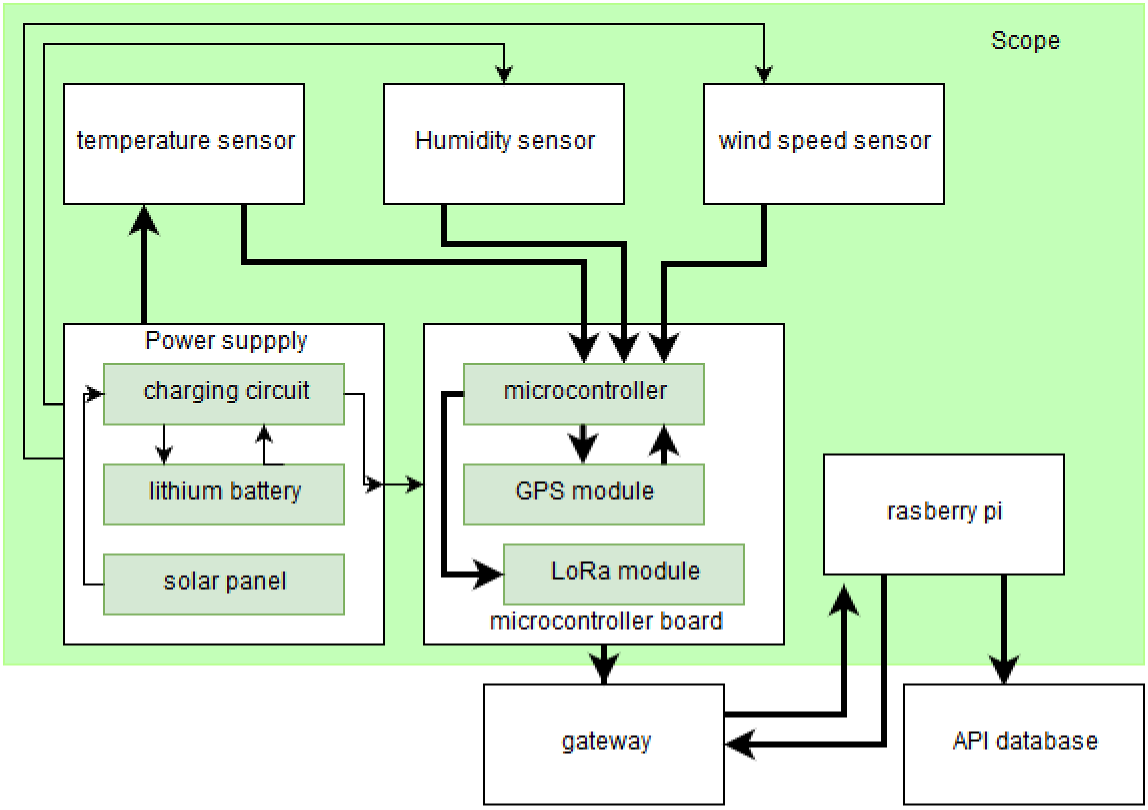


Figure 7: Hardware functional architecture diagram

In the functional architecture diagrams below the software architecture of the microcontroller and raspberry pi are depicted.

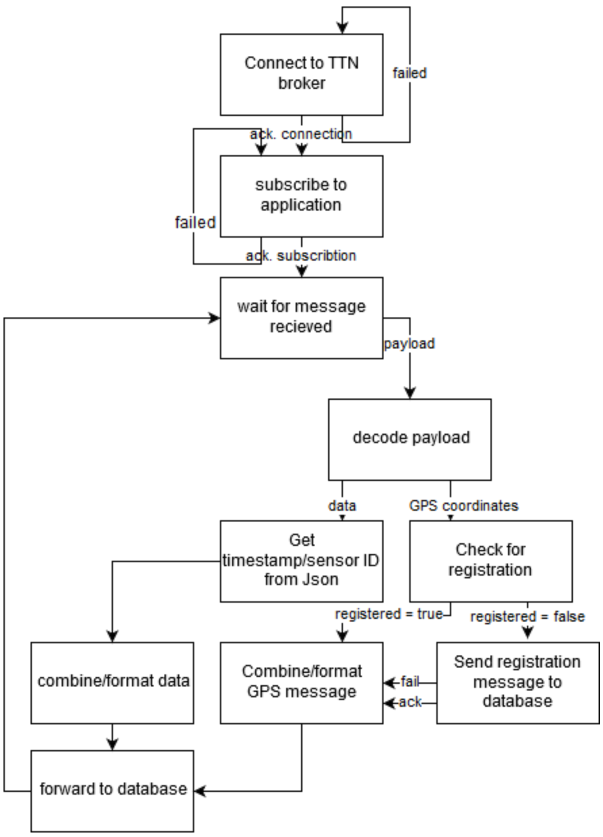


Figure 8: Functional architecture diagram back-end

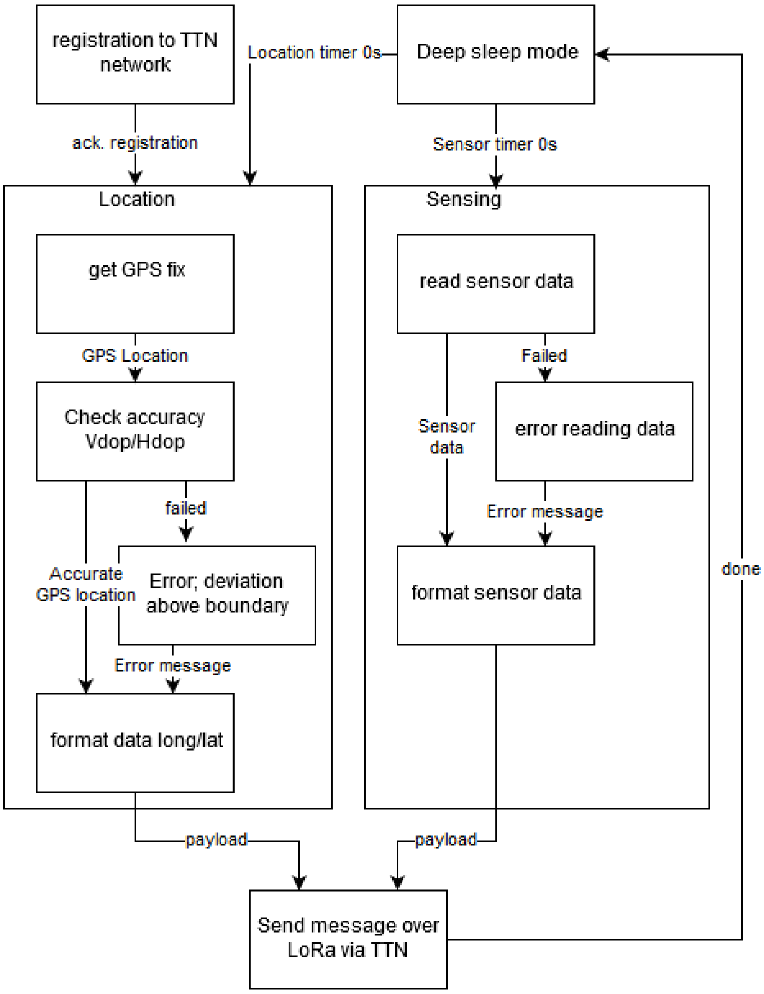


Figure 9: Functional architecture diagram microcontroller

5.5 Conclusion specification

In the specification phase the idea of the sensor node was worked out in detail. Requirements were formulated using the information from stakeholders and state of the art. These requirements where used to create the functional architecture diagrams of the hardware and software. These diagrams describe the exact workings of the sensor node and the communication of the database and gave sufficient information to start with the realisation of the sensor node.

Chapter 6: Realisation

In the realisation phase the steps of the realisation and testing of the prototypes was documented. The chapter is divided in two main parts. These parts describe the creation of the first and second prototype. Procedures of the tests conducted with these prototypes are documented in the methods chapter under paragraph 3.5 and the results of these tests are discussed in the evaluation.

6.1 First prototype

Housing

The housing design of the first prototype was based on the design from Tom Onderwater [8]. Below the complete housing including solar module is depicted with two detailed views of the position of the new wind speed and humidity sensors. The wind speed sensor will be mounted on the top of the sensor node. Holes are made on the top of the node to partly embed the sensor inside the housing. Tests will prove if this is enough to make sure the sensor will not detach when the sensor is exposed to high wind speeds. The small off-centre hole in the top is to accommodate the wire from the wind sensor to go to the main compartment. The compartment on the side of the sensor node will hold the humidity sensor. The cap has upwards sloping horizontal holes to keep out rain while still allowing the atmosphere to reach the humidity sensor. The compartment for the humidity sensor has a downwards sloping surface to make sure the water drains through the small holes on both sides of the bottom surface of the compartment. For the model and the details mentioned above, see appendix H.

Interfacing cup anemometer

The wind sensor Froggit WH1080 is a cup anemometer that measures rotations with a reed switch. The reed switch gives a pulses four times per full rotation. According to the datasheet [45] the reed switch gives a pulse one per second if the wind speed is 2.4km/h. From this it can be derived that if the reed switch pulses once per 1.5s the wind speed is 1m/s. See appendix F for the complete calculations. The amount of pulses is measured over a period of 3s. From this amount the wind speed can be calculated according to the following formula: $wind\ speed = \frac{C}{P} * \frac{2}{3}$ where C=amount of pulses and P=Period in seconds. The anemometer is put in series with a 100nF resistor to get rid of the phenomenon of bouncing contacts. This decreases the chance on false measurements. The resistance of the closed reed switch was measured with a multi-meter and is 6Ω. With 3.3V power supply and a capacitor of 0.1µF this leads to a charging time of 0.1µs. this is so small that it will not interfere with the wind speed measurements at high speeds. See appendix F for complete calculations. Anemometer is connected to a I/O pin on the microcontroller with the capacitor in parallel. The sensor pin provides 3.3v. the ground wire from the anemometer is connected to ground. The amount of pulses from the reed switch can be sensed via the I/O pin.

Interfacing humidity sensor

The humidity sensor is a SHT15 capacitive humidity sensor breakout board form sparkFun [46]. The board is fully calibrated and only needs two communication wires. The humidity sensor itself also includes a temperature sensor which is used in calculating relative humidity. These calculations are done by the board itself. The board's ground and power supply pin are connected to the 3.3v and ground pin of the microcontroller. The data and clock pin are both connected to one of the I/O pins. The clock pin serves to synchronize the communication between the board and microcontroller. Data is requested and received by the microcontroller trough the data pin.

Interfacing temperature sensor

The Dallas DS18B20 temperature sensor [47] is programmable digital temperature sensor. The version used for the first prototype is watertight and outfitted with a metal probe for more accurate sensing. The DS18B20 communicates over a 1-Wire bus that requires only one data line and a connection to the ground for communication with a central microprocessor. A 4.7KΩ resistor is connected from the data line to the 3.3v line. This is good practice because the 1-wire bus requires that the control signal be pulled high, so the master device can pull it low to ask for data, and the slave device can pull it low to give the data. This allows you to have multiple 1-wire devices on the same one wire. The data pin is connected to one of the I/O pins. The 'DallasTemperature.h' software library was used to retrieve data from the sensor.

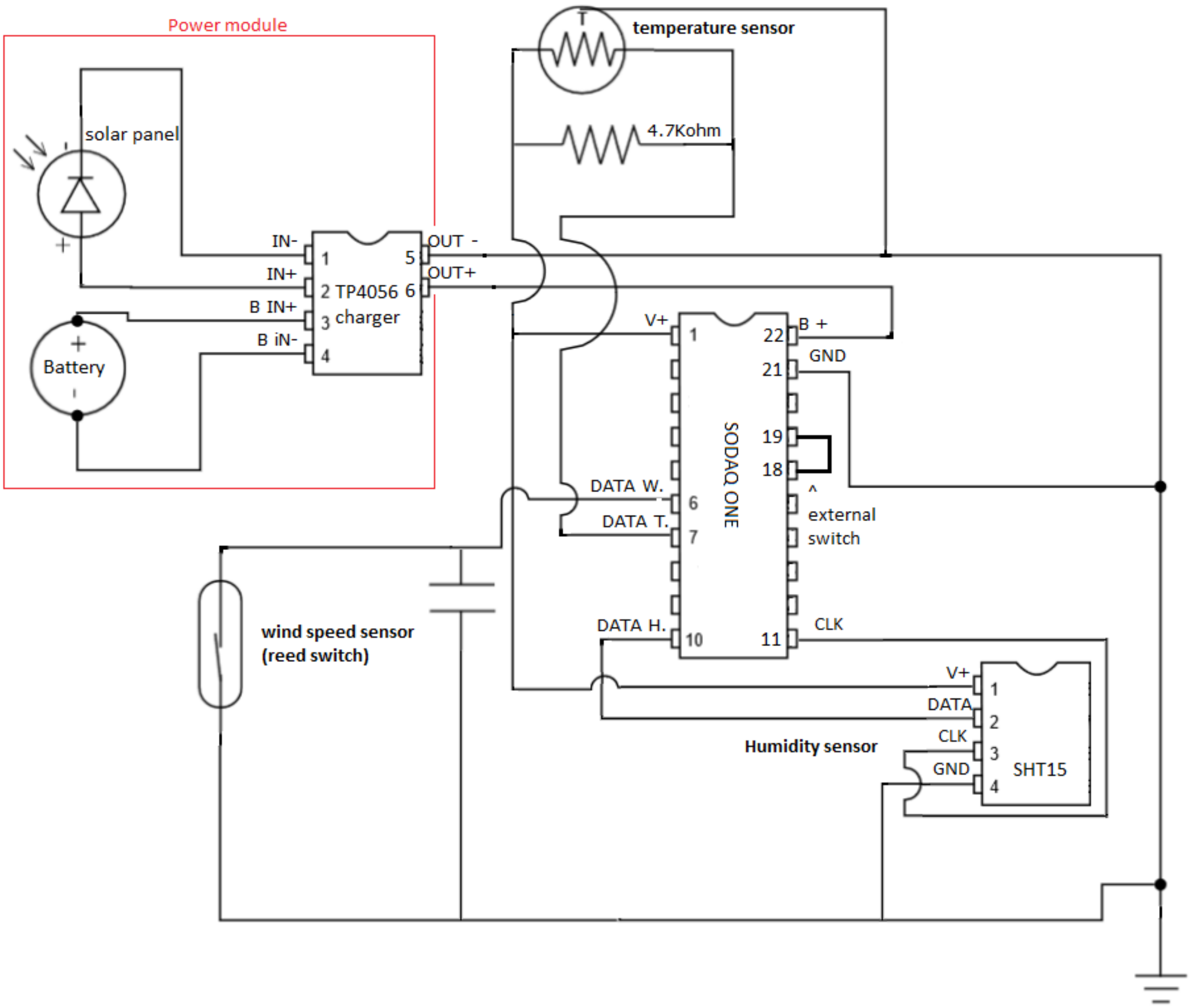


Figure 10: Electrical circuit. See appendix J for detailed description of assembly and pin descriptions of Sodaq one.

Sending data

The data from the sensors inside the sensor node is read from the sensors and compiled into a message. In front of each value is a letter that identifies the value. The message is send using the TTN protocol. This protocol translates the ascii[10] values in the message to hexadecimals and the

[10] Binary representation of common characters. See appendix N for explanation.

message is forwarded to the gateway. Here the message is put into a Json package. This package contains extra information about the message such as timestamp, gate way ID and device ID. For now, the data is collected via the TTN dashboard. An example message can be found in appendix G

Deployment

The second prototype was put on top of the ITC hotel next to one of their weather stations. These weather stations are very accurate and will be used for testing the accuracy of the sensors. It was placed there for a bit more than a week. A picture of the placement of the sensor node can be seen in figure 12.

Figure 11: deployment of first prototype

6.2 Second prototype

Housing

With the results of the first prototype in mind, a few changes were made to the housing. First of all, the part where the sensor node attaches to a pole was fortified. An extension above the place where the tightening band is attached should provide extra stability. The attachment to the main part of the housing is also elongated to prevent breakage. Furthermore, the compartment for the humidity sensor was made slightly bigger. It also features two small drainage gutters leading to the drainage holes. This should make it easier for water to escape the hatch. The model including a close-up of the compartment for the humidity sensor can be found in appendix H.

Interfacing sensors

The sensors were all functional in the first prototype, so no changes were made in the electrical circuit. However, the sensors were outfitted with convenient connectors between the sensors and the microcontroller. This way, it becomes easier to replace faulty sensors if necessary without disassembling the whole sensor node. Although it does make the process of assembly a bit more difficult because of the extra soldering.

Sending data

Sending messages is done in the same way as in the first prototype. Only the kind of data send is slightly different. For testing purposes, the microcontroller will only send messages wit sensor data. This was done because the code for sending the GPS data is not functioning as it should at the time the second prototype had to be deployed. Therefore, this functionality was disabled. Not sending GPS data ensures that this does not get in the way of testing sensor accuracy.

GPS testing device

To still able to test the GPS accuracy of the second prototype, it will be tested with GPS testing software loaded on a Sodaq ONEF. The hardware of the sensor node and this device are very similar. The GPS testing device is powered by the same battery and regulator. The big difference is that the GPS testing device has no external sensors, so it is not able to measure temperature, humidity or wind speed. The software of the sensor node and GPS testing device are similar except for the sensor node not sending its GPS location. The GPS testing device uses the HDOP[11] to judge of a measurement is accurate. The HDOP was chosen because it is the only measure of precision supported by the Sodaq Ublox GPS library. Measurement with a HDOP larger that 3 are seen as inaccurate and no GPS location is forwarded. The GPS testing device does send messages with sensor values, even though there are no sensors attached. This was chosen to make sure the software of the GPS testing device is as close to that of the sensor node as possible. If there are any issues with sending the GPS location related to the retrieving data part of the software, this is noticed. See appendix I for a detailed description of the design of the device.

Deployment

The second prototype was put on top of the ITC hotel next to one of their weather stations. These weather stations are very accurate and will be used for testing the accuracy of the sensors. It was placed there for a bit more than a week. A picture of the placement of the sensor node can be seen in figure 12. The GPS testing device was deployed on three different locations: next to the Zilverling, on the Van Heek square and on the Pijpenstraat next to the public library.

Figure 12: deployment of second prototype

6.3 Third prototype and communication with the server

The third and final prototype was an improved version of the second prototype. All must have requirements were considered in the design. The housing was improved to be able to fit two straps for extra stability in high winds.

Interfacing sensors

The sensors themselves were functioning fine in the second prototype, but because of the chance of the jumper cables wiggling free when the sensor is shaking, the jumper cables were fixed in place by small dabs of hot glue. In the process om putting together the third prototype a lot of care was taken to carefully finish all the soldering with heat-shrink tubing. This reduces the risk of a short circuit and corrosion when the sensor node is outside.

Sending data

No changes were made in the way data is sent by the third prototype in respect to the second prototype. However, the kind of data send has changed. The formula for calculating the wind speed was adjusted to decrease all wind speed measurements a factor 10. Furthermore, the third prototype sends its GPS location at initialisation and when the location of the sensor node changes more than 30 meter. It checks the GPS location every five hours. The accuracy of the measured location is judged using the HDOP and a minimum number of satellites. If the location measurement passes the accuracy threshold, it is compared to the previously determined location. A message is only send when the location changed by more than 25 meters. This means that the senor node is awake for a longer period of time but also makes sure no unnecessary messages are send. Which leads to less power consumption while still checking if the sensor node has moved. The GPS location comes in as a string. To be able to compare how much the GPS location differs from a previous location, the last two digits

[11] horizontal dilution of precision. Is expressed in a value between 1 and 20. See appendix N for further explanation.

of the latitude and longitude are converted to integers and compared to the integers representing the last two digits of the previous location. Comparison was done this way because it was not only necessary to check if the digits were the same or not, but also how much this difference is. Which is easier to do with an integer value than with a string. The following piece of code shows how the comparison was done. The code of this particular part of the program can be found in appendix M.

