SHELTERSUIT MEETS TECHNOLOGY: SENSING THE RISK OF HYPOTHERMIA

Graduation Project Bachelor Creative Technology

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Abstract

For homeless people who sleep on the streets the cold Dutch winters can be a serious risk for their health and safety. The Sheltersuit Foundation strives to make their lives safer by freely distributing the Sheltersuit, which is a jacket with zip-on sleeping bag designed to keep homeless warm. The focus of this graduation project is to develop a product that will be placed inside the Sheltersuit, which helps preventing mild hypothermia (a core temperature between 35°C and 32.2°C) by detecting the risk of mild hypothermia and notifying the user.

Background research about the situation of homelessness in The Netherlands showed that the number of homeless has been increasing significantly since 2009. Conversations with a social worker and two ex-homeless showed that some people deliberately choose to sleep outside instead of sleeping in a shelter, for which every person has his own reason. It also became clear that sleeping on the streets in winter can be very tough, and multiple strategies are described how homeless kept warm. Literature research showed that the homeless population is characterized by a high percentage of addiction and mental illness. Intoxication by alcohol is a serious risk factor for mild hypothermia, as are malnutrition and chronic exposure to cold. Hence, the homeless population has a high risk of mild hypothermia because of the excessive use of alcohol and the chronic exposure to cold.

Different concepts are considered for the development of the envisioned product. Different places inside the Sheltersuit are considered, as well as distributed sensing systems versus integrated sensing systems. The chosen final concept for this graduation project is an integrated sensing system where all functions are placed inside a module. This module can be put inside an extra chest pocket on the inside of the Sheltersuit.

This module should detect the risk of mild hypothermia and notify the user if this risk is present. One main symptom of mild hypothermia is that the person starts to shiver. This is combined with the temperature inside the Sheltersuit to estimate the comfort and risk of the user. The relationship between the comfort of the Sheltersuit user and the temperature and relative humidity inside the Sheltersuit is investigated. An experiment inside a freezer confirmed the theory that the relative humidity has no influence on the perceived temperature when ambient temperatures are below 26°C. The test also gave three threshold temperatures for which the majority of test subjects indicated to feel colder or more uncomfortable. These temperatures are transformed into comfort levels and risk levels of the user. The risk level is converted to a notification level and outputted as an auditory signal. This signal changes the frequency, volume, and inter-pulse interval to let the notification be perceived as more urgent as the risk level increases.

A prototype is constructed that can detect the risk of mild hypothermia and notify the user in the previously described way. This prototype is able to execute all necessary functions except the shivering detection. It does contain the code and filters that should be able to detect shivering when the correct threshold values are inserted. However, in the scope of this graduation project these thresholds could not be found.

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Table of Contents

1. Introduction

1.1 Introduction

February 2018 was one of the coldest months in a long time [1]. Remarkably, there are still people that sleep on the streets, instead of using a shelter [2]. People sleeping rough have the chance to suffer from hypothermia, especially in winter. Various organisations are motivated to help these people. Most of these organisations provide sleeping places in night shelters, like the Salvation Army [3] in the Netherlands. An organisation that provides help in another way is the Sheltersuit Foundation [4]. The Sheltersuit Foundation makes and distributes the Sheltersuit. This is a coat that is waterproof and windproof, and to which you can zip a sleeping bag. A backpack is provided with the Sheltersuit for when the sleeping bag is not used. The Sheltersuits are distributed for free among the homeless that sleep rough and among refugees on Lesbos. In this way the foundation aims at making rough sleepers' lives a little easier and safer when it's very cold outside.

1.2 Problem statement

The Sheltersuit Foundation wants to analyse the possibilities for the Sheltersuit to be more innovative, and therefore they are looking into incorporating technology into the suit. Building on the foundation of a previous Graduation Project of Creative Technology [5], a system should be designed to detect conditions for mild hypothermia of the Sheltersuit user. Furthermore, it should give the user and/or the people around him a notification. This will hopefully make the life of Sheltersuit users safer. A previous Graduation Project [5] has looked into ways to detect hypothermia. The result is a way to detect shivering and measure the temperature and humidity inside of the Sheltersuit. These factors combined could give a good indication into the probability of the risk of mild hypothermia of the user. Currently, the relationship between the temperature inside the suit, humidity inside the suit, and shivering are not yet investigated. The relationship of these factors is essential for the product. Furthermore, the detection system is currently a large prototype, which does not fit conveniently into the Sheltersuit. Also, the notification system is currently designed without involvement of the end user.

1.3 Goal

The goal of this project is to build upon the findings in the previous study [5], in order to make the lives of the users of the Sheltersuit safer. To do this, ways to detect the symptoms and/or conditions of mild hypothermia should be explored further. A combination of these detection techniques should be integrated into a module to attach to, or place in the Sheltersuit. This module should also notify the user when the temperature and humidity inside the suit could lead to mild hypothermia of the user. The design of this notification system should be designed to the needs of the target users. The costs, robustness, detachability, safety, possibility to repair, and sustainability [6] of the module could also be considered in the designing process.

1.4 Research question

In this project, the following question is aimed to be answered. The question is derived from the problem statement, the goal of this project, and the wishes from the Sheltersuit Foundation.

- How to develop a Sheltersuit module that detects and notifies a user in case of risk of mild hypothermia?
    - What symptoms of mild hypothermia should be detected?
    - Wat are the necessary functions to implement in the Sheltersuit to detect mild hypothermia of the user?
    - How can the functions be implemented in the Sheltersuit in a convenient way?
    - What is the best way to notify the user when the risk of mild hypothermia is detected?

1.5 Report outline

This report contains all different elements of the design process of the Sheltersuit with technology (Sheltersuit+). Chapter two will start with a context analysis, divided in background research, literature research, and relevant products. Thereafter chapter three will describe the ideation phase, which will start with identifying the stakeholders. Then the situation is analysed through a PACT analysis, preliminary requirements are listed, and the Sheltersuit is examined in more detail. Chapter three will conclude with different concepts for the placing of the sensing system, and the choice and description of the final concept. In chapter four this final concept is worked out in more detail using functional block diagrams. Also, the preliminary requirements are adapted and a test is executed to find the relationship between the temperature inside the Sheltersuit and the comfort level (or perceived temperature) of the Sheltersuit user. Chapter five describes the realisation of the module through selecting the used hardware, software, and prototype design. This prototype will be tested and evaluated in chapter six. In chapter seven conclusions will be drawn and the research question will be answered. The last chapter, chapter eight, will discuss future work that can be done as a continuation of this graduation project.

2. Context analysis

In this chapter, the different factors of the context that this graduation project is influenced by are handled. Firstly, the situation of homelessness in The Netherlands is described in the background research. This is based on data from the Dutch Ministry of Economic Affairs (‘Centraal Bureau voor de Statistiek’ in Dutch) and on conversations with two ex-homeless and a social worker. Secondly, the related topics are explored in literature, and conclusions related to this graduation project are drawn. The subjects discussed are homelessness, mild hypothermia, the relationship between these two, wearable sensor systems, and persuasive technology. Thirdly, products related to this graduation project will be explored, divided into three categories: homelessness, wearable technology, and persuasive technology. Lastly, the relevance of the previously stated research question will be presented.

2.1 The situation of homelessness in The Netherlands

This section aims at sketching a picture of the current situation of homelessness in The Netherlands. This is done in two ways: firstly, the official data from ‘Centraal Bureau voor de Statistiek’ (CBS) [7], is used to give insight into the actual numbers, percentages and distributions of the situation in The Netherlands. Also, a recent report from ‘Rekenkamer Metropool Amsterdam’ [8] (Amsterdam Audit Office in English) will shed light on the current situation of social housing in the municipality of Amsterdam. Combined, this will portray the official situation of homelessness in The Netherlands. Secondly, the situation of homelessness is supplemented by real-life experiences of experts, to clarify the mentality and behaviour of Dutch homeless. This is done through conversations with people who work with, or have been part of the homeless population in The Netherlands. In the end, the reader should have a valid understanding about this subject.

2.1.1 Official data by CBS and Amsterdam Audit Office

According to a survey taken on the 1st of January 2016 from ’CBS’, a total of 30,5 thousand people was labelled homeless in The Netherlands [7]. The majority of these people (48,8%) are between the ages of 27 and 50 years old. Next are the people between 18 and 27 years old with 35,1%, and finally 16,1% of the homeless people are between 50 and 65 years old. The Dutch government defines homeless people as (literally translated): *“People who sleep in the open air, in roofed public spaces, like porches, bicycle sheds, stations, shopping centers or a car, or sleeping indoors in passers-by of the social shelters and one-day emergency shelters, or on a non-structural basis with friends, acquaintances or family, without a permanent residence.”* [9].

The total amount measured in 2016 (30,500) is almost equal to the amount measured in 2015 (31,000) [10]. However, between 2009 and 2015 the amount of homeless in The Netherlands had increased by 74% [11]. The distribution of ages, locations and sexes stayed approximately the same through these years. Around 40% of the homeless are registered in the four biggest Dutch cities (Amsterdam, Rotterdam, The Hague, Utrecht). Out of every 5 homeless, one is female and four are male. The group of homeless people with a migration background has increased the most over the last 7 years. Where in 2009 46% of homeless had a migration background, in 2016 this percentage had increased to 58%. It is important to note that illegal immigrants who sleep on the streets are not included in these numbers. Furthermore, the precise number of people actually sleeping on the street, and not in shelters or with family, is not known.

The journey from being homeless to getting your own place, or a suitable place with a care organisation, is not easy according to a report from the 'Amsterdam Audit Office' (Dutch: Rekenkamer Metropool Amsterdam) [8]. In December 2017 they published a report in which they examine the situation of social shelter and protected living in Amsterdam. The main shortcomings of the current system that they encountered are firstly the difficult admission process, and secondly the shortage of available social housing. Especially the application for social shelter is a difficult process, due to the big number of steps it involves and the unclear and time-consuming actions from the organisations. Because of the long waiting lists for social shelter, a lot of people must wait long periods of time before they are admitted. In 2016, there were 1107 rejections. Moreover, these people do not get the right help to find the right care for them. A percentage of these rejected people can end up on the streets.

2.1.2 Lifestyle and behaviour of the homeless in The Netherlands through field research

More insight in the behaviour of the homeless in The Netherlands was gathered by conversations with people who have experience in this field[1]. From a conversation with a social worker who works with homeless in the province of Utrecht, it was observed that in some cities homelessness is well managed. When there are sufficient places in shelters, like the city that she works in, most people stay at the shelters at night. During the day those people go to day-shelters or community centres. The situation in Twente and Enschede is very different than the previous described situation, according to a conversation with someone who has lived on the streets in Enschede. He stated that there are a lot of homeless in this region, but not everyone can use the shelters. Either because they cannot pay the entrance fee, or the shelters are full. Many people sleep on the streets, searching for a private place preferably with the warmth of nearby buildings. He confirmed the conclusion of the Amsterdam Audit Office (described in 2.1.1) that it can be hard to get off the streets. The waiting lists for permanent shelter can be very long, and processes for the right help can be confusing. It can also be difficult to find the way through the bureaucracy and vast number of organisations. Another ex-homeless who stayed on the street in Amsterdam for 8 years chose to sleep outside to stay close to the drug dealers.

There can be various reasons why people end up on the streets, like a (sudden) lack of money, fights or anger with their partner, unfortunate circumstances, or a lifestyle choice. It is often combined with addiction. To get money to buy drugs, one of the contacted people helped out at IKEA or at lunch cafes, or he would beg money for a night shelter that he would use for drugs instead. Sleeping outside helps to always get drugs when someone needs them.

When it is very cold outside, homeless people go inside as much as possible during the day. This can be, for example, in a public library, a café, a day-shelter, a community centre, or even a train. When outside they walk a lot to stay warm, and typically go from place to place. In the night emergency shelters can open to provide a place for everyone when the temperature is very low. In Enschede they open when the temperature is below two degrees. However, some prefer to still sleep rough instead of using the emergency shelters. They

[1] The cooperating people wished to stay anonymous. The conversation with the social worker was held on April 4th, 2018 in Kampen. Both talks with ex-homeless were held by phone on April 4th and April 18th, 2018. A summary of these conversations can be found in Appendix A.

usually wear multiple layers of clothes inside a sleeping bag, and try to find a relatively warm, dry place without a lot of wind. Lying on carton boxes can also help to keep warm longer. In these temperatures some shelters provide sleeping bags for homeless to use during the day. However, one person that was contacted still woke up cold every time, and had to stand in the sun for almost an hour to get his body working. One time he has suffered from hypothermia. After four nights without sleep because of the drugs, he collapsed on the street made of concrete. After hours of sleep a guard found him and woke him up, but he could not move. The guard put him in a metro, which he rode 8 times from end to end until his body worked again. But after 9 hours, he still couldn't make a cigarette. Still, he preferred to sleep on the streets since the only thing that mattered to him in those days was getting drugs.

Most homeless people make use of technology. Phones are owned by almost everybody, and are used to e.g. contact family, read the news, check the weather report, or contact drug dealers. They can be charged in shelters or in public spaces like the library. Sometimes they are charged at hidden places like football stadiums that do not secure their electricity enough. According to the social worker, some people even own tablets or laptops. However, those are primarily the people staying in the (permanent) shelters.

All in all, the behaviours of people who are homeless differs from person to person. Some choose to stay at shelters at night, while others prefer to sleep rough. Most own a sleeping bag and a mobile phone. When the temperature drops people try to stay warm to go inside to public places, day-shelters, or unlocked garage boxes, or they walk around a lot to keep warm. The situation can be very rough, but according to an ex-homeless person there are also a lot of interesting people to meet.

2.2 The influencing factors according to literature

The context of the graduation project will be explored in this section by analysing existing literature. The first subject explored will be homelessness. The definition, characteristics, and mentality of the homeless population found in literature will be discussed. Thereafter, the definition, symptoms, rewarming techniques, and risks of hypothermia will be made clear. This will focus further on the case of mild hypothermia, since that is the situation chapter 1 focusses on. Then the connection between homelessness and hypothermia will be analysed. The fourth section will search for factors to consider when placing electronics in clothing. Finally, the last section will seek ways to encourage a user to use a product.

2.2.1 Homelessness

Definition

In section 2.1.1 *Homelessness in The Netherlands* the definition of homelessness used by the Dutch government is stated:

> *"People who sleep in the open air, in roofed public spaces, like porches, bicycle sheds, stations, shopping centers or a car, or sleeping indoors in passers-by of the social shelters and one-day emergency shelters, or on a non-structural basis with friends, acquaintances or family, without a permanent residence"* [9].

The definition that is preferred in most United States based research is similar to this one. There the definition of "literal homeless" is used, who are people who sleep in homeless shelters, on the streets, or in other open places that are not meant for sleeping [12].

These definitions do not differentiate between people who sleep rough and people who make use of shelters at night. However, in various studies from different countries this separating definition is present. The

European Federation of National Organizations Working with the Homeless (FEANTSA) [13] separates in four categories: houselessness, rooflessness, living in insecure housing, and living in inadequate accommodation [14]. In the U.S. the terms for the first two groups are "homeless" and "street people", in the United Kingdom the term "rough sleepers" is used instead of "street people", and the French terms are a translation of these words [12]. Another definition that can be found, and which is used by the United Nations, is the distinction between "absolute homeless" and "relative homeless", where absolute homelessness is similar to the previous definition of "street people" and "relative homelessness" are people who sleep in sheltered places which are not good for health and safety [15].

All in all, homeless people include people without a permanent staying address who sleep rough or who stay in shelters for the homeless. A distinction between these groups is made, and some countries or organisations include people living in insecure housing and in inadequate accommodation. These definitions are not mere formalities, but they decide whether someone can participate in a program or can get help. Moreover, definitions decide the responsible entity for the problem (e.g. what agency is responsible in a country) and prevent underestimating the number of homeless [14]. On this definition, adequate solutions and policies can be built. In this graduation project, the focus will be on the "roofless" i.e. "street people", "absolute homeless".

Characteristics

Like all subgroups of society, every homeless person is unique and has their own characteristics and reasons for living on the streets. However, overall there are some characteristics that a vast percentage of homeless people have. Toro [12] researched homelessness in different countries and cultures, and compared e.g. the characteristics and behaviours of the homeless of these countries. For comparison of characteristics he found that *"studies in and outside of the United States generally find more men than women among the adult homeless, high rates of substance abuse and mental illness, and an overrepresentation of groups that have traditionally been discriminated against"* [12]. Firstly, the percentage of males under homeless that Toro found is between 70% and 80%. This is consistent with the data from the Dutch Statistical Office, which state that about 80% of homeless in The Netherlands are male [10].

Secondly, the high rates of substance abuse and mental illness that Toro mentions are also observed by Spence [16]. Spence describes his research about mental illness occurrence and treatment under homeless in Sheffield, United Kingdom. He found that the percentages of different diagnoses of mental illnesses are significantly higher under the homeless than the average in the country. He found that half of the homeless suffer from depression, 20% deal with personality disorders, and about 10% have a learning disability [16]. Toro [12] states slightly different data: between 20% and 40% of the homeless single adults are severely mentally ill, 20-25% suffer from severe depression, and schizophrenia is an illness that 5-15% of the homeless single adults deal with. Even though the numbers vary in different researches, the overall conclusion is that the percentages in the homeless population are certainly high. Besides mental illness, the alcohol and drug use under homeless is also high. Spence [16] found that 30-50% of homeless in their study have alcohol problems. According to Hwang [15] alcohol use is 6-7 times more present than generally in the country. Not only the current use of alcohol or other substance abuse is higher in the homeless population, also the history of it is more present. Between 60% and 70% of homeless single adults have a history of substance abuse but may not currently use it, but also the history of substance abuse in their families is common [12]. This high use could be explained by the fact that some homeless use substance abuse as an escape from the reality of living on the street [12].

Other, but less prominent, characteristics are the similarities between the homeless population and the population of poor people, minority groups, and majorities in large cities [12]. In The Netherlands the cities with the most homeless people are the four largest cities: Amsterdam, Rotterdam, The Hague, and Utrecht [10]. In these large cities, the most homeless can be found in the traditionally poor neighbourhoods, which inhabitants are similar to the characteristics of the homeless [12]. The combination of scarce housing and low income can result in people or families ending up in the streets when they cannot pay the available housing options [17]. The overrepresentation of minority groups in the homeless population can be explained by the distribution of wealth. Minorities often have lower paying jobs, discrimination, and less wealthy social networks to depend on when income is low [17]. As stated before, the amount of homeless in The Netherlands with a migration background has largely increased in the last years [10].

Mentality and behaviour

Homeless people can be very cautious about their privacy and often like to be left alone. Working with this target group requires an approach that does not lead to any suspicion [16]. However, if they think it is important most will accept care [18]. Le Dantec and Edwards [19] noticed that it is hard to stay in contact with people from this group. Most homeless people do own a mobile phone. Both McInnes *et al.* [20] and Moczygemba *et al.* [21] measured a percentage of 89% that own a mobile phone, Le Dantec and Edwards [19] measured 61,5% but had a small testing group (13 participants). Most use this to stay in contact with friends, or with their families [12], [19]. From this it can be concluded that the approach for developing technology for the homeless should be different. Technology is not as present in their lives as in the average life of 'regular' people. For example, a homeless person does probably not encounter a smart thermostat, smart tv's, or fitness watches, which all become more normal in society today. They are used to handling technology in the form of mobile phones, but technology is not further entangled in their daily life. Therefore, a technological product or service made for the homeless population should convince its relevance to their life and win their trust.

2.2.2 Mild hypothermia

Definitions

A person can suffer from hypothermia when his core temperature is lower than normal (36.5°C – 37.5°C). There are three kinds of hypothermia: mild, moderate, and severe [22] [23] [24]. Mild hypothermia occurs when the core temperature is between 32.2°C and 35°C, between 28°C and 32.2°C moderate hypothermia is present, and a core temperature below 28°C means the person suffers from severe hypothermia.

The human body loses heat in different ways: radiation, conduction, convection, evaporation [24]. McCullough and Arora [22] add respiration to this list of body mechanisms. Epstein and Anna [24] explain radiation as the transfer from body heat to its surroundings through infrared radiation, and conduction as the heat transfer from the body to near objects through touch. They state that with convection heat transfers via the air, and with evaporation heat is lost by the conversion from water to vapor on the skin. The heat lost via breathing is called respiration.

Symptoms and rewarming

The symptoms and treatment are dependent on the severity of the hypothermia. While mild and moderate hypothermia can be treated easily with the current techniques and resources in medical facilities, severe hypothermia is harder to treat and outcomes depend on the resources available [22].

Mild hypothermia

As stated before, mild hypothermia occurs when the core temperature is between 32.2°C and 35°C. In this stage, the person is still conscious and his body is shivering to generate warmth [25]. According to McCullough and Arora [22] shivering can increase the body's energy production in rest, also called basal metabolic rate, by two to five times. They note that besides shivering, the body also generates power through the increased production of thyroxine and epinephrine (adrenaline). Furthermore, the body will react by narrowing the blood vessels, and increasing the heart rate and the breathing pace to a higher rate than in rest [22] [24]. If the body loses too much energy to fuel these processes, the judgement, voluntary muscle movement, apathy, concentrating ability, and kidney functionality may be impaired [22] [23]. Although these symptoms are troublesome they are not yet life-threatening, but actions should be taken to raise the body's core temperature.

The best way to treat mild hypothermia is passive rewarming. Shivering is the most powerful source of the body's heat production, but this mechanism can be stopped by surface warming of the person [26]. Techniques for passive external rewarming include the removal of wet clothes, moving the person to a warm and dry place, warm drinks, and active movement [22] [25]. Epstein and Anna [24] suggest rewarming people suffering from mild hypothermia by covering the head and body with warm blankets. The most important thing for someone suffering from mild hypothermia is to go indoors to prevent a lower drop of the core temperature, and thereby prevent a life-threatening situation [22].

Moderate and severe hypothermia

The symptoms of moderate and severe hypothermia are significantly more dangerous than the ones present by mild hypothermia. When the core temperature drops below 32.2°C, and moderate hypothermia is present, the bodily process slow down. The person will be less consciousness, the shivering and muscle contractions will stop, the heart rate and breathing rate will slow down, and the heart will display irregular behaviour [22] - [24]. When the hypothermia further deteriorates, the person can fall into a coma and other vital signs can disappear [22] - [24]. These symptoms are so dangerous that professional help is needed.

Moderate and severe hypothermia cannot be resolved by using passive rewarming techniques, but require active rewarming preferably in a hospital. Active rewarming uses direct exposure to a heat source, such as forced-air warming systems or warm fluids that are inserted into the veins [22], [24]. Even if rewarming is successful, moderate and severe hypothermia can lead to lasting damage, although in most cases no consequences permanent. It all depends on the resources present that are available to treat the person.

Risks

There are many factors that increase the risk of getting hypothermia. The first and most obvious one is chronic exposure to cold. In a study by Tanaka and Tokudome [27] they found that 85% of the deaths took place when the minimum temperature that day was below 5°C, and 50% of the occurred outdoor deaths happened while the external temperature was between 0°C and 5°C. Other factors that increase the risk to hypothermia are an old age, reduced metabolic rate, immersion in water, and intoxication [22], [24]. Immersion in water, or even damp or wet clothing, intensifies the risk of hypothermia because the conductivity for heat of water is much greater as compared to air [24]. Alcohol intoxication is dangerous in three ways. Firstly, it causes the veins to widen resulting in more heat loss form the body [22]. Secondly, alcohol consumption can lead to malnutrition, a situation where the body does not have enough fuel to heat the body [24]. Thirdly, intoxication of drugs or alcohol can lead to bad behavioural responses to the cold environment, or even impaired awareness of the low temperature [22], [24]. Tanaka and Tokudome [27] found that 64% of the cases of accidental hypothermia had high levels of alcohol in their blood. They also mention a similar, earlier study that found a percentage of 70% [28]. All in all, the factors to be aware of when temperatures are low, and for the development of the envisioned product, are intoxication, physical conditions that slow down the metabolic rate, and immersion in water.

2.2.3 Connection between homelessness and hypothermia

One factor that is prominent in both the homeless population and the risk factors for hypothermia is alcohol use. As stated before, 30-50% of the homeless population is dependent on alcohol intake [16], and the alcohol usage is 6-7 times more present than the national average [15]. Inebriation combined with long-term exposure to cold temperature when sleeping on the street increases the risk of mild hypothermia that roofless have. Alcohol can lead to malnutrition, it widens the veins in the body, and it can impair judgement and awareness of the external temperature [22] [24]. This connection is confirmed by Caroselli, Gabrieli, Pisani, and Bruno [29] who state that *"In the developed countries, the majority of hypothermic patients are intoxicated with ethanol or other drugs"* [29]. From this data the risk for getting hypothermia in the homeless population seems major.