Database ant data retrieval

The data send by the third prototype is forwarded to the database made by Joeri Planting. Because of the time constrains of this project ant the amount of new knowledge needed to make a program which collects messages, translates data and forward the correct data to the database, this program was made by Jonathan Juursema. Together with the database it forms the back-end of the system. The back-end works as follows: The program is subscribed to the TTN application which contains the sensor nodes. When a json package comes in from one of the nodes the payload is retrieved from the package and translated from hexadecimal to ascii. Next, the translated payload is checked for marker characters. They are used to determine what kind of data is in the payload and the position of the data inside the payload. If the letter L and l are encountered the payload contains GPS data, if the letter t, w and h are encountered the message contains environmental data. Now, If the payload contains GPS data there is a possibility that the node is not registered yet. From the Json package the sensor ID is retrieved and translated to an integer. The program will check its list of ID's of already registered sensor nodes. If the ID from this message is not in there, it will be inserted. The program will then send a message with the sensor ID, sensor type ID, latitude and longitude to the server. The sensor type ID for These types of sensor nodes is 2. This message also contains a possibility for location precision, but this is not used for now. The database adds a timestamp to this when the message is received. Below an example command to the database for registering a sensor node can be seen:

```
registersensorsystem/SENSORSYSTEM_ID/SENSORSYSTEM_TYPE_ID/LAT/LONG/LOCATION_PRECISION
```

If the sensor is already registered and the payload contains location data, the location of the sensor node must be updated. For this message the same information is needed as for registering the sensor node. Here the database also adds a timestamp when the message is received. This way it is clear that all environmental data received after this time, with no new location registered in between, is collected at this location. The database adds a timestamp to this when the message is received. Below an example command to the database for updating the location can be seen:

```
updatelocation/SENSORSYSTEM_ID/SENSORSYSTEM_TYPE_ID/LAT/LONG/LOCATION_PRECISION
```

If the payload contains environmental data, the measurements are forwarded to the database with their type ID. This is 3 for air temperature, 4 for humidity and 5 for wind speed. The timestamp from the Json package is added to this message to register as precise as possible when the measurement was taken. The database adds a timestamp to this when the message is received. Below an example command to the database for registering measurements can be seen:

```
registermeasurement/SENSORSYSTEM_ID/SENSORSYSTEM_TYPE_ID/MEASUREMENT_TYPE_ID1/VALUE
1/MEASUREMENT_TYPE_ID2/VALUE2/MEASUREMENT_TYPE_ID3/VALUE3/YYYY-MM-DD:HH:MM:SS
```

Deployment

The final prototype was deployed on top of the ITC hotel on the same position as the second prototype. It was secured with tie wraps. In figure 18 the sensor node can be seen with next to it the ITC weather station for reference measurements.

Figure 13:Deployment of the third prototype

Chapter 7: Evaluation

In the evaluation chapter the results from the tree prototypes are recorded and evaluated. The testing procedures used to evaluate the prototypes are described in paragraph 3.7. Each result was used in the next iteration of the sensor node except for the results of the third, and final, prototype. This prototype was also evaluated on meeting all the must have requirements.

7.1 Results of the first prototype

The first prototype was assembled in approximately nine hours. This is a bit longer than expected because it was the first time the design was assembled so; the process was not very efficient. During assembly it was discovered that the case for the humidity sensor was too small. The humidity sensor fit in after cutting of some of its corners, but the size of the case must be changed in the next iteration.

The first prototype was tested on the transmission of data, the functionality of the sensors and the quality of the assembly. The method used for these tests can be found in paragraph 3.7. The sensor node was put inside a bag for 6 hours during the day because the sensor node was moved to another location at Witbreuksweg where there might be a bit more wind. This location did not have LoRaWAN coverage, so it was moved back. At the start of the testing period the battery was charged until full. The voltage measured over the battery was 4.1V. At the end of the week the voltage over the battery was 4.0V even though it missed 6 hours of sunlight. from this it can be concluded that the nodes power consumption is well within the range of the current power module. The software mostly worked as expected except for the fact that the sensor node never sends its GPS location. Something it should have done every hour. This can be explained by the fact that the GPS mode is only enabled when a counter has reached a certain value which is never reached. Every time the microcontroller goes into deep sleep the counter is reset. In future versions there must be a way to make sure the GPS location is send. Nevertheless, sensor data was received from the sensor node every 10 minutes. The data stream from the sensor node was recorded for approximately eight hours on three different days. During this time, it never occurred that the sensor node failed to transmit two messages in a row and 95% of the messages sent were transmitted successfully to the gateway. So, it can be concluded that the communication between the sensor node and the TTN network works. Furthermore, the data received was sensible. The different sensors all seemed to function perfectly. The temperature and humidity measured by the sensor node roughly matched the data from the KNMI weather station at Twente Airport. Any significant deviations could be explained by the difference in environment of both sources. Due to the placement of the node in a secluded area surrounded by high walls, the wind speed sensor was not tested extensively, but when there was a small gust the wind speed sensor did report this. Finally, there were a few small problems with the housing. When it was attached to the rain pipe for the first time a piece of the housing broke and had to be fixed with hot glue to continue testing. This part was not sturdy enough and must be improved before the prototype is placed on the ITC building. Otherwise it might not be able to withstand high wind speeds. Nevertheless, the housing seemed to be waterproof. The only water found inside was a bit of condensation in the hatch for the humidity sensor. When water was poured over it from different directions the water did not leak inside the power module or the main housing of the sensor node. From this it is concluded that the housing is sufficiently water resistant.

7.2 Results of the second prototype

The second prototype was constructed using the test results from the first prototype. The housing was improved to allow for more secure attachment to poles and the dimensions of the attachment piece were changed to fit the poles on top of the ITC building. Next to this, the box for the humidity sensor was made slightly bigger to make the humidity sensor fit properly.

When the sensor node was put up on the ITC hotel it stopped sending messages after twenty hours due to the software being stuck after a contact came loose. The sensor node was retrieved and repaired in a day and put back on top of the ITC hotel.

Measure accuracy of temperature humidity and wind speed

The measurements were taken on Friday the 22th of June between 14:13 and 17:30 and on Sunday the 24th of June between 12:00 and 14:00. From the measurements taken during this period half of them were rejected because the sensor node sent an error message instead of valid sensor data. These errors were most likely caused by connectors that were shaken slightly loose by the strong winds. This has to be taken into account when designing the third iteration. Because of this there was a total of 21 valid data points of which 18 were recorded in a row on Friday. This at least allows to judge the quality of the measurements over time. The data was compared to the data from the ITC sensor. Of the 21 measurements 18 matched the temperature measured by the ITC sensor within a range of 0.5 °C and 17 of the 21 measurements matched the relative humidity measured by the ITC sensor within a range of 3%. From this can be concluded that 86% of the temperature and 81% of the humidity measurements matched the measurements from the ITC. None of the wind speed measurements were in the range between minimum and maximum measurements from the ITC sensor, bit when the measurements of the sensor node were decreased by a factor ten, 16 of the 21 measurements were in this range. From this it can be concluded that the accuracy requirements of all three sensors were not met.

Get a fix on GPS coordinates with an accuracy of 20m

The GPS was tested with a GPS testing module on three locations in Enschede. On two of the three locations the GPS testing module was able to get a GPS fix on the second try to fifth try. These locations were next to the Zilverling and on the Van Heekplein. On the Van Heekplein the four GPS fixes did not differ more than 0.3 seconds in longitude or latitude from the actual location found with the help of Google Maps. Next to the Zilverling one of the four measurements did differ more than 0.3 seconds from the location found with google maps. On the third location, next to the public library, the GPS testing module only got a fix three out of five times, but all three measurements were within the 0.3 second range. Out of these 11 measurements only one of the measurements was inaccurate. This means that more than 90% of the measurements were accurate. So, the requirement that the GPS has an accuracy of 20m is met.

Generate sufficient power to function on a cloudy day with 8 hours of sunlight.

On Monday June 18 2018 the sensor node was put outside with a fully charged battery (4.2V) outside between 10 in the morning until six in the afternoon. During the evening and night, it was inside. In the morning the voltage over the battery was measured. The voltage was 3.9 V. This corresponds with an 85-90% charge [36]. This is higher than the required 70% charge. Therefore, it can be concluded that the sensor node has sufficient power production to function on a cloudy day with 8 hours of sunlight.

Transmit data successfully at least every half hour

The timestamps measurements that were taken on Friday and Sunday were reviewed. During this time six messages of the 28 messages that should have been received were not received by the TTN network. 78% of the messages that should have been send were received. It never happened that the TTN network did not receive a message two times in a row. therefore, the requirement of transmitting data successfully at least every half hour was met.

Send all packages within a 1% duty cycle

Messages were send every 10 minutes by the sensor node. Using the uptime calculation sheet from TTN [48], with a spreading factor of 12 and a payload of 15 to 17 characters the average uptime per message was 925.696ms. To meet the 1% duty cycle requirements the average uptime per message needs to be below 6 seconds. So, with an average uptime of 925.696ms this requirement is met.

7.3 Results of third prototype

The third prototype was constructed using the test results from the second prototype. An extra place to attach the sensor node to the pole was added for extra stability. This prototype was used to evaluate the functionalities of the software and to check the calibration implemented using the results of the second prototype. Next to this all must have requirements were checked if they were met.

The Sensor node was monitored on the 9th of June between 11:30 and 20:30. This resulted in 49 data points. It can be assumed that one data point was missing because the GPS location was checked during a wake-up from sleep mode. This means that 4 messages were not received by the gateways. The message counter included in the LoRa protocol shows that these messages were send by the sensor node, but not received by a gateway. This means that more than 90% of messages are received.

Sensor accuracy

The accuracy of the measurements taken by the sensor nodes can be seen in the graphs below. In figure 13 the comparison between reference and measured air temperature can be seen. In general, the measured air temperature is relatively close to the reference air temperature. There are two extremes where the measured and reference air temperature differ more than one degree. There in no clear pattern in the difference between the two. Sometimes measured values are slightly lower, sometimes they are slightly lower. This could correlate with the intensity of the solar radiance, rainfall or wind speed, but such a correlation has not been found.

In figure 14 the same comparison can be seen for the humidity. At three points in time the difference between the reference and measured humidity is clearly larger than the required accuracy of 3%. There are also two spots, around 16:50 and 19:18, where there are multiple measurements which are significantly higher than the reference. This may be because some moisture got into the humidity sensor and it took some time before it evaporated, but this is not certain. Apart from this, the measurements match the reference closely.

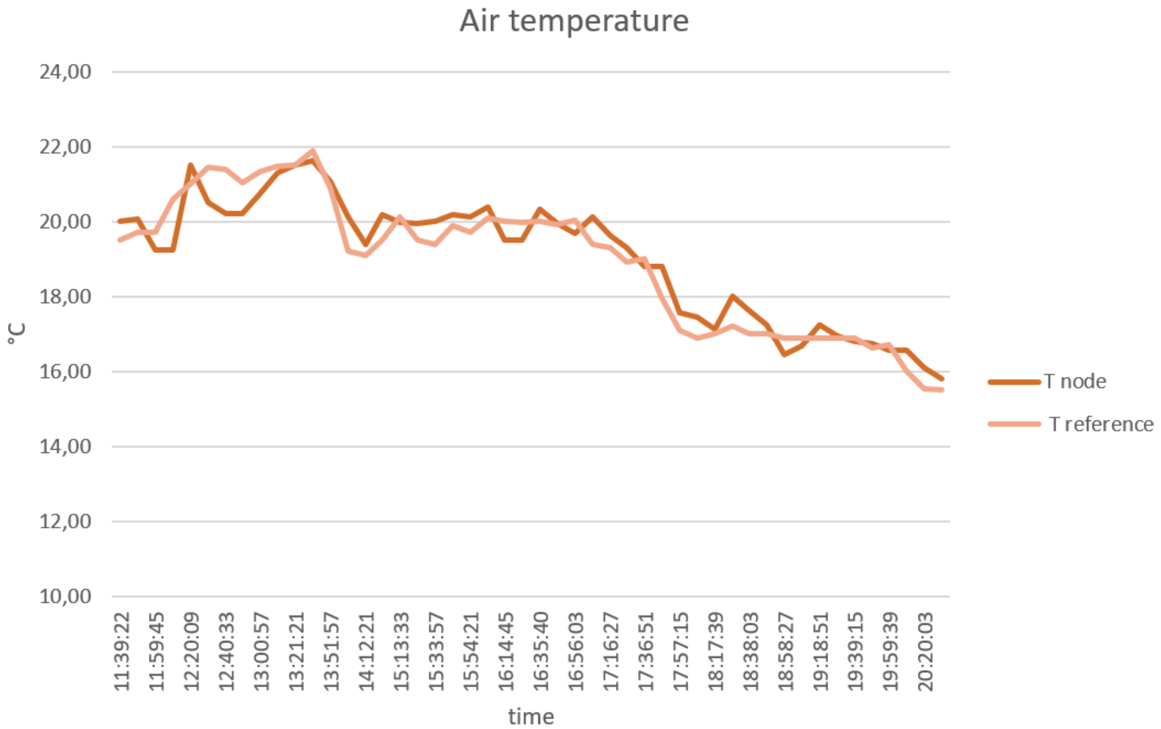


Figure 14: comparison between reference and measured temperature

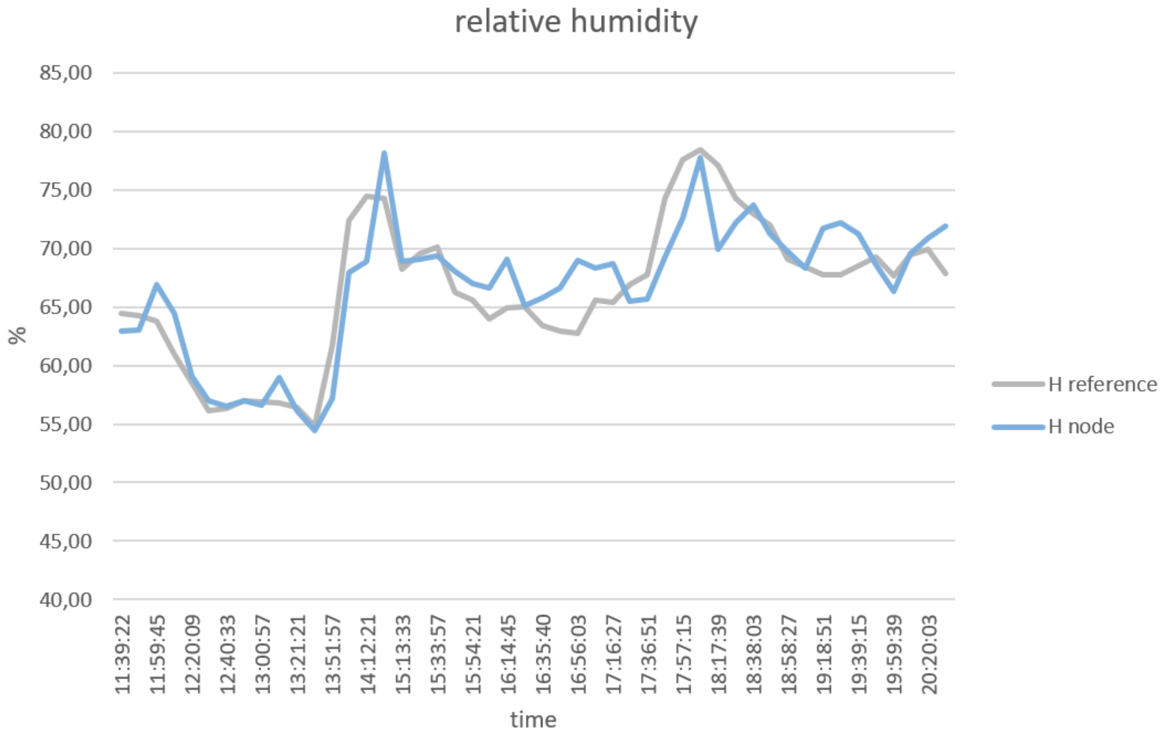


Figure 15: Comparison between reference and measured humidity

In figure 15 the minimum and maximum wind speed from the minute the measurements were taken in, are matched to a measurement taken by the node. The reference minimum and maximum wind speed are plotted in blue. The red line represents the wind speed measured by the node. As you can see, the red line generally stays between the maximum and minimum reference wind speed. There is a small overshoot between 12:00 and 12:30. This kind of continues inconsistencies is not repeated anywhere else in the graph. It could be something caused by a strange draft around the pole the sensor is attached to, or a problem in accuracy. From this it can be assumed that the wind speeds measured by the current wind speed sensor is within the limits of actual wind speed occurring at the time of the measurement, but the accuracy of the sensor node cannot be determined.

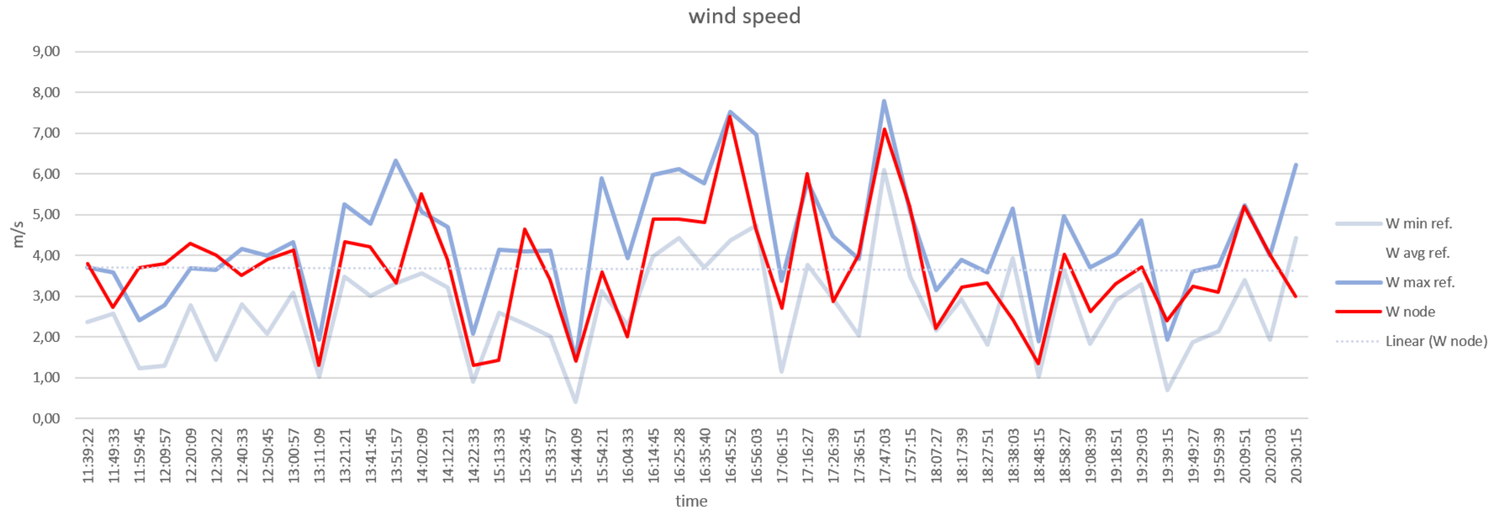


Figure 16: Comparison between reference and measured wind speed

Frome these graphs it can be concluded that the accuracy of the sensors is almost, but not entirely in the required limits. 88% of temperature measurements and 84% of humidity measurements are within the required range of 0.5°C and 3% relative humidity. 79% of wind speed measurements seem to me in reasonable limits, but the accuracy cannot be determined.

Evaluation of requirements

Most of the must have functional and non-functional requirements were met. For some requirements there was not enough data available to conclusively say the requirement was met. If this is the case it is specified in the second column. In the third column the prototypes where this requirement was evaluated with tests can be found.

Functional requirements	Met?	Prototype
The system MUST		
Measure temperature with an accuracy of 0.5°C	Yes, with 88%	3
Measure humidity with an accuracy of 3%	Yes, with 84%	3
Measure wind speed with an accuracy of 0.1m/sec	Data insufficient with 79% within reasonable limits	3
Get a fix on GPS coordinates with an accuracy of 20m	Yes	2
Generate sufficient power to function on a cloudy day with 8 hours of sunlight.	Yes	1, 2
Send all packages within a 1% duty cycle	Yes	2
Transmit data successfully every half hour	Yes	2, 3
Measure relative humidity between 20% and 90%	Yes	Spec. *

Measure wind speed within the range of 2m/s to 40m/s	Data not sufficient	
Measure temperature within the range of -20°C to 50°C	Yes	Spec. *
The system SHOULD		
Be able to withstand precipitation of 100mm/hour	Yes	1
Be able to withstand wind speeds up to 133km/hour	Data not sufficient	
Fit all data transmission within 12 bytes of payload per package	No	
Be able to function with a 3.3V power supply and current limit of 1A	Yes	1, 2, 3
Be able to function for 12 hours with a temperature of 36°C	Data not sufficient	
Be able to function for 12 hours with a temperature of -15°C	Data not sufficient	
The system COULD		
Have adaptive update rates	No	
Have accurate prediction of solar radiation at position using data from ITC	No	
The system WON'T		
Measure solar radiation with an accuracy of 1W/m	No	
Measure surface temperature	No	
Measure air quality	No	
Allow for over the air software updates	No	

*Table 4: Evaluation of functional requirements *this was concluded from specifications sheet of sensors used*

Non-functional requirements	Met?	Prototype
The system MUST		
Be attachable to medium sized pole	Yes	2, 3
Have a humidity sensor in contact with outside air	Yes	1, 2, 3
Have a wind speed sensor on the outside of the housing	Yes	1, 2, 3
Have a temperature sensor shielded from direct solar radiation	Yes	1, 2, 3
Have a colour with a high albedo value	Yes	1, 2, 3
Send comprehensible data packages in a stable format	Yes	1, 2, 3
Generate enough power to function continuously	Yes	1, 2, 3
Check the GPS location at least once a day	Yes	3
Be able to save data in a database	Yes	3
The system SHOULD		
Be associated with a sky view factor in percentages	No	
The system COULD		
Have a non-obstructive design for deployment in urban areas	Data not sufficient	
The system WON'T		
Be housed in a type of plastic that is more durable that PLA	No	
Have a wind direction sensor on the outside of the housing	No	

Table 5: Evaluation of non-functional requirements

Chapter 8: Ethical considerations for deployment

There are some important ethical considerations which have to be made when taking measurements in public spaces regarding the privacy of citizens in public spaces and the availability of public data. The city of Enschede is funding this project. That means the project is funded with public money. The sensors will be placed in public spaces in the city and gather public data. Nevertheless, the data is not publicly available. You could argue that this is because it infringes on citizens privacy, but the data measured is completely anonymous and by not publishing this data the city of Enschede might appear to be hiding something. The fact that citizens cannot access the data in any way can also make them distrustful of sensors being placed everywhere around the city. It can be imagined that when the government places a sensor in front of your house and you do not know what measurements they are taking you can feel like they are monitoring you.