However, when investigating the researches about death causes of the homeless population, hypothermia is just a small factor. A study by Henwood, Byrne and Scriber [30] found that 6% of the deaths among homeless was caused by hypothermia. Romaszko *et al.* [31] found that 3.25% of the deaths in their collected data was caused by severe hypothermia. Compared to the hypothermia deaths in the general population, which was 0.15% of the total amount of death cases, hypothermic deaths are twenty-three times more present in the homeless population then in the general population [31]. Furthermore, deaths from hypothermia are not the only way cold temperatures influence the deaths among homeless. Comparing homeless deaths by season, it can be concluded that in colder temperatures there is a higher risk of mortality [31], [32].

To summarize, people living on the streets have a high percentage of alcohol and drug usage and are therefore more likely to suffer from hypothermia. Different researches concluded percentages between 3-6% of the deaths in the homeless population that are caused by hypothermia. Although this seems small, in one study [31] it is twenty-three times more than in the general population. Also, hypothermia is not the only way low temperatures influence the health and deaths of the homeless. The connection between homelessness and hypothermia can be confirmed to be significant.

2.2.4 Wearable sensing technology

Implementing electronics in clothing comes with a lot of challenges and additional factors to consider than the conventional use of electronics. The factors that need to be considered when implementing electronics in clothing must be explored to make the design of wearable electronics viable. Furthermore, strategies to comply to the found factors must be formed. This section will start with identifying the key factors to take into account when implementing electronics in clothing. From these factors three are chosen to be examined individually in more detail. These factors are: robustness, unobtrusiveness, and energy efficiency.

Identification of factors

Technological wearables are used for countless different applications in various fields, but they frequently share the same focus and design challenges. Gawali and Wadhai [33] describe the typical parts of a wearable sensor system as a sensor node to gather data, a processor to filter for the right information, and a wireless transceiver to send the data. Zhang *et al.* [34] add a data storage part to the previously mentioned components of a sensor node. From this it can be concluded that the primary goal of the typical wearable sensor system is to transfer the desired information of the measured data to an external device.

The design challenges that come with wearable sensing technology are to a different extend than conventional electronic systems that are used for example in mechanical systems. Zheng *et al.* [35] identify the necessary points to be considered for wearable technological devices: *"the main issues to be addressed for the ubiquitous use of wearable technologies can be summarized as (..) security, unobtrusiveness, personalization, energy efficiency, robustness, miniaturization, intelligence, network, digitalization and standardization"* [35]. Some of these issues, e.g. security, digitalization, standardization, intelligence, and network, need to be considered in technological applications in many fields. On the other hand, unobtrusiveness, personalization, energy efficiency, robustness, and miniaturization are specifically important to wearable sensing technologies. From these issues, robustness, unobtrusiveness and energy efficiency are chosen to be examined individually in more detail.

Robustness

It is vital that sensing technologies in clothing are not damaged by frequent use and wear. The main point to tackle is how to make the sensing system resistant to external influences. Common external influences on wearable sensing technologies are operational exposures (e.g. laundry, chemicals, bending, and sweat) and atmospheric conditions (e.g. temperature and humidity) [36]. The part of the sensing technology that is most vulnerable is the wiring of the system, since they are likely not flexible and can break easily [37]. Thus, various ways to strengthen the wiring of the electronics should be identified.

One way to strengthen the wiring is to add extra protection around the wires. This not only improves the endurance to external influences as mentioned before, but also reduces noise the noise present in the system. Both the papers of Hussain, Kennon, and Dias [38], and Sibinski, Jakubowska, and Sloma [39], mention encapsulating the core of the wire to protect it. Sibinski *et al.* study different ways to encapsulate the sensor and the wiring. Their final design is to coat the sensor with a liquid silicon paste, creating a nanotube layer structure. Hussain *et al.* choose to embed the wire into a knitted fabric. In this way the fabric itself improves the isolation and strength of the wire, as well as enhancing the textile feel of the sensor [36].

Another way to make wearable sensing technologies more robust is to make the wiring more flexible. Nesenbergs [37] suggests making wires in a way that enhances elasticity, but at the same time keeps its electric characteristics such as resistance. Wires are proposed which meet these requirements: solid copper wires in the form of electrically conductive particles which are implemented in elastic substances [37]. Furthermore, as another option he mentions the solution by Vieroth *et al.* [40]. They propose circuits with a sinusoidal shape that are flexible by shape and not by material. Through their form they can expand and are therefore less likely to break. A drawback for using these techniques is that the materials should be chosen very careful so that their electric properties stay consistent. Nevertheless, increasing the flexibility of the wiring could be an interesting option to make the sensing technology more resistant to operational influences.

Unobtrusiveness

The clothes with implemented electronics should still be comfortable to wear, hence it should be unobtrusive to the user. Both Zheng *et al.* [35] and Chen and Rodriguez-Villegas [41] state that by keeping both the size and the weight to a minimum, the obtrusiveness of the electronics can be reduced. The main element in sensing technologies that dominates the size and weight is the battery [41], [42]. Since power efficiency is also an important factor in wearable sensing technologies, a trade-off should be made between the size of the battery and the unobtrusiveness of the device.

Another way to reduce the obtrusiveness of the electronics is to make it flexible. One way this can be done is to use flexible electronics [35]. These are electronic circuits which are printed onto flexible materials, like paper, fabric, or even on the human body. Jakubas, Lada-Tondyra, and Nowak [36] argue that conventional sensing technologies, which are placed on top or between layers of the textile, are too stiff and can therefore cause discomfort and irritation to the skin. Another way to make the electronics more flexible is to use textile technology [35], [36]. This is the implementation of electronic properties into the textile itself, such as sensing, heating and light emitting [43]. Both of these techniques can make the electronics more flexible and therefore make it more comfortable for the user.

Power efficiency

As stated before, the size of the battery is the dominating factor in the size of the whole device. In order to reduce the battery size, the system could be made power efficient. One option is to reduce the power that is needed for the wearable sensor device to operate. This can be done at different levels of the device, e.g. the systems hardware, the software, the used battery technology, the data protocols, but by far the most power is used by the wireless transceiver [33]. To minimize the power usage of the wireless transceiver, the amount of data that is sent can be kept as low as possible. The most efficient way to do this is by using on-node data processing [33], [44]. This means that the incoming sensor data is filtered and the unnecessary data is discarded. The useful data is compressed on the node, and the minimal required amount of data is sent by the wireless transceiver. Both Trakimas, Hwang, and Sonkusale [45] and Lian [42] suggest that a good way to process data on-node is to use asynchronous, signal dependent sampling. This works by only sampling data when a significant signal is measured by the sensor. In this way no unnecessary energy is used by the wireless transceiver, and therefore the overall power can notably be reduced.

Another option, next to reducing the used power of the device, is to charge the battery while it is used simultaneously. Technology that can be used and that currently is widely being explored is energy harvesting [46]. Energy harvesting is the generation of power by converting ambient energy such as kinetic (motion), thermal (heat), photon (light), and electromagnetic radiation. An example of such a system is analysed by Pasko, Mrazik, and Elleithy [47]. They look into the amount of energy that can be generated with the current technology, by collecting motion, temperature and solar energy from a smart watch. This is tested in five different use cases of moving, and the results are compared. With their setup, only two of the use cases generated enough energy to feed some energy back into the battery, after powering the system. Another technology to power the device while in use, is Radio Frequency charging, or wireless far-field power transfer [48]. To limit the size of the battery, energy harvesting techniques could be a good option next to on-node data processing.

Conclusion

Three design factors that are specifically important for wearable sensing technologies were found: robustness, unobtrusiveness and power efficiency. To make it robust the wiring should be strengthened. This can be done by e.g. encapsulating the wire, or embedding the wiring into the fabric. To make the electronics unobtrusive the sensing technology could be made flexible, or it could be made light and thin. The biggest problem with making the wearable electronics small and light is the size of the battery, which is the biggest part of a wearable sensing technology. A trade-off between the battery and the unobtrusiveness should be made. To keep the battery as small as possible, techniques for power efficiency can be applied. An effective way for this is on-node processing of the sensor data. An upcoming technique for power efficient wearables are energy harvesting techniques, which convert ambient energy to fuel the sensing device.

In this section, just three of the factors that need to be considered when designing wearable sensing technologies are treated. For a complete view on the topic, the other factors mentioned by Zheng *et al.* [35] are: *"(…) security, unobtrusiveness, personalization, energy efficiency, robustness, miniaturization, intelligence, network, digitalization and standardization,"* could be examined in more detail.

2.2.5 Encouraging the use of a product

An important aspect of every product is to make sure the product will be used. This is especially valuable to consider since the subject of this graduation project is a device that is an addition to an already working product. Through two prominent pieces of literature about persuasive technology this aspect will be explored.

Influencing people's choices

Thaler and Sunstein [49] wrote about indirectly influencing people's choices by understanding human behaviour and adjust a design accordingly. The first way to do this is by making the desired option the default option. Since humans are lazy creatures and will most of the time choose the option that takes the least effort, making the desired option the default will increase the wanted use of the product [49]. Another way they mention to influence people to do the desired thing is by providing feedback about their actions. The user should be told when an executed action is good and when the user makes a mistake. The system should also have good error recovery [49]. These three characteristics influence people in a logical way for the human brain, and will therefore encourage them to use the product as desired by the designer.

Key factors to influence behaviour

A model that describes the elementary behaviour of the human brain is the Fogg's Behavior Model. Fogg based his model on three main factors that influence behaviour: motivation, ability, and triggers [50]. These three factors should be present simultaneously for a behaviour to happen.

According to Fogg, motivation is the first factor that humans need to make the choice to perform an action. Three big drivers for human motivation are stated. The first one is either *pleasure* or *pain*, which are two sides of the same kind of motivator [50]. Pleasure and pain are immediate motivators, where people act to get or avoid an almost instant consequence. Although these are two strong motivators, Fogg adds that these may not be the best things to incorporate into a design, especially fear is in most cases not desirable. The second motivator also has two sides which are *hope* and *fear* [50]. These are linked to the eventual outcome of an action. He states that when this outcome is expected to be positive the motivator is hope, whereas fear is the prospect of something bad happening from the action [50]. The third motivator mentioned by Fogg is a social factor, again one with two sides. On the one hand *social acceptance* and on the other hand *social rejection* [50]. People in general are motivated to do things that are socially acceptable so they won't be socially rejected. Involving social factors in the design of a product or service can motivate people substantially.

The second factor that humans need to choose an action is the ability to do so. This can be done by teaching the user what to do, or by making it easier to do. The second way is the best way, since humans are lazy beings and do not want to put extra effort in learning a task [50]. This is the same conclusion that Thaler and Sunstein [49] made about the nature of humans. To respond to this human characteristic in a design, it should be kept simplistic. Fogg mentions six elements of simplicity that need to be considered: time, money, physical effort, brain cycles, social deviance, and non-routine [50]. The user should have the time and money available to execute the action. The physical effort required should not be a lot, or too much for the person. The action should not need a lot of serious thinking before, and it should not go against the social norms. Lastly, activities that are not routine behaviours are often found more difficult. Keeping these six elements in consideration will make the action simpler for the user to execute, thus probably being executed more.

The third factor an action needs is to trigger the user to do it. There are three kinds of triggers [50]. Sparks are triggers that increases motivation for the action. Facilitators increase the simplicity of the action. And signals are triggers to remind the user to do it. For triggers to be effective they need to be noticed by the user, to be associated with the desired action, and to be present at the same time as motivation and ability [50].

To summarize, the Fogg Behavioural Model describes motivation, ability, and triggers to be the three key factors for influencing human behaviour. Motivation can be fuelled by pleasure/pain, hope/fear, and social acceptance/rejection. Ability can be reached by keeping it simple. Triggers can serve as a spark, a facilitator, or a reminder. If these three factors are present at the same time, the user is likely to perform the desired action.

2.3 Related products and services

The following section aims at providing an overview of the related products and services that have already been developed, starting with products and services created to help the homeless population. This is followed by different kinds of wearable technology products and sensing technologies. Last but not least, products are mentioned that convince their user to do the good thing.

2.3.1 Homelessness

StreetLink

Like the envisioned product, this service exists to help homeless sleeping outside. The website, app and phoneline called StreetLink [51] aims at offering support to people who are sleeping rough in England and Wales. People that see someone sleeping rough can contact this organisation. Street outreach teams will look for a rough sleeper of which they have been notified by StreetLink. They will assess the situation and look for a solution for this individual person.

Figure 2.1. StreetLink logo

EMPWR Coat

A similar product to the Sheltersuit is the EMPWR coat [52], developed by The Empowerment Plan based in Detroit, Michigan, USA. The coat is water-resistant and can be folded out into a sleeping bag. When not used, the coat can be rolled into a shoulder bag. The used materials are donated by companies, and are durable and upcycled. One coat costs $100 to sponsor. The company also employs homeless to work in their factory, and find accommodation. The product, sustainability and service to workers of this company are very similar to the Sheltersuit foundation. However, it does not focus on technological innovation yet.

Figure 2.2. The EMPWR Coat

WeatherHYDE

WeatherHYDE [53] is a tent that can fit a family of five, and that is suitable for all weather. The tent is lightweight, water resistant, and uses a reflective layer to either keep the heat inside, or to reflect the heat of the sun to keep it cool. The tent can be installed in 15 minutes by a single person, and does not need any tools. WeatherHYDE is currently on Kickstarter. Similar to the Sheltersuit, the WeatherHYDE is distributed to vulnerable people sleeping outside e.g. refugees.

Figure 2.3. WeatherHYDE tent.

Duffily bag

The Duffily Bag [54] is a heat-reflecting, lightweight, waterproof, non-flammable sleeping bag specially made for homeless. The bag is initiated by Emily Duffy in Ireland, and is made by homeless people. It provides comfort and warmth for people sleeping on the streets. Like The Empowerment Plan and the Sheltersuit foundation, the bags are made by homeless and thereby stimulates rehabilitation. There is no technological innovation in the suit.

Figure 2.4. The Duffily Bag.

Helping Heart

Helping Heart [55] is a novel innovation by N=5 in collaboration with ABN Amro bank. It is a device build into a coat to gather money from pedestrians. People can donate one euro by contactless payment to a homeless person wearing the coat. The gathered money can be used to get a meal, a place to sleep, or to save money for later, at a participating shelter. In this way, the donator knows his donation will be used in a good way. This product is the only one that, like the envisioned product, uses wearable technology to help the homeless population.

Figure 2.5. Helping heart [96].

2.3.2 Wearable technology

OptimEye S5

The sports tracker called ‘OptimEye S5’ [56] developed by Catapult gives insight in the performance of the athletes who wear it. The data is collected by accelerometers, gyroscopes, magnetometers, and a satellite based positioning system. This data is sent real-time via Bluetooth to a mobile application. The device consists of a little box and a wearable garment containing a heart-rate sensor. By using this system, the trainer will have insights about the positions and playing style of players, and can adjust the playing and training techniques accordingly. The unobtrusiveness and integration of the sensing could be useful in the envisioned product.

Figure 2.6. OptimEye S5 tracking system [97].

Athos Training System

Athos [57] is a company that makes wearable sensor fabric that forms a training system. It comes in the form of a men’s sports shirt, and both a male and female sports short. It uses a new micro-EMG sensor to measure the activity of muscle fibers all over the body, and thereby captures how well certain parts of your body are working while training [58]. The shirt contains more than 12 sensors on different groups of muscles. The EMG sensors are sown into the clothing, and can withstand sweat, the washer and the dryer. The data is send to an application running on a mobile phone via a Bluetooth connection in the core. This core is the processing unit of the system and collects and processes the data of all sensors before sending it to the application. Like the OptimEye S5, the integration of the electronics and the unobtrusive sensing is relevant for the envisioned product.

Figure 2.7. Athos Training System [98].

Nadi X Yoga Pants

A start-up called Wearable X developed a pair of yoga pants, Nadi X Yoga Pants [59], that provide feedback while doing yoga poses. The yoga pants provide heptic feedback through implemented bands of neoprene [60]. A sensor network is implemented in the fabric, which data is collected in a battery pack and controller behind the knee. The vibrating patterns differ with the kind of feedback, and the aim is that the user will subconsciously change their pose to the given feedback. The position recognition and technology integration are also significant for the envisioned product.

Figure 2.8. Nadi X Yoga Pants.

Neopenda

Neopenda [61] is a monitoring system for new-borns. It's integrated in a cap, and contains four sensors to keep track of the vital signs of the baby. The system measures heart rate, respiratory rate, blood oxygen saturation and temperature [62]. This data is sent via low-power Bluetooth to the nurse's tablet. The nurse will have a total overview of the vital signs of all the babies (up to 24) on the ward. The electronics are placed inside a 3D printed case, and placed inside of the hat. The company aims at providing the hats for less than $1 when produced at scale, and having the battery last for 5 days. Neopenda will likely be brought to East African markets in 2019 [63]. The unobtrusive sensing, electronics integrated into textile, and low cost are matching characteristics of the envisioned product.

Figure 2.9. Neopenda hat with sensors.

LifeFone

LifeFone created an Emergency Response Service [64] for the elderly. It consists of a wearable emergency button and a base unit placed in the house. When pressed, the service will contact the LifeFone monitoring station where an agent will contact either the emergency services or loved ones. Another version of this system works with automatic fall detection integrated into the wearable pendant. There is also an 'on the go' version that has a GPS signal and will contact the LifeFone services when the button is pressed away from home. Especially the automatic fall detection is related to the shivering detection in the envisioned product.

Figure 2.10. LifeFone Emergency Response Service.

2.3.3 Persuasive technology

Nest Learning Thermostat

The learning thermostat created by Nest [65] encourages people to save energy by consciously controlling their heating system. The user can adjust the temperature of their house via a mobile application. The thermostat also learns from the behaviour of the owners, and will adjust the temperature accordingly. The user can see the amount of energy they saved on a linked app. In this way the thermostat stimulates people to behave in a good way with their energy. This system convinces the user to do the good thing, which is something the envisioned product expectedly also does.

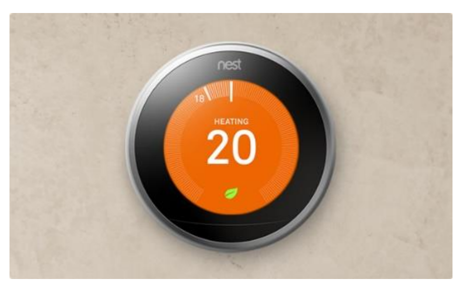

Figure 2.11. Nest Learning Thermostat.

Slightly robot

Slightly robot [66] is a wristband especially designed to cut bad habits. The bracelet detects certain movements of the wrist and will notify the user when this is detected. In this way the user can quit bad habits like nail biting, hair pulling, or scratching. The bad movements are saved by an application on a phone, to keep track how the person is doing. This product helps the user to do the right thing and take care of themselves, as the envisioned product will be designed for.

Figure 2.12. Slightly robot.

Smart Electric Toothbrush

The Oral-B SmartSeries Electric Toothbrushes [67] are designed to make the user aware of the time they brushed their teeth. The toothbrush is connected to a mobile app via Bluetooth, and keeps track of the brushing behaviour real-time. This makes the user more conscious about the importance of brushing their teeth. The focus on selfcare and health is consistent with the aim of the envisioned product. Making the user aware of what is the healthy thing to do could be a useful component to integrate in the envisioned product.

Figure 2.13. Oral-B Smart 6 6500.

2.4 Relevance of the research question

Since homelessness has increased drastically from 2009 until now, it cannot be viewed as a temporary problem any longer. From the background and literature research it has become clear that cold temperatures make life hard for people who are homeless, especially for the homeless who sleep rough rather than sleeping in shelters or with friends. Furthermore, substance use is high under homeless, and is a risk factor for getting mild hypothermia. This can obstruct the Sheltersuit user from noticing that his core temperature is decreasing, thus that he is in danger. Although there are various products available to keep people warm (e.g. sleeping bags, coats, and tents) there are no products available that tell the user when it is not helping enough. Parts of such a system are available, e.g. services where citizens can report a homeless person in need, emergency buttons, wearable sensors, technology to motivate people to do the good thing. But a system that combines all these factors into a new product is a novel and useful concept that could make the life of homeless safer when outside temperatures are low, and the risk of getting hypothermia is apparent. Concluding, considering all that is mentioned above it can be confirmed that the research question is relevant.

3. Ideation

The aim of this chapter is firstly to find the preliminary requirements for the envisioned product, and secondly to find a final concept. The preliminary requirements will be found using stakeholder analyses, PACT analysis, and a user scenario. Thereafter the preliminary requirements will be listed, grouped in functional and non-functional requirements, and classified using the MoSCoW method. From these requirements different concepts will be drawn and the advantages and disadvantages of every concept will be listed. In the end, the best concept will be chosen to work with in the following chapters.

3.1 Stakeholders

For the development of any product it is important to identify the people who are affected by this product, and who gain something from it. These people are known as stakeholders. Stakeholders are both people involved in the development process, and people, groups or organisations whose behaviour directly or indirectly affects or is affected by the product [68]. In this section stakeholders will be identified by the use of a paper by Sharp, Finkelstein, and Galal [69]. The relation between these stakeholders will be made clear using a concept map. Thereafter, the influence of every stakeholder will be mapped in a power/interest matrix.

3.1.1 Stakeholder identification

There are various tasks and influences that stakeholders can have over the design process and product. One way to identify relevant stakeholders is proposed by Sharp, Finkelstein, and Galal [69]. They start with a baseline stakeholder, and the network of stakeholders that influence the baseline. In their paper they provide a basic structure of a concept map (Figure 3.1) to identify relevant stakeholders.

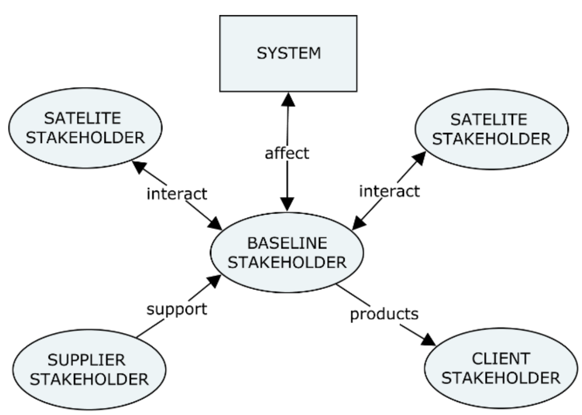

Figure 3.1. The main elements of stakeholder identification addressed by Sharp, Finkelstein, and Galal [69].

In their approach it all starts with the baseline stakeholders, which are divided into four categories: Users, developers, legislators, and decisionmakers. Supplier stakeholders give information to the baseline stakeholders, or fulfils supporting tasks. The products made by the baseline stakeholders are inspected by client stakeholders. Satellite stakeholders are all the other people or parties that interact with the baseline. The design process for the envisioned product is part of the 'system' block in Figure 3.1, and is only affected by the baseline stakeholders. For this reason, this stakeholder identification is focussed on the baseline stakeholders of this project. They will be identified in the next section.

3.1.2 Baseline stakeholders

As mentioned before, baseline stakeholders can be categorized in four categories: users, developers, legislators, and decisionmakers [69]. Users are people or parties who interact with the system directly, and who use the product. Developers are people or parties who are involved in the design process of the product. Legislators are professional bodies, e.g. government sections, who can make rules about the making and the use of the product. Decisionmakers are involved with the development of the system, and have influence in the made decisions about the product. Since there are many baseline stakeholders, they are listed below.

- Homeless people in The Netherlands (user)
- Sheltersuit foundation (decisionmaker)
- Creative Technology student (developer/decisionmaker)
- Creative Technology supervisor (decisionmaker)
- Municipalities (legislator)
- Local shelters (legislator)

3.1.3 Relationship between stakeholders

Now all the relevant stakeholders are identified, the relationships between them should be examined. This is done by visualizing them in a concept map, with the Sheltersuit Foundation as the central node. The concept map is displayed in Figure 3.2 below.

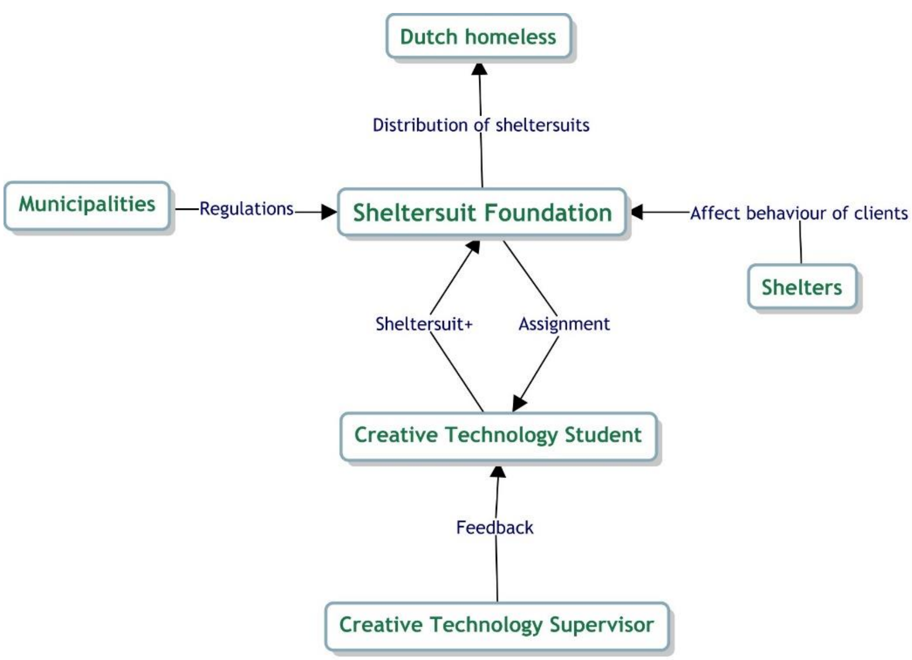

Figure 3.2. Concept map of the relationship between different stakeholders.

3.1.4 Stakeholders' influence

Another analysis method is classifying the stakeholders in power / interest matrix [70] [71]. Here, the stakeholders are sorted into four classes: keep satisfied, encourage and influence, monitor, and keep informed. This is done on the level of power and interest the stakeholders have in the product and/or design process. The stakeholder power / interest matrix for this project is displayed in Figure 3.3. Thereafter, the placement will be justified by addressing all stakeholders individually.

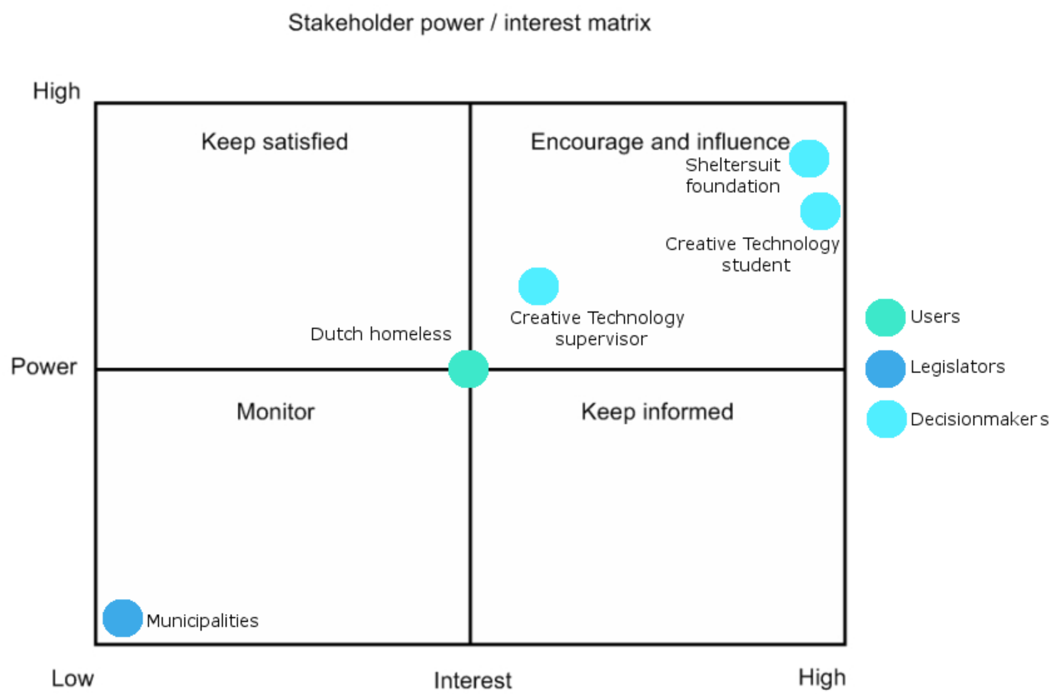

Figure 3.3. Stakeholder analysis based on [71].

3.1.4.1 Encourage and influence

Sheltersuit foundation

The Sheltersuit foundation, which is the client of this project, has the most power in the end. Since they give the assignment and express desired requirements of the device, they have a big influence in the development process of the envisioned product. Their interest is high because they can improve their product (the Sheltersuit) with the envisioned product.

Creative Technology student

The student who works on developing the envisioned product has the highest interest in the development process of the envisioned product, for she has the most to gain or lose from the result. Although the client decides the requirements and conditions for the envisioned product, the student decides the implementation of them. So her power is also high, but not as high as the client's power.

Creative Technology supervisor

The supervisors from Creative Technology have regular meetings with the student and provide feedback, this gives them high power over the design process and final product. They want the design process to go well, which gives them a high interest in the product.

3.1.4.2 Monitor

Local municipalities

The local municipalities make the regulations about homelessness in The Netherlands. The policy of the municipality of Enschede is to get people off the streets and offer them a track of rehabilitation that suits them [72]. Their vision does not match with the vision of the Sheltersuit foundation. However, the municipality of Enschede has a policy for low outside temperatures: when temperatures drop below 2°C they provide an emergency night shelter. Their behaviour should be monitored in the development and possible launch of the envisioned product.

3.1.4.3 Unknown interest and power

Dutch homeless

Besides the client, which is the Sheltersuit foundation, the users (Dutch homeless) are an important stakeholder in the development process of the envisioned product. However, as can be seen in Figure 3 above, how much interest and power they have is unknown. Since this population group is very closed to and suspicious of outsiders, it is difficult to identify the interest they have and the power they will take in the developing process. The aim of the envisioned product is to make the life of the homeless person safer by making them aware of the risk of mild hypothermia. The question to ask is: how important is the interest of the Dutch homeless in their own health and safety? Should the product force them to react when the risk of mild hypothermia is high? And maybe even contact others when they do not react? Or is their autonomy more important, and should the product give them the choice to react or ignore the notification?

For this design process the autonomy of the user will be respected. They should not be forced to react to the notification from the envisioned product when they do not want to. The envisioned product will tell them when risk of mild hypothermia is high, but they have the final choice to warm up or not. If someone does not want to use the module at all, he/she can choose to do so. He or she could also sell or dispose the envisioned product when he/she doesn't want to use it. Thus, the interest of the Dutch homeless in their own health and safety is a key factor in the successful use of the envisioned product.

3.2 PACT

To develop the envisioned product into something people want and are able to use, the target group should be investigated. The main users of the envisioned system are the homeless people in The Netherlands. This group will be analysed by using the PACT analysis as described by D. Benyon in his book 'Designing Interactive Systems' [73]. The people, activities, context and technology of the homeless population in the Netherlands will be examined. As a pre-analysis information from V. Trulock is used [74] to explore the PACT factors in a broader way. The outcomes of the PACT analysis will be implemented into a user scenario.

3.2.1 PACT pre-analysis

People

The homeless people user group is heterogeneous, which means that it consists of many different types of people with different interests and values. Every user will be different, and cognitive characteristics of the user group are not applicable to everyone. Derived from the context analysis in chapter 2, the age of the users ranges between approximately 18 to 65 years old. A big part of the users (48,8%) will be between 27 and 50 years old, and 80% are male. Furthermore, a high percentage of the user group will suffer from mental illnesses and/or addiction. These mental illnesses vary, and could be e.g. depression, anxiety disorders, personality disorders, schizophrenia. Therefore, their perception of their surroundings might be flawed. It is essential that people under influence or suffering from mental illness will be able to interact with the envisioned product. The language that the user group will speak is most likely Dutch and/or English. They will almost all be novice with the use of the envisioned product. Because the user will not handle the interface often and the user might be intoxicated, the cognitive load of the interface should be minimal. It could be considered to take (colour)blind and/or deaf people into account.

Activities

The user does not need to do a lot to keep the envisioned system running. In the beginning the system might be needed to be calibrated, with the help of the user. How this should be done is not clear yet. While wearing the Sheltersuit the user should keep the battery charged. The system will give a notification when the battery power is low, and the user needs to react to this. This is a regular, active task for the user. When the risk of mild hypothermia is detected, the user should react to this by starting to move and finding a warmer place, preferably inside. For this the user should get instructions what to do, and what the notification is for.

Context

The user of the product will always be outside. The outside conditions are most likely cold and wet, since these are risk factors for hypothermia. The risk of mild hypothermia is most likely when the user is asleep, for this is the time people do not move a lot. Also, the user is most likely on his own, hidden to other people passing by. Most likely, the user does own a phone to contact people.

Technologies

The system will give real-time feedback about the risk of mild hypothermia. The conditions for risk of mild hypothermia are sensed by the envisioned product. Also, the shivering of the user is measured, and combined with the conditions to determine the risk of mild hypothermia. The output data are in the form of notifications. There are different possibilities for the technology. The envisioned product might have a display to show battery charge and risk factors. The notification will be focussed on the user, and could be done through vibration, sound, lights, or a combination. It could possibly connect with emergency services when the user does not react to the notification.

3.2.2 PACT analysis

The specific characteristics that will be used in this scenario have been derived from the PACT analysis in section 3.2.1. This scenario is focused on the homeless in The Netherlands. Since conversations have taken place with this user group, the information in this scenario is based on real stories.

People:	A 49-year-old male, homeless, sleeping rough, addicted, mentally unstable.
Activities:	Switch on the Sheltersuit to have it measure the risk of mild hypothermia. Reacting to feedback of envisioned product.
Context:	Sleeping on the street. Alone. Cold and wet conditions.
Technology:	A module in the Sheltersuit that measures the inside conditions and notifies the user when risk of hypothermia is high. Something robust, energy efficient, user-friendly, and unobtrusive.

Frank is a 49-year-old divorced male, living on the streets of Amsterdam, The Netherlands. He used to work as a carpenter at a successful building company, but lost his job after a reorganisation. Every day is focussed on gathering enough money to afford the drugs he needs at night. Today is a cold, cloudy and windy February morning. Frank just had a sandwich he got from a shop where he knows the owner. Now he is on his way to the Museum square to ask people for money. Since this part of Amsterdam is full of tourists, it's a good place to collect some money. On the way, he passes the library and chooses to go in to warm up a bit and drink a cup of free coffee. In the toilet of the library he checks his appearance so he won't look like a gross hobo, he wants to look like a person.

When he gets to Museum square it's almost noon, and it's packed with people. He manages to collect enough money to buy his fix. He calls his dealer with his mobile phone and tells him to bring the usual stuff to the usual place. When he arrives at his usual place, the dealer is already there to make the transaction. He takes the drugs, installs himself in a recess between two buildings, and zips the sleeping bag to his Sheltersuit+. It's already getting dark, and it starts to rain. Luckily, he found some leftover plastic that he uses to shield himself from the rain. When the drugs start working his wandering mind finally stops, and he falls in a long-needed sleep. During the night, the shelter breaks and the outside temperature drops quickly. The air inside the Sheltersuit+ also starts to cool down. Frank's body starts to shiver and his body temperature starts to drop. Because of the drugs he used earlier he doesn't notice that he is in danger. Luckily, the Sheltersuit+ notices that the conditions inside the suit are bad, and that Frank's body is shivering to stay warm. The module gives a notification that wakes him up. When he is awake, he realises that he is very cold and his body is trying to stay warm. He packs up his things and starts to walk around to find a place with more warmth.

A few weeks later Frank is having lunch in the Vondelpark. When searching for something in his shirt's pocket, he notices that a different notification is given by the Sheltersuit+. One of the elements of the module has stopped working. He reads the instructions that he got with the Sheltersuit+, and follows the steps. Soon the product will work again, and his life will be safer than without the monitoring of the Sheltersuit+.

3.3 Preliminary requirements

From the context analysis in chapter 2, the stakeholder analysis in section 3.1, and the PACT (pre-) analysis in section 3.2, information is gathered about the requirements of the envisioned product. Through brainstorming this information is translated into preliminary requirements. These are divided into functional (what it should do) and non-functional requirements (how it operates). To establish the importance of every requirement, they are classified with the MoSCoW method (which stands for: must, should, could, won't). The requirements categorized as 'must' are the core functions the envisioned product should do to operate. They are derived from the project description given by the client. The other functional requirements are classified as 'should', and are established through talking with the client and the Creative Technology supervisor. 'Should' requirements are important to the functioning of the system, but the system could function without them. The non-functional requirements are gathered through company visits, talking with the client, and brainstorming. They make the envisioned product more user-friendly, but they are not essential for the functioning of the system. The 'could' requirements are implemented when there is time to spare, and the 'won't' requirements are interesting to consider in the future. The preliminary requirements for this project are listed below.

Functional requirements

- Measure humidity in suit (Must)
- Measure temperature in suit (Must)
- Measure shivering of user (Must)
- Make predictions on measurement data about risk of mild hypothermia (Must)
- Notify user of high risk of mild hypothermia (Must)
- Shows level of battery charge of the product (Should)
- Notify user when product needs to be charged (Should)
- Notify user when one part of the product stopped working (Should)

Non-functional requirements

- Unobtrusive for sewing process (Should)
- Easy to sew for Sheltersuit employees (Should)
- Unobtrusive to user (Should)
- Robust (Could)
- Easy way to charge battery (Could)
- Discouragement of reselling (Could)
- Cheap (less than 25 euro) (Won't)
- Possibly easy to repair (Won't)
- Possibly recyclable / non-disposable (Won't)

3.4 Sheltersuit production process

For the design process of this project it is essential to know the production process of the Sheltersuit. This can be used to fit the envisioned product into the Sheltersuit in a way that is efficient and convenient for the production line. Therefore, this section will describe the different layers and elements the Sheltersuit is made of. Thereafter the stages of the production line will be explained. The Sheltersuit is displayed in Figure 3.4.

Figure 3.4. The Sheltersuit.

3.4.1 Fabrication of the sheltersuit

The Sheltersuit is made of different parts that are sown together. Figure 3.5 shows the jacket of the Sheltersuit. The segments that the jacket is made of are one back piece, two sleeves, one hood, and two front pieces which each consist of two separate pieces of fabric and pockets[2]. The shoulder linings are shown in Figure 3.6. The sleeping bag consists of a front piece, back piece, and closing strip. The outer layer and inner lining are cut and sown into the whole model separately, and brought together at the very end. A Sheltersuit is supplied with a bag to store the sleep bag in when not in use.

Figure 3.5. Jacket of the Sheltersuit.

Figure 3.6. Shoulder linings of the Sheltersuit.

3.4.2 Production line

The production of the Sheltersuit starts in the cutting room. Here the outer material and lining are cut out of big pieces of fabric. The pieces of fabric are stacked on top of each other, and cut at once into the right pieces for the sewing room. The sewing process has a lot of stages where many people contribute. Firstly, the

[2] The first three pictures are from the old Sheltersuit design, which had two pockets at each side of the front. The current design, which is shown in the other pictures, has one pocket per side. In this new model each front piece is made of two different pieces of fabric.

outer lining of one piece (jacket or sleeping bag) are sewed all together. Simultaneously the isolating inner lining is sewed into a jacket or a sleeping bag. If both are done, they are sown together inside out, and then the whole piece is inverted so the outer lining is now outside. For the jacket, the inverting is done through a narrow hole in the bottom of the jacket. Figure 3.7 to 3.11 display different views of the outer linings of the Sheltersuit.

Figure 3.7. The outer lining of the sleeping bag.

Figure 3.8. The outer lining of one front piece with pocket.

Figure 3.9. The outer lining of the jacket, half open.

Figure 3.10. The outer lining of the jacket, open.

Figure 3.11. The outer lining of the jacket, closed.

3.4.3 Design consequences

The makeup and the production line of the Sheltersuit should be considered when developing a module that can measure conditions for mild hypothermia. For the placing of the envisioned product, the seams should be taken into account. During the sewing process, parts of the solution cannot cross a seam that still has to be sewn. For example, the arm, the hood and the front piece all come together in the shoulder, which thus has a lot of linings. The inverting of the fabric means that if the module needs to be implemented between the inner and outer layer, it should be able to handle the forces of inverting. Also, it should be small enough to fit through the hole and flexible enough not to break.

3.5 Concepts

The requirements mentioned earlier can be implemented in the existing Sheltersuit in multiple ways. Different concepts which capture most of the important requirements from section 3.3 are explored. The concepts in this section are based on a wired system. Wireless systems are not considered because that would need extra components to send the data. This would not only increase the cost of the module, but also the power consumption would increase significantly. Also, the concepts only consider a notification system, and not a heating process inside the suit. As mentioned in chapter 2 in the section about hypothermia, the best way to warm up when suffering from mild hypothermia is to move to a warm place and to keep moving your body. In this way your body will heat up itself. However, if heating pads would be applied to the body, the body's natural heating process will be slowed down. Only the body's skin temperature will rise, not the core temperature. For this reason, heating pads are not considered in the concepts.

This section will firstly consider the placing of the envisioned product, both distributed and integrated. Secondly the notification system will be explored. In the end the final concept will be chosen.

3.5.1 Placing of system

Two options for the placing of the envisioned product are considered: a module with integrated sensing functions, and a module distributed sensing functions. The main advantages and disadvantages of the two options are displayed in a table below. Thereafter, multiple concepts in both categories will be described below, and for each the advantages and disadvantages will be listed. The advantages and disadvantages are largely derived from the preliminary non-functional requirements established in section 3.3. The elements that originate from the preliminary requirements are shown in italics. From these the final concept for the module will be chosen.

3.5.1.1 Module with integrated sensing functions

The first general way to place the envisioned product in the Sheltersuit is integrating the sensing functions all in one single module. In this section, different places are considered and the advantages and disadvantages are listed in a table below each sketch.

Shoulder

The first concept is an integrated sensing system placed on top of the shoulder. It is placed on the inside of the Sheltersuit, integrated into the linings. The sketch of this concept is shown in Figure 3.12, and the comparison table is shown in Table 3.1.

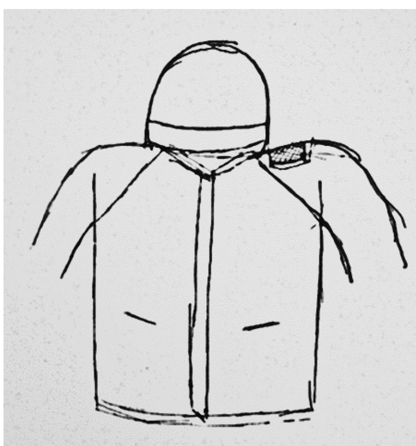

Figure 3.12. Drawing of concept: module with integrated sensing functions, shoulder.

Advantages	**Disadvantages**
Good place for *measuring shivering (must)*	*Obtrusive to user* when wearing backpack *(should)*
Unobtrusive to user because of the placing *(should)*	*Uneasy to sew for Sheltersuit employees* because of the many linings around the place *(should)*

Table 3.1. Comparison table: module with integrated sensing functions, shoulder.

Chest

The integrated sensing system can also be placed at the chest of the Sheltersuit, again integrated into the linings of the jacket and placed on the inside. The sketch of this concept is shown in Figure 3.13, and the comparison table is shown in Table 3.2.

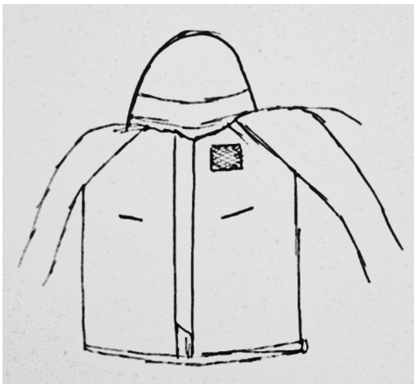

Figure 3.13. Drawing of concept: module with integrated sensing functions, chest.

Advantages	Disadvantages
Good place for *measuring shivering (must)*	
Unobtrusive to user because of the placing *(should)*	

Table 3.2. Comparison table: module with integrated sensing functions, chest.

Existing pocket

Instead of implementing the integrated sensing system in the linings of the Sheltersuit, it could also be placed inside a pocket sown on the inside. This concept uses an existing pocket to hold the integrated sensing system. The sketch of this concept is shown in Figure 3.14, and the comparison table is shown in Table 3.3.

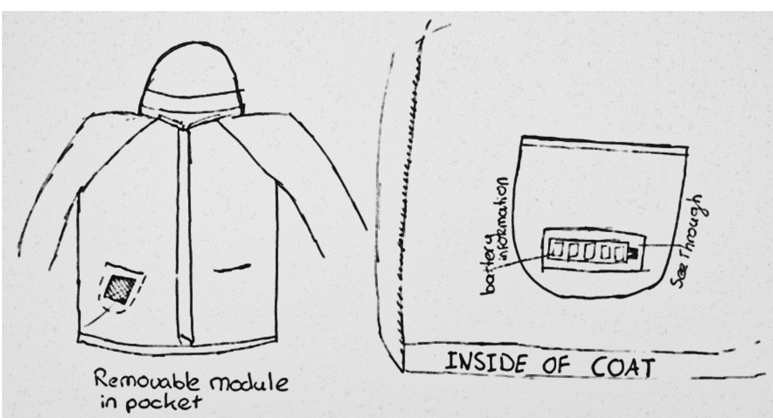

Figure 3.14. Drawing of concept: module with integrated sensing functions, existing pocket.

Advantages	Disadvantages
Unobtrusive for sewing process (should), since it gives minimal impact on the Sheltersuit production line	Bad place to *measure shivering (must)*

Easy to sew for Sheltersuit employees, since minimal effort is needed from the Sheltersuit employees *(should)*	Module *could be sold by user (could)*
Unobtrusive to user because of the placing *(should)*	Pocket cannot be used by user
Module *easily* removable for *repairing (won't)*	
Module *easily* removable for *charging (won't)*	
Can turn any Sheltersuit into a Sheltersuit+	

Table 3.3. Comparison table: module with integrated sensing functions, existing pocket.

Extra chest pocket

The pocket approach could also be done by adding an extra pocket to the Sheltersuit. In this concept, an extra pocket is added on the inside of the Sheltersuit at the chest. The integrated sensing system could be placed inside this pocket. The sketch of this concept is shown in Figure 3.15, and the comparison table is shown in Table 3.4.

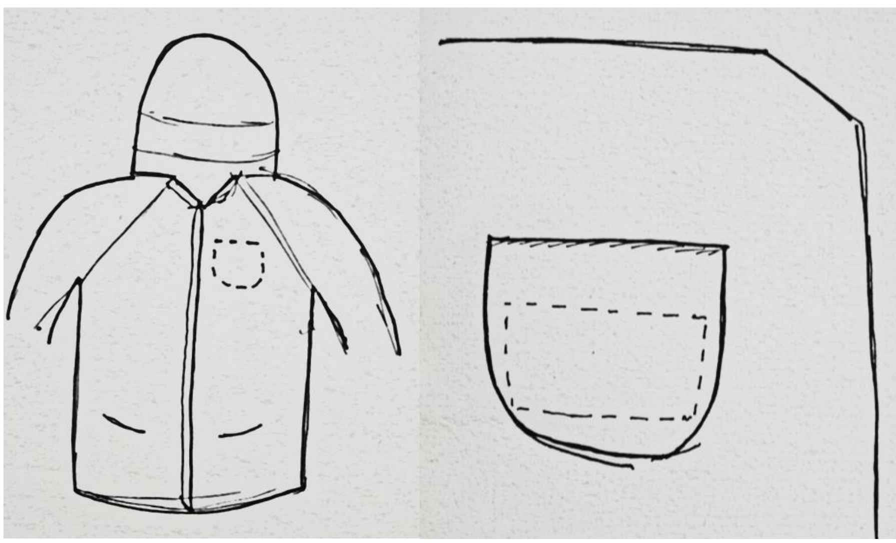

Figure 3.15. Drawing of concept: module with integrated sensing functions, extra chest pocket.

Advantages	**Disadvantages**
Good place for *measuring shivering (must)*	Module *could be sold by user (could)*
Unobtrusive to user because of the placing *(should)*	
Unobtrusive for sewing process (should), since it gives minimal impact on the Sheltersuit production line	
Easy to sew for Sheltersuit employees, since minimal effort is needed from the Sheltersuit employees *(should)*	
Module *easily* removable for *repairing (won't)*	
Module *easily* removable for *charging (won't)*	

Table 3.4. Comparison table: module with integrated sensing functions, extra chest pocket.