These ethical and societal issues and how they could affect this project will be discussed in this chapter. First, the chapter will explore the definitions of public spaces and public data. Next, privacy and data gathering in public spaces on a more general level, including several examples from data gathering projects all around the world. What ethical issues often arise with these kinds of projects? Should the government and other parties be able to freely gather people's data when they are visiting a public space? Who should own the data gathered in public spaces by a project funded with public money? These are all questions that are hopefully answered in this section. Then this will be used to assess any ethical issues regarding data gathering in my own bachelor assignment and see what issues translate from the general level to my assignment.

8.1 Defining public spaces and public data

First, a distinction must be made between public and private spaces. In the European journal of sustainable development, the public space is defined as spaces that provide opportunities for social life, include various activities, convenient to use by access and linkage, and have unique identity with image. It is accepted that all these features contribute to publicness of public spaces. According to E. K. Karacor [49] the publicness of spaces differs, but there is no clear line between public and private space. Some spaces are less public than others because they fit the definition of public space in a lesser degree. Private spaces are spaces that are governed by a private owner. The more private a space, the more rules governing the space are decided by the owners. These definitions are also true when speaking of digital spaces [50]. For example, a forum without behavioural code where everybody can submit a response without creating an account is clearly a digital public space, as it creates opportunity for social life, does not prohibit certain activities and is accessible. The more rules the owner of this forum would require users to follow, the more specific the possible activities are and the harder the forum is to access, the more private the digital space becomes.

Furthermore, it is important to distinguish between public and private data and determine under which circumstances this data may me gathered and processed. Public data is data that can be accessed by everyone. Public data is all data in the public domain does not contain sensitive information about persons. But where is the line between public and private data. According to the EU General Data Protection Regulation (GDPR) the definition of personal data is: " 'personal data' means any information relating to an identified or identifiable natural person ('data subject'); an identifiable natural person is one who can be identified, directly or indirectly, in particular by reference to an identifier such as a name, an identification number, location data, an online identifier or to one or more factors specific to the physical, physiological, genetic, mental, economic, cultural or social identity of that natural person." In short: all identifying information of a natural person. Public data is the opposite of private data, so is data that is non-identifying of a natural person in any way. For example, the energy consumption of a neighbourhood in Enschede can be regarded as public data, because it says nothing about a specific inhabitant of that neighbourhood. The energy consumption of Hengelosestraat 13 is private data, because it contains information about the economic identity of the owner of Hengelosestraat 13. The processing and use of personal data is illegal unless the owner of the data has given consent. Consent is defined by the GDPR as: "any freely given, specific, informed and unambiguous indication of the data subject's wishes by which he or she, by a statement or by a clear affirmative action, signifies agreement to the processing of personal data relating to him or her." Once this consent is given data can be used for the purposes specified in the conditions of the given consent. If the conditions change the consent must be given again for the new conditions. For gathering public data no consent needs to be given. Although, it is important to realize that a certain set of data that can be specified as public can become personal when the data is combined.

8.2 Examples of data gathering in public spaces

Using these definitions Different examples of data ownership and consent when collecting data in public spaces will be explored. First of all, there is the car industry. Using the sensors inside a car as an IoT network is getting more and more common. In the old days you could buy a car. The car was yours and that was the end of it. Nowadays a car is much more than a vehicle to transport you from A to B. Every modern car is outfitted with a range of sensors and gathers copious amounts of diagnostic data. The car operates in a public space but not all data gathered is public data. It contains private data like location and driving habits. If this data is sold to third parties, insurance companies for example, it can have negative effects on your insurance costs or other aspects of your life. Often this data is used locally to improve your driver experience but is also often send to the car manufacturer [51]. The question now is: if the sensors in the car are yours and the car is yours, is the data gathered by this car also yours? And what about giving consent to the car company to use and process the data? Although the answer to this question seems straightforward, there is much discussion about this. The owners of these cars seem to think that the data is theirs according to a European survey by the General German Automobile Club (ADAC) [52]. Car manufacturers seem to think otherwise [53]. They think it is theirs to use for research purposes but also monetize the data by selling this partly private data to third parties. The European Association of Automobile Manufacturers (ACEA) expresses their desire to be able to charge for access to the data generated by the vehicle. They argue that car companies should be the data guardians and be able to impose a regime of, No Data Access without Compensation [54].

According to the ethical theory of libertarianism [55] the ACEA has a point. Libertarianism in the narrow sense holds that agents have full moral ownership of the self and can morally fully own inanimate objects. Full ownership consists of several rights including the right to control over the object and the right of compensation if someone uses the abject without permission. If these rights are translated to the situation of the car owners, the car companies owe them compensation if their data is used by them without explicit permission. According to this theory the European public owns the data gathered by their cars and therefore has a right to demand compensation from car companies monetizing their data. On the other hand, a car is not a natural person. Using the definitions of public spaces and data one could argue that because the car is in a public space and the car is not a natural person that the data gathered from the car is public data and therefore, consent is not necessary. However, this is not true, consent is required when the data gathered is de-anonymizing in any way. According to the definition this also includes behaviour. Therefore, in this case explicit consent is needed and it is at least questionable if this is always given according to the ADAC [52]. From this example we can learn that if data is gathered in a public space, it is not necessarily public data and that consent is crucial when private data is involved.

The question of data ownership and consent does not only come forward in the car industry. It is also a huge topic in electronic public spaces like social media platforms. This example of a social media platform was used to explore the line between legal and illegal acquirement of private data in the public space. The internet is regarded as a public space according to the definition specified above. But of course, not all information on the internet is regarded as public data. Many people put private data online to a greater of lesser extent. But the free use of this data is not allowed according to European law [56]. This seems based on the theory of individualism. According to this theory [57] one has full ownership over the self and thus, if ones resources, such as labour or data, are used by someone else, the use is only lawful if the individual agrees. When making an account on a social media platform this agreement is given in the form of agreeing to the terms of use of the platform. This can by law be seen explicit consent for everything that is specified in the agreement. Nevertheless, some processing and use of data is still prohibited. The European union's e-privacy directive [56] gives some insight in what is allowed in the public space called the internet. It gives citizens the right on privacy in the electronic communication sector. There are two main provisions in the directive. The first obliges providers of services to inform and protect subscribers of risks. The second is about maintaining the confidentiality of information. It prohibits states from interception of communications without consent from users. This information is regarded as private and can therefore not be gathered without consent.

When data is gathered and distributed to third parties for so called 'value adding services' and a user has given consent, the data must be anonymized, and the user must be informed about the nature of the data stored. Interpreting this it would mean that data that is de-anonymizing and/or required without consent is private data. The owner of the data will always be the individual yielding the data, but it can be used by external parties when they are following the e-privacy directive. For collecting and handling private data on social media platforms consent and anonymization seem to be key. If the user has given this consent and the data is kept securely handling private data is not a problem. Social media often use the data put on their platforms for 'value adding services' like targeted advertising etc. If these services are specified in the conditions of use this is perfectly legal as long as the use of the data is in line with the directives of the European union. From this example we can conclude that collecting private data in public spaces is not necessarily problematic, as long as explicit consent is given, data is stored securely and is anonymized when forwarded to third parties.

The next example is an IoT network which is deployed into the city of Chicago. It is a good example of ethical data gathering in public spaces as it deals with data gathering and private data transparently and securely. This network called the Array of Things in one of the most professional and extensive government owned IoT networks in the world. The network consists of nodes which measure temperature, humidity, barometric pressure, light, noise, and vibration; air-quality sensors, which will measure the presence and concentration of up to eight different gasses. Activity sensors measure standing water and urban flooding while counting pedestrians, bicycles, cars, trucks, and buses. Once the data is processed it will be used to make sensible improvements om infrastructure and city services. The data is publicly available, so citizens can personally benefit from the data by being able to choose a less busy way to work or avoid asthma triggers. This project is a good example of a sensor network funded with public money collecting data in public spaces. Now the question is, how is private and public data handled in this project?

Extensive information about this can be found in their operating policies [58]. Here private data is defined as: "any information that can be used to distinguish or trace an individual's identity, such as name, social security number, date and place of birth, mother's maiden name, or biometric records; and any other information that is linked or linkable to an individual, such as medical, educational, financial, and employment information.” It is clear from this policy that the system is not focussed on gathering private data, but that it can accidentally collect private data in the process. The Array of Things deals with this by processing all data which could contain private data within the node that collected the data and deleting it afterwards. This allows the system to retrieve useful public data from for example photographs without retrieving the private data which might be contained in the photograph. A downside to this is that the nodes need to be very secure. Otherwise malicious individuals can still access the private data and store it on another device. The data is published and open for use by individuals and for research purposes. This approach ensures that the public can benefit from this project which is funded by public money. So, the people who paid for the project get the benefits. This is a great advantage but can also have its downsides. The main problem with publishing such a dataset is that if a mistake is made in processing data and private data does end up in the final dataset, it can have a huge negative impact on the image of the project and is contrary to European law [56]. From this example it is clear that collecting data in public spaces can sometimes lead to accidental collection of private data. This does not have to be a problem if this data is handled in a way that it cannot be accessed and if there is transparency about what data is and isn’t processed.

8.3 Distrustfulness of data gathering

Second the ethical issue that will be discussed is the distrustfulness of citizens towards data gathering. Even though the data gathered might not include sensitive data from citizens, the fact that certain data is gathered by the government can still make them feel watched. This feeling of being watched in the extremes is described in the well-known novel ‘1984’ from George Orwell [59] In this novel a dystopian socialist future is depicted where your every movement is monitored to keep citizens in line. If you do not comply and keep your head down, you might be punished. The future this book sketches may be a dramatized and extreme version, but it perfectly conveys the uneasy feeling one gets when governments insist on: “if you have nothing to hide you have nothing to fear. If you have nothing to fear, why would you close the curtains?”. This last statement might sound a bit intense, but mass surveillance is already part of daily life in some European countries. The British government reacts with indifference on the Guardian exposing the mass surveillance going on in Britain by the GCHQ [60]. The government does not seem to mind. The reasoning the government uses to justify this behaviour is that surveillance information is needed to identify individuals that engage in criminal behaviour and protect state security [61]. But, it can lead to a large power difference between government and citizen.

Surveillance definitely has benefits in some situations e.g. for deterring and identifying individuals conducting criminal behaviour. But it is difficult to know the benefits of a policy for outsiders. Some say this divide in opinion between government and citizens may be solved by transparency. If citizens are aware of what is and isn’t collected about them they are less distrustful [62]. For the government transparency is not a solution. Knowledge about some facts and conclusions do not benefit the general public and may even harm the government. That is why a policy of translucency might be the best option for both [62]. This way of sharing and keeping information shows the general mode of operation and function of data collected to the public while keeping the exact workings and conclusions from the public. This way the ‘big brother is watching you’ feeling when collection of data in public spaces by the government might be avoided. Next to this, if the government has to be open about the type of data collected and what is stored, abuse of data against citizens could be avoided. In this example it can be seen that distrustfulness about monitoring from the government can be a real issue for citizens. The distrustfulness from these citizens towards a monitoring system can be at least partly avoided by communicating about what data is gathered and what data is stored.

8.4 Ethics regarding 'climate measurements in public spaces'

The final part of this chapter is about how the dilemmas from the examples come forward in the project 'climate measurements in public spaces'. The sensor nodes of this project are placed in a public space where they gather four types of data: location, wind speed, temperature and humidity. The environmental data can be identified as public data as they do not give any de-anonymizing information about individuals. The location data in combination with the environmental data could give away some accidental private information if sensor nodes were placed on or in people's homes. At the moment this is not the case but should also be avoided in future iterations of the sensor node. However, the fact that the data the sensor nodes are currently collecting is public data does not mean that this will always be the case. Future iterations of the sensor node might include sensors that are able to collect data on traffic and pedestrians. Although the chance of this happening in the near future is small due to the data and power constraints of the sensor nodes and the high power and data requirements of sensors that are able to gather this kind of information, there is still a possibility that de-anonymizing data is collected by a future iteration of the sensor node. Next to this, a combination of variables measured can give information about the climate in a neighbourhood. This is not private data but can still influence for example the value of houses in this neighbourhood. If the living conditions are uncomfortable, a house can drop in value. The situation of accidental private data collection and how to handle this securely is illustrated in the 'Array of Things' example earlier in this paper. To minimize the chance of future sensor nodes collecting accidental private data every addition of a sensor the risk of gathering private data is evaluated and, if the risk is deemed relevant, steps are taken to make sure this private data does not end up in the dataset. From the 'Array of Things' example we learn that a possible solution is to process information locally and only send data to the server that is already anonymized. Possible private data must be destroyed immediately after processing. If this solution is used network security is crucial, so sensor node will not be hacked.

Which brings us to the question of data ownership. The data that is currently gathered by the sensor node is collected in a database at The University of Twente. The data is used by the municipality of Enschede who also fund the project together with the university. The resources for retrieving and storing the data are owned by The University of Twente but this does not give them automatic ownership of the data as illustrated by the examples of the car industry. There is no clear consensus about who owns the data generated by smart cars although there are no questions about the ownership of the car. The social medial example also shows this dilemma. Social media companies own resources to gather and store data but are not the owner of this data and are therefore not allowed to freely process this data. At the moment data ownership is not a big issue according to the representatives from the university and municipality but they do not agree on the subject. The project is funded by two publicly funded organisations and does not gather any private data. Because of this it would make the most sense to say that the data should also be common property.

A common misconception that also the municipality seems to have about common property is that there is no control over the use and storage of the resource, data in this case. This is also why the municipality is hesitant to make the data publicly available. But, according to Hugh Breakey [63] this is not the case. Regulations can be put in place to ensure fair use of the data and keeping it a common property. Agreements about this should be clearly agreed upon by the university and municipality. Otherwise, one of them might claim the ownership over the data and refuse access to other parties. This could halt improvement on the project, prohibit valuable research and lead to legal struggles between the two parties. To minimize the chance of this situation occurring clear agreements must be made about the ownership, administration and use of the data as soon as possible. These agreements could be documented in a fair use policy or included in a privacy policy or another medium deemed suitable by the two parties. A solid agreement does not mean that there will be no discussion over ownership as can be seen in the social media example but makes the chance of the discussion having significant impact on the project much smaller.

Finally, the distrustfulness of citizens could be a real issue for the 'climate measurements in public spaces' could be a real issue for the success of this project. To get a good image of the urban heat island in Enschede the deployment of a large number of sensors is needed. It could be that citizens feel watched and are distrustful towards sensor nodes hanging on every street corner. This could not only have negative effects on the project but also on the municipality. As can be seen in the paragraph about surveillance this is an effect that occurs in cities with widespread CCTV installations. It is not unimaginable that this effect might also occur when there are large numbers of nodes distributed throughout the city. The fact that the sensor nodes only collect public data makes the issue easier to resolve. Because of this it is not a problem to publish the data gathered in a suitable way to inform citizens about what data is gathered. If the municipality communicates to its citizens about the project, what types of data they collect and what they are doing with the data, the possible distrustfulness can most likely be greatly reduced. This communication can for example be done by writing a solid use policy and publishing this on their web site, or by inviting citizens for an information evening if there seems to be a need for it.

8.5 Conclusion

To conclude, in this chapter the definitions of public spaces and public data were explored. Using these definitions a few real-world examples of dilemmas regarding these three subjects were used as an example to identify possible ethical issues regarding the 'climate measurements in public spaces' project. Three possible future ethical issues were identified. First, the dilemma of accidental private data collection is discussed. Although the chance of this happening is low, in future iterations of the sensor node the risk of accidental private data gathering when new functionalities are added. If there is a relevant risk, fitting actions need to be taken to keep the chance of accidental private data gathering as low as possible. Second, the question of data ownership is raised. It seems right if the data is common property, but if the data becomes valuable in the future this might be jeopardized. To avoid disputes about the data ownership the stakeholders in the project have to get their agreements about data ownership and use on paper. The last issue that has come forward is the possible distrustfulness of citizens towards the sensor nodes. Because the data gathered in the project is public data there is no reason why the municipality cannot publish the data and information about the project in a suitable way to inform citizens about the nature of the project. This could decrease the chance of a negative attitude from citizens towards the project. If these issues are kept in mind during future iterations of the project, the project and the knowledge gained with the data from this project will be more robust.

Chapter 9: Conclusion

This chapter provides answers to the research questions stated in the first chapter. Furthermore, it points out other interesting discoveries done during this project that were out of the scope of the research questions but could be interesting to investigate in the future.

9.1 Discussion

In the first chapter the main research question was broken up into multiple sub-questions which need to be answered before the main research question can be answered. But first some general points of interest will be discussed.

First of all, the tests of accuracy were not foolproof. The final tests of accuracy with the first prototype were done in the field with reference measurements from another weather station. These reference measurements had an interval of one minute. The sensor node sent data with a varying interval of approximately 10 minutes. The measurements of the reference and sensor node were not taken on exactly the same time. This makes calibrating the sensors nearly impossible.

Second, the functionality of the hardware and software was not tested in all possible conditions. The sensor node seems to function flawlessly at the moment but was not tested in winter conditions and has only been functional for one week. It could be that the software will experience an overflow after a few months or one of the newly implemented sensors stop working. The chance of this happening is slim, but more extensive testing could have prohibited this kind of future problems.

Last, the Fusion 360 model is quite messy. The previous model was copied and changed without first looking into the inner-workings of the model. Because of this, the already slightly messy model became hard to work with while editing it. This could have been prevented by first looking into the inner-workings of the model, linking certain measurements, checking what sketch was used for which part, naming them appropriately and keeping the number of additional sketches as low as possible. This would have kept the model usable for future users.

now the sub question will be answered, so it will be possible to answer the main research question. The first sub-question is: **Which variables are dominant in gaining insight in the drivers behind the urban heat island effect?** During the state of the art, six variables were found in existing literature that have a strong correlation with the urban heat island effect. These variables were: humidity, solar radiation, wind speed, wind direction, chemical makeup of the air and surface temperature. During the ideation phase the importance of these variables was further explored by interviewing Wim Timmermans, an expert on measuring climatological variables, and by looking into the climate of Enschede. From this was concluded that absorption of solar radiation, wind speed and temperature where the most dominant variables regarding the urban heat island effect from a scientific perspective. If the purpose of the sensor nodes is to measure human comfort, humidity and air quality also become important.

During the interview with Wim Timmermans it came forward that air quality sensors required too much power to be implemented in a system with an autonomous power supply with a size appropriate to attach to the sensor node. This was a conformation of reasoning within other projects regarding autonomous sensor nodes, which were researched during the state of the art. At the end of the ideation phase it was decided that only measurement systems for three variables could be implemented in the prototype due to time constrains. Together with the stakeholders it was decided that these variables were humidity, wind speed and temperature. For these three variables the sub-question: **How measure these variables with relevant accuracy?** was answered by the results of the tests run with the second and third prototype. The conclusion of these tests was that the accuracy required for improving the models of the urban heat island Wim Timmermans is working on, was not met. The current system is not able to take measurements with an accuracy relevant for this goal. However, when looking at the goal of the other stakeholder, the municipality of Enschede, the accuracy of the measurements needed is different. The goal of the municipality is to get informed about the urban heat island effect in Enschede by getting a more detailed view on the scale and urgency of the urban heat island effect in Enschede. To reach this goal it is important that the difference between rural and urban areas can be measured. To do this the accuracy required is a bit lower than when the data needs to be used for a precise model. Because the accuracy of the third prototype was only a few percent lower than accuracy required by Wim, it can be concluded that the measurements are accurate enough to reach the goal of the municipality.

The last sub question that needs to be answered is: **How to implement the extra sensors and power supply in such a way that sensor nodes can be stand-alone for at least a year?** This question was answered during the realisation phase. In the specification phase the sensor node was designed to keep the power consumption as low as possible by limiting the amount of GPS measurements taken and reducing the amount of GPS measurements which need to be send by checking if the location has changed in respect to the previous location. The results of the specification phase proved that these measures were sufficient for making sure the sensor does not consume more power than the power module of the sensor node can generate, regardless of the extra sensors implemented.