3.5.1.2 Module with distributed sensing functions

Instead of placing all the elements of the module in one place, the sensing elements could also be moved to other parts of the Sheltersuit. The main advantage of distributing sensing elements is the possibility to measure conditions in different places. The sensing elements could be placed on the spot where the measured conditions return the best result. One way to make this distribution possible for the production line is to fit everything on a belt that can be sown into the Sheltersuit at the last stage of production. When designing without a belt, the linings should be considered to not damage the module's elements in the production process. Note: In these concept drawings the sensors are placed in a random place on the belt. In the real situation these places are chosen to maximise the measurement quality. In this section, different places are considered and the advantages and disadvantages are listed in a table below each sketch.

Horizontal belt lower abdomen

The first way the belt could be placed is at the lower abdomen. The processing module would be placed around one of the front pockets, and the sensors are placed where the measured quantity is the best. The sketch of this concept is shown in Figure 3.16, and the comparison table is shown in Table 3.5.

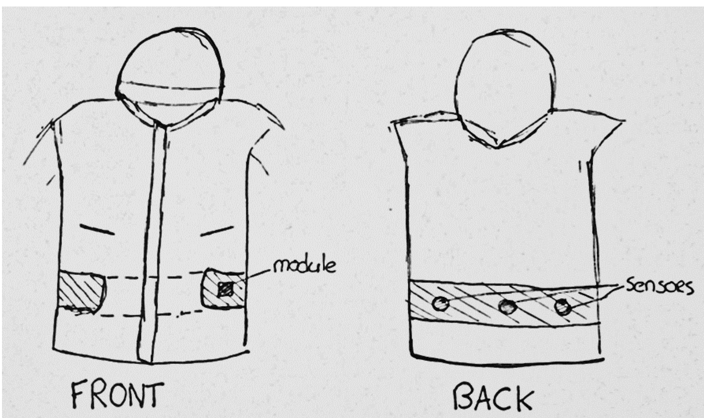

Figure 3.16. Drawing of concept: module with distributed sensing functions, horizontal belt lower abdomen.

Advantages	**Disadvantages**
Unobtrusive to user because of the placing of the main module *(should)*	Bad place for *measuring shivering (must)*
Unobtrusive to user because of the belt *(should)*	*Obtrusive for sewing process (should)*
Multiple sensing points, so possibly *better predictions (must)*	

Table 3.5. Comparison table: module with distributed sensing functions, horizontal belt lower abdomen.

Vertical belt on back

Another way the belt could be placed is over the shoulder to the back. In this way, the processing module could be located where the shivering is measured well. The sketch of this concept is shown in Figure 3.17, and the comparison table is shown in Table 3.6.

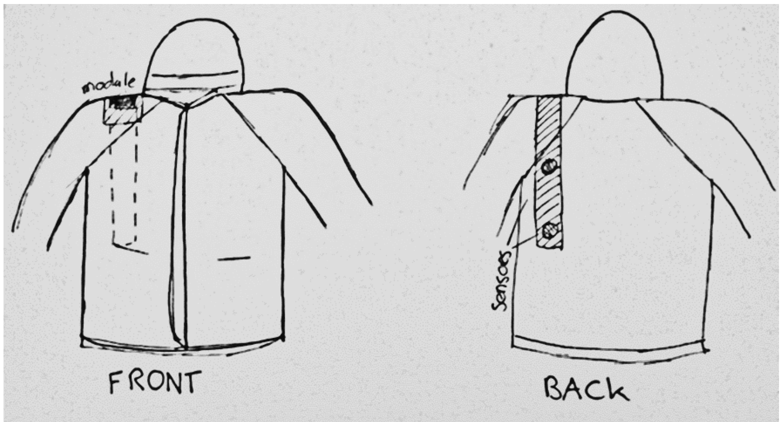

Figure 3.17. Drawing of concept: module with distributed sensing functions, vertical belt on back.

Advantages	**Disadvantages**
Bad place to *measure shivering (must)*	*Difficult to sew for Sheltersuit employees*, since it crosses a lot of linings *(should)*
Multiple sensing points, so possibly *better predictions (must)*	*Obtrusive to user* because of the placing of the belt on the back *(should)*
Unobtrusive to user because of the placing of the main module *(should)*	Much tension on sensing points when back is bend

Table 3.6. Comparison table: module with distributed sensing functions, vertical belt on back.

Diagonal belt

The belt could also be placed diagonal over the back, placing the processing module at the place of one of the front pockets. The sketch of this concept is shown in Figure 3.18, and the comparison table is shown in Table 3.7.

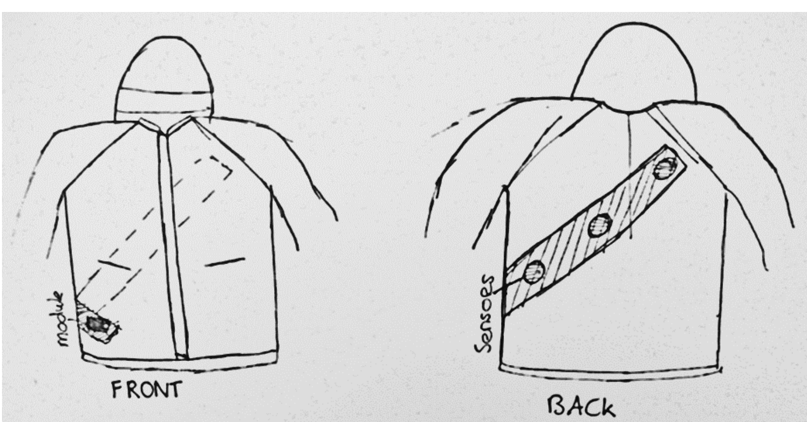

Figure 3.18. Drawing of concept: module with distributed sensing functions, diagonal belt.

Advantages	Disadvantages
Bad place to *measure shivering (must)*	*Obtrusive to user* because of the placing of the belt on the back *(should)*
Multiple sensing points, so possibly *better predictions (must)*	Much tension on sensing points when back is bend
Unobtrusive to user because of the placing of the main module *(should)*	

Table 3.7. Comparison table: module with distributed sensing functions, diagonal belt.

3.5.2 Notification system

Besides the placement of the module in the Sheltersuit, the way of notifying the user should also be explored. The notification system should alert the Sheltersuit user that the risk of mild hypothermia is present, or possibly that the system stopped working. This notification could be focussed on the Sheltersuit user alone, possible bystanders, or even collaborated shelters or emergency services. The level of the notification could increase when the user does not react to it, thus when the temperature and the shivering do not improve. For example, it could start by just notifying the user. When nothing changers, the volume level of the sound could increase to notify possible bystanders. When this also brings no reaction, collaborated shelters or emergency services could be automatically contacted.

A question to be asked is if the user of the Sheltersuit wants other people to know about his/her possible condition of mild hypothermia. From the conversations with ex-homeless in the context analysis, different answers were given to this question. What all had in common is that homeless do not like to be a burden to anyone around them. Therefore, it is good to at least start with only a notification for themselves. Increasing the notification's volume entails that people will know where the homeless person is sleeping. One person indicated that he would not like unknown people to bother him. But someone else stated that if it is a matter of life and death his answer would be very simple, the person should be helped. It is questionable if notifying people around them will work. Homeless tend to sleep in isolated places and even if someone would hear it, they should also recognise it as a notification they should react to. Again, the question is how important the opinion of the homeless person is in deciding the system's behaviour. Is their safety more important than their likings? And will they keep using the Sheltersuit+ even if they do not like the way of notification? In section 3.1.4.3 it is concluded that the autonomy of the user will be respected. The notification will be focused only on the user, even if they do not react to it. The user will not be forced to react.

3.6 Final concept

Taking all the concepts from section 3.5 into consideration, comparing the advantages and disadvantages, and consulting the stakeholders that encourage and influence from section 3.1.4.1, the final chosen concept is the 'extra chest pocket' from section 3.5.1. The module will be fitted inside the Sheltersuit in an extra pocket that is attached on the chest. This pocket is placed on the inside of the jacket, with an opening on the inside of the coat. The concept drawings are shown in Figure 3.19 below.

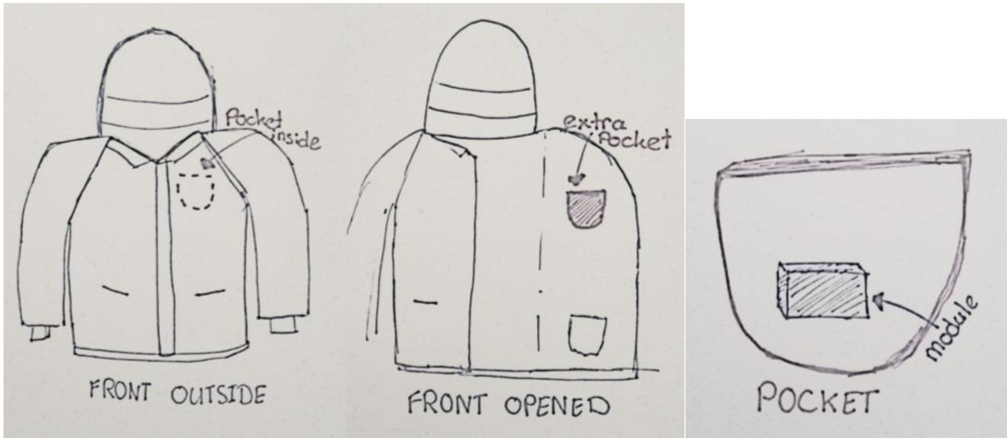

Figure 3.19. Drawings of final concept.

Advantages	**Disadvantages**
Good place for *measuring shivering (must)*	Module *could be sold by user (could)*
Unobtrusive to user because of the placing *(should)*	
Unobtrusive for sewing process (should), since it gives minimal impact on the Sheltersuit production line	
Easy to sew for Sheltersuit employees, since minimal effort is needed from the Sheltersuit employees *(should)*	
Module *easily* removable for *repairing (won't)*	
Module *easily* removable for *charging (won't)*	

Table 3.8. Comparison table: final concept.

The advantages of this concept are that the place is unobtrusive to the user and good for measuring shivering. The pocket is easy to attach by the Sheltersuit employees, since pockets are a routine job for tailors. The pocket also provides an easy way of charging and repairing. The module inside the pocket will measure the temperature and humidity inside of the suit. It will also measure the movement of the user to detect shivering. A disadvantage could be that the module could be removed by the user and disposed or sold. For now, it is assumed that the envisioned product is of enough value for the user so that it won't be resold.

The system will only notify the user of the Sheltersuit, not people around them or emergency services. This respects the autonomy of the user. The user gets the choice to react to the notification or not. It is also cheaper and more energy efficient. The specific components of the sensing module will be considered in the next chapter.

4. Specification

The goal of this chapter is to work out the final concept described in section 3.6 in detail. Based on the previous graduation project by Bosch [5] it is assumed that the humidity inside the Sheltersuit has an influence on the perceived temperature of the user. This chapter will start with analysing the relationship between temperature, humidity, and the comfort of the user. This is done by approaching it through theory and executing an experiment to estimate this relationship. The conclusions of this experiment will be used to design the functional system architecture of the envisioned system. This will start with level 0: the black box view of the system. This black box will be broken down into smaller parts in level 1. Then, in level 2, these smaller components will be specified individually. For these specifications functional block diagrams are used. The input and output data will also be handled. The findings of section 4.2 will be summarized in revised functional requirements in section 4.3. In the end, the individual parts should be clear for the realization in the next chapter.

4.1 Comfort estimation

4.1.1 Relationship between temperature and humidity

Since the core temperature of the Sheltersuit user cannot be measured, the risk of mild hypothermia should be estimated. Unfortunately, there is no direct relationship between air temperature and relative humidity, and the risk of mild hypothermia. In general, it holds that relative humidity goes up if the temperature goes down. When looking at atmospheric moisture conditions, a rule of thumb given by Utah State University [75] is that the relative humidity doubles when the temperature decreases by 20°F, which converts to approximately 11.11°C. The National Weather Service [76] brought one of the most used ways to measure the influence of air temperature and relative humidity on the apparent temperature of the air to humans. There are a lot of factors influencing the apparent temperature, i.e. clothing, core temperature, wind speed [77]. A simplified version takes these in account by calculating the apparent temperature by just using temperature and relative humidity as input. This is called a heat index, and is displayed (in Fahrenheit) in Figure 4.1.

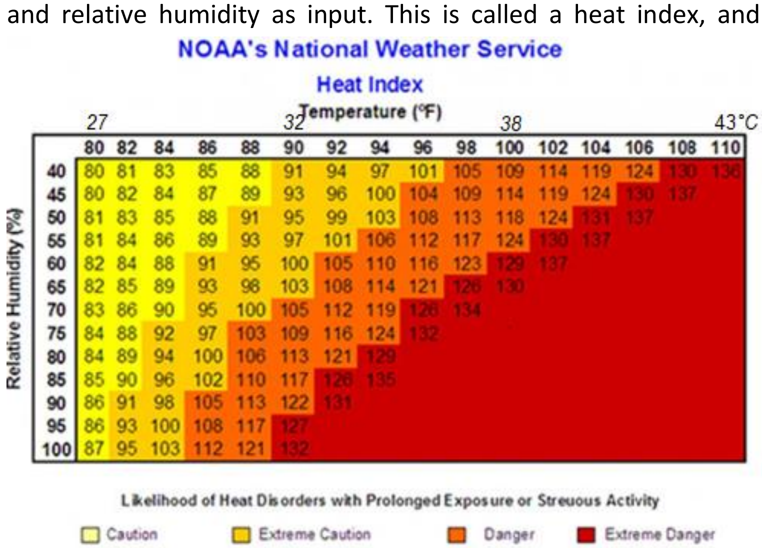

Figure 4.1. Heat index chart of the NWS. [76] [77]

As can be seen in Figure 4.1, high relative humidity makes the temperature feel warmer than it is. Looking at a temperature of 90°F, it is perceived as 91°F when the relative humidity is 40%. However, when the relative humidity increases to 80%, the perceived temperature is 113°F, and with 100% relative humidity it increases to 132°F. Since the heat index does not focus on cold, but on heat, and since it doesn't tell anything about the core temperature of a person, this cannot be used in this project. A similar table should be found that is applicable to the current project, and is focussed on low temperatures. This table that would give the relationship between temperature and relative humidity at cold temperatures will further be referred to as the cold index.

In her Graduation Project, Bosch [5] has investigated the relationship between temperature, relative humidity (cold index), and the threshold for shivering. She found a relationship between the temperature threshold and humidity. $TempThreshold = 0.375 * Hin - 5.5$ [5] where Hin is the humidity in the Sheltersuit. The assumed threshold line is shown in Figure 4.2.

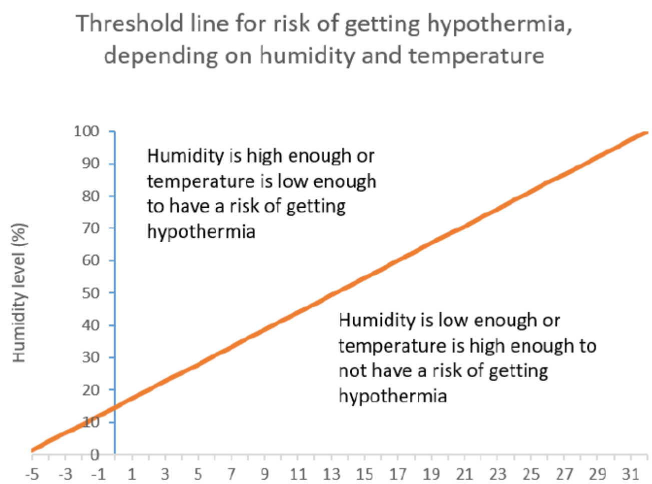

Figure 4.2. The assumed threshold line that can be used to determine what the temperature needs to be, based on a given humidity level, such that the shivering movement that is detected can be due to getting at a risk of hypothermia. Taken from [5] p. 52.

She concluded that if the situation is below this line, the person is not at risk of getting hypothermia. However, these results were based on assumptions here and are not confirmed in practice.

A formula from the USA National Weather Service [78] presents another relationship between temperature and relative humidity in the cold index. It states that the relative humidity has hardly any influence on apparent temperature when temperatures are below 80 °F (≈26°C). Generated using their formula, Figure 4.3 shows the temperature versus the apparent temperature with a relative humidity of 90%. Where the high relative humidity increases the perceived temperature significantly at temperatures above 30°C, the temperature and perceived temperature are almost equal below 26°C. Clarification of the figure and corresponding formulas can be found in Appendix D.

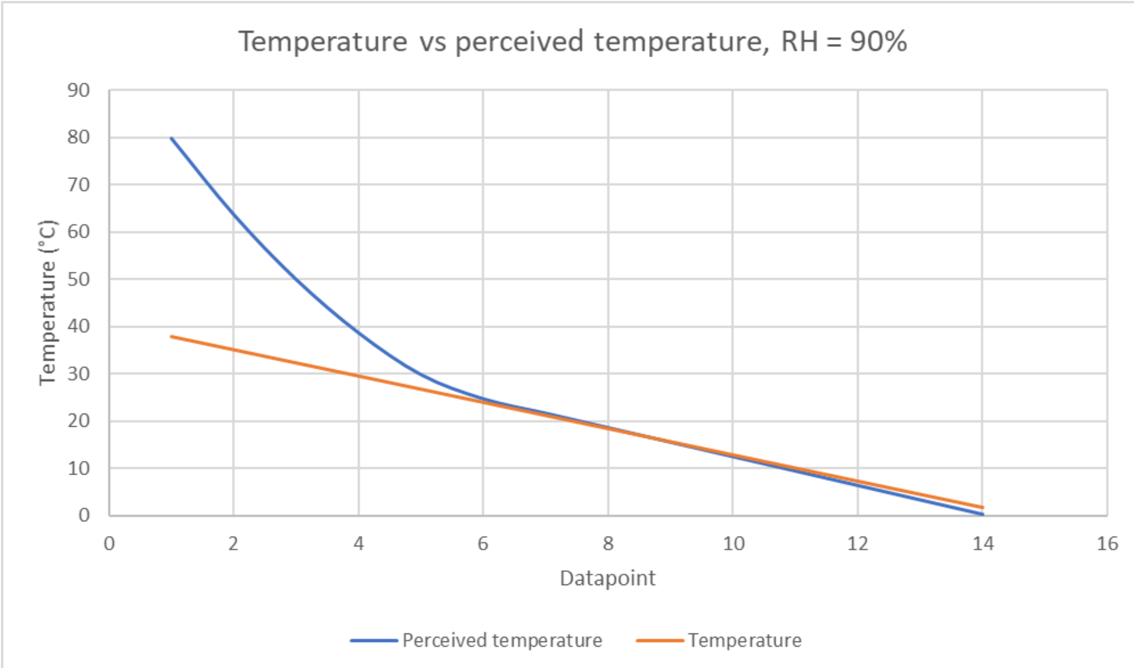

Figure 4.3. Temperature vs. perceived temperature with a relative humidity of 90%.

4.1.2 Experimental results

An experiment is carried out to find the relationship between the cold index and the prelude of shivering (or comfort) of the user wearing the Sheltersuit. The experiment consists of five measurements where a participant went into a freezer wearing the Sheltersuit and a temperature sensor. Temperature, thermal comfort, and thermal sensation data was collected for 18 minutes each measurement. A detailed description of the setup and method of the experiment, and visualisations of the separate measurements can be found in Appendix B. Sections 4.1.2.1 and 4.1.2.2 show the results and corresponding conclusions about 'the influence of relative humidity' and 'the relationship between temperature and comfort level' respectively.

4.1.2.1 The influence of relative humidity

This section goes over the results of the experiment regarding the influence of relative humidity on the perceived thermal and thermal sensation. Figure 4.4 up to and including Figure 4.8 show the relative humidity as a function of the temperature. The results are separated in columns on thermal comfort level indicated by the participant, and separated by colour showing thermal sensation.

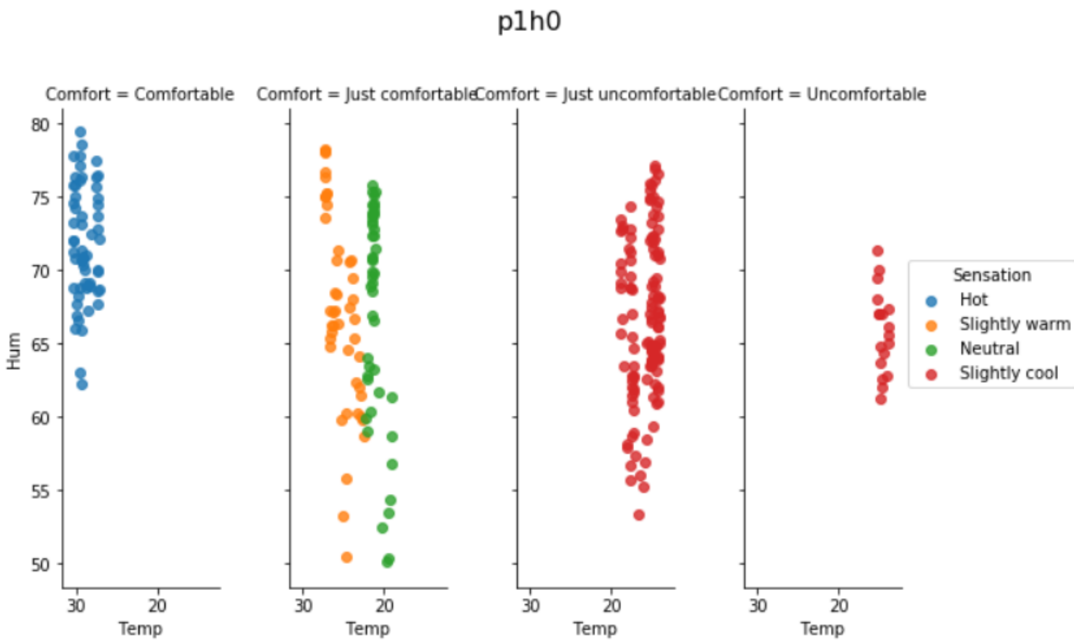

Figure 4.4. Relative humidity as a function of the temperature, separated by the thermal comfort as columns and thermal sensation as colours. The data is of the first measurement of p1.

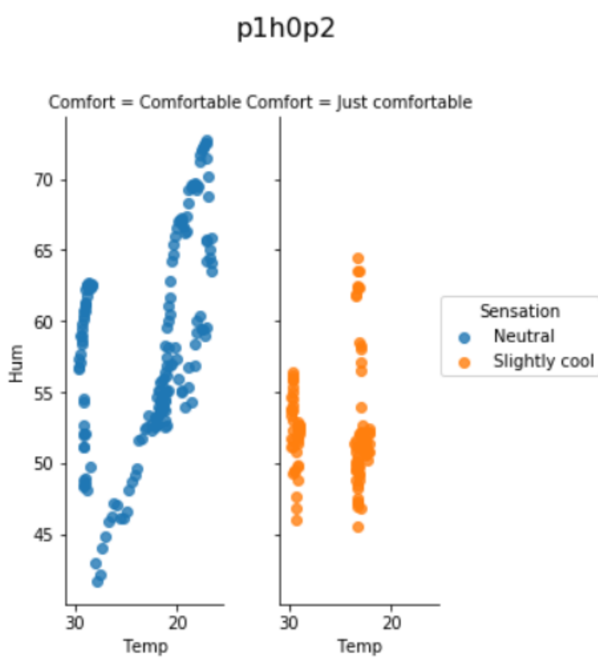

Figure 4.5. Relative humidity as a function of the temperature, separated by the thermal comfort as columns and thermal sensation as colours. The data is of the second measurement of p1.