The main research question was: **How to develop an outdoor sensor system that measures dominant variables linked to the drivers causing an Urban Heath Island effect in the city of Enschede?** From the results and the sub-questions, it can be concluded that this can be done by finding the dominant variables which are feasible to measure with an autonomous sensor node. These are humidity, wind speed and temperature. It is possible to measure these variables with an accuracy sufficient to get informed about the urban heat island effect in Enschede, but the measurements are not accurate enough to improve a detailed model. All of this can be done within the power constrains of a sensor node with no external power supply.

9.2 Future work

There are many interesting opportunities to improve this system or make the data gathered by the system more valuable. Many of these possibilities occurred during this project without the time or resources to look into them further. Here these possibilities were listed.

Implementing solar radiation measurements

Solar radiation is one of the variables which can give valuable information about the urban heat island. Implementation of this variable pretty simple. A 180° picture has to be taken with a fish eye lens above the sensor when the sensor is placed. From this picture the percentage of sky visible can be calculated. This can be done by had, but it would be more future proof if this is done by an algorithm, because if the amount of sensor nodes increases it becomes a lot of work to do this by hand. The database already features an extra column for linking the sky view factor to a location. With this the solar radiation of a certain sensor node at a certain moment can be calculated using the sky view factor and data from the ITC's irradiance sensor. Due to time constraints during this project solar radiation measurements were not implemented in the system, but this could be a great feature to implement in a future project with this system.

Adaptable update rate

At the moment, the update rate of sensor nodes in not adaptable. It could be useful to be able to remotely adapt the update rate if more information is required at a certain location. If this could be done remotely the sensor nodes does not have to be taken down to update them. This could save a lot of time. An adaptable update rate could be possible by programming different options which can be activated via an up-link message.

Up-link message for requesting GPS location

Currently, the GPS is only checked every five hours. But, when sensor nodes are not moved around much this is still a waste of power. It is possible to adapt the current program running on the microcontroller, so an up-link message can be used to request a GPS location from a sensor node. This can be done when the sensor node is moved or when it is lost or stolen.

Further expansion of the network

Now, there are eight sensor nodes operational. Seven of them are of the first generation. To get more information on the urban heat island effect in Enschede and get the sensor network to its full potential, the sensor network needs to be expanded. Sensor nodes need to be placed on strategic points like street corners and squares with reference nodes in the rural area around Enschede. to achieve this, suitable locations for these nodes need to be found and nodes need to be manufactured. It is important that during placement and deployment of the sensor nodes the ethical considerations from chapter 9 need to be kept in mind, so the project does not suffer any backlash due to bad decision making.

More durable housing

The current housing is made out of PLA. This material is weather resistant, but UV-rays and water freezing in little crevices in the housing can eventually break down the housing. There are very interesting 3D printing materials out there like ABS or PETG, but during this project there was not enough time to research this. Before the sensor nodes are going to be manufactured on a larger scale, this might be something which is worth looking into.

Determining and improving accuracy wind speed

During this project the accuracy of the anemometer could not be determined. It could only be proven that almost all of the wind speed measurements fell within the range of maximum and minimum wind speed measured by the reference weather station. It would be great if the accuracy of the anemometer could be determined, so it is clear how trustworthy its measurements are.

Integrating humidity sensor in more suitable compartment

The humidity sensor is currently in an external compartment at the side of the main part of the housing. This seems to work, but sometimes measures relatively high values. The rest of the time it is performing fine. It might be that despite of the air and drainage holes the humidity sensor, still some moisture gets stuck in the compartment. Improving the compartment and changing the placement of the compartments hatch from the side to the top, where it is protected by the bottom disk, could lead to more accurate humidity measurements.

Bibliography

[1] Population Reference Bureau, "world population datasheet 2017," population reference bureau, Wachington D.C., 2017.

[2] R. M. Rehan, "Cool city as a sustainable example of heat island management case study of the coolest city in the world," *HBRC Journal,* vol. 12, no. 2, pp. 191-204, August 2016.

[3] Y. Jabareen, "Planning the resilient city: Concepts and strategies for coping with climate change and environmental risk," *Cities,* vol. 31, pp. 220-229, april 2013.

[4] J. Vanos, S. Cakmak and L. Kalkstein, "Association of weather and air pollution interactions on daily mortality in 12 Canadian cities," *Air Quality, Atmosphere & Health,* vol. 8, no. 3, pp. 307-320, June 2015.

[5] M. Nuruzzaman, "Urban Heat Island: Causes, Effects and Mitigation," *International journal of enviromental monitoring and analysis,* pp. 67-73, 2015.

[6] M. Masiola, C. Agostinelli, G. Formenton, E. Tarabotti and B. Pavoni, "Thirteen years of air pollution hourly monitoring in a large city: Potential sources, trends, cycles and effects of car-free days," *Science of The Total Environment,* pp. 84-96, 1 October 2014.

[7] Tubantia, "Spaanse Pluim brengt hittegolf naar Twente," ADr News media, 22 july 2016. [Online]. Available: https://www.tubantia.nl/overig/spaanse-pluim-brengt-hittegolf-naar-twente~ad9a2f85/. [Accessed 04 April 2018].

[8] T. Onderwater, "Developing a sensor network for real time temperature monitoring in enschede," Enschede, 2018.

[9] K. Ward, S. Lauf, B. Kleinschmit and W. Endlicher, "Heat waves and urban heat islands in Europe: A review of relevant drivers," *Science of The Total Environment,* pp. 527-539, 1 November 2016.

[10] A. Mohajerani, J. Bakaric and T. Jeffrey-Bailey, "The urban heat island effect, its causes, and mitigation, with reference to the thermal properties of asphalt concrete," *Journal of Environmental Management,* pp. 522-538, 15 July 2017.

[11] Y. Jiachuan, W. Zhi-Hua and E. Kamil, "Environmental impacts of reflective materials: Is high albedo a 'silver bullet' for mitigating urban heat island?," *Renewable and Sustainable Energy Reviews,* vol. 47, pp. 830-843, July 2015.

[12] P. P. Hui Li, "Literature Review on Cool Pavement Research," *Pavement Materials for Heat Island Mitigation,* pp. 15-42, 12 February 2016.

[13] S. Lehmann, "Low carbon districts: Mitigating the urban heat island with green roof infrastructure," *City, Culture and Society,* vol. 5, pp. 1-8, March 2014.

[14] K. R. Gunawardena, M. J. Wells and T. Kershawa, "Utilising green and bluespace to mitigate urban heat island intensity," *Science of The Total Environment,* pp. 1040-1055, 15 april 2017.

[15] Y. Qin, "A review on the development of cool pavements to mitigate urban heat island effect," *Reviews, Renewable and Sustainable Energy,* vol. 52, pp. 445-459, december 2015.

[16] Y. Wang, U. Berardi and H. Akbari, "Comparing the effects of urban heat island mitigation strategies for Toronto, Canada," *Energy and Buildings,* vol. 114, pp. 2-19, 15 February 2016.

[17] S. I. Bohnenstengel, I. Hamilton, M. Davies and S. E. Belcher, "Impact of anthropogenic heat emissions on London's temperatures," *Quarterly Journal of the Royal Meteorological Society,* vol. 140, no. 676, 2013.

[18] A. J. Arnfield, "Two decades of climate research: A review of turbulence, exchanges of energy and water and the urban heat island," *International journal of climatology,* vol. 23, pp. 1-26, 2003.

[19] L. Dan, C. Xin and H. Chongwei, "Intelligent Agriculture Greenhouse Environment Monitoring System Based on IOT Technology," in *Intelligent Transportation, Big Data and Smart City (ICITBS), 2015 International Conference*, Halong Bay, 2015.

[20] M. Jha, P. R. Marpu, C.-K. Chau and P. Armstrong, "Design of sensor network for urban micro-climate monitoring," in *Smart Cities Conference (ISC2), 2015 IEEE First International*, Guadalajara, 2015.

[21] S. M. S. ,. D. V. V. K. Dr. M. Newlin Rajkumar, "IOT Based Smart System for Controlling CO2 Emmission," *International journal for scientific research in engeneering, computer science and information technology,* vol. 2, no. 2, pp. 284-288, 2017.

[22] M. Alderton, "Redshift," autodesk, 6 january 2016. [Online]. Available: https://www.autodesk.com/redshift/wireless-sensor-networks/. [Accessed 26 march 2018].

[23] A. Cenedese, A. Zanella, L. Vangelista and M. Zorzi, "Padova Smart City: An urban Internet of Things experimentation," in *World of Wireless, Mobile and Multimedia Networks (WoWMoM), 2014 IEEE 15th International Symposium*, Sydney, 2014.

[24] Busan city, "International telecommunications union," april 2016. [Online]. Available: https://www.itu.int/en/ITU-D/Regional-Presence/AsiaPacific/Documents/Events/2016/Apr-Digital2016/S3_Present_Kim_Yunil.pdf. [Accessed 26 march 2018].

[25] A. Augustin, J. Yi, T. Clausen and W. M. Townsley, "A Study of LoRa: Long Range & Low Power Networks for the Internet of Things," *Sensors,* vol. 16, no. 9, p. 1446, 2016.

[26] A. v. B, "Limitations: data rate, packet size, 30 seconds uplink and 10 messages downlink per day Fair Access Policy," The things network, 12 May 2018. [Online]. Available: https://www.thethingsnetwork.org/forum/t/limitations-data-rate-packet-size-30-seconds-uplink-and-10-messages-downlink-per-day-fair-access-policy/1300. [Accessed 22 May 2018].

[27] W. J. Shuttleworth, "Evapotranspiration measurement methods," Universiry of Arizona, Arizona, 2008.

[28] P. A.Mirzaei, "Recent challenges in modeling of urban heat island," *Sustainable Cities and Society,* vol. 19, pp. 200-206, 2015.

[29] P. Kumar, L. Morawska, C. Martani, GeorgeBiskos, M. Neophytou, S. D. Sabatino, M. Bell, L. Norfordk and R. Britter, "The rise of low-cost sensing for managing air pollution in cities," *Enviroment international,* vol. 75, pp. 199-205, 2015.

[30] A. Mader and W. Eggink, "A design process for creative technology," in *International Conference on Engineering and Product Design Education*, Enchede, 2014.

[31] B. Boehm, "Spiral Developement: Experience, Principles and Requierements," University of Calefornia, Los Angeles, 2000.

[32] H. Sharp, A. Finkelstein and G. Galal, "Stakeholder Identification in the Requirements Engeneering Process," in *Proceedings of 10th International Workshop on Database & Expert Systems Applications*, 1999.

[33] D. Reidsma, H. Koppelman, R. v. Delden and M. Bruijnes, "Intelligent interaction design," University of Twente, Enschede, 2017.

[34] N. Walliman, Research methods: the basics, Abigdon: Routledge, 2011.

[35] S. Bringkkemper and S. Pachidi, "Functional Architecture Modeling for the Software Product Industry," in *Software architecture*, Utrecht, University of Utrecht, 2010, pp. 189-215.

[36] Adafruit. inc, "voltages," 01 01 2018. [Online]. Available: https://learn.adafruit.com/li-ion-and-lipoly-batteries/voltages. [Accessed 13 june 2018].

[37] KNMI, "klimatologie," ministerie van infrastructuur en waterstaat, 15 May 2018. [Online]. Available: http://projects.knmi.nl/klimatologie/. [Accessed 16 May 2018].

[38] Nova Lynx, "wind speed and direction," NovaLynx Corporation, 2018. [Online]. Available: https://novalynx.com/store/pc/Wind-Speed-and-Direction-c19.htm. [Accessed 01 April 2018].

[39] Campbell Scientific, "Wind Speed and Wind Direction Sensors," CAMPBELL SCIENTIFIC, INC., 2018. [Online]. Available: https://www.campbellsci.com/wind-speed-direction. [Accessed 26 March 2018].

[40] E. Dertien, Sensors for creative technology, Enschede, 2013.

[41] D. Han, S. Kim and S. Park, "Two-dimensional ultrasonic anemometer using the directivity angle of an ultrasonic sensor," *Microelectronics Journal,* vol. 39, no. 10, pp. 1195-1199, 2008.

[42] KNMI, "Wind speed and wind pressure," KNMI, 1 january 2018. [Online]. Available: https://projects.knmi.nl/hydra/faq/press.html. [Accessed 24 may 2018].

[43] Mousser electronics, "Sensors," Mousser Inc., 22 may 2018. [Online]. Available: https://nl.mouser.com/Sensors/.

[44] D. K. Roveti, "Choosing a Humidity Sensor: A Review of Three Technologies," Sensors online, 1 July 2001. [Online]. Available: https://www.sensorsmag.com/components/choosing-a-humidity-sensor-a-review-three-technologies. [Accessed 22 may 2018].

[45] SparkFun electronics inc., "SparkFun weather meters," 2015. [Online]. Available: https://cdn.sparkfun.com/assets/8/4/c/d/6/Weather_Sensor_Assembly_Updated.pdf. [Accessed 04 june 2018].

[46] Sparcfun inc., "sparFun humidity and temperature sensor breakout-SHT15," 01 january 2018. [Online]. Available: https://www.sparkfun.com/products/retired/13683. [Accessed 08 june 2018].

[47] Dallas semiconductor, "DS18B20 programmable resolution digital thermometer," 01 01 2015. [Online]. Available: https://cdn.sparkfun.com/datasheets/Sensors/Temp/DS18B20.pdf. [Accessed 13 june 2018].

[48] TTN network, "LoRa(WAN) airtime calculator," 01 February 2016. [Online]. Available: https://docs.google.com/spreadsheets/d/1QvcKsGeTTPpr9icj4XkKXq4r2zTc2j0gsHLrnplzM3I/edit#gid=0. [Accessed 24 June 2018].

[49] E. K. Karacor, "Public vs. Private: The Evaluation of Different Space types in Therms of Pubicness Dimention," *European journal of sustainable development,* vol. 5, no. 3, pp. 51-58, 2016.

[50] N. Jacobs and R. Cooper, Living in Digital Worlds: Designing the Digital Public Space, New York: Routledge, 2018.

[51] McKinsey&company, "Monerizing car data," September 2016. [Online]. Available: https://www.mckinsey.com/~/media/McKinsey/Industries/Automotive%20and%20Assembly/Our%20Insights/Monetizing%20car%20data/Monetizing-car-data.ashx. [Accessed 30 may 2018].

[52] ADAC, "Europäer wollen Datenhoheit über ihre Fahrzeuge," Stadt-Informationen EURIP Cities, 05 april 2016. [Online]. Available: http://cities.eurip.com/article/news/entry/345911.html. [Accessed 29 may 2018].

[53] Pinsent Mansons, "Connected and autonomous vehicles: The emerging legal challenges," p. 15, april 2016.

[54] ACEA, "Strategy Paper on Connectivity," 15 april 2016. [Online]. Available: http://www.acea.be/publications/article/strategy-paper-on-connectivity. [Accessed 29 may 2018].

[55] P. Vallentyne and B. v. d. Vossen, "Libertarianism," Stanford Encyclopedia of Philosophy, Stanford, 2014.

[56] European parliament, "Directive 2002/58/EC of the European Parliament and of the Council of 12 July 2002 concerning the processing of personal data and the protection of privacy in the electronic communications sector," *Official Journal,* vol. 201, pp. 37-47, 2002.

[57] T. Machan, "The right to private propery," 12 June 2018. [Online]. Available: https://www.iep.utm.edu/home/about/.

[58] Array of Things, "Array of Things Oparating policies," 15 August 2016. [Online]. Available: https://arrayofthings.github.io/final-policies.html. [Accessed 30 May 2018].

[59] G. Orwell, Nineteeneightyfour, Londen: Arcturus Publishing, 2014 (originally 1949).

[60] L. Harding, "The Gardian," 26 January 2015. [Online]. Available: https://www.theguardian.com/world/2015/jan/26/mass-surveillance-threat-human-rights-council-europe. [Accessed 31 May 2018].

[61] K. Macnish, "Surveillance ethics," 12 june 2018. [Online]. Available: http://www.iep.utm.edu/surv-eth/.

[62] R. Simcox, "SURVEILLANCE AFTER SNOWDEN," the Henry Jackson society, London, 2015.

[63] H. Breakley, "Property," 06 june 2018. [Online]. Available: https://www.iep.utm.edu/prop-con/#SH10b.

[64] B. Boehm, "Spiral Development: Experience, Principles, and Refinements Spiral Development Workshop," University of calefornia, Los Angeles, 2000.

[65] RayMan, "researchgate," december 2015. [Online]. Available: https://www.researchgate.net/figure/Fish-eye-lens-photography-to-aid-Sky-View-Factor-SVF-calculations-by-RayMan_fig2_293990540. [Accessed 10 july 2018].

[66] Autodesk, "Measuring Light Levels," Autodesk Inc., 2017. [Online]. Available: https://sustainabilityworkshop.autodesk.com/buildings/measuring-light-levels. [Accessed 09 April 2018].

[67] Intorobotics, "Most common and most budgeted Arduino light sensors," Intorobotics, 26 January 2015. [Online]. Available: https://www.intorobotics.com/common-budgeted-arduino-light-sensors/. [Accessed 09 April 2018].

[68] Adafruit, "Using a Photocell," Adafruit Inc., 26 December 2017. [Online]. Available: https://learn.adafruit.com/photocells/using-a-photocell. [Accessed 09 April 2018].

[69] D. Brose, "Risk analysis: A quantitative guide," in *John Wiley and Sons, Ltd*, Chichester, 2008.

[70] Population Reference Bureau, "world population datasheet 2017," population reference bureau, Wachington D.C., 2017.

Appendix

Appendix A: Interviews

Interview with Wim Timmermans 16-03-2018

W: Wim Timmermans A: Adam L: Laura

-----------Interview starts on the start of the second question-------------

A: We are working with the UT and the municipality to make a sensor network across Enschede and it's outskirts to monitor the urban heat island effect, and to identify whether it is a problem, or if it will become a problem in the future. At the moment the proof of concept has been made, do you know anything about this?
W: More or less, because I am in contact with them for a couple months only. I know that they were doing some measurements with temperature related. I've only talked to them twice for an hour or so though. But it seems like there is a lot of overlap. To me it seems what they have been measuring, the temperature, could be used to validate the models that i am working on. Of course, we do these measurements as well ourselves, we do it in one spot, but in a very sophisticated way. We measure on top of the ITC hotel. We measure measure several things there, we measure an integrated signal, which measures the exchange of water and heat of the entire city. So, we shoot a beam from "place" tower towards the Horst and the measurement is basically an integrated signal of the whole city. We would basically want to monitor that with a sensor network. So that is why I got in contact with them about your project basically.
A: So, the project ended by them having 5 sensors and they were just measuring temperature. Our goal now is to scale up the network and add additional sensors to the nodes if necessary.
W: Yes this is very good
A: So we were researching into what variables would be the most suitable to research the UHI but also what is the most important for you if we are going to make this network of sensors.
W: And what is feasible i imagine as well.
L: For now, in the literature we found that the pollution, air humidity, wind speed, and sun radiation might play important roles, but we were wondering what your opinion on this was.
W: Well it depends on really what you want to measure because as I said before, I'm coming from the agriculture background, so urban stuff is relatively new to me. I am doing the same as you guys, diving into literature. If you want to map the UHI obviously you need to measure the heat. So there is no need to expand the measurements. However, if you want to model this stuff you need to know what the driving factors are. So basically, you should measure incoming radiation, solar radiation, and another thing to measure is the wind speed, definitely. An in principle that is more or less sufficient, with the respect to the sensors you are mentioning. However, if you also want to map the problem that the people that the people are experiencing, then that is different. It could be 25 degrees but sometimes that's pleasant and sometimes that's not pleasant, so you need to seek the combination with other parameters and probably you know that if you combine them humidity, when its too humid it's not that pleasant anymore. So, humidity is a factor as well. And then you can think of additional factors as anthropogenic influences, exhaust caused by traffic, by factories, air quality becomes and issue as well. But then you go towards mapping something which is like a comfort index or something that's different from the UHI. So you can make it as broad as you want
A: So basically, solar radiation and wind speed are the main things we want to investigate
W: If you want to add on that I would say that humidity is easiest to implement. Air quality, you probably want to monitor CO2. We do, but then you get into what is practical. It is going to be rather difficult to manufacture that.
L: Yeah, it's not the easiest one.
A: Because, Richard said you also have a lot of expertise in air quality.
W: No, i'm not an expert in anything. No, im not, not at all
L: well then Richard told us something different
W: No, um, It's related obviously, but i'm not an expert in air pollution at all.
A: okay, and so once we have this data and we collect it, how could this help with your research. How would you want to plug it in, you said for validation?
W: And for calibration as well.
A: And so how much data would be necessary for you? Maybe once every hour, once every day, once every five minutes?
W: I would prefer to have at least half an hour measurement. If it's not a big issue, 5 minutes is even better, and depends also on the type of the information.
L: Yeah in the previous project the network that they used to send the data over was not very reliable. They're sending data over the LoRa network. It sometimes happens that packets get lost, and there is no validation or resending packets, is it a problem for you that there might be gaps in the data.