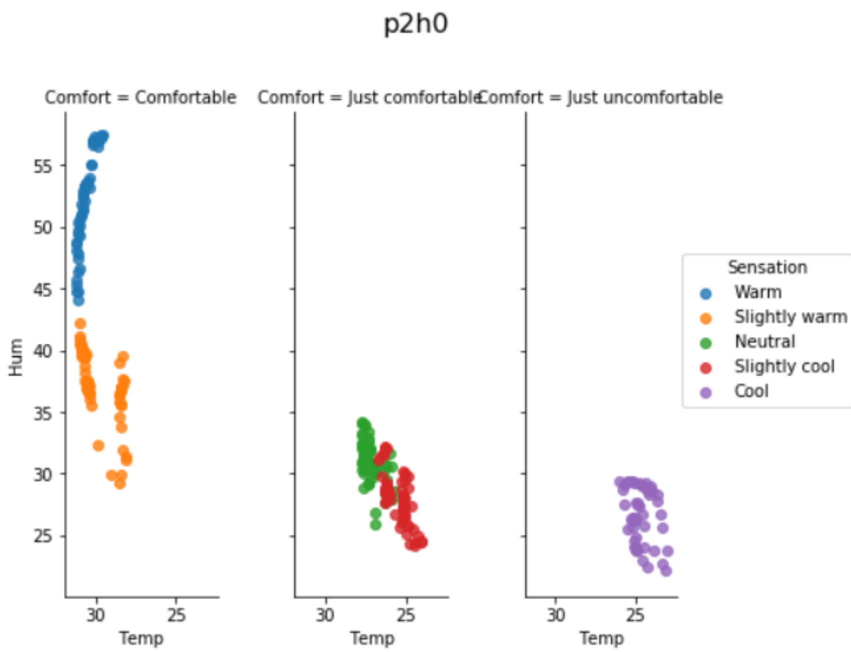

Figure 4.6. Relative humidity as a function of the temperature, separated by the thermal comfort as columns and thermal sensation as colours. The data is of the first measurement of p2.

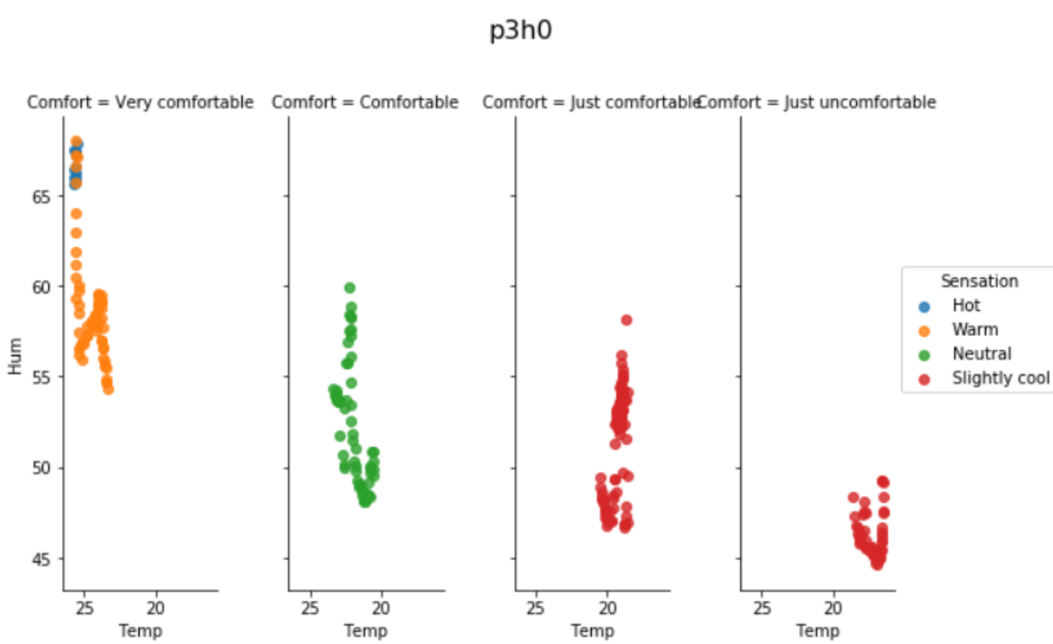

Figure 4.7. Relative humidity as a function of the temperature, separated by the thermal comfort as columns and thermal sensation as colours. The data is of the first measurement of p3.

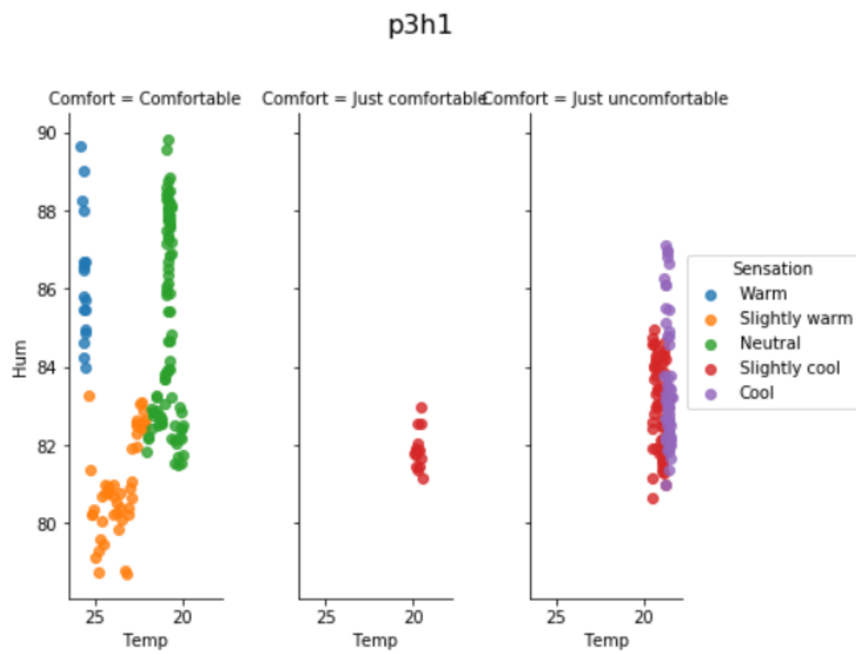

Figure 4.8. Relative humidity as a function of the temperature, separated by the thermal comfort as columns and thermal sensation as colours. The data is of the second measurement of p3.

When comparing the results from the five measurements it becomes apparent that measurement 'p1h0p2' is odd. Taking the other graphs in Appendix B into consideration, it is likely that something went wrong in that measurement. Therefore, this one will not be considered in the further discussion of the data. From Figure 4.4 to 4.8 it can be concluded that if the temperature decreases, the thermal comfort and thermal sensation also decrease. In Figure 4.6 and 4.7 the relative humidity also decreases with temperature, however when adding the other three measurement no relationship becomes apparent. The measured data suggests that the relative humidity has no influence on the thermal comfort and thermal sensation of the Sheltersuit user, and thus on the prelude to shivering. This conclusion is in line with the data from the USA National Weather Service [78] mentioned in section 4.1.1.

4.1.2.2 The relationship between temperature and comfort level

Excluding the relative humidity from the data, the relationship between temperature, thermal comfort and thermal sensation becomes more apparent. Figure 4.9 to 4.12 show the temperature on the y-axis and the thermal comfort level on x-axis. The data is separated on colour by the thermal sensation.

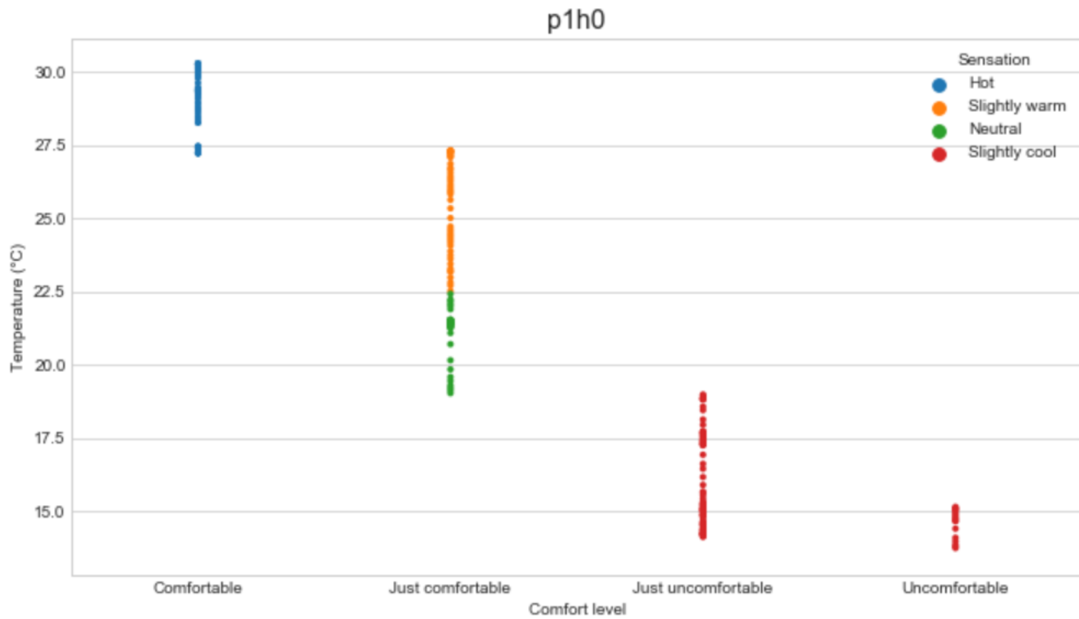

Figure 4.9. Temperature as a function of the thermal comfort, separated by thermal sensation as colours. The data is of the first measurement of p1.

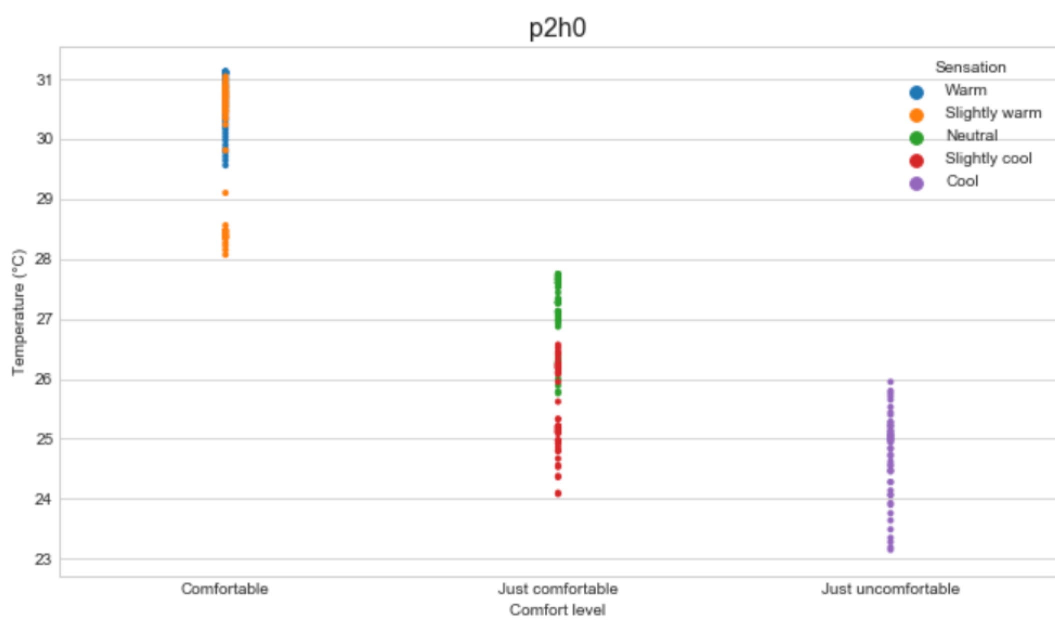

Figure 4.10. Temperature as a function of the thermal comfort, separated by thermal sensation as colours. The data is of the first measurement of p2.

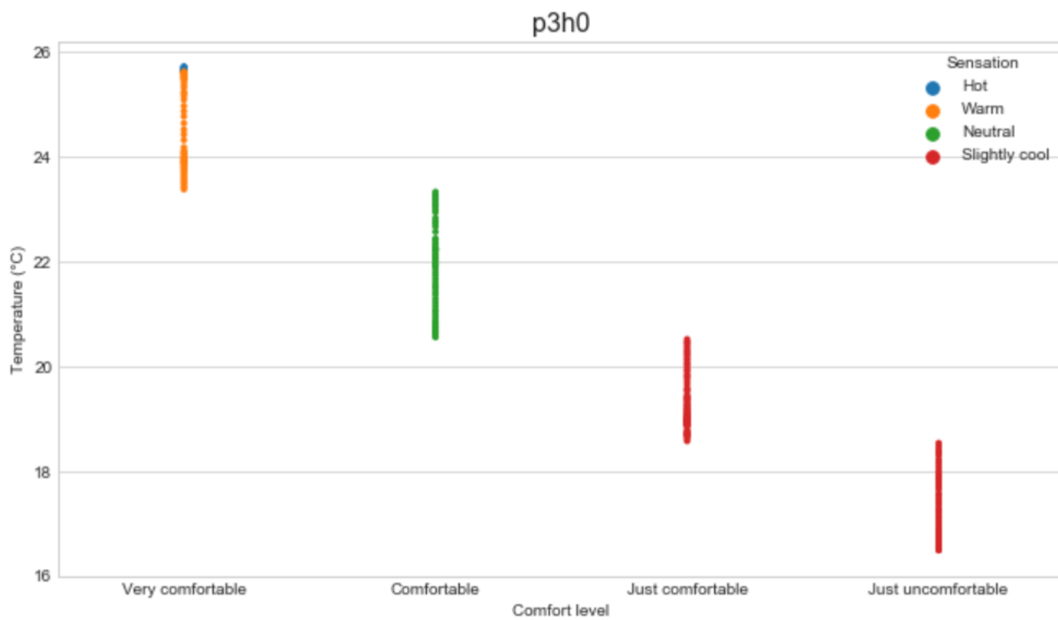

Figure 4.11. Temperature as a function of the thermal comfort, separated by thermal sensation as colours. The data is of the first measurement of p3.

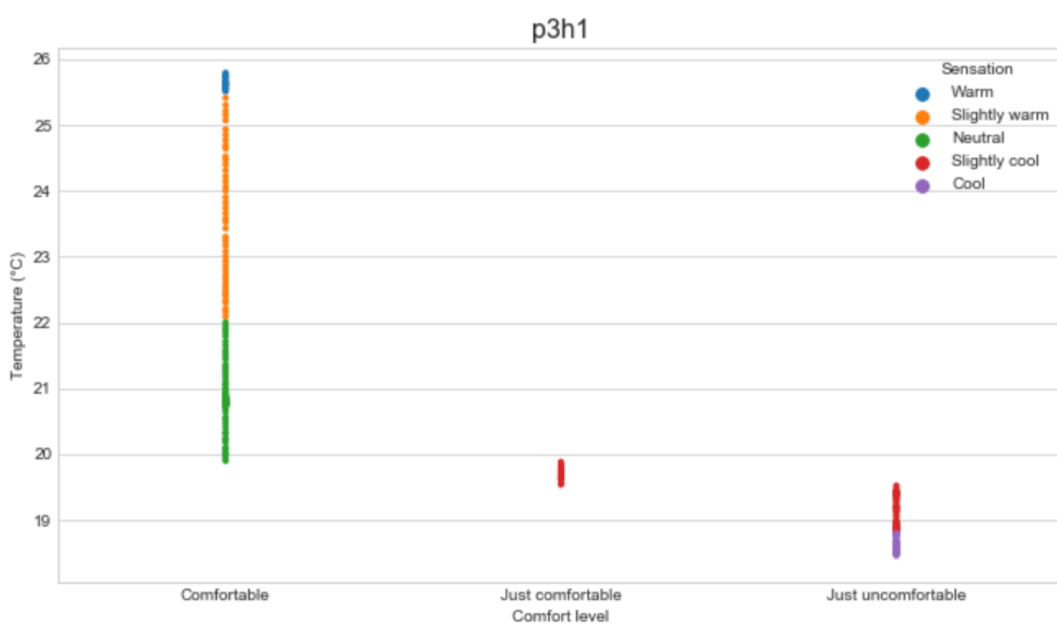

Figure 4.12. Temperature as a function of the thermal comfort, separated by thermal sensation as colours. The data is of the second measurement of p3.

Several statements can be made about the relationship between temperature, thermal comfort and thermal sensation in this experiment. Firstly, in all measurements it is very clear that the comfort level of the participant goes down as the temperature inside the Sheltersuit decreases. The same holds for the thermal sensation.

Secondly, the comfort and sensation are strongly related: every time the comfort level changes, the sensation also changes. Thirdly, the changing temperatures of either the thermal comfort or the thermal sensation are interesting. Since the indication for the thermal comfort and thermal sensation are subjective, the true values do not give a good indication with such a low number of participants. The temperature that someone feels comfortable/uncomfortable and warm/cold is different per person, and dependent on several factors (e.g. weight, sex, age). Although no conclusions can be formed solely on the values in this experiment, the changing points do show a pattern. The changing points of all four measurements are shown in Table 4.1, and displayed in Figure 4.13.

Measurement	P1h0	P2h0	P3h0	P3h1
Temperature of changing point (°C)	27,5	31	25,5	25,5
	22,5	28	23	22
	19	26	20,5	20
	15	24	18,5	19,5
				19

Table 4.1. Changing points of thermal comfort and/or thermal sensation in the measurements.

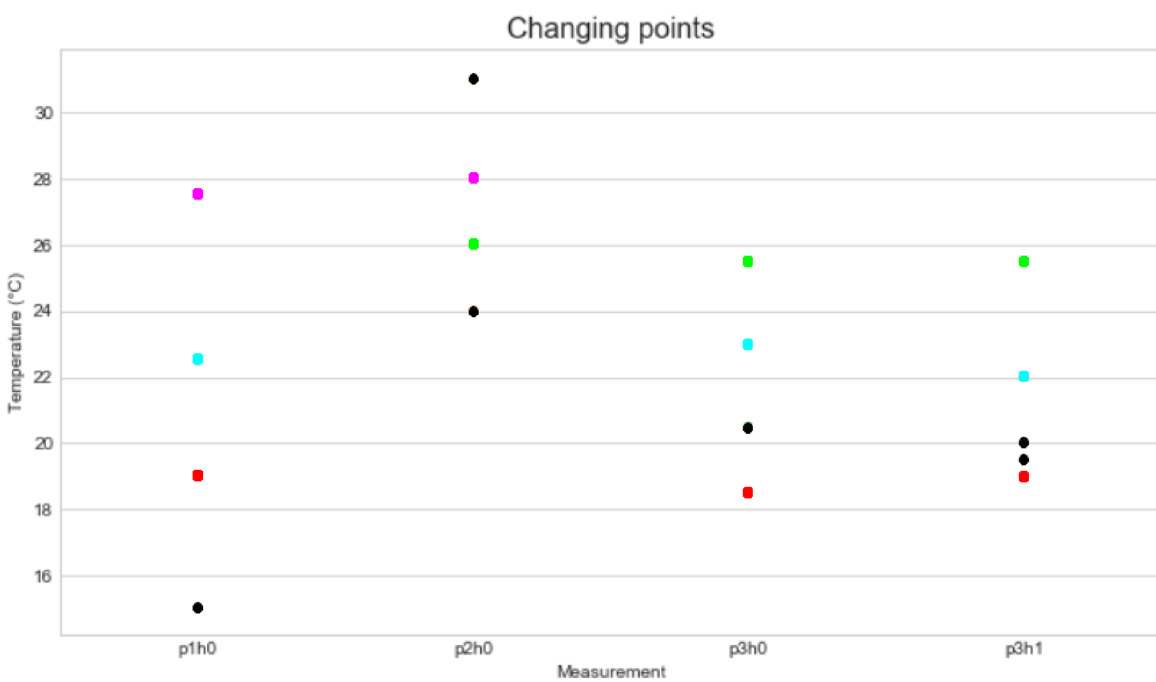

Figure 4.13. Changing points of thermal comfort and/or thermal sensation in the measurements.

The changing points of this experiment are around certain temperatures, independent of the participants and the starting temperature. The different colours in Figure 4.13 indicate the changing points around the same temperature. Two measurements have a changing point close to 28°C (pink). Three measurements have a changing point at 25.5°C (green). Two participants indicate to be 'just comfortable' at this temperature, but the third participant still felt 'comfortable'. Also, the sensation ranges from 'warm' to 'slightly cool' at this temperature, so no solid conclusions can be drawn from it. The blue dots indicate the changing temperature around 22.5°C, where all three participants switch their thermal sensation to 'neutral', and thermal comfort is either 'comfortable' or 'just comfortable. Another temperature that stands out is around 19°C. Three measurements have a changing point around 19°C (red), where three of the four participants indicated to be the 'slightly cool' and 'just uncomfortable'.

From these points it can be concluded that the crucial changing point is around 19°C. Lower than that temperature shivering is surely possible because of mild hypothermia. 22.5°C can also be used as a point for a light risk. Although it's not felt as cold, it is indicated as 'just comfortable', which could turn into 'uncomfortable' quickly.

4.1.2.3 Conclusions and discussion

From the executed measurements it can be concluded that relative humidity does not influence the perceived thermal comfort or thermal sensation of the Sheltersuit user, which is consistent with theory. Furthermore, the results provided three temperatures at which the thermal comfort and/or thermal sensation changed for the majority of the participants: 25.5°C, 22.5°C, and 19°C. These temperatures can be used in the functional system architecture and realization for this project.

In this experiment it is assumed that feeling 'just comfortable' and 'just uncomfortable' can lead to mild hypothermia when exposed to these temperatures for a long time. The found changing points give a clear indication of the temperatures inside the Sheltersuit for which the risk of mild hypothermia increases. For more accurate temperatures the experiment could be repeated with a larger and heterogeneous group of participants.

4.1.3 Heat distribution in the Sheltersuit

The results from the experiment in section 4.1.2 give a small indication of how the temperature behaves inside the Sheltersuit. To analyse this behaviour a temperature distribution diagram can be used, like is done by Suarez, Nozariasbmarz, Vashaee and Öztürk [79] in their research about thermoelectric energy harvesting. Their temperature distribution diagram is shown in Figure 4.14.

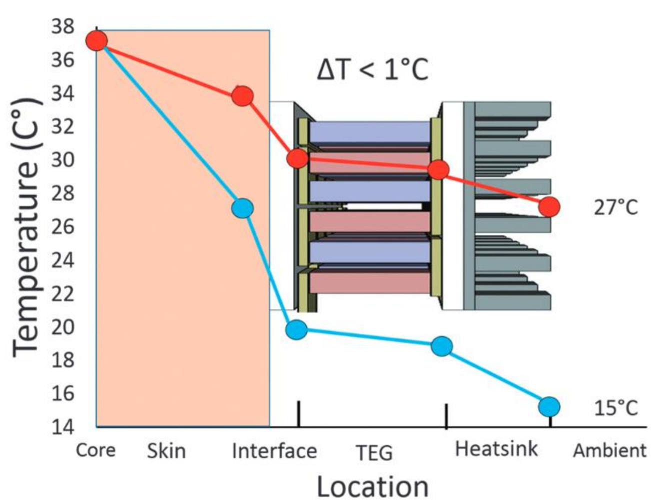

Figure 4.14. Temperature difference from core body temperature to the ambient air on the forearm. From [79].

The skin temperature of a person is dependent on the ambient temperature (as can be seen in Figure 4.14). Webb [80] measured mean body temperatures on various different places on the body influenced by warmth and cold. For this project the relevant data is the data measured on the chest. The results of Webb [80] are displayed in a graph in Figure 4.15. These measured temperatures are confirmed by the found results of Huizenga, Zhang, Arens, and Wang [81] . The core temperature continuously stayed approximately at 37°C.

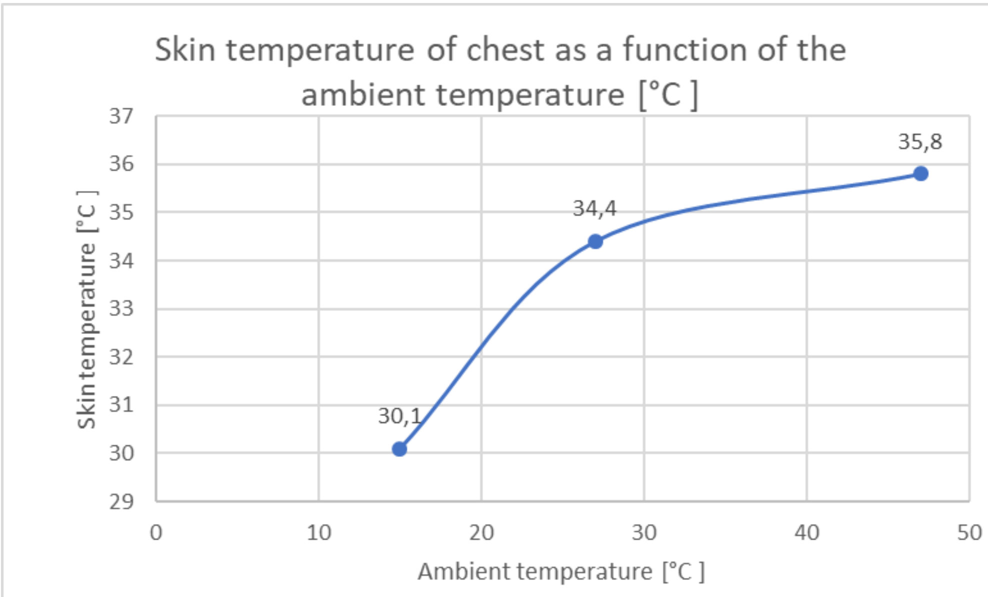

Figure 4.15. Skin temperature of chest as a function of the ambient temperature [°C]. Based on data from Webb [80].

The measured temperature data, the freezer temperature of the experiment in section 4.1.2, and the temperatures from Figure 4.15 can be combined into the temperature distribution diagram of the experiment. The temperature distribution diagram for the measured temperature of 19°C is shown in Figure 4.16.

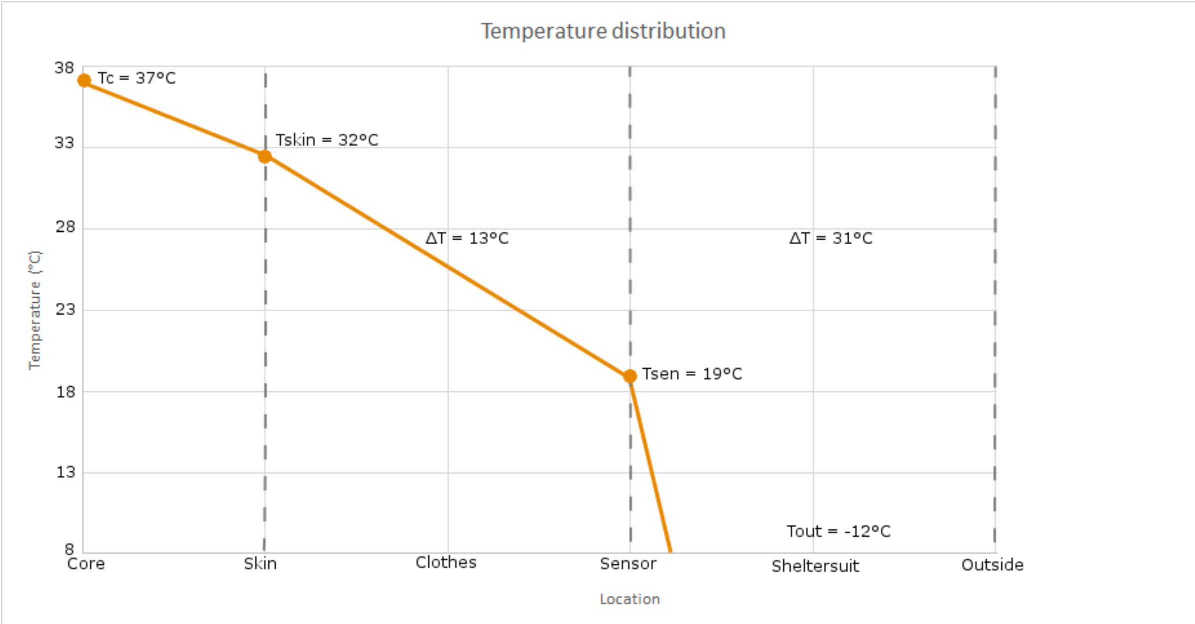

Figure 4.16. Temperature distribution of the temperature inside the Sheltersuit.

The graph in Figure 4.16 indicates that the thermal resistance of the Sheltersuit is much higher than the thermal resistance of the clothes. The Sheltersuit absorbs around 31°C, whereas the clothes only catch approximately 13°C. This is expected since normal clothes isolate less than the material of the Sheltersuit.

4.2 Functional system architecture

The functionalities of the envisioned system are decomposed in this section. Starting with a black box view displaying the input and output, and ending with a detailed description of all identifiable functions of the system. The aim is to clarify the complete functional operation of the envisioned system.

4.2.1 The black box: level 0

The first way to display the functional architecture of the envisioned system is to use the black box view. This is merely focussed on the inputs and outputs of the system. What happens inside the system is still a mystery that will be solved in the deeper levels. For now, the focus is on the inputs which are the measurable factors, and the output which is the notification. The illustration of this level is displayed in Figure 4.17 below, after which the inputs and output will be specified further.

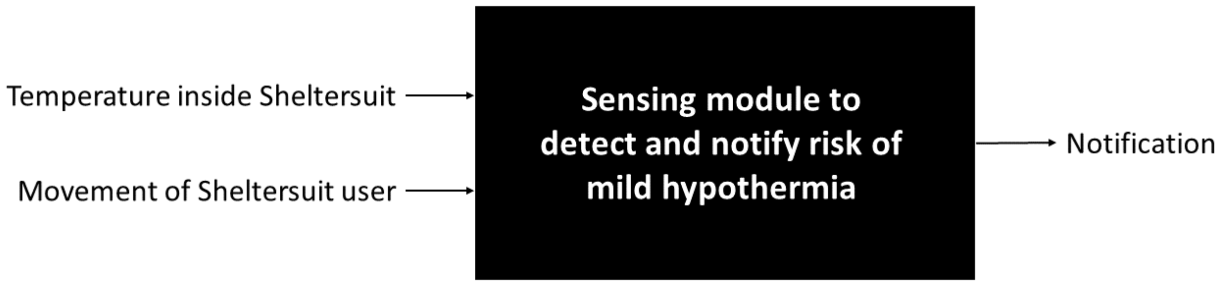

Figure 4.17. Functional block diagram for level 0.

4.2.1.1 Input data

Temperature inside Sheltersuit

For measuring the temperature in the suit, a sensing function should be able to register all temperatures the outside air can be. The annual data of 2017 and 2016 from the KNMI [82] [83] is used to find the maximum and minimum limits of the temperature in The Netherlands. The lowest measured temperature in 2017 was -10.8°C and -12.3°C in 2016. The highest measured temperature was both in 2016 and 2017 35.2°C. However, the maximum temperature will likely increase in following years due to climate change. Sterl, van Oldenborgh, Hazeleger, and Dijkstra [84] estimated a maximum temperature of 44°C for The Netherlands in the next 100 years. The sensing function in the Sheltersuit should be able to function and measure in these temperatures. With an added margin, the temperature sensing function should have a range between -20°C and 45°C. The accuracy should preferably be +/- 1°C, certainly for the expected temperatures present in the Sheltersuit (5°C -35°C).

Movement of Sheltersuit user

The shivering of the Sheltersuit user can be measured by the sensing function. In technical terms this is called an accelerometer. This is a component that measures movements in three dimensions, the X, Y and Z axis. According to Dadafshar [85] the movements created by the human body range between 10Hz and 12Hz. This is confirmed by the Graduation Project of H. Bosch [5] which found frequencies between 8 and 11Hz. The sampling frequency should be at least twice the signal frequency according to Nyquist theorem, which in this case leads to a sampling frequency of at least 24Hz.

4.2.1.2 Notification

The black box has multiple inputs but only one output: notification. The notification of the user could be through lights, vibration, sounds, or a combination of these. Visual notification could be done by using lights, however this does not wake the user of the Sheltersuit when sleeping. Since vibration in the module's pocket could be missed by the layers of clothes worn in the Sheltersuit, this option is not favourable. Vibrating as a notification could work by moving it to a more noticeable place, like the inside of the hood. Saket, Prasojo, Huang, and Zhao [86] did research about the perceived urgency of vibration based notifications. They found that the gap lengths, patterns, and lengths of vibrations influence the urgency of the vibration notification. Unfortunately, not a lot of research can be found about vibration based notification systems, and the relation to urgency or alcohol.

The most common way of notification is through audio, e.g. fire alarms, car alarms, doorbells. Haas and Edworthy [87] researched the influence of pitch, speed and volume on the perceived urgency of an audible signal. Fundamental frequencies of 200Hz, 500Hz and 800Hz, inter-pulse intervals of 0, 250ms, and 500ms, and volumes of 5dB, 25dB, and 40dB were used. They found that increase of frequency, speed and volume all increases the perceived urgency of the signal. According to another paper by Edworthy [88], the appropriate volume of auditory notification is 15 to 25 dB above the environmental noise. Assuming environmental noise for homeless sleeping on the street is limited (since it's likely cold and night-time), the system's notification should not exceed 30dB following Edworthy's theory.

A study by Hasofer and Thomas [89] looked into the relationship between sound volume, kind of sound, and alcohol percentage in the blood of the subject. They tested alcohol levels of 0.05 BAC and 0.08 BAC, and sound intensities of 35dBA, 40dBA and 95dBA. Sound intensities above 95dBA were not considered since hearing damage could occur. Hasofer and Thomas concluded that females are more sensitive to sounds than males and need a lower sound intensity to wake up. Averaging, sober adults wake up with a sound intensity between 50 dBA and 70 dBA [89]. When alcohol was involved, the mean increased to between 65 dBA and 100 dBA. Although this is a significant difference between sober and non-sober participants, it differs per person and is influenced by many personal factors (e.g. weight, size, tolerance, fatigue). It can be concluded that intoxicated people need more volume to wake up from a signal. However, it should be considered that alcoholics need more drinks to reach a high alcohol level in their blood. But, no research can be found about the volume or vibration tolerance of alcoholics.

Since more scientific research can be found about audible notification than about vibration based notification, audible notification is chosen for the envisioned system. From the information above, the envisioned system should produce an auditory notification with a difference in frequencies, inter-pulse intervals, and volume. When the risk of mild hypothermia increases, the frequency and volume of the notification should increase, and the inter-pulse interval should decrease. In this way the notification will likely be perceived more urgent when the risk level increases.

4.2.2 Functionality blocks: level 1

After the black box view of the functional architecture of the envisioned system, the next step is to break down this box into smaller components. This next level is displayed in Figure 4.18.

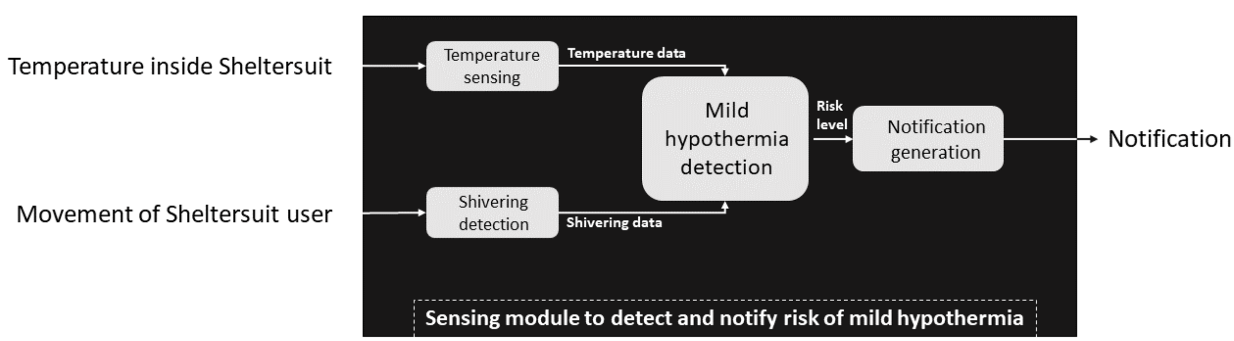

Figure 4.18. Functional block diagram for level 1

The input signals (temperature and movement) are fist processed by a sensing function inside the black box. Then all processed data goes into the 'mild hypothermia detection' block. This block processes the input data into the hypothermia risk level. The last block is the notification component, which decides what kind of notification will be given. These blocks are individually broken down into smaller segments in the next level.

4.2.3 Decomposed functionality blocks: level 2

This section will decompose the functionality blocks stated in the previous section and shown in Figure 4.18. The functional block diagrams from the sensing inputs are taken from an earlier Graduation Project of Creative Technology by Bosch [5]. Then, the 'mild hypothermia detection' and 'notification generation' parts will be broken down further and explained.

4.2.3.1 Temperature sensing

The functional diagram of the temperature sensing block is displayed in Figure 4.19. It consists of four sub components: sensing, converting temperature to voltage, A/D converting, temperature calculation. The temperature sensing function changes the outcoming voltage as a function of the surrounding temperature. This is converted to a digital signal, which are the bits shown in Figure 4.19. These bits can be interpreted as temperature data and is the output of this function.

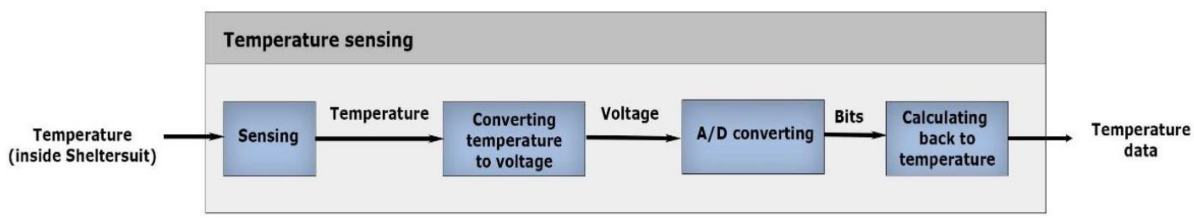

Figure 4.19. Functional block diagram Temperature sensing [5] p. 48.

4.2.3.2 Shivering detection

The functional block diagram for the movement sensing and shivering detection is more complex than the other inputs. Movement detection consists of three dimensions, the X, Y, and Z axes. These three axes are independently converted to voltage, and from an analog to a digital signal. From this digital signal, the acceleration of the axis is calculated. The three axes are combined into one single magnitude vector with the formula:

$$magnitude = \sqrt{x^2 + y^2 + z^2}$$

This vector is generated in the 'composing vector' part in Figure 4.20 below, and is used in 'signal filtering' to extract information.

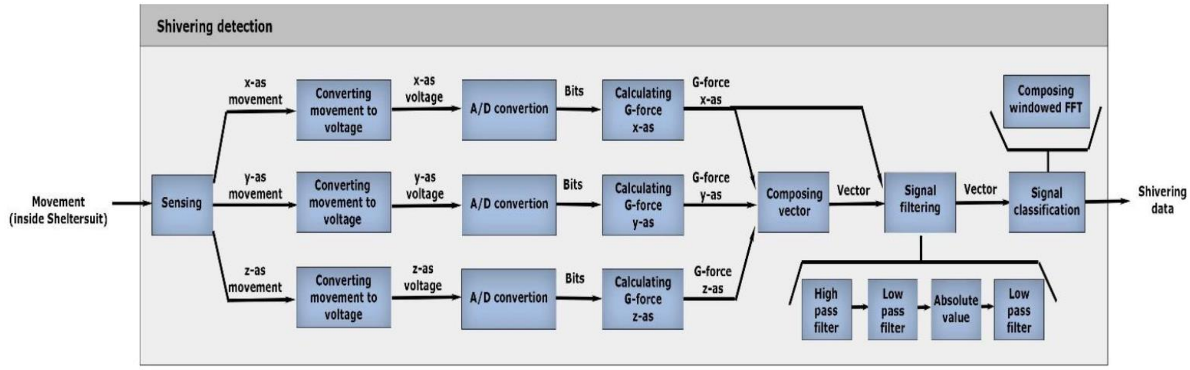

Figure 4.20. Functional block diagram Shivering detection [5] p. 50.

The magnitude vector can be used to find if the user is shivering or not. Bosch has done this in her Graduation Project [5], which partly focusses on the 'signal filtering' and the 'signal classification' components. She starts with using the X-axis data to detect if the user is laying on the left side or if he is sitting straight. Those are the two positions where shivering can be detected. The corresponding magnitudes are 300mg for sitting straight and -200mg for laying on the left side straight. The found cut off frequencies that relate to shivering are 8Hz and 10Hz for sitting straight and 9Hz and 11Hz for laying on the left side straight. The signal is filtered in the 'signal filtering' component by converting it all to positive values, smoothing the signal, and extracting the envelope. Then a 2nd order low pass Butterworth filter is used for both postures, with both a cut off frequency of 0.7Hz. The 'signal classification' uses a rectangle windowed FFT with 64 sections. If the signal is strong enough and passes the threshold, it is classified as shivering. The output signal is simply either a yes or a no. [5]

4.2.3.3 Mild hypothermia detection

This component is the main processing function in the system. As can be seen in Figure 4.18 all inputs go into the mild hypothermia detection function. The purpose of this part is to determine the risk level of the Sheltersuit user. The functional block diagram is shown in Figure 4.21.

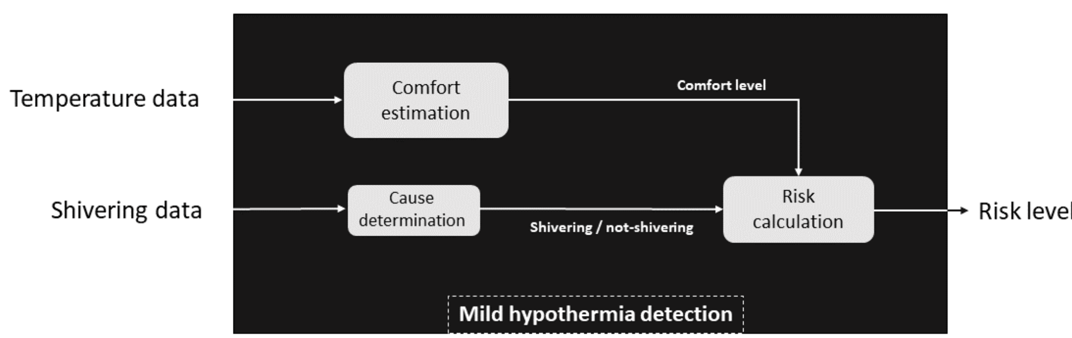

Figure 4.21. Functional block diagram of the 'mild hypothermia detection' component

Comfort estimation

The incoming temperature and humidity data will be used to estimate the comfort level of the user. This will be done by estimating the perceived temperature to the user. Firstly, the temperature data is transformed into an estimation factor in the 'comfort estimation' component. The calculation for this factor is based on the three temperatures found in section 4.1. The comfort estimation will be used to identify if the temperature inside of the Sheltersuit brings the user at risk.

Cause determination

The incoming shivering data is reshaped and analysed to determine the cause of the movement. If the movement is classified as shivering, the 'Cause determination' function will give 'Shivering' as output to the 'Risk calculation' function.

Risk calculation

The output of the 'Cause determination' function and 'Comfort estimation' function come together in the 'Risk calculation' function. The risk level ranges between 'no risk' and 'very high risk', depending on the comfort level and if the person is shivering. When shivering is detected, the 'risk calculation' component will count the time of the duration of the circumstances. If the comfort estimation stays low enough and shivering is consistent, the risk level will increase. When no shivering is detected, there could still be a risk when the temperature is low enough. The flow diagram of the risk calculation function is shown in Figure 4.22.

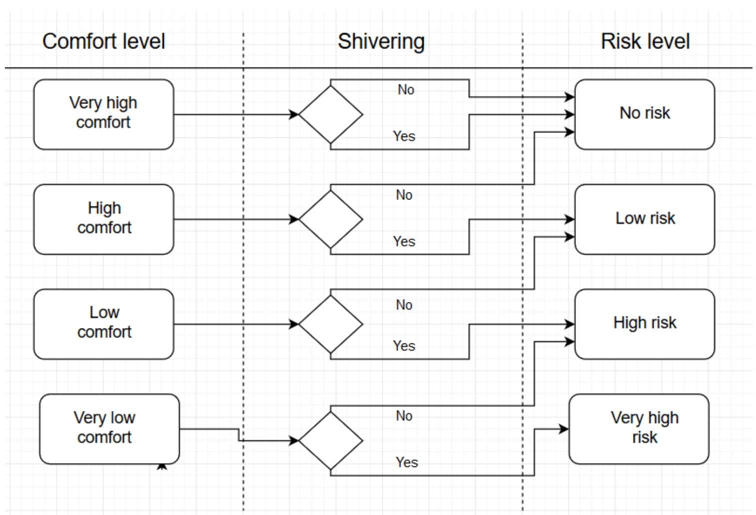

Figure 4.22. Flowchart of the relationship between comfort level, shivering, and risk level.

4.2.3.4 Notification generation

The notification generation function is responsible for giving the right notification as output. The functional block diagram is displayed in Figure 4.23.

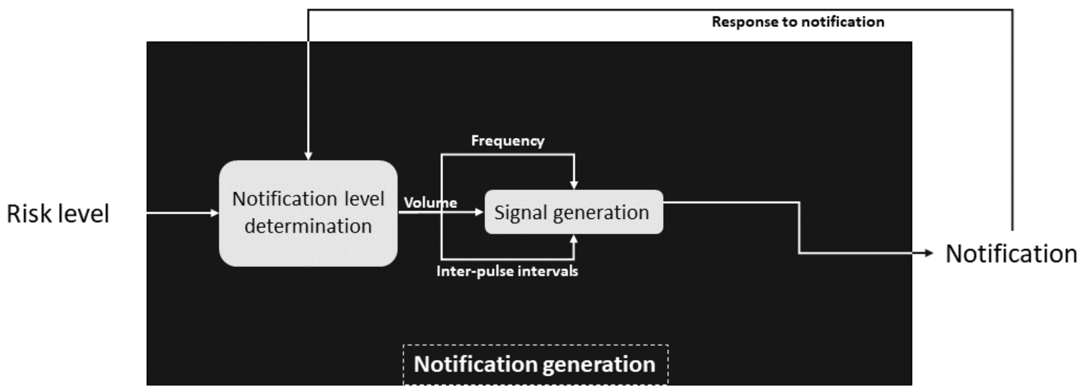

Figure 4.23. Functional block diagram of 'Notification generation'.

As described earlier in section 4.2.1.2., the output notification can have different degrees. The auditory notification can start relatively calm and increase when the situation does not change, thus when the user is not responding. According to Haas and Edworthy [87] [88] this can be done with differences in frequencies, inter-pulse intervals, and volume. The magnitude of these three factors will be decided in 'notification level determination', where the risk level will be used to determine the notification level. From the notification level the magnitudes of the frequency, inter-pulse interval, and volume are calculated and the signal is generated. This signal is outputted as the notification.

4.3 Functional requirements

The preliminary requirements described in section 3.3 are specified with the information of this chapter. The revised requirements are listed below.

- Measure temperature in suit between at least -20°C and 45°C with an accuracy of +/- 1°C between 5°C and 35°C. (Must)
- Measure shivering of the Sheltersuit user. (Must)
- Make predictions on measurement data about risk of mild hypothermia. (Must)
- Notify user of high risk of mild hypothermia by auditory notification. (Must)
- Have different levels of notification by changing the magnitudes of the frequency, inter-pulse interval, and volume. (Must)
- Shows level of battery charge of the product. (Should)
- Notify user when product needs to be charged. (Should)
- Notify user when one part of the product stopped working. (Should)

5. Realisation

The final concept of chapter 3, which is described in detail in chapter 4, is realised in this chapter. Firstly, the separate hardware components are stated, and the way to connect them is described. Then the different parts of the software are explained. The hardware and the software come together in the prototype, which has a 3d-printed casing to hold and protect the hardware. The casing can be placed inside the sown pocket. Lastly, the functionality of the prototype is described.

5.1 Hardware

This section describes the chooses for the hardware of the prototype. For every functional requirement in section 4.3 appropriate hardware is chosen.

5.1.1 Measuring movement

An accelerometer is used to measure the movement of the Sheltersuit user. From this movement shivering will be detected. As mentioned in section 4.2.1.1, the sensor should be able to measure between 8Hz and 12 Hz, and have a sampling frequency of at least 24Hz. For the prototype, the MMA7361L [90] is used in a breakout from SparkFun, which is shown in Figure 5.1. The voltage input is between 2.2V and 3.6V. The sensitivity can be chosen to be either 1.5g or 6g. Here 1.5g is chosen, since it consumes the least energy. It gives an output for the X, Y and Z axis between 0 and 3.3V.

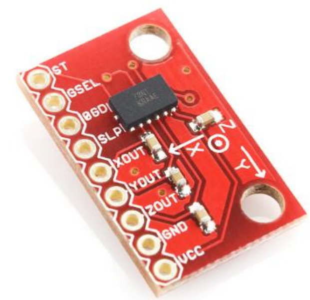

Figure 5.1. MMA7361L breakout SparkFun [100].

5.1.2 Measuring temperature

To measure the temperature the SHT15 [91] from Sensirion, with a breakout from SparkFun is chosen (Figure 5.2). It fulfils the requirements stated in chapter 4. It functions well between -20°C and 100°C. It can handle input voltages between 2.4 and 5.5V. Between 5°C and 45°C the temperature is measured with an accuracy below 0.5°C. For the other temperatures in its range the accuracy is between 0.5°C and 1.7°C.