W: Sure of course that's a problem
L: Is it a big problem?
W: depends on how large the gap is. As a scientist you should always answer, well it depends. The thing is we don't have the model running yet. I need to set it up still and getting in contact with Richard and Hans is part of this like getting to know about what people really want from it. Therefore, i'm also trying to get into contact with the people in the municipality to learn from them what they want. Because in principle everything can be done, it's just a matter of money and time availability, how complex you want to go. And the same is valid for your data streams. Just as i was looking for temperature images over enschede over the last 3 years, and i only found 5 of them that were suitable. There are other observations possible as well, but you have to work with what you have at hand. And I imagine for you that it's not that big of a change if you have data every 5 minutes or every half hour.
A: yeah it depends on the things that we want to measure, because the networks have a certain bandwidth and how much you can send per day. So we need to make it as effective as possible, how were sending the data. So we can send as much as possible, but that's still to be investigated, what the limit of sending is.
L: And how much we need to send, because if we want to send more, then we have to send less times per day. So for that were still not sure, if you prefer at least half an hour, for us that's pretty good. Because now we have every 5 minutes data, with sometimes data missing, but you'll have at least 2 measurements per half an hour.
A: But when we send every 5 minutes and lose some packets, then the impact is much lower on the data, then if we were to send it only once every half an hour and the packet gets lost.
W: Yeah, I was more thinking if you do it in 5 minutes and have a quality flag attached. Like hey look guys in the last half an hour 2 packets were lost. Then we will know the quality of the data that you are looking at. But half an hour is on the lower limit.
A: and then another question is how long the data should be stored on our servers.
W: how many years?
A: Yeah if its like 5 years
W: It would be nice if it is stored continuously. Because its climate related data, so the longer you collect the data the more valuable it is going to be. So for that purpose I would say we would have to look for at some storage capacity at the ITC or at the UT. It's not a big problem. If it's for calibrating a model, the yeah, a couple of days would be enough, it all just depends on what the purpose.
A: But it's obviously best to store as long as possible and don't make any cut backs.
L: Is it necessary to keep all the data in a database or could it also be stored offline for your purposes.
W: For my purposes it could be stored offline.
L: Because it makes the database problem a lot less complicated.
A: like after a year keep it on a hard drive. Another question is about how you want to format the data or how you want to access the data. If a csv file would be good.
W: yeah that could be, it could be in ASCII, it doesn't really matter, as long as I know the format, then its usable.
A: So just make it as easy as possible.
W: I would say, also in relation to the other question, because the longer the time series is, the more people are going to be interested in it. These days you have to make everything available that you do research in, because it is funded by public money. I would say make the data format as simple as possible. ASCII I would say. And also make the data available, but that has to be discussed with Richard as well, because I do not know under what conditions the project is working under. I imagine the city council would want to have access as well.
A: Yeah, we talked about that and who's going to have access to the data and the visualization. For us it's not really an issue to have the data public, if that's what the city wants.
L: Have you already seen the current visualization of our project.
W: No
------stuff about the visualization------
-----Wim says he doesn't care about our visualization----
L: Okay that was all from our side, but are there any questions that you have for us?
W: Yeah, I wanted to ask about how much sensors you want to place in Enschede. How much you are going to expand the network?
L: Yes, we are definitely going to expand the network, that is what the Richard and the municipality have in plan. I already heard from Richard that Tom, the guy who previously worked on my part, the sensors, that Richard asked him to stay involved and keep working on new sensor nodes. But for us, we still have to make plans and find out how many sensors it is feasible to make in this half a year.
W: The more nodes the better, of course you always work with boundary conditions, time and money. Once you have the number of nodes you also have to figure out where to locate them. Because what I heard from Richard, is that they just gave them to the municipality and they just placed them somewhere. But it is also an issue of where you place them, you need to find suitable locations for this.

A: yes, we were looking into the WMO and it's guidelines, but do not have a concrete plan for the placement yet.
W: There is two issues, the first is that for certain measurements you need to have specific standards, like with evaporation it's quite a hassle. But in an urban area there are certain hotspots where you definitely need to measure, for example in the harbor where you have a lot of industry, you have really a lot of exhaust air. So you can be sure that in those areas you are going to have a lot of warm air. You want to be sure to cover these extremes. You will also want one or two outside of the city, so you can have a reference from the rural to the urban areas. And so there is more criteria than just simply spreading them across the city randomly.
L: Yeah that is definitely something we are going to look into
W: You can look at the heat map of the city to identify these hotspots. You see the industries and where the hotspots are, and also where the parks are.
W: Wim Timmermans L: Laura

Interview with Wim Timmermans 03-05-2018

--------------interview starts after short update about what L has done the last 10 weeks--------------

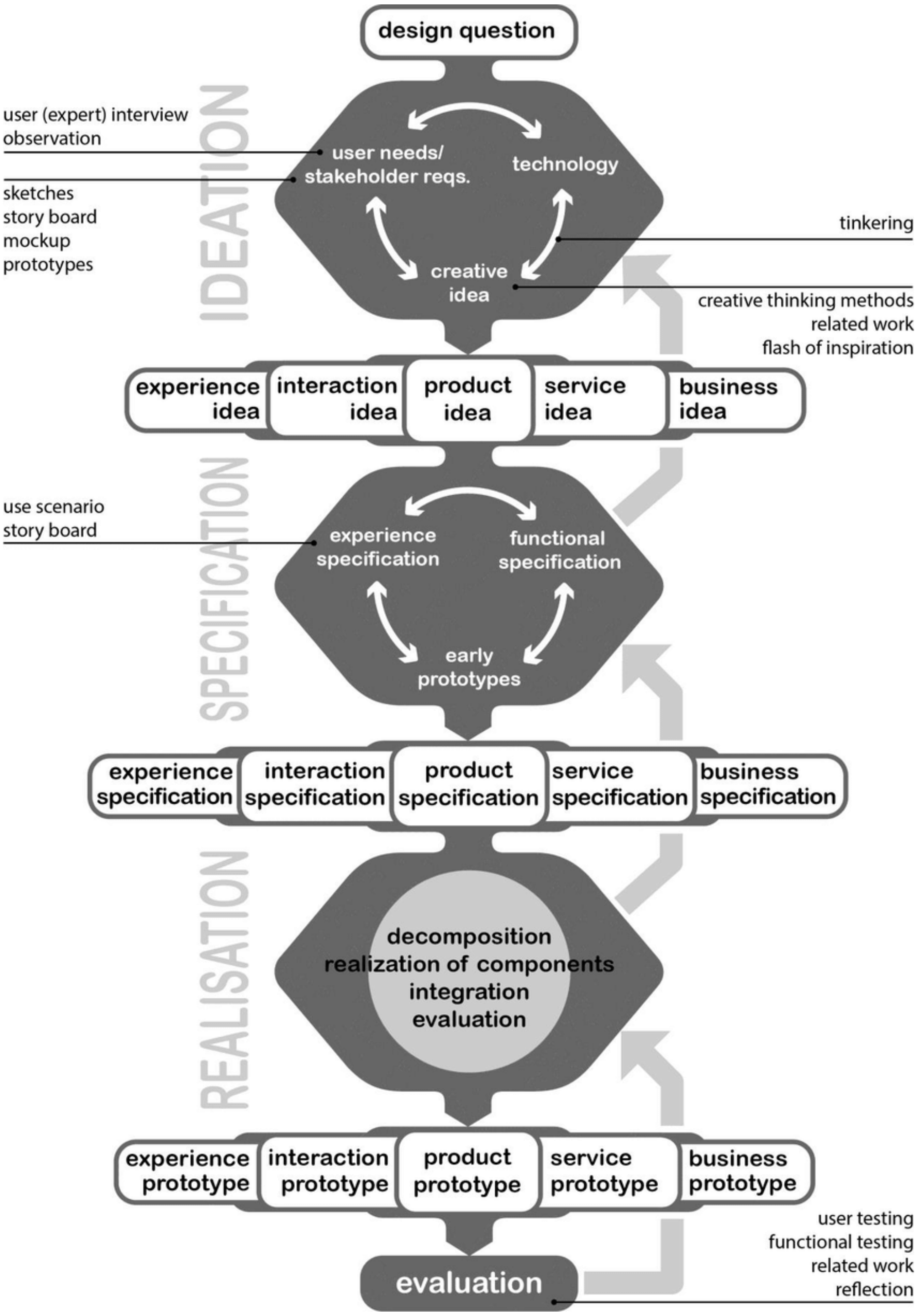
L: my first question is if you agree with the 5 drivers of the urban heat island effect I have found?
W: - shows a scientific paper with a formula definition of the urban heat island effect-
L: I have seen that formula before.
W: yes probably, this is a very simple empirical formula which has been developed to measure the urban heat island effect.it includes the skyview factor, that is the percentage of sky visible when you look up, vegetation fraction, incoming radiation, delta of the days temperature and the wind speed at 10M.
L:Yes that includes almost all drivers.
W: those are most important.
W: -points to increased greenhouse gases- this is an indirect effect.
L: yes, that is also what I found in my literature. If you have a lot of greenhouse gases, more heat is contained by them and the effect will increase in magnitude.
W: It depends on how you define the urban heat island effect.There are different opinions about that. This is a definition about the maximal difference in temperature between a point in the city and a rural location. That is what they use that is why those factors are important. The other factors are only indirectly included. If you define the UHI as how uncomfortable it is for people. That is totally differend. Because sometimes it is nice if it is 25 degrees. This is related to your definition.
L: I think this also depends on the exact goal of hendrik-jan, because if he wants to know how citizens experience it, other factors will be important to measure.
W: even if you prefer a scientific definition. There are different definitions available.
L: I found some measurable variables correlating with the drivers. For all of them I have the question how important are they actually in regard of the urban heat island effect?
W: That also depends on what you want to measure. If you want to measure it this way -Points to the formula- It is very sraightfoward.
L: that is everything inside the formula.
W: Yes
L this one is very clear which is nice, but if you aim more for the human comfort…
W: still you can analyse the formula and see how big a part each variable plays an how they influence the outcome. Some factors can only vary in a certain range which makes that some variables have more effect on the outcome than others. But that is purely analytical.
L: you can get that from the formula.
W: indeed
L: this is harder if you focus on human comfort.
W: yes, also because human comfort is relative.
L: of course what is comfortable…
W: research has been done in wageningen about how people perceive temperatures. It also depends on what you are used to. 30 degrees in a dry climate is not a problem where 30 degrees in the dutch moist climate is perceived as uncomfortable.There in not one answer for that and that is also why you will not find it in literature.
L: yes, scientific literature always tries to be unambiguous and this is not unambiguous in any way.
W: This is a very vague area of research for a beta scientist.If i might advice you something I would just choose a certain formula and this one is generally accepted. And is also cited often enough. It is developed for north-western europe. A reasonably wide area. Thay you have solid ground to do certain assumptions. You can prove that this is often used.
L: you have to build your project on something, a good foundation is important.
W: in principle all your variables are measurable and in relation to the urban heat island effect.
L: which variables do you prefer?

W: I would keep it relatively simple, radiation is important but especially in combination with a skyview factor. Because in a city there are always building in the way and radiation bounces off and gets reflected.
L: How dou you measure skyview?
W: officially with a fisheye lens. You know them?
L: yes, those big lenses that film 180 degrees.
W: yes, this is a measurement you only have to do once. So that is not too interesting to incorporate in your sensor node. Because this is a constant factor.
L:If you want to know that you would do the measurements once at every location. And..
W: thats it
L: then it becomes meta data for the sensor node location.
W: or you can get it from a digital terrain model, they exists. You can find that in the general height database of the netherlands. As measurements it is not that interesting. You will need it but probably not in your sensor node.
L: just like albedo, that is something you can determine once. If your sensor is in the same spot the albedo of that spot will not change much.
W: That is dangerous to say in this building.
L: is that not true
W: no, it also depends on how the sun hits the surface.
L: so it is on one day
W: it depends on the angle and direction of the sun. suppose you have a field with a flowing pattern. If the sun is perpendicular to these patterns the albedo will be different than when the sun is in line with these patterns.
L: so in a Certain angle and direction it would be the same..
W: it depends on the surface, if it is yellow,black or red sand but also on the angle and orientation of the solar radiation.
L: so it does change…
W: yes but in a city the surface is so inhomogeneous that you often work with these general terms.
L: it is not the same but it is negligible.
W: i would not say that but you can incorporate that within other factors. And that is what happens because it is way too complex to do that in a city.
L: the most detailed I have found was a research where they worked with percentages of trees, asphalt etc. to approach the albedo. That is also not perfect.
W: You see that a lot in this branch of research also because it is relatively new in combination with the fact that it is very complex and there are some processes of which it is not known how
They physically work exactly. People work a lot with approximations. And then you have 3 factors left which are temperature, wind speed and humidity.
L:and humidity is more…
W: a factor of perception.
L: yes, if it is 30 degrees and dry it is pretty nice and no one complains about it but if it is 30 degrees an moist that is horrible. So that olso depends, what is now the exact goal of the system. To include it or not.
W: -points to formula- you see it is not included here.
L: true, that one is more scientific it is not about how people experience it.
W: Indirectly it is included in the radiation measurements. If there is more moisture in the air there will be more infrared radiation because water absorbs more radiation. Same as the sea. During the day the sea is cooler that the beach but during the night it will be warmer. You also have that with moisture in the air.
L: of cource, it still has the same properties as a gas.
W: clouds have the same effects. If it is cloudy, nights will be warmer than when the skies are clear.
L:yes that also happens when it snows. Than the next question which variable swould you like to see? You are also one of the stakeholders so you should also have a say in this.
W:I am interested how the systems physically work so i am primarily interested in temperature wind speed and radiation.
L: oke that is easy. In the next phase i will have to select sensors and i do not have a clear idea of how the accuracy of the sensors needs to be for the data to be useful. For the variables you mentioned. What is the minimal accuracy to make the data useful?
W: temperature on 0.5 degrees accurate
L: we are already there with the previous project.
W: in would be better if it was 0.1but 0.5 is a minimum. Wind speed is 0.1 M per second is okay. Radiation would be in W per M2 10Wm2 accuracy would be good enough.
L: that is doable if I would buy sensors, not if i would make them myself. That is good to know.
W: How real is the chance that you would make then yourself?
L: that depends on me and with these accuracies I would say that it is very unlikely. Also due to time constraints.

W: It is also important what the goal is of the whole project. For me there is a different goal as for richard and the municipality.
L: For me the goal is graduating, for you the goal is getting useful data. Than I have one last question. Do you know any other sources where this data could be found? I know that this information for CO_2 is available city wide but not very detailed.
W: I do not think there are any official, so maintained by the KNMI, weerstations in the city. I think the only one is at vliegveld twenthe.
L: maybe the CO_2 levels I found are coming from there.
W: to answer your question I should know what you have found and compare that with my lists.
L: at this moment I have the KNMI Which dous basically everything but on a large scale. All measurements are taken on an too large scale. I could not find anything about specific wind directions inside the city.
W: you will not find that.
L: Surface temperature are satellite images but they are not recent enough to use.
W: these images are made every hour or even every five minutes but the resolution is 10 KM so it is unusable for this goal. Images with a useful resolution are made every 16 days but that is still 60m but it is not always clear skies so in practice they are often ½ year old.
L: maybe useful for sensor placement considerations but that's it.
W; Exactly, where you want to go is a model which simulates that.
L: for humidity the best source i could find was the network of weather stations Hans is also following. The question is how accurate are these measurements.
W: it all depends on where they put there weather station. The specs are easy enough to find, but do they put it on the roof or in a cellar? That is a big difference.
L: it would be good if they would all put it on the roof.
W: yes, you do not know that. There are around 50 at the moment. Because you do not know where the stations are, you have to approach it statistically.
L: than the data could be useful. I did not really find anything else.
W: I do not think other sources exist. Mainly because the detail that is needed. It should come from us. I think it is best to start with making as many sensors as possible and placing them on representable places, but that is not something you are not going to do in the time you have.
L: I hope to get at least som sensors up and running but that depends on how good the first prototype will be.

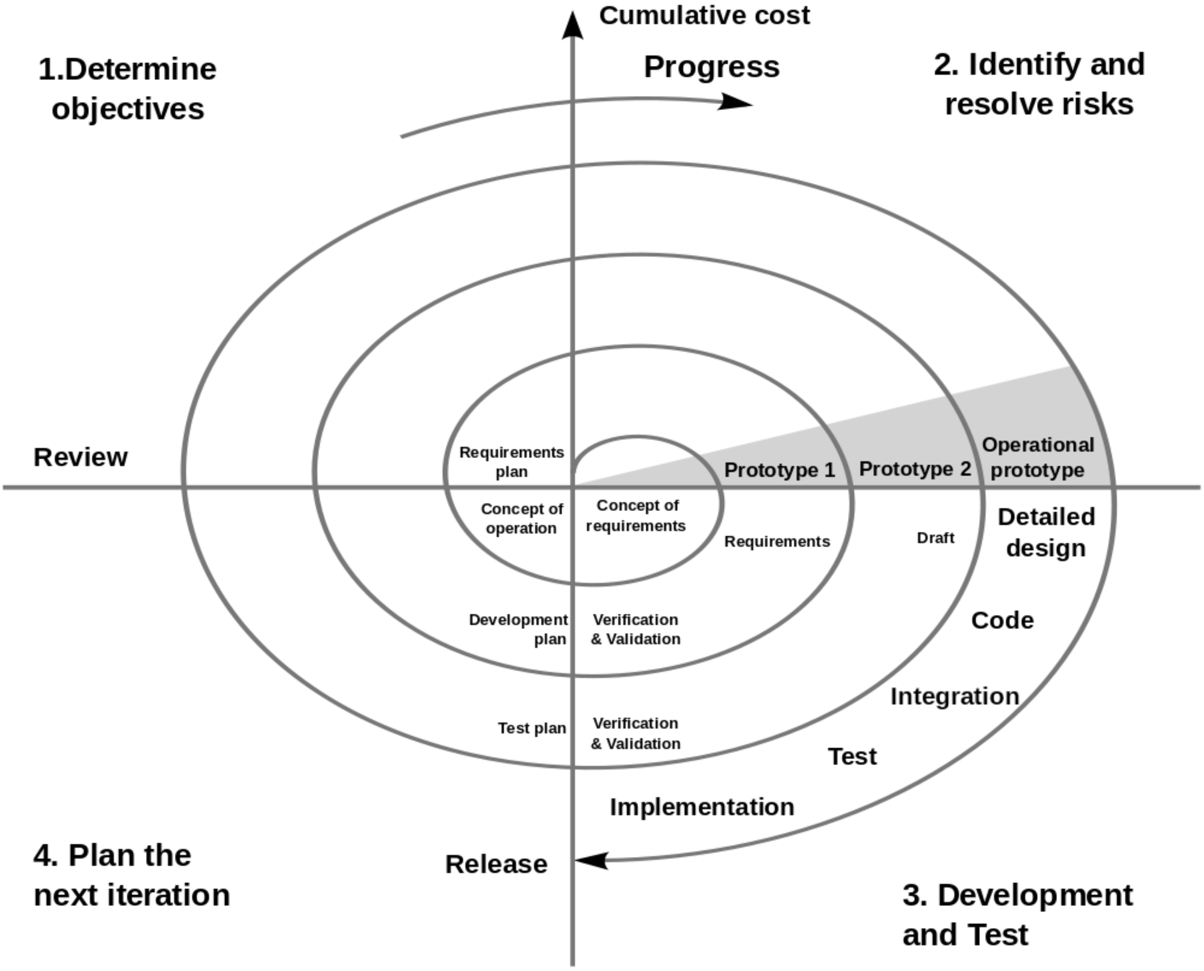
Appendix B: Methods

Design process for creative technology



Source: [30]

Spiral model:

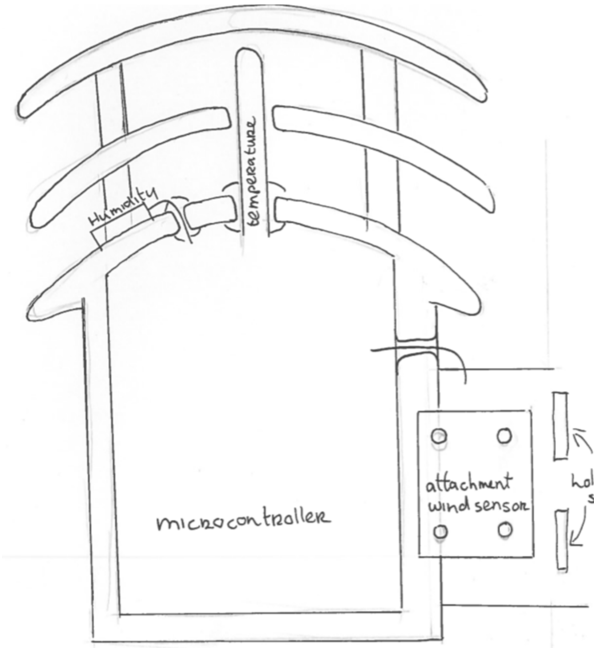

Cumulative cost
Progress
1.Determine objectives
2. Identify and resolve risks
Review
Requirements plan
Concept of operation
Concept of requirements
Prototype 1
Prototype 2
Operational prototype
Requirements
Draft
Detailed design
Development plan
Verification & Validation
Code
Integration
Test plan
Verification & Validation
Test
Implementation
Release
4. Plan the next iteration
3. Development and Test

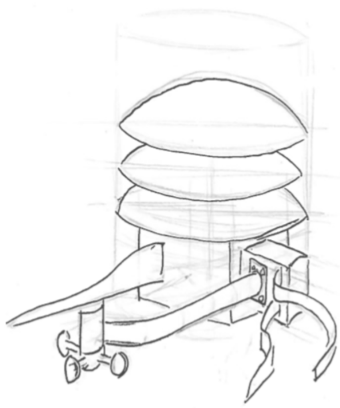
Source: [64]

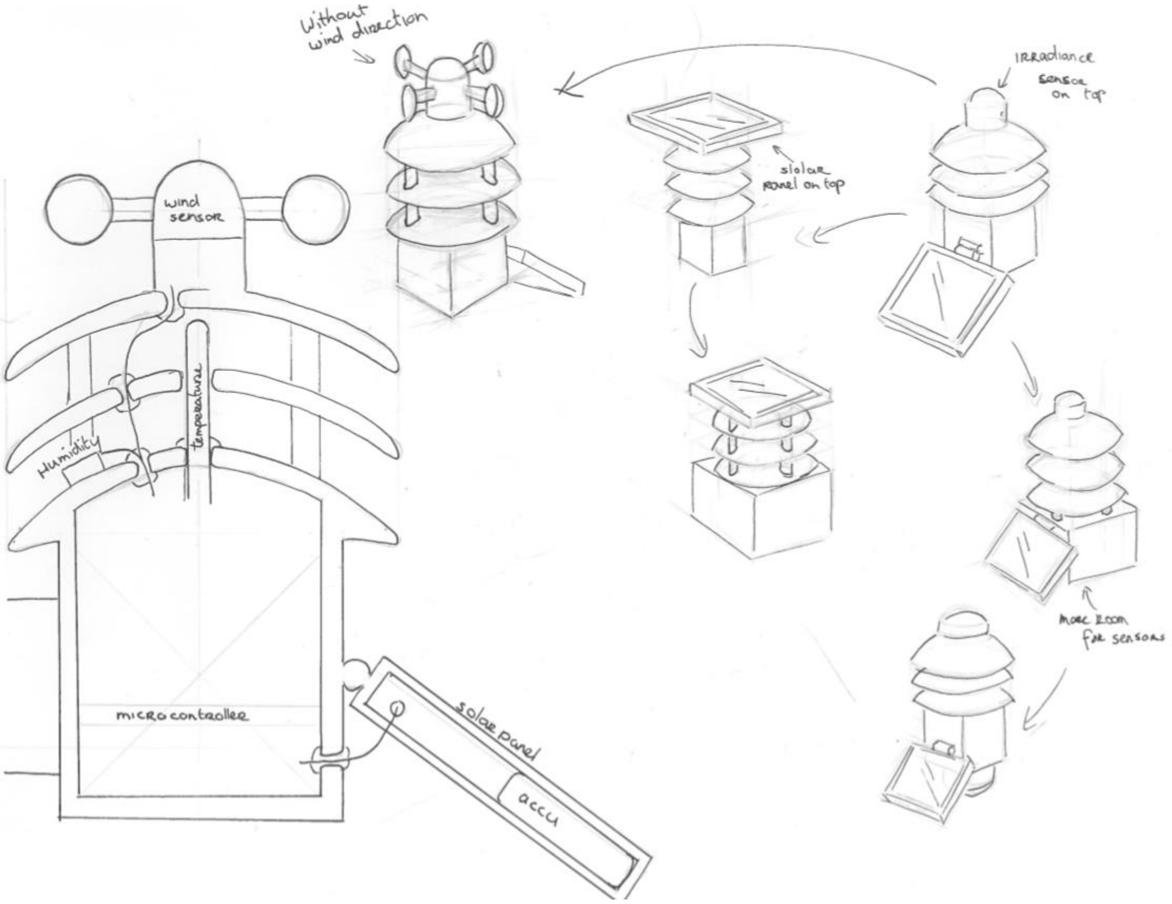
Appendix C: Planning

Week number	phase	goal
17	Ideation	- Planning - Developing plan for gathering requirements
18	Ideation	- Gathering information on requirements (interviews) - Drawing up multiple rough ideas
19	Ideation/specification	- Evaluating results interviews - Selecting variables to measure
20	Specification	- Designing final idea - Determining and analysing requirements
21	Specification/realisation	- Ordering hardware - Designing first case
22	Realisation	- Interfacing hardware separately - first prototype done
23	Realisation	- Testing functional requirements - Designing new prototype, Start with building prototype 2
24	Realisation	- Building prototype 2 - Researching placement sensors
25	Realisation	- Finish prototype 2 - Testing functional requirements
26	Realisation /evaluation	- Testing user requirements - Preparing presentation
27	Evaluation	- Presenting final results - Evaluate process

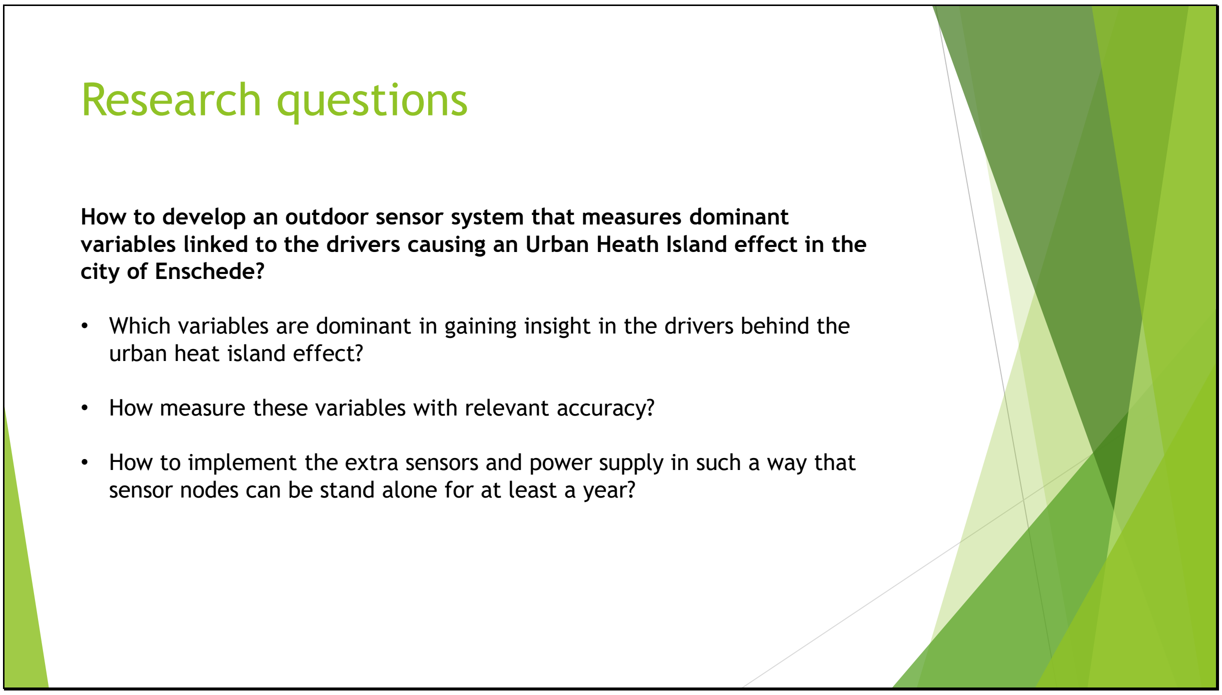
Appendix D: Sketches ideation

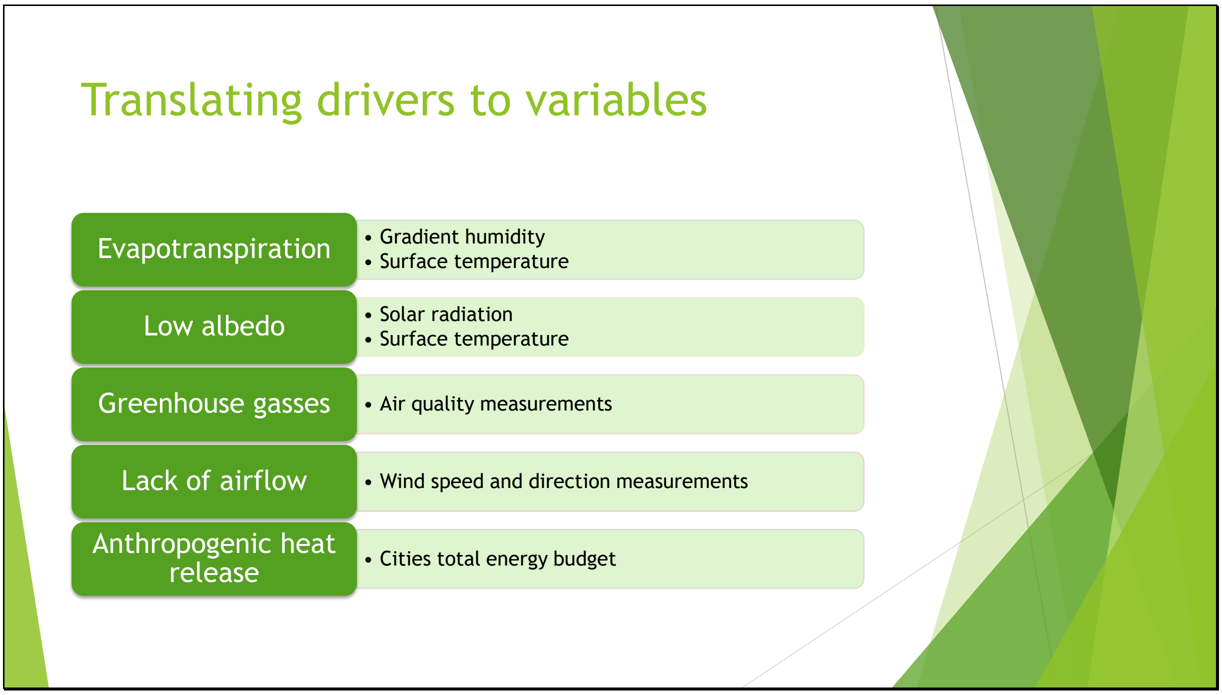






Appendix E: Presentation Hendrik-Jan Teekens





Translating drivers to variables

Evapotranspiration	• Gradient humidity • Surface temperature
Low albedo	• Solar radiation • Surface temperature
Greenhouse gasses	• Air quality measurements
Lack of airflow	• Wind speed and direction measurements
Anthropogenic heat release	• Cities total energy budget

Choices in measuring variables

Solar radiation

- Gives qualitative information on the cause of locally rising temperatures
- Generally equal values throughout the city

Wind speed and direction

- Important for measuring the mitigating effect of drafts
- Wind meter can make the housing bulky
- Little information available about drafts within the canopy layer

Surface temperature

- Gives information on albedo of local surface
- Albedo is a constant factor that can be found with other techniques

Air quality measurements

- Important for measuring the scale of the amplifying effects of greenhouse gasses
- High power consumption makes implementation difficult
- General data is available from other sources

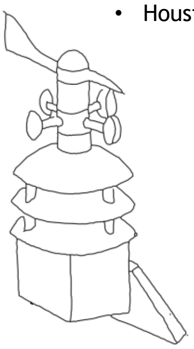
Humidity

- information about intensifying factor of humid weather and mitigating factor of evaporation
- Difficult to determine what the source of the humidity is

Design of the housing

Pros
- Extra room for light measurement sensors on top
- Easy attachment due to placement of wind meter

Cons
- More fragile due to long extension arm
- Housing could affect draft



Pros
- Minimal effect on draft by housing
- Compact design is less vulnerable

Cons
- Implementation of light measurements more difficult
- Housing could affect draft

Appendix F: calculations wind speed sensor

According to the datasheet [45] the reed switch of the Froggit WH1080 makes contact closure once every second at a wind speed of 2.4km/h. This results in contact closure once every second for a wind speed of 0.667m/s.

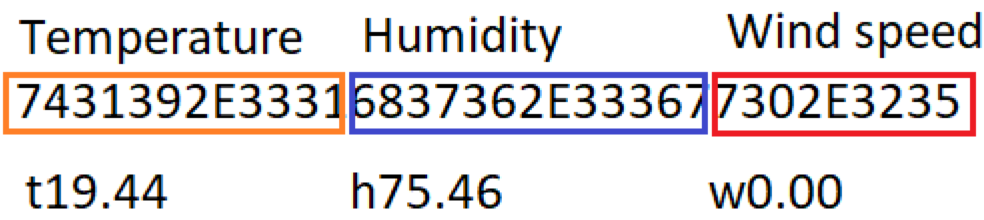
$$\frac{2{,}4 * 1000}{3600} = \frac{2}{3}$$

This results in contact closure every 1.5s for a wind speed of 1m/s. This ratio is used to calculate the wind speed using the measurement period.

$$\frac{2}{3} * \frac{2}{3} = 1 * \frac{2}{3}$$

$$1 = 1{,}5$$

Appendix G: TTN messages

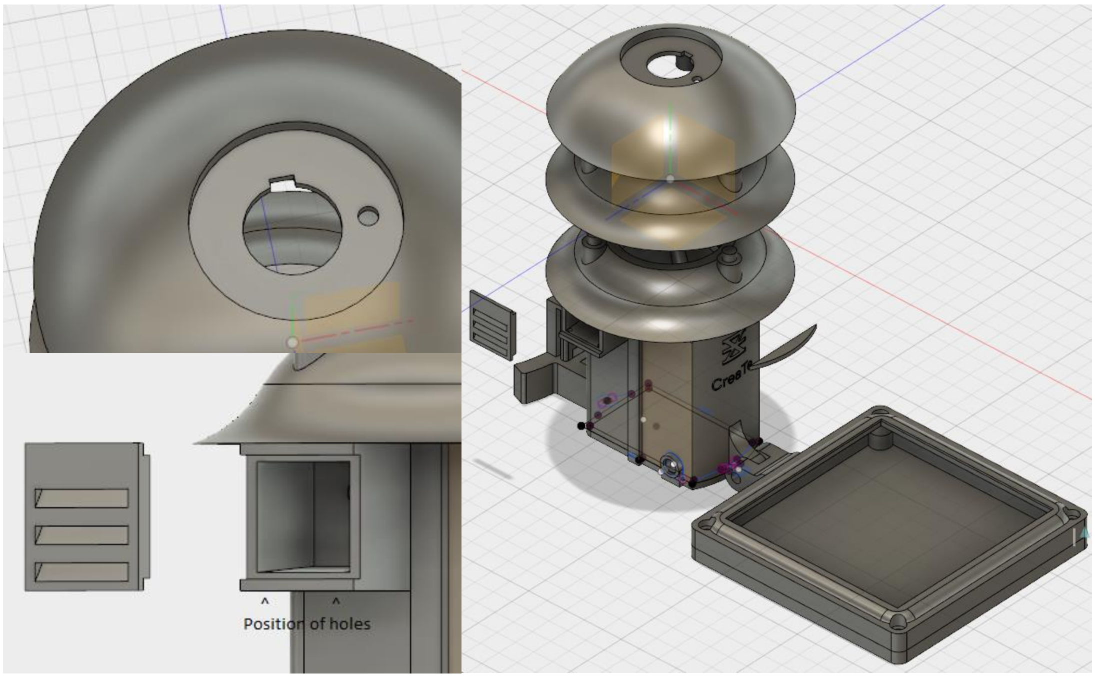


Raw TTN message

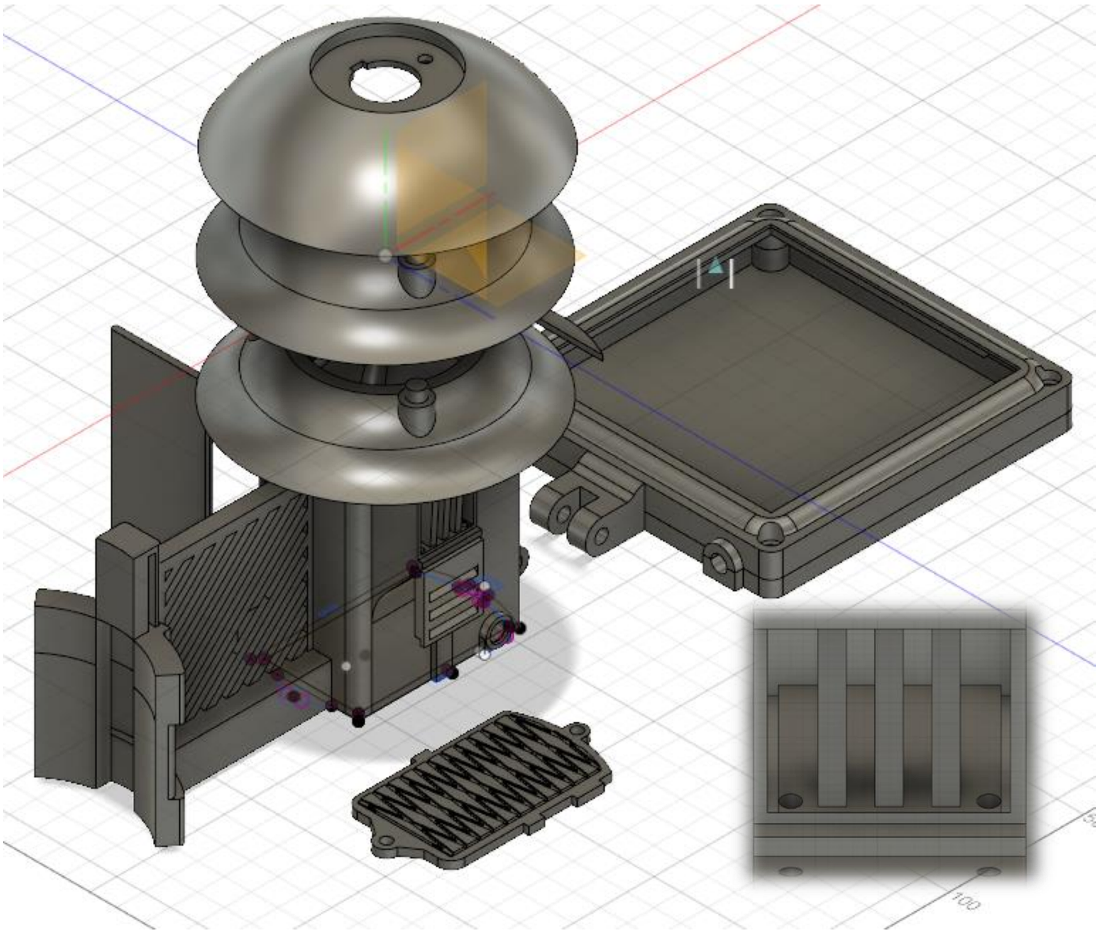

```
{
 "time": "2018-06-18T15:08:28.592632648Z",
  "payload":7431392E33316837362E333677302E3235,
 "frequency": 868.1,
 "modulation": "LORA",
 "data_rate": "SF9BW125",
 "coding_rate": "4/5",
 "gateways": [
   {
    "gtw_id": "eui-1dee0ef5516be6d3",
    "timestamp": 2969505164,
    "time": "",
    "channel": 0,
    "rssi": -108,
    "snr": 8,
    "rf_chain": 1,
    "latitude": 52.23923,
    "longitude": 6.85554,
    "altitude": 24
   }
 ]
}
```

Appendix H: Fusion models

Fusion 360 model first prototype

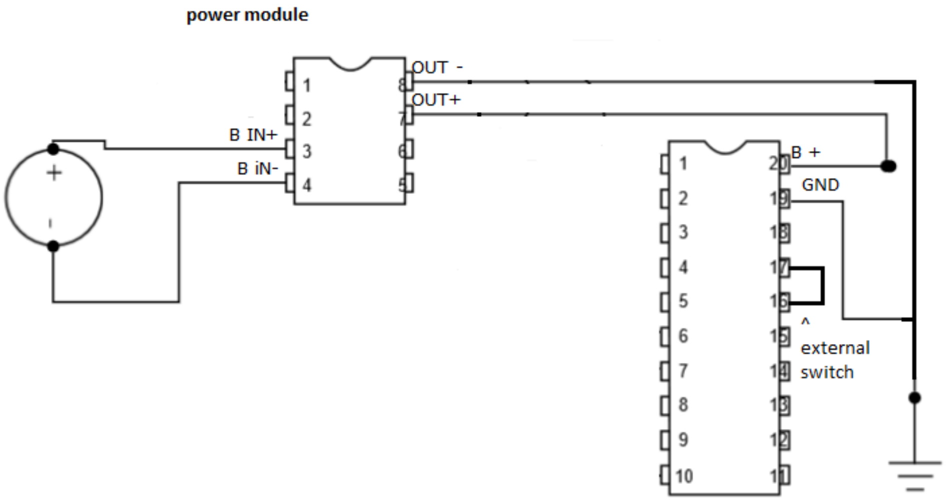


Fusion 360 model of second prototype



Appendix I: GPS testing device

The GPS testing module has the same software as the sensor node. Only some small changes were made to improve the detecting of the GPS. Electrical circuit are included below.