Figure 5.2. SHT15 breakout SparkFun [99].

5.1.3 Microcontroller

The incoming data needs to be transformed, analysed, and combined to give a correct output notification. Thus, a microcontroller is needed for e.g. applying of the filters for shivering, estimating the comfort, calculating the risk, generating the output signal. The Arduino Nano [92] is chosen because of its size (18 x 45 mm), its weight (7g) and it's user-friendly programming environment. It runs on the ATmega328P microcontroller chip, and operates on 5V. A picture of the Arduino Nano is shown in Figure 5.3.

Figure 5.3. Arduino Nano microcontroller [92].

5.1.4 Notification

For the auditory notification the piezo audio buzzer HFP-1136 [93] is used, and can be seen in Figure 5.4. It can give a volume of minimal 92dB and a frequency between 3900kHz and 4700kHz.

Figure 5.4. Piezo audio buzzer [93].

5.1.5 Schematic

The hardware elements described above are combined into the hardware for the prototype. The temperature sensor has two data outputs which are connected to analog ports A4 and A5 on the Arduino Nano. It is charged with 5V from the Arduino Nano, and the ground is connected to the shared ground. The MMA7361 is the accelerometer. The X, Y and Z outputs are connected to the A0, A1 and A2 inputs of the Arduino Nano respectively. Both the voltage input and sleep output are connected to the 3.3V from the Arduino Nano, and the VDD is connected to the shared ground of the circuit. On the right the piezo buzzer is connected to digital pins 9 and 10, with a 100Ω resistor between the buzzer and pin D9. The schematic of this prototype is shown in Figure 5.5.

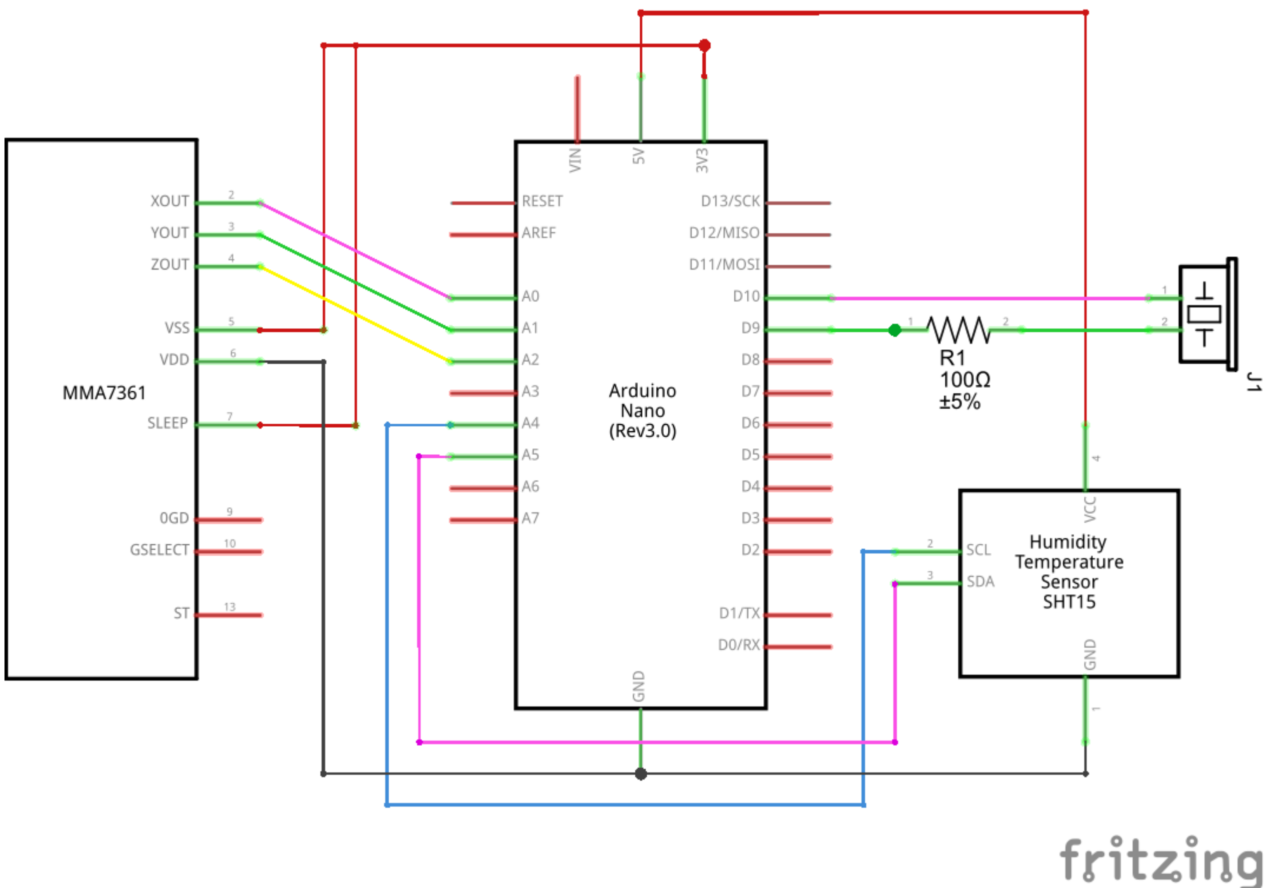

Figure 5.5. Hardware schematic of the prototype.

5.2 Software

The software of the system is based on the functional system architecture described in section 4.2. The first three functions are based on the functional block diagram from 'mild hypothermia detection' displayed in Figure 4.21. This function consists of three functions: 'comfort estimation', 'cause determination', and 'risk calculation. These functions, as well as the 'notification level determination' and 'signal generation' from Figure 4.23, are implemented into the software. The separate functions are described in this section.

5.2.1 Comfort estimation

To find the comfort of a Sheltersuit user with different temperature the results from the test described in section 4.3.2 are used. The three temperatures at which the majority of the participants switched their thermal comfort and/or thermal sensation level are 25.5°C, 22.5°C and 19°C. These temperatures are transformed into comfort levels, shown in Table 5.1.

Temperature	**Comfort level**
Above 25.5°C	Very high comfort
Between 22.5°C and 25.5°C	High comfort
Between 19°C and 22.5°C	Low comfort
Below 19°C	Very low comfort

Table 5.1. Temperatures and comfort level.

5.2.2 Shivering detection

The software to measure the shivering of the user is based on the code from a previous Creative Technology Graduation Project [5]. This code measures, transforms and filters the incoming signal in two different positions: 'sitting straight' and 'laying on the left side straight'. These positions are determined through the value of the X-axis of the accelerometer. The code is adapted so it works with the hardware described in 5.1.5. The filter and accelerometer classes are reconstructed into header and CPP files, as is customary in C++. Furthermore, redundant variables are removed and parts of the main code are put into functions to make the loop function of the Arduino IDE simpler. The complete code can be found in Appendix E.

5.2.3 Risk calculation

The risk calculation function combines the 'comfort estimation' output and 'cause determination' output into a risk level. The relationship between the comfort level, shivering, and risk level is shown in the flowchart displayed in Figure 4.22.

5.2.4 Notification level determination and signal generation

In the notification level determination function the intensity of the notification is determined. The program changes the risk level information into the notification level. The notification level is used to change the frequency, volume, and duration of the signal. The signal is played in an on-off rhythm by playing the signal five times and waiting the duration each time after it is played.

5.3 Prototype

The prototype consists of a casing in which all the above-mentioned software and hardware parts are implemented. The hardware is assembled to use the smallest space possible. Around the hardware a casing is 3d-printed to protect it. The casing can be placed inside the sown pocket to simulate the situation inside of the Sheltersuit. The separate components are described in this section.

5.4.1 Casing

To protect all the hardware components mentioned in section 5.1 a casing is made that fits them all. The dimensions are as small as possible for the hardware to fit in but not touch each other. The casing consists of two parts: a box and a lid. These parts are constructed using a 3d-printer. The 3d-model is shown in Figure 5.6.

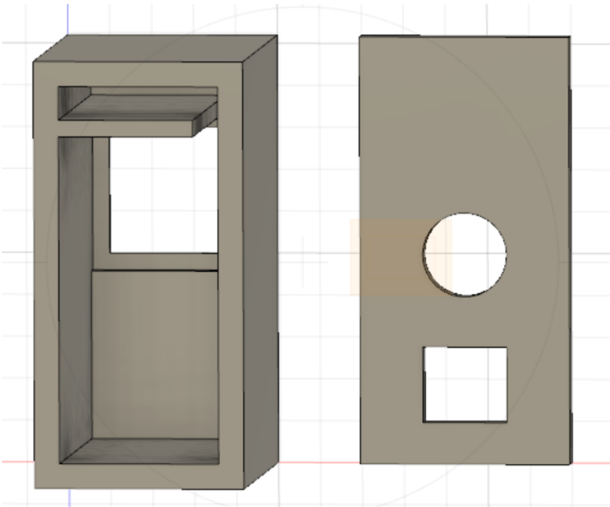

Figure 5.6. 3d model of the prototype casing.

The dimensions of the casing's box are: 25mm width by 51mm height by 47mm depth. The edges are 3mm in thickness to make the casing robust. The box contains a slit to fit the accelerometer and an indentation to fit the temperature sensor at the back. The lid has two holes: a square to fit the cable and a circle for the piezo buzzer. The printed casing is shown in Figure 5.7 and 5.8, where a hair tie is used to keep the two parts together.

Figure 5.7. Outside of the prototype, front view.

Figure 5.8. Outside of the prototype, sideview.

5.4.2 Electronics

The electronics inside the casing are mentioned in section 5.1. The electronic circuit displayed in the schematic in Figure 5.5 is built and fit into the casing. The assembled electronics are shown in Figure 5.9 and 5.10.

Figure 5.9. Electronic circuit placed in the casing of the prototype, shown from the front.

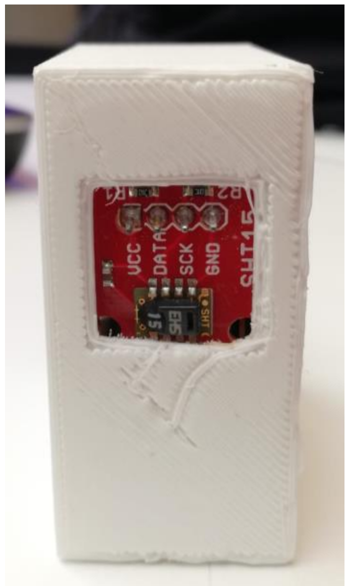

Figure 5.10. Electronic circuit placed in the casing of the prototype, shown from the back.

At the bottom of the casing the Arduino Nano is placed. The accelerometer is inserted into the slit at the top. At the back of the casing there is a hole against which the temperatur sensor is placed. At the front the piezo buzzer is connected, held in place by the wires connected to the Arduino. All the electronics are soldered together on female header pins, which are placed on top of the pins. In this way the soldering does not affect the electronics directly and they can be reused later.

5.4.3 Pocket

The final concept for the Sheltersuit+ (section 3.6) has a pocket sown inside in the production process. Since the Sheltersuit currently has no pocket at the chest, the situation should be simulated. To simulate the position and location of the module in the Sheltersuit+ a pocket is sown that can be pinned inside the Sheltersuit. This pocket is shown in Figure 5.11. The size of the pocket is 10cm by 18cm.

Figure 5.11. Pocket of the prototype to hold the module.

5.4.4 Functionality

The functionality of the prototype is to conform the incoming temperature and movement data into an audible notification. The movement data is sensed by the accelerometer and send to the Arduino Nano, which takes samples of 64 values. The movement data is split in three axes: X, Y, and Z. The X-axis data is used to determine the body posture, which can be 'sitting', 'laying', or 'no posture'. Both detectable postures have their own values for the filter parameters. The incoming data gets filtered by the software using these filter parameters. When both the threshold of the filtered signal and the threshold of the FFT is passed in one sample, the movement is registered as shivering.

After 13 samples, which is around 20 seconds, the notification is generated. Firstly, the samples registered as shivering are counted. If 4 out of 13 samples looked like shivering, the software assumes the person is shivering. Secondly, with the temperature data the comfort level is established. The risk level is set using the comfort level and if the person is shivering or not. When the person is shivering, the comfort level is higher than without shivering. From the risk level the notification level is decided, and the notification is played by the piezo buzzer. The complete code can be found in Appendix E.

6. Evaluation

In this chapter the prototype will be evaluated. There is no evaluation done with the end users because it was not possible to find homeless persons who could give valid informed consent, were sober, and wanted to cooperate. Therefore, the prototype is evaluated in two other ways. Firstly, the fulfilment of the functional requirements listed in section 4.3 will be checked. Secondly, the prototype is shown to the client for evaluation.

6.1 Functional requirements evaluation

The functional requirements from the specification chapter (section 4.3) are evaluated. The requirements are categorized in different sections according to their MoSCoW classification. To evaluate the performance of the prototype, the prototype was tested both in normal conditions and in a freezer. The test setup for the freezer evaluation can be found in Appendix F. The results of these tests are used to verify the fulfilment of the requirements. For every requirement it is analysed if and how it is fulfilled.

6.1.1 Must

All the requirements in this section are must have functional requirements. This means that the described function should certainly be implemented in the prototype to work properly.

- Measure temperature in suit between at least -20°C and 45°C with an accuracy of 1-3°C.

In theory, the used sensor has an accuracy below 0.5°C if the temperature is between 5°C and 45°C (section 5.1.2). For the other temperatures in its range the accuracy is between 0.5°C and 1.7°C. Assuming the data of the manufacturer is correct this requirement is fulfilled in the prototype.

- Measure shivering of the Sheltersuit user.

The shivering function is based on the code from Bosch [5] which is adjusted only in structure, not in function. The function was tested both under normal conditions and outside of the freezer (Appendix E). When tested in normal conditions, the simulated shivering was not detected. Moving the prototype with the hand did result in a recognition of shivering for some frequencies. When pinned inside a jacket and worn, the prototype did register if the user sat or laid down. However, it did not recognise it when the user shivered. This could either be caused by the thresholds in the software or by the fact that the simulated shivering was not the same as real shivering. To check if the system does recognise real shivering, the prototype was tested in a freezer.

When the test subject started to shiver, the prototype did not recognise this as shivering. It could be that the test subject shivered in another way than in the study from Bosch [5]. Another explanation is that the thresholds in the code were not accurate for the test simulation. This function could possibly be adjusted by executing the experiment by Bosch [5] again with different test subjects to find the correct thresholds. It could also be that the applied filters and filter values are not correct.

Due to time constraints this function was not analysed further. Therefore, the requirement is not fulfilled.

- Prediction of the risk of mild hypothermia.

The made predictions are based on the flowchart from Figure 4.22. In the software (Appendix E), the predictions are made in the 'Risk_level' function, which combines the comfort level function and shivering data. From the evaluation test in the freezer it showed that the temperatures with which the risk level changes are accurate. While in the freezer, the test subject indicated the perceived comfort level. When the subject felt more uncomfortable, the notification level changed. Thus, the temperature thresholds were accurate for this test subject. All in all the prediction of the risk of mild hypothermia is well implemented in the prototype.

- Auditory user notification of high risk of mild hypothermia

The auditory notification is produced by the piezo buzzer (section 5.1.4). The program converts the risk level into the notification level in the 'Play_notification' function (Appendix E). The perceived urgency of the signal is dependent on the notification level, and is changed by the magnitudes of the frequency, inter-pulse interval, and volume.

- Have different levels of notification by changing the magnitudes of the frequency, inter-pulse interval, and volume.

The different magnitudes of the frequency, inter-pulse interval, and volume are decided by a formula for which the notification level is used as input. The notification level can be a 0 for no risk, 6 for low risk, 8 for high risk, and 10 for very high risk. The frequency is computed by multiplying the notification level by 50. The volume is set by the used library, which uses a number between 0 and 10 as input. The higher the risk level, the louder the signal. The duration is computed by: 1500 - (notification * 100) [ms]. This time interval is also used as a pause between the signals, and together they are played 5 times to produce an on-off signal.

From the test in the freezer it resulted that the different levels of notification also have a different perceived urgency. The notification could be heard well in the silent freezer. However, it was not loud enough to wake someone up. An improvement would be to increase the volume of the notification so it can also be heard with loud environmental noises or when sleeping. For the current hardware the volume of the signal is the highest it can produce, so to realize a higher volume a different speaker is needed.

6.1.2 Should

The functional requirements mentioned in this section are classified as 'should'. This means that these requirements should be implemented into the prototype when possible, but are not necessary for the main functioning of the prototype.

- Shows level of battery charge of the product.

The battery charge of the product is implemented in the prototype. In the ideation chapter it is considered to use an external power bank as charge for the module, instead of a normal battery. Most power banks show their battery charge. Therefore, the prototype does show the battery charge by using the display of the connected power bank.

- Notify user when product needs to be charged.

The user is not notified by the prototype when the product needs to be charged. Since the prototype uses a power bank to charge, the software does not know the charge of the power bank. However, some power banks do notify the user when the power runs low. This requirement could potentially be fulfilled by connecting the right power bank. Another way to fulfil this requirement is to change the concept for the envisioned product to include a battery. Then the system could read the battery charge and notify the user when the battery runs low.

- Notify user when one part of the product stopped working.

This requirement is not implemented in the prototype due to time constraints

6.2 Non-functional requirements evaluation

The non-functional requirements from section 3.3 are evaluated. These requirements are not about what is done, but about how it is done. Like in the previous section, it is analysed for every requirement if and how it is fulfilled.

6.2.1 Should

- Unobtrusive for sewing process

The unobtrusiveness of the prototype to the sewing process is considered in the ideation phase (chapter 3). A sew-on pocket is chosen to hold the prototype which makes it easy to implement in the current Sheltersuit design. Since the pocket would be easy to add to the production line, this requirement is fulfilled.

- Easy to sew for Sheltersuit employees

Like the previous requirement, this requirement is considered in the ideation phase (chapter 3). Since a sew-on pocket is an easy part to sew, this requirement is fulfilled.

- Unobtrusive to user

In the ideation phase (chapter 3) unobtrusive placing of the product is considered. However, the prototype is larger than a final product would be. It cannot be determined how obtrusive the envisioned product is to the user while the prototype is not the same size and weight as the final product. When the final product is made professionally, the obtrusiveness can be evaluated by executing user tests.

6.2.2 Could

All the non-functional requirements mentioned in this section are classified as 'could', which means that these functions could be added to the prototype when there is time left.

- Robust

The prototype does not have wires outside the casing, which makes it robust to some extent. The casing is not water resistant and not made for extensive use. The envisioned product should have a better casing, resistant to water, sweat, and extensive use.

- Easy way to charge battery

Since the prototype uses a power bank as a battery, the prototype is easy to charge.

- Discouragement of reselling

This requirement is not implemented in the prototype due to time constraints.

6.2.3 Won't

Requirements classified as 'won't' are not implemented into the prototype, since they are the least important to the functioning of the system and the user experience. However, they could be considered in a later stage of the design process. The ‘won’t’ requirements for this prototype are listed below and are not implemented in the prototype.

- Cheap (less than 25 euro)
- Possibly easy to repair
- Possibly recyclable / non-disposable

6.3 Evaluation with client

Besides the requirements evaluation and the evaluation test in the freezer, the prototype was also evaluated with the client. The evaluation interview was executed as a fully structured interview, and for the answers a Likert scale was used. The questions and answers of the complete interview can be found in Appendix G.

Overall the reaction of the client was very positive. He was very satisfied with the final concept described in chapter 3. Furthermore, he was very content with the contacting of the ex-homeless people and social workers. What could have been improved was the executed experiment in the specification. Since the experiment was only executed with three participants of the same sex and age, nothing could be concluded about the different values for both sexes. The client would have liked to see this separation and execution with more participants. However, the experiment was sufficient for the scope of this project. He was surprised about the results of the experiment. He did not expect different levels of comfort and risk as a conclusion. As a consequence of this conclusion he stated that the accuracy of the temperature sensor should be very high, since the comfort levels are very close together. The prototype was received very positive, especially the casing around it. For further research, the module should be made more robust, durable and ergonomic.

7. Conclusion

This aim of this graduation project was to develop a module for inside the Sheltersuit to detect and notify the user when the risk of mild hypothermia was present. In the introduction chapter the research question and four sub-questions were formulated. The main research question is:

How to develop a Sheltersuit module that detects and notifies a user in case of risk of mild hypothermia?

To answer this research question the context was analysed in chapter 2. It was found that the number of homeless in the Netherlands has been increasing since 2009, and that sleeping on the streets can be rough. Furthermore, it was found that the homeless population has an increased risk to get hypothermia because of chronic exposure to cold in winter and high use of alcohol. In this chapter the first sub question was answered as well:

What symptoms of mild hypothermia should be detected?

From literature it became clear that the symptoms of mild hypothermia are shivering, increased heart rate, and increased breathing rate. Since shivering can be measured without being intrusive to the user, and since a previous graduation project focussed on this, shivering was chosen as the symptom to detect by the module.

The second sub question is about the implementation of the measurement of the symptoms of the user and the conditions inside the Sheltersuit.

What are the necessary functions to implement in the Sheltersuit to detect mild hypothermia of the user?

To measure if the Sheltersuit user is shivering the module should be able to measure movement. This movement should be filtered and analysed by the module, and it should know if the movement is shivering or not. Besides shivering, the conditions in which the user finds himself should be measured. This is done by measuring the temperature and humidity inside the Sheltersuit and estimating the comfort of the user. From the test executed in the specification it became clear that the humidity has no influence on the comfort (or perceived temperature) when the temperature is below 26°C. Therefore, the functions to implement in the Sheltersuit to detect mild hypothermia of the user are the measurement of movement and temperature.

How can the functions be implemented in the Sheltersuit in a convenient way?

The implemented shivering function is based on the code made by Bosch [5] in a previous graduation project. Approximately every twenty seconds the filtered movement measured by an accelerometer is analysed to find out if shivering occurred. Unfortunately, in the scope of this project the correct values for the filters could not be found and the shivering function could not be made correctly operable. Nonetheless, the code for the shivering function is present and the expected result is integrated in the program. The temperature measuring function was implemented by adding a temperature sensor. From the test in the specification chapter three threshold temperatures were found for which the comfort of the user changed. From these temperatures different comfort levels were derived. The comfort levels and the shivering function were combined to determine the risk level of the user. The output notification is dependent on this risk level, and is the answer to the fourth sub-question.

What is the best way to notify the user when the risk of mild hypothermia is detected?

From literature research it was concluded that auditory notification is the best way to notify the user when the risk of mild hypothermia is detected. Since the context analysis showed that homeless individuals that choose to sleep outside prefer to be left alone, it is concluded that the best way to notify is to only notify the user. Auditory notification is chosen rather than vibration based notification because of two reasons: more scientific research could be found about it and the urgency of the signal can be varied. Literature research showed that the urgency of the signal can be varied by a difference in frequencies, inter-pulse intervals, and volume. When the risk of mild hypothermia increases, the frequency and volume of the notification should increase, and the inter-pulse interval should decrease. The level of the signal's urgency is decided by the risk level that the module calculates.

8. Future work

This graduation project focussed on finding a way to develop a Sheltersuit module to detect the risk of mild hypothermia and notify the user if this risk is present. Since this was a short-term project, there are several aspects that should be worked on before the envisioned product could be launched. This chapter will discuss how current functions could be improved and new functions that could be added.

8.1 Improvement of current functions

Firstly, more research should be done about the shivering function in the detection module. In the scope of this project the function could not be made fully operable. Different things could be the reason why it did not work. It could be that the test subject was not able to shiver at the right frequency, or that it was a different sensor with different output values, or that there was an error in the thresholds. To find the error, the steps executed by Bosch [5] should be re-executed with multiple test persons of different sex, age, and built. Hopefully the error in this project can be found and the function can be realized.

Another aspect that should be improved is the research conducted, both the test in the specification chapter and in the evaluation chapter. The research in the specification chapter is a first step in estimating the comfort of the Sheltersuit user at different temperatures. As stated in the context analysis, the homeless population is a very broad user group. Due to constraints in time and resources the tests done in this research were conducted with a small number of participants, all of the same age, gender and fitness level. To make this research represent the whole homeless population, the tests should be repeated with a larger heterogeneous test group. Factors that should be considered are sex, age, height, weight, and fitness level [94]. For the evaluation it is also important to test the prototype with a more varied test group.

Thirdly, the prototype could be improved further. The prototype is now constructed out of hardware that was available. However, it could be made much smaller by just using the chips in the hardware, instead of the breakouts used in this project. A PCB could be designed which includes all the chips of the used hardware. In the evaluation talk with the client it showed that a new prototype should also be more robust, durable, and ergonomic to really be implemented in the Sheltersuit.