Appendix J: Component list and building manual

Components needed:	Amount

3D printed:

• Top_disc	1x
• Disc	2x
• Bottom_disc	1x
• Housing including extra support	1x
• Cap	1x
• Inside	1x
• Bottom_panel	1x
• Top_panel	1x
• Small hatch	1x

Screws:

• M5x25	1x
• M4x10	2x
• M2.5x8 (wood screws)	4x

Nuts:

• M5	1x
• M4	2x

Electronics:

• Sodaq One	1x
• DS18B20	1x
• TP4056	1x
• 8K resistor	1x
• 4.7K resistor	1x
• 100nF capacitor	1x
• LiPo battery 1200mAh	1x
• GPS antenna	1x
• Solar Panel 1W	1x
• Female jumper cables	10x
• Male jumper cables	5x
• 3-Way cable with JST connector	2x
• LoRaWAN antenna	1x
• SHT15 sparkfun humidity sensor	1x
• Froggit WH1080 anemometer	1x

Tools needed:

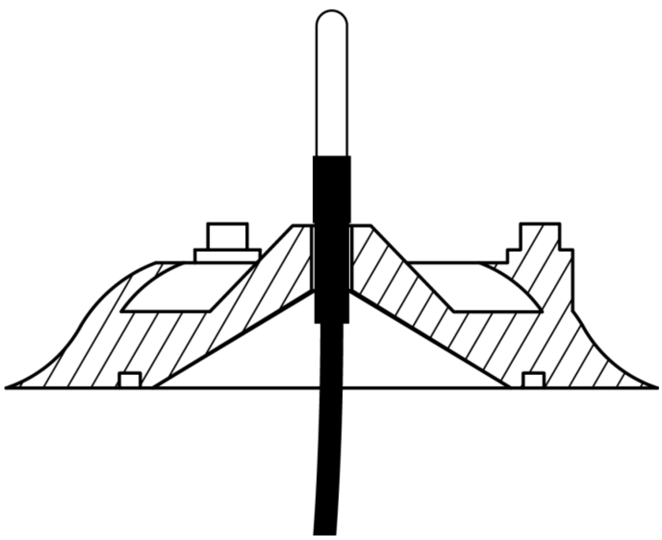
- Screwdriver 1x
- Soldering iron 1x
- Solder 1x
- Large tie wraps or clamping strap 2x
- Hot glue 1x
- Electrical tape 1x
- Stanley knife 1x
- Contact glue
- Snipping pliers 1x

Optional:

- Heat shrinks 15x
- Electrical tape 1x

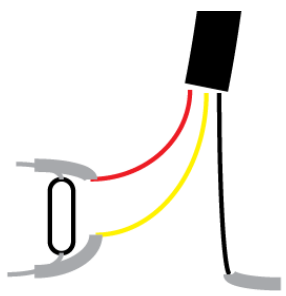
Setup:

1. Begin with removing the brim from the 3D printed parts.
2. Cut the DS18B20 temperature sensor so that the cable attached is 5 cm long.
3. Keep the cut cable, this will be needed later.
4. Strip the individual cables from the DS18B20 so that the copper is exposed



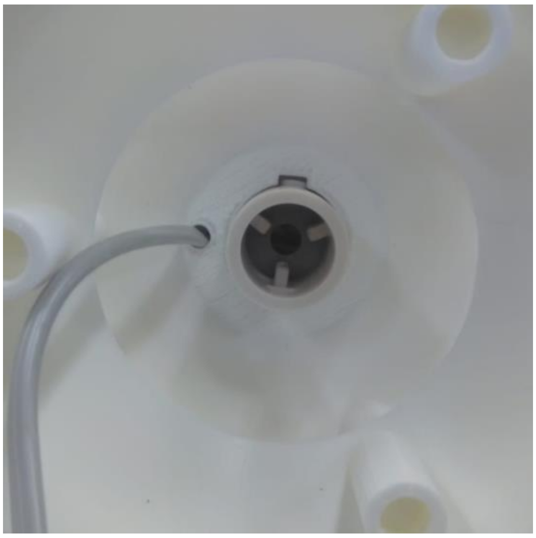
5. Insert the DS18B20 into the bottom disc part like shown:

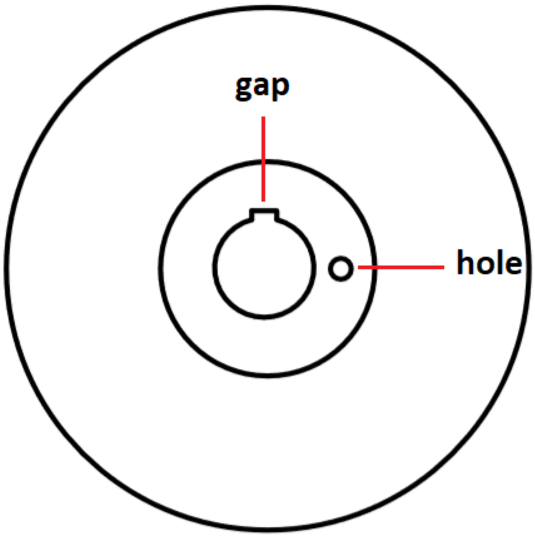
6. Solder a 4.7K resistor between the data cable and the VCC cable coming out of the DS18B20 like shown:

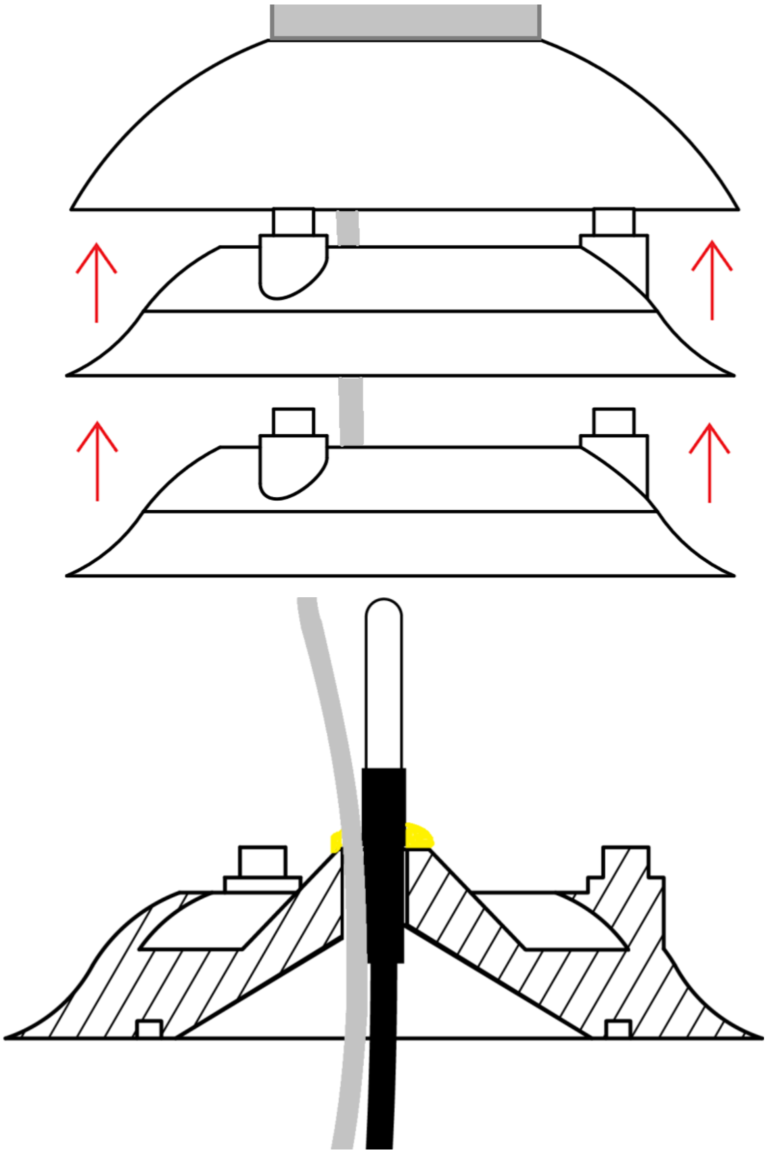


7. Cut a red and black male jumper cable and yellow female jumper cable and solder these to the open connections corresponding with their colours.
8. Snip the wire of the anemometer at a length of 15 centimetre.
9. Strip the wire so the copper is exposed.

10. Put the wire in the small hole of the top disk and pull it through while aligning the notch on the side of the anemometer with the gap in the top disk and push it in.



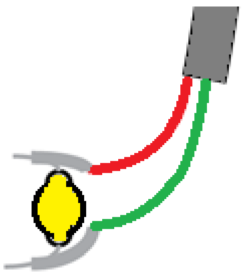




11.
Press the top disk and the two middle disks together. Use super glue in the holes if needed to keep the disks together.

12. Put the temperature sensor trough the large hole in the bottom disk and the wire from the wind sensor trough the smaller hole. Try to get the grey wire as far through the bottom disk as possible while still being able to glue them in place with hot glue.

13. When the hot glue has cooled press the bottom disk on the other disks. Use super glue in the holes if needed to keep the disks together.



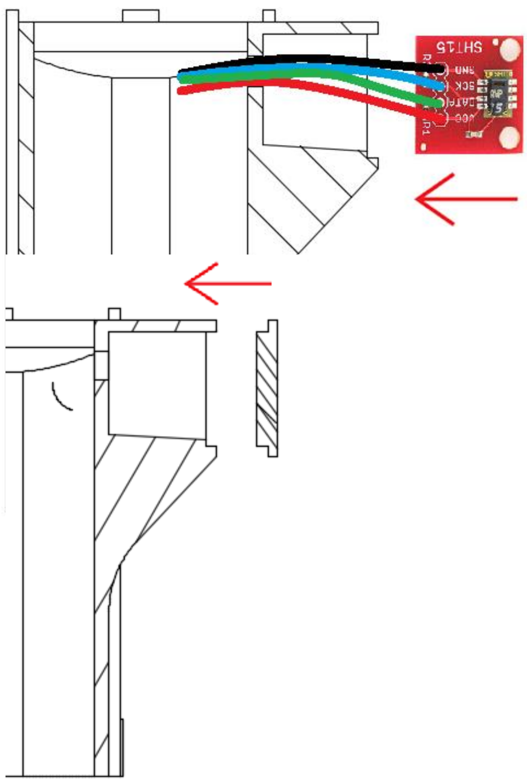
14. Solder the 100nF capacitor between the red and green wire.

15. Solder a black male jumper cable on the green wire and a female jumper cable to the red wire. Cover with electrical tape.

16. Snip the 3-Way cables at 2cm. Strip the tree ends of each connector, so the copper is exposed.

17. Solder the tree ends of the first cable onto a black jumper wire. Do the same with the second cable only with a red jumper wire. Cover with electrical tape.

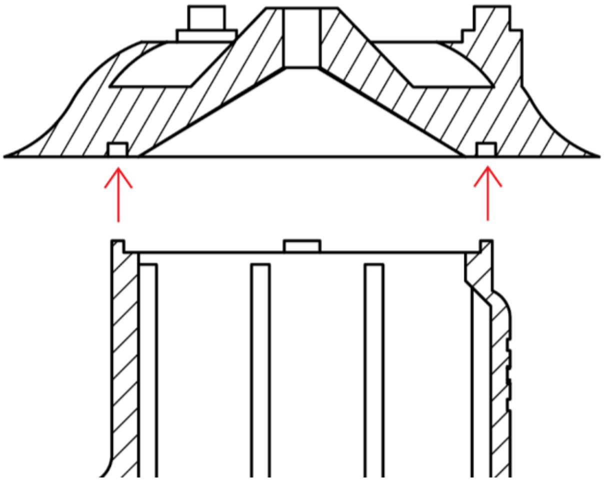
18. Get the humidity sensor SHT15 and solder a black male jumper cable to the GND, a red male jumper cable to the VCC and female jumper cables to the DATA and CLK.



19. Insert the humidity sensor into the compartment by putting the wires trough the hole one by one. Put some hot glue on the inside of the hole to make it watertight.

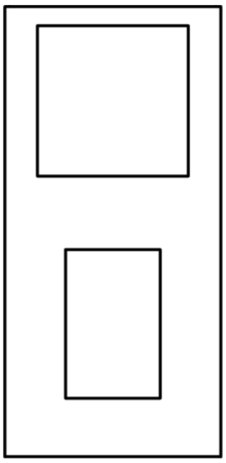
20. Close the compartment by gluing the small hatch on the compartment with contact glue. Be careful that the hatch is not placed upside down. Otherwise water will be able to get in through the air holes.

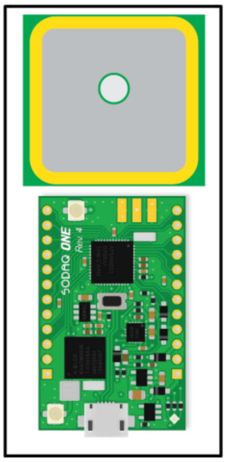
21. Attach the housing to the bottom disc, **cover the entire top of the housing with superglue** for a water tight seal (IMPORTANT!!!):



22. Attach the GPS sensor and the LoRa antenna to the Sodaq One by attaching them to the labeled antenna connections.

23. Glue the Sodaq One onto the inside (3d printed part), and the GPS sensor too, they should fit in the holes in only one way, make sure the Sodaq's USB connection faces downwards.

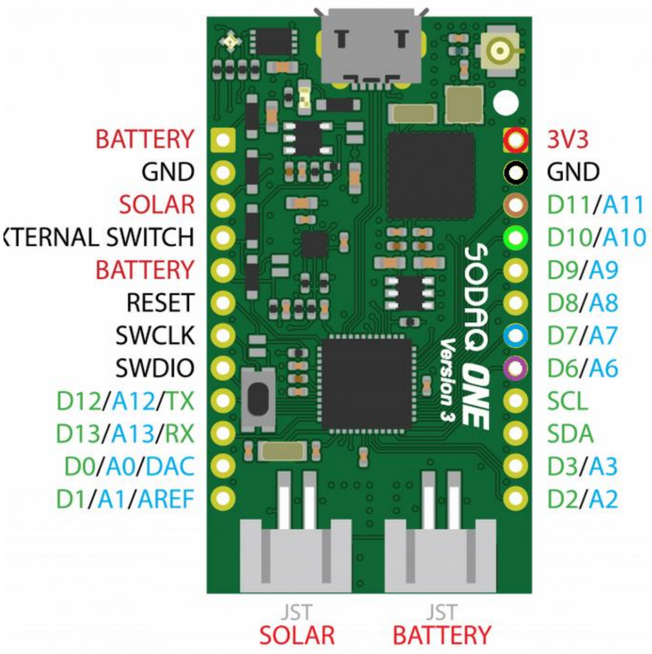


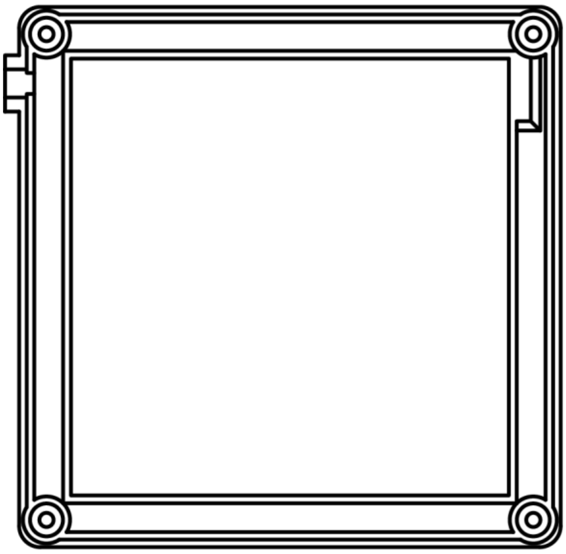


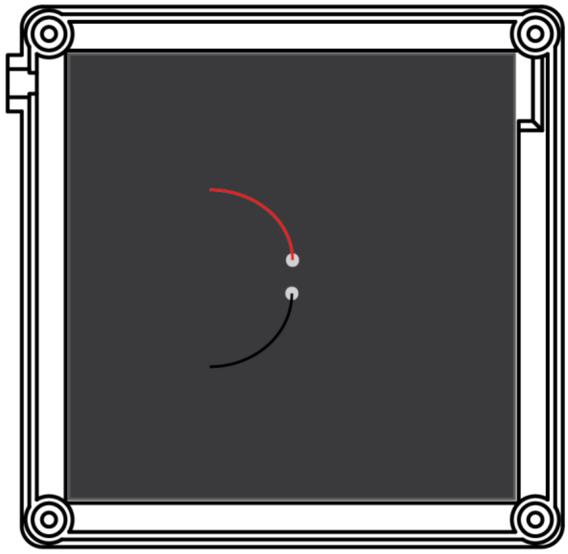
24. Slide the inside into the housing, use the rail closest to the back (away from the logo).

25. Attach all the red male jumper wires to the 3-way connector with the red wire. Connect all black male jumper wires to the 3-way connector with the black wire.

26. Connect the DATA wire of the humidity sensor to pin 10 (green) and the CLK wire to pin 11 (brown). Connect the remaining wire of the temperature sensor to pin 7 (blue) and the remaining wire from the anemometer to pin 6 (purple).

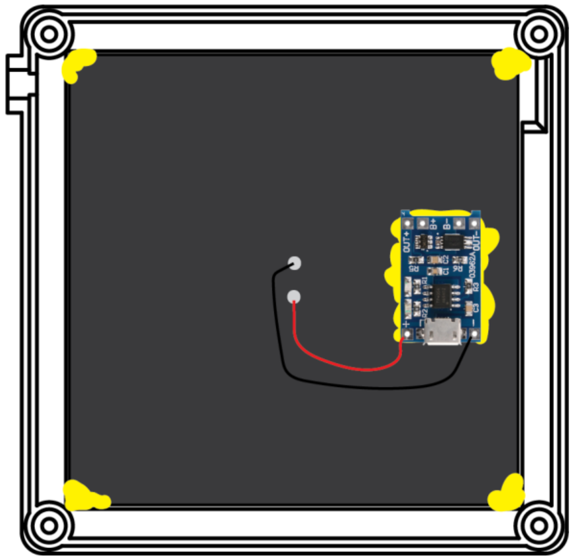






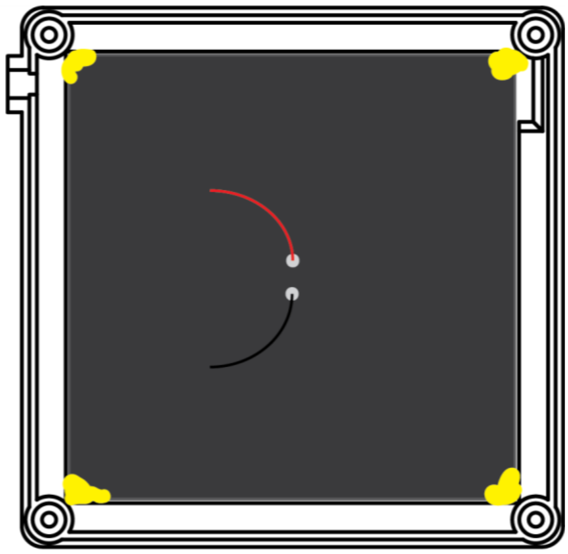
28. Get the solar panel and remove the plastic covering it.

29. Place the solar panel in the indent in the top solar panel.
30. Glue the solar panel in place with a couple of dabs of hot glue
31. Glue the TP4056 in place

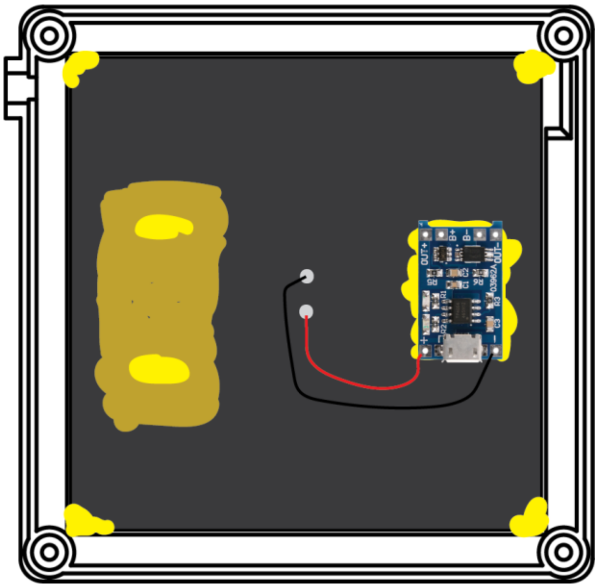


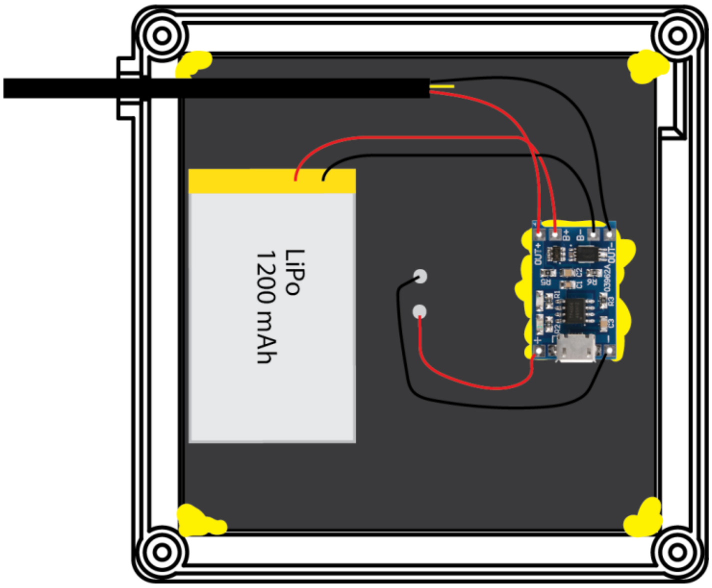
32. Solder the red and black connection from the solar panel to the positive and negative terminals on the TP4056.

33. Add a lot of hot glue to the solar panel and wait for it to cool of until it becomes solid (wait 5 minutes)



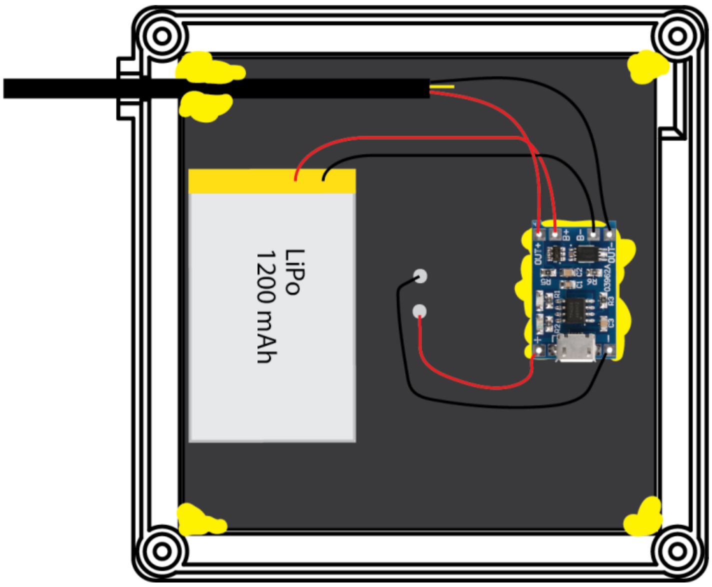
34. Add a little bit of new hot glue and attach the battery on it. *Explanation: LiPo batteries don't handle heat well, we add the hot glue as an insulating layer, to remove it from the heat from the solar panel in the summer. We can't glue it directly to the solar panel with hot glue however, this would heat the LiPo battery too much. This is why we only use 2 small dabs, the LiPo battery is capable of handling this little amount of heat.*



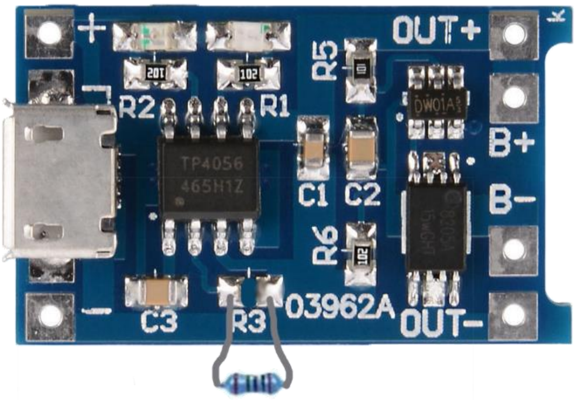


35. Wait for it to cool a little bit and attach the battery and solder it to the B+ and B- pin on the TP4056.

36. Take the leftover piece of cable from the DS18B20 sensor and place it in the hole in the solar panel and solder the red and black cable to the output of the TP4056.

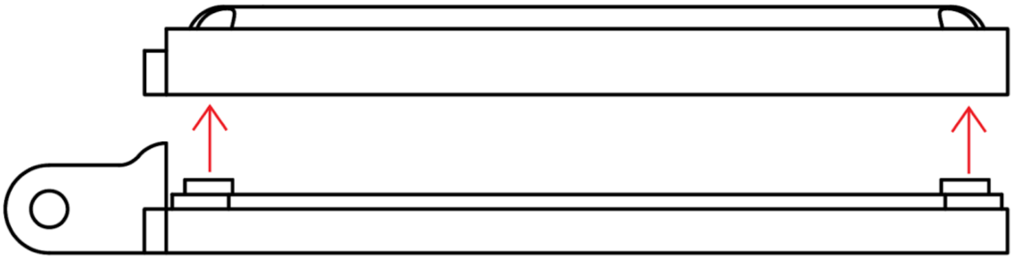


37. Glue the cable in place so it does not tear the TP4056 from the solar panel.

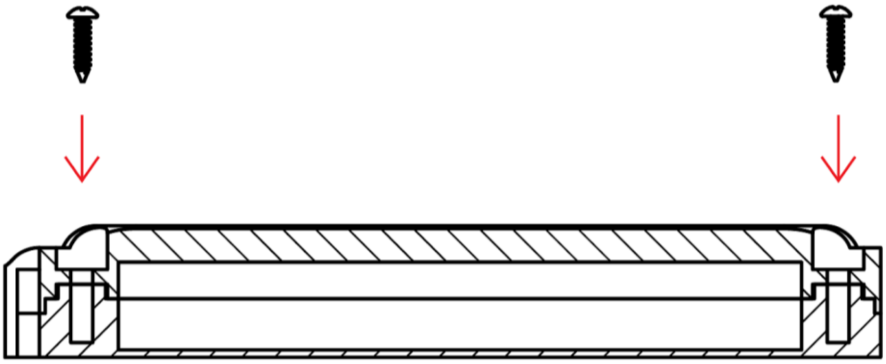


38. Solder the 8K resistor between the two exposed pieces of metal of R3. It is good practice to use something which can hold the resistor firmly in place.

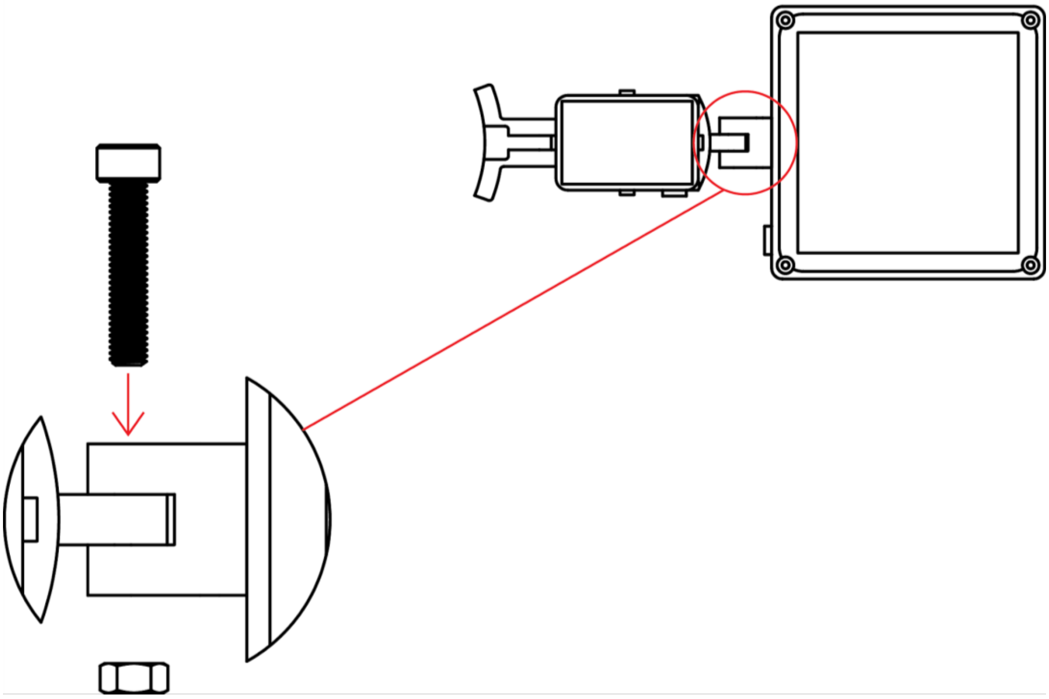
39. Charge the battery, using the USB port



40. Close the solar panel housing
41. Add M2.5 wood screws to secure it in place:



42. Insert hot glue in the holes above the screws so that water can't enter.
43. Fill the gaps around the cable coming outside the panel to ensure that no water can enter.
44. Attach the solar panel to the main housing using the M5 bolt and nut



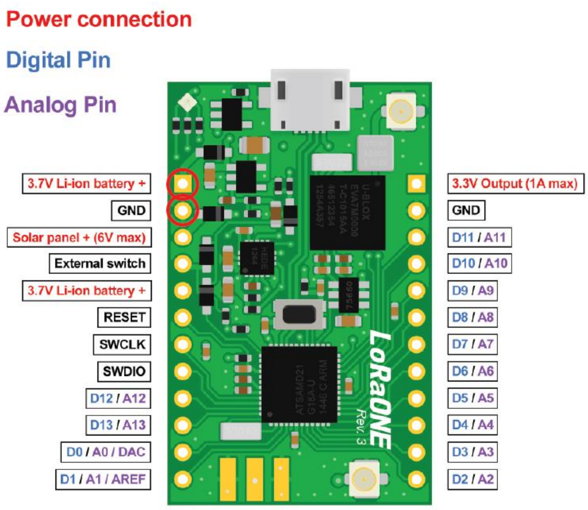
45. Create a device in the TTN dashboard. Copy the dev UI and app key and fill these in in the ensketempV2.ino program.

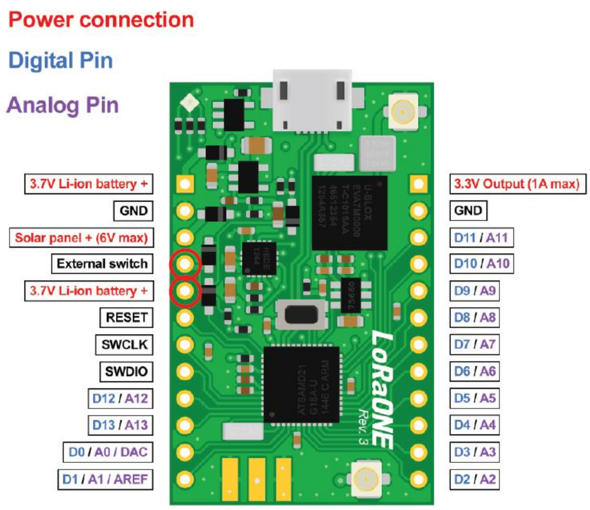
46. Connect the Sodaq one to the computer and upload the ensketempV2.ino program on the Sodaq one.

47. Pull the cable into the housing and solder 2 female connectors to the Sodaq one's 3.7V li-Ion + pin and the GND pin.

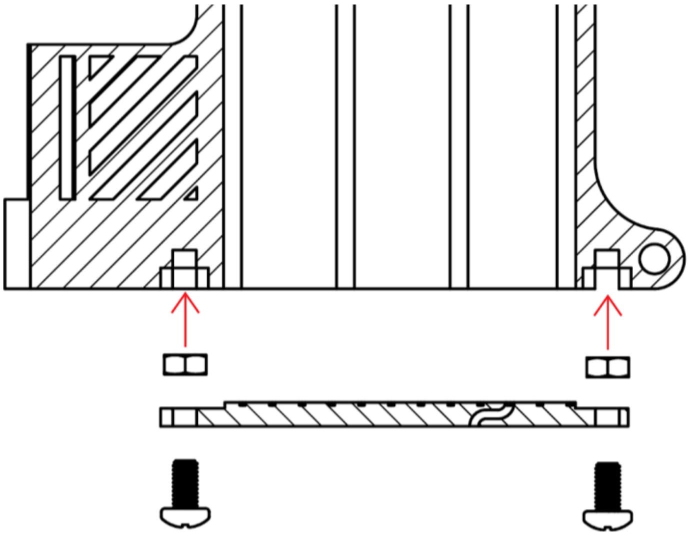
48. Fill the gaps between the cable and the hole in the housing with hot glue.

49. Add a jumper between the external switch pin and the secondary 3.7V Li-Ion battery+ (5th pin from up) *This is needed for the Sodaq One to turn on.*

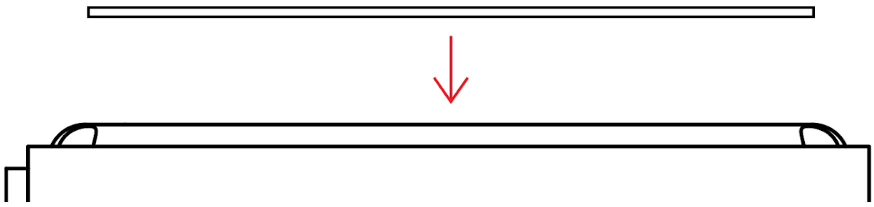




50. Push the M4 Screws in the holes below the housing. *You can use a soldering iron to push them in, heating the screws will momentarily melt the plastic and allow the screws to go in smoothly.*



51. Screw the cap onto the housing
52. Glue the delrin cover on the solar panel. Use contact glue to make it waterproof. Make sure you cover the entire.



53. Place the sensor node outside with the tie wraps or strap.

Appendix K: GPS calculations from degrees to meters

At 51 degrees latitude a degree is has a length of 111267,313 meters.

$$\frac{111267.313}{3600} = 30{,}90$$

So, every second has a length of 30,90 meter

$$\frac{20}{30{,}90} = 0{,}647$$

With latitude this is even less:

$$\frac{68677{,}99}{3600} = 19{,}08$$

$$\frac{20}{19{,}07} = 1{,}05$$

An accuracy of 20 meter would mean that GPS measurements cannot differ more than 0.647 second. Because it is not certain that the first GPS location is completely accurate a change in location larger that 0.3 seconds will be regarded as an inaccurate measurement. A change in location of the sensor node will be recorded when a difference larger than 0.5 second is recorded

Appendix L: Installation of the program

The back-end is compatible with Windows or Linux. To run it on a computer NodeJS 8 or higher needs to be installed. During the installation of NodeJS it is important that 'npm' and 'node' are added to PATH.

- First, the two files in the program needs to be put in the same folder.
- Open the main program and fill in the correct application ID and access key. This key can be found on the TTN dashboard.
- Now, open the command prompt in the folder containing the two files and type `npm install`. The program should be installing now.
- After installation enter `npm run` in the command prompt. The program should start. Check the database if data is coming in.

The code can be found on GitHub: https://gist.github.com/jonathanjuursema/f7c892067e10c05894678b8e531c72e6 or in the ZIP file accompanying this report.

Appendix M: Code Comparison old and new location

```
tempLat = lat;
tempLon = lon;
String copyLat = tempLat;
String copyLon = tempLon;
// stings are copied to make sure to keep the original stings int
copyLat.remove(0,tempLat.length()-2);
copyLat.trim();
byte tempLatByte = (byte) copyLat.toInt();
// string is trimmed to leave only the last two digits and conver
copyLon.remove(0,tempLon.length()-2);
copyLon.trim();
byte tempLonByte = (byte) copyLon.toInt();
// same for the copy of lon
if(abs(compareLat-tempLatByte)>5||abs(compareLon-tempLonByte)>7){
  //1 second lat and 1.5 second of lon of GPS location at 52 degr
  //so if assuming that the previous gps location was as inaccura
  //a difference of 0.5 lat and 0.7 lon is sufficient
  compareLat = tempLatByte;
  compareLon = tempLonByte;
  // if the location has changed,the new location is the location
  String packet = "";

   packet += "L" + lat + "l" + lon ;

  delay(10000);
   sendPacket(packet);
   // only send packet il location has changed
```

Appendix N: Definition and their explanations

Internet of things: is the network of physical devices, vehicles, home appliances, and other items embedded with electronics, software, sensors, actuators etc. This allows them to transfer information and integration of physical things into computer-based systems. This creates opportunities for more efficient systems, an increase of knowledge and a better understanding of our world.

HDOP: is the horizontal dilution of precision. It gives information about the possible error in the GPS measurements taken. The higher the dilution of precision, the more the satellites are dispersed when the measurements are taken. If all satellites are more clustered on one side of the location where the measurement is taken, the dilution of precision is larger.

DOP Value	Rating	Description: source - wikipedia
< 1	Ideal	Highest possible confidence level to be used for applications demanding the highest possible precision at all times.
1-2	Excellent	At this confidence level, positional measurements are considered accurate enough to meet all but the most sensitive applications.
2-5	Good	Represents a level that marks the minimum appropriate for making accurate decisions. Positional measurements could be used to make reliable in-route navigation suggestions to the user.
5-10	Moderate	Positional measurements could be used for calculations, but the fix quality could still be improved. A more open view of the sky is recommended.
10-20	Fair	Represents a low confidence level. Positional measurements should be discarded or used only to indicate a very rough estimate of the current location.
>20	Poor	At this level, measurements are inaccurate by as much as 300 meters with a 6-meter accurate device (50 DOP × 6 meters) and should be discarded.

Sky view factor: The sky view factor is the percentage of clear sky visible from a certain point. This is expressed in a number from 0 to 1. A picture taken with a 180° fish-eye lens. From this a cut-out can be made of the clear sky. This can either be done by hand or by an image recognition program. The percentage of the image which is cut out is the sky view factor.

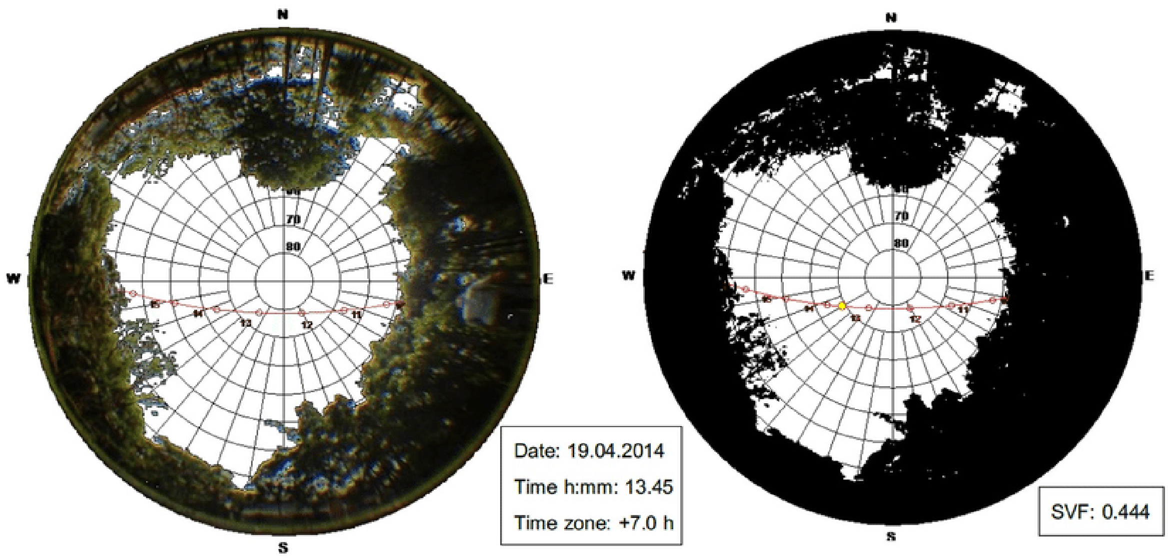


Figure 17 Fish eye lens photography to aid Sky View Factor (SVF) calculations by RayMan [65]

Vegetation factor: The vegetation factor is the amount of vegetation in a certain area. The vegetation factor is not a very precise measure. It is often estimated according to a table which ranks the amount of vegetation in a certain area with a score. This score is used in formulas to calculate the magnitude of the urban heat island.

Second (GPS): GPS uses the geographic coordinate system as its coordinate system when determining a location. This coordinate system divides the earth horizontally (latitude) and vertically (longitude) in 0° to 90°. The length in meters of these degrees can be around 100 km. Therefore, degrees are split up in minutes and seconds. One minute is 1/60 part of a degree and one second is 1/60 part of a minute. Thus, a second is 1/3600 part of a degree.

PSI: The pound-force per square inch is a unit of pressure or of stress based on avoirdupois units. It is the pressure resulting from a force of one pound-force applied to an area of one square inch. In SI units, 1 psi is approximately equal to 6895 N/m2.

ASCII: is a character encoding standard for electronic communication which stems from the days of telegraph communication. ASCII codes represent text in one byte. Most modern character-encoding schemes are based on ASCII.