For the evaluation and further design of the notification system, it is important to involve the end user. As further design, the notification volume needed for the different levels could be investigated. Contacting this user group and finding homeless individuals or organisations that wanted to cooperate was found very difficult during this project. The contacted people in this graduation project were found through personal connections, which was found to be a better strategy than asking organisations. Although it is very difficult to find participants, it is essential for the evaluation and user testing of the envisioned product.

8.2 Addition of new functions

There are several new functions that could be added to the current prototype to make it better or more user-friendly. Firstly, personal calibration could be added to make the system more accurate. Personal calibration data is data that characterizes the user, and defines various constants that influence the perception and risk of mild hypothermia. From the background research in chapter 2 is became apparent that alcohol and drug consumption reduces the awareness and correct perception of the person's surroundings. This also causes people to cool down quicker than when being sober. Other factors mentioned in section 2.2.2 are old age, reduced metabolic rate, malnutrition, and immersion in water. Factors mentioned by the Health and Safety Executive [94] are size, weight, age, fitness level, and sex. These factors could be used as input so that the system only works accurately for that specific user, making it work accurate. It could also be used to discourage the reselling of the module. If the module or the Sheltersuit would be sold, it would not work for the new user. Although, a disadvantage is that the module would become obsolete when the Sheltersuit gets a new user.

Another way to discourage the reselling of the module is by making removal of the module from the Sheltersuit very difficult for the user. For the single module design extra security could be added. The module could be connected to the Sheltersuit with strong materials (e.g. rip ties, locks, metal wire). Since the final design makes use of a pocket, this pocket could be sown tight so the user would be unable to open it. Although all these solutions would make the detachment of the module harder, it would not make it impossible. Especially when the user is in possession of a pair of scissors or a knife, everything could be detached by damaging the suit. A disadvantage of securing the module tightly closed to the Sheltersuit is that the charging of the battery could become more difficult. All things considered, the way to discourage the reselling of the module could be investigated more.

Thirdly, a function that was not added to the prototype due to time constraints was system functions monitoring. The user should get feedback with information about the functioning of the system. When using the product, the user will trust the module to do its job. However, when one of the components fails, the system should inform the user about it. There are various ways in which this can be accomplished. A light could turn on when the system cannot be trusted. With this a sound could play to inform the user. But it should be made clear that the sound is for this reason, and not because the user has risk of mild hypothermia. Another way to inform the user could be to send him/her or his contact person an email. It could also send a direct message to a cooperating organisation that the module needs to be replaced.

A drawback for the last two ideas (the email and the organisation) is that the module would need an extra component to send information. This would cost more and take more energy. Also, sending an email or a message to the organisation would make the user traceable. This is not desirable because privacy is important for most homeless (see chapter 2). If a light would show the information it could be combined with the battery information. For example, a multi-coloured light could show red-green for the battery, but blue for the failing of the system. This would make the system simpler, less energy consuming, and cheaper.

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Appendices

Appendix A. Conversation summaries.

This appendix contains the summaries of the held conversations with the client and field experts. Since none of the conversations was recorded, these are not literal transcripts but recaps of the conversations.

A.1 First visit Sheltersuit 21-02-2018.

Introduction

On Wednesday the 21st of February, the introductory meeting with Sheltersuit was held. A summary of the main points of the meeting are handled here.

Expectation

The first think to be made clear is the expectation that we had from each other. My expectation from Sheltersuit was for them to help me along the way with resources and knowledge, and to give feedback. Their expectation for me was to continue in the direction that Hinke chose. This means to focus on detecting shivering, and with that mild hypothermia. Furthermore, they wanted me to be proactive, especially in the contact with homeless people. A starting point here is to investigate how homeless people accept technology.

Hardware requirements

To meet the idea that they have of the electrics that are to be designed, their requirements were listed. One of the most important things is that the hardware should be safe for the user. Secondly, it should be a model that can be taken out of the suit, and that is easy to repair. Also for the washing of the suits the module should be easily removable. Since Sheltersuit values recycling, it would be good if the components are recyclable or recycled, and if the electronics is not disposable. When designing the hardware, it could be taken into account how the selling of the hardware can be discouraged. Lastly, the module should be cheap, with a maximum of 25 euros per module. Sheltersuit has no requirements regarding the placement of the module.

Distribution process

The distribution process of the suit is done in a lot of different places. In the Netherlands the suit is distributed via small organisations that provide shelter. There are also some requests of people that have friends or family living on the street to get a Sheltersuit for them. The last batch of suits has been distributed on Lesvos via 'Movement on the ground'. The suits were distributed between refugees, and were accompanied with a lamp/charger of Waka Waka. Furthermore, the Sheltersuit is sometimes distributed in other countries, like London. After the distribution there are no check-ups on the suit.

A.2 Conversation with social worker 04-04-2018.

I talked with someone who works with homeless people in Amersfoort, The Netherlands. The aim was to get a better view into the situation in the Netherlands, and to get acquainted with the way of thinking of people who live on the streets. In the Netherlands, people can have various reasons of living on the streets. It can be a (sudden) lack of money, fights or anger with their partner, circumstances that do not work in their favour, or a lifestyle choice for freedom. Most people stay in shelters at night. When they have to get out during the day they can stay outside or go to day-shelters or inloophuizen. When it is very cold outside, shelters sometimes give sleeping bags to the homeless when the night-shelter closes. When the temperature is below zero, organisations are obliged to have a place for people to sleep. Almost all homeless have a mobile phone, that they keep charged at the shelter or at the public library. Some even own tablets or laptops. They use these to keep up to date about the news, and to keep in touch with friends or relatives. For a notification system, it is not a good idea to notify people around the homeless of their danger to hypothermia. Most homeless do not want to be seen, because they can feel ashamed of sleeping outside. They want to be invisible to people that they don't know and don't have/want any relation to.

A.3 Conversation with ex-homeless from Enschede 04-04-2018.

I talked with John* about the time he lived on the streets in Enschede, the Netherlands. He told me that his experience had two sides. On the one hand it was very educational, and he met many interesting people, but on the other hand he was dealing with addiction. Usually he slept outside on the streets, and not in shelters. Because shelters in Enschede always cost money, and he did not have an income. In Enschede, you could reserve a place for that night in the shelter in the morning. And when it freezes more than 2 degrees, there's an extra emergency shelter to stay warm. However, he still slept outside preferably to a warmth outlet of a cafe. He never slept together with others, because he did not trust anyone. Sometimes he begged for money to get a drink in one of the cafes, and drank it as slow as possible, to stay inside for a long time. When it was cold through the day, he sometimes took a long train to get some warmth, and hoping no conductor would come since he had no ticket. He also went to the library to stay warm. Generally, when it is cold, homeless people tend to walk around a lot.

In The Netherlands there are a lot of organisations to help people living on the streets. However, in John's experience, it is difficult to get out of being homeless. The waiting list for the permanent shelter at the Salvation Army in Enschede was 2 years at that time. And people never got out to let new people in. Also, it is difficult to know what forms to fill out and what organisations to ask for help.

About my project he remarked that you have to ask yourself if they will take care of my product when they are under influence and on the move. As for the notification system, he did not see a problem with notifying other people when hypothermia conditions were detected. He reasoned that when it is about life and death, notifying is just necessary. It sometimes happened that people got picked up by an ambulance because they could not stay warm, or they could not move anymore.

In Enschede/Twente there are around 1000-1500 homeless, which is a lot. And there are not enough facilities for them.

A.4 Conversation with ex-homeless from Amsterdam 18-04-2018.

I called with someone, a 48-year-old male, who had lived on the streets of Amsterdam for 8 years. He had coped with a drug addiction for 25 years, both heroin and cocaine. In this time, he hardly ever stayed in shelters. He had a backpack with clothes, a bike, and a sleeping bag, and would sleep on porches and bushes at night. Sleeping on the streets could be rough, but it meant that he was close to the dealers. Also, shelters had rules that he did not want to follow, since the only thing he wanted were drugs. He got addicted to drugs because of insecurity he acquired when he was little, and when he got into relationships.

The money for the drugs was earned by helping people load their furniture into their cars at IKEA, helping taking out trash for little restaurants, or begging for money. He would often ask for money to pay for the night shelter, but he always used it for drugs later. In the first years he also used to break into houses to steal, so he could pay for the drugs. But after he was treated in a clinic, he wanted to get a clean plate. He went to the police, and went to jail for 1.5 years. Afterwards he again lived on the streets, but without stealing this time.

When it was cold outside, he would sleep on carton boxes and wear two pairs of clothes, a sleeping bag, and a hat. Still, it was a matter of surviving. Every morning he would need to stand in the sun for almost an hour to get his body working again. He tried to move a lot, since moving will prevent getting hypothermia. For sleeping places, he made sure to be warm, out of the wind, and dry. Sometimes he would sleep sitting up under an umbrella. One time he has suffered from moderate hypothermia. After four nights without sleep because of the drugs, he collapsed on the street made of concrete. After hours of sleep a guard found him and woke him up, but he could not move. The guard put him in a metro, which he rode 8 times from end to end until his body worked again. But after 9 hours, he still couldn't make a cigarette.

All this time he did own a phone, even though they were not very common back then. A dealer gave it to him so he could call when he needed drugs. He would charge the phone at a secret place at the stadium of Ajax. Or sometimes he would go into garage boxes that people did not lock.

He liked the idea of the Sheltersuit and the notification of the user when the risk of hypothermia was present. Most homeless stay on their own, so the best way would be to notify themselves. Even though homeless are very cautious to stay warm, sometimes through substance abuse or over-fatigue it can happen. He said that if only one person is helped, it's still worth it.

Appendix B. Experiment setup and results.

This appendix describes the setup of the experiment executed in section 4.1.2. It also contains more visualizations of the obtained data.

Aim

The aim for this experiment is to find the relation between the cold index and the prelude of shivering of the user.

Hypothesis

The humidity is expected to influence the perceived temperature in a reversed way. The higher the humidity, the colder it feels to the participant.

Method

Every participant will go into the freezer individually. The subject will wear a Sheltersuit with a temperature and humidity sensor placed inside. The sensors will be connected to an Arduino Nano, which is wired to a laptop outside of the freezer. Every 2-4 minutes the participant is asked to indicate their thermal comfort and thermal sensation. If the thermal comfort and thermal sensation are both low, this is a prelude for shivering. From this data the cold index (relationship between temperature, humidity, and perceived temperature) can be constructed. At the same time the Processing application will automatically log the temperature and humidity in the Sheltersuit to a CSV file. For possible further improvement of the accuracy of the system, the age, height, weight, sex, and fitness level of the subject should be noted.

1. First, one participant will go into the freezer wearing a dry t-shirt in the Sheltersuit.
2. He will stay inside the freezer until the temperature difference with the beginning is significant enough.
3. Then, the person comes out of the freezer, and the temperature inside the Sheltersuit will be brought back to room temperature.
4. The Processing application should be saved by pressing any key.
5. The name of the CSV file will be changed in the Processing application.
6. Step 1-5 are repeated with 100 ml water sprayed on the t-shirt.
7. Step 1-5 are repeated with 100 ml more water sprayed on the t-shirt
8. Step 1-7 are repeated by the second participant.

Materials

- At least 2 participants
- Freezer
- Sheltersuit
- Temperature sensor for inside Sheltersuit

- Humidity sensor for inside Sheltersuit
- Arduino microcontroller
- Wires
- Comfort scale
- Laptop
- Arduino software (Appendix C)
- Processing software (Appendix C)
- 3 T-shirts
- Spray bottle with volume marks

Figure B.1. Spray bottle with volume marks.

Participation information

Participation number: ....

(circle the relevant)

Sex: male / female

Age: ....

Height: ....

Weight: ....

Fitness level: very poor / poor / acceptable / good / very good

Figure B.2. Participant information form.

Comfort scale

The prelude of shivering of the user will be determined by using a comfort scale. The comfort scale that will be used is based on the scale used by Bird, House, and Tipton [95] in their research about the cooling of children while swimming. It measures the thermal sensation and thermal comfort of the user.

Thermal Sensation

○	○	○	○	○	○	○	○	○
Very cold	Cold	Cool	Slightly cool	Neutral	Slightly warm	Warm	Hot	Very hot

Thermal Comfort

○	○	○	○	○	○
Very uncomfortable	Uncomfortable	Just uncomfortable	Just comfortable	Comfortable	Very comfortable

Figure B.3. Comfort scale from Bird, House and Tipton [95].

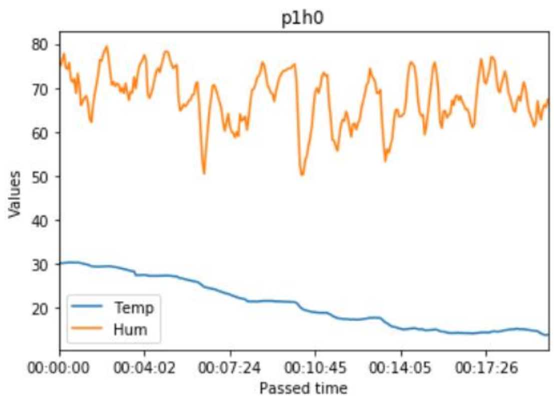
Execution

The experiment was executed with three different participants. Five measurements were done. All three participants (p1, p2 and p3) went into the freezer without a sprayed t-shirt. Thereafter, p1 and p3 did a second measurement with a different humidity. The participants stayed in the freezer for 18 minutes, since this gave a significant drop of measured temperature and comfort.

The humidity was not the same for all participants. For this reason, the specific spray bottle was only used for the second measurement for p3. Here, 100 ml water was sprayed on the shirt worn by the participant. During the first test for p1 the humidity was very high, therefore the second test for p1 was measured wearing a dry t-shirt.

Results

The code to produce these plots in Jupyter notebook (Python) can be found in Appendix C.



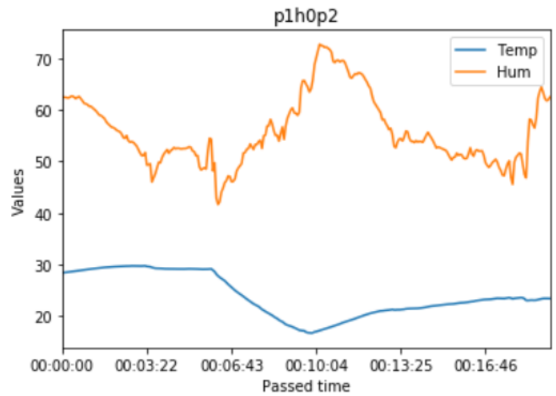
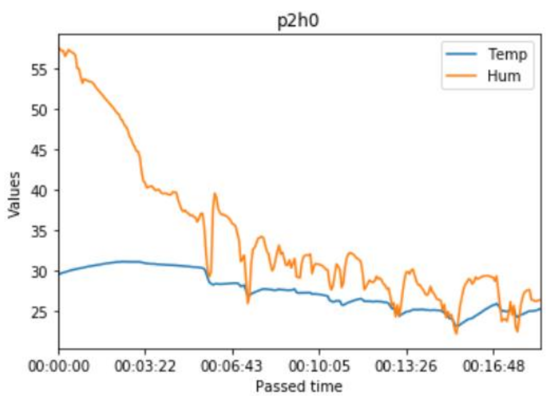


Figure B.4. Temperature and relative humidity as a function of the passed time. The data is of the first measurement of p1.

Figure B.5. Temperature and relative humidity as a function of the passed time. The data is of the second measurement of p1.



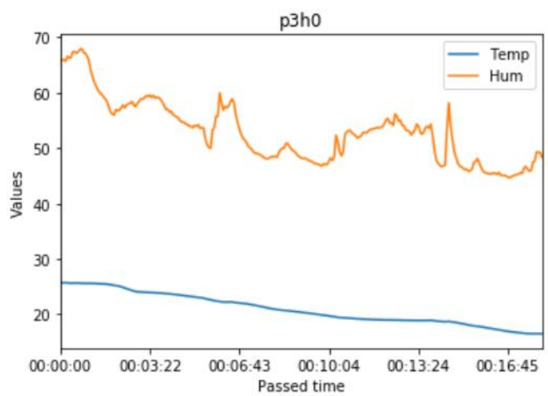


Figure B.6. Temperature and relative humidity as a function of the passed time. The data is of the first measurement of p2.

Figure B.7. Temperature and relative humidity as a function of the passed time. The data is of the first measurement of p3.

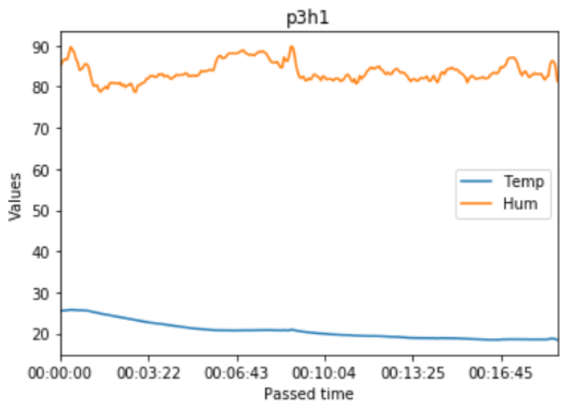


Figure B.8. Temperature and relative humidity as a function of the passed time. The data is of the second measurement of p3.

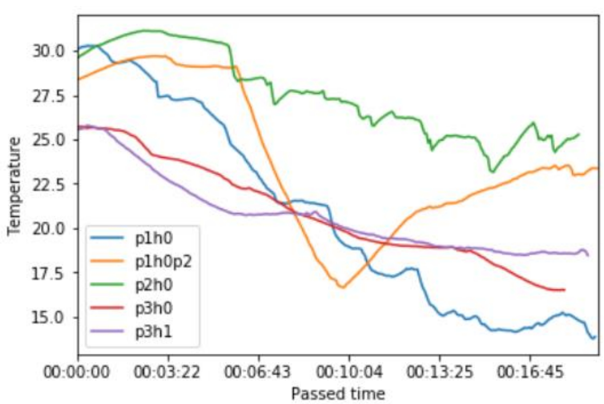


Figure B.9. Temperature as a function of the passed time. The data is from all measurements.

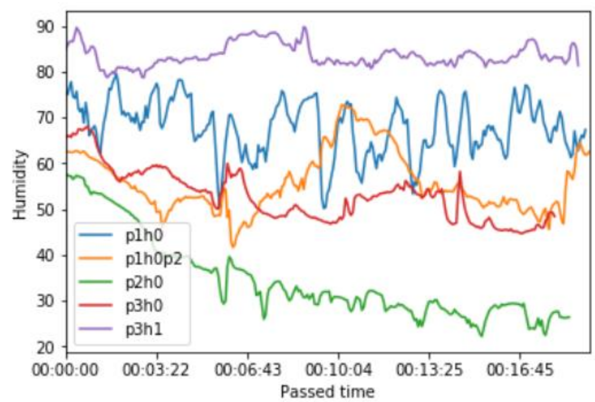


Figure B.10. Relative humidity as a function of the passed time. The data is from all measurements.

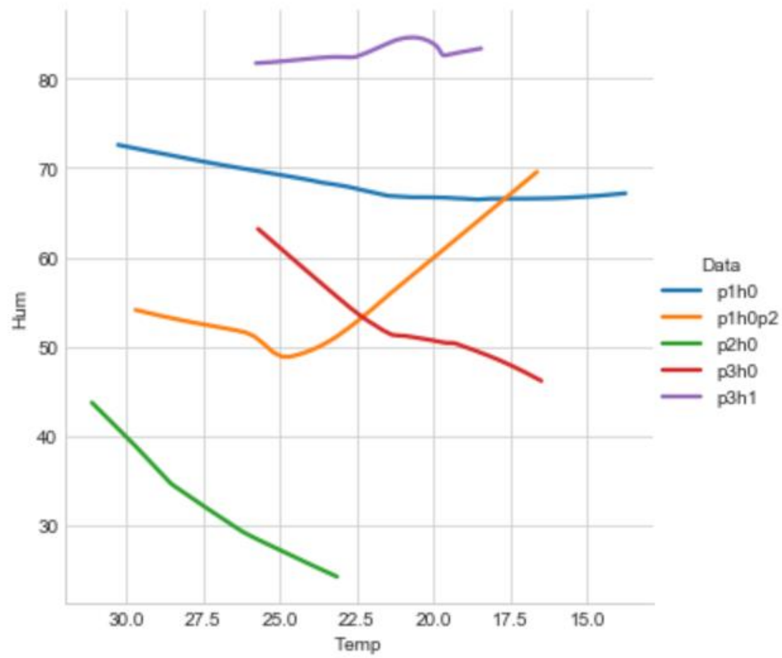


Figure B.11. Relative humidity as a function of the temperature. The data is from all measurements. The graph displays the LOWESS of each scatterplot.

Appendix C. Experiment code.

This appendix contains the code used in the experiment executed in section 4.3.2 and described in Appendix B. The software used is the Arduino IDE (C++), Processing IDE (Java), and Jupyter notebook (Python).

Arduino

```
/*
Temperature and Humidity measurement
Read sensor data, and send it to the serail port
Created by Daniëlle Kwakkel
June 2018
*/
#include <SHT1X.h>
SHT1x sht15(A4, A5); //Sensor object
float temp = 0;
float hum = 0;
unsigned long time;

void setup() {
  Serial.begin(9600);
}

void loop() {
  //Print temperature and humidity every 3 seconds to console
  Serial.print("T");
  Serial.println(sht15.readTemperatureC());
  Serial.print("H");
  Serial.println(sht15.readHumidity());
  delay(3000);
}
```

Processing

```
/*
Temperature and Humidity measurement
Saving incoming data from the serial connection to a CSV file
Created by Daniëlle Kwakkel
June 2018
*/
//Connection with Arduino
import processing.serial.*;
String buff = "";
int NEWLINE = 10;

Serial serialPort;

//Variables for the incoming data
Table table;
String temp;
String hum;
Boolean tempchanged;
Boolean humchanged;

void setup() {
  //create table
```

```
  table = new Table();
  table.addColumn("Time");
  table.addColumn("Temp");
  table.addColumn("Hum");

  //Serial connection
  println("Available serial ports:");
  println(Serial.list());
  serialPort = new Serial(this, Serial.list()[0], 9600);
  serialPort.bufferUntil(' ');

  temp = hum =  "";
  tempchanged = humchanged = false;
}

void draw() {
  while (serialPort.available () > 0) { //Read incoming information
    serialEvent(serialPort.read(), serialPort);
    //if new information comes in save it once in the table
    if (tempchanged == true && humchanged == true) {
      saveData();
      tempchanged = false;
      humchanged = false;
    }
  }
}
void keyPressed() {
  //Save the table to a CSV file and exit the sketch
  saveTable(table, "data/p3hum1.csv"); //change name every measurement
  exit();
}

void saveData() {
  //Add new row with timestamp, temperature and humidity
  TableRow newRow = table.addRow();
  int h = hour();
  int m = minute();
  int s = second();
  String timestamp = h+":"+m+":"+s;
  newRow.setString("Time", timestamp);
  newRow.setString("Temp", temp);
  newRow.setString("Hum", hum);
}

//Read incoming serial data
void serialEvent(int serial, Serial myPort) {
  try {
    if (serial != NEWLINE) {
      buff += char(serial);
    } else {
      // The first character tells us which variable
      char c = buff.charAt(0);
      // Remove it from the string
      buff = buff.substring(1);
      // Discard the carriage return at the end of the buffer
      buff = buff.substring(0, buff.length()-1);
      // Parse the String into an integer
```

```
        if (c == 'T') {
          temp = buff;
          tempchanged = true;
          print('T');
          print(temp);
          print('\t');
        } else if (c == 'H') {
          hum = buff;
          humchanged = true;
          print('H');
          println(hum);
        }
        // Clear the value of "buff"
        buff = "";
      }
    }
    catch(Exception e) {
      println("no valid data");
    }
}
```

Visualizations

The visualizations were created in the python environment called Jupyter Notebook (http://jupyter.org/), which is focussed on data analysis and visualization and runs on Python.

Jupyter notebook Figure B.4 to B.11 (Appendix B).

```
#import libraries
import pandas as pd
import numpy as np
import seaborn as sns
import matplotlib.pyplot as plt
%matplotlib inline
import datetime

#read files
p1h01 = pd.read_csv("Test data/p1hum0.csv")
p1h02 = pd.read_csv("Test data/p1hum02.csv")
p2h0 = pd.read_csv("Test data/p2hum0.csv")
p3h0 = pd.read_csv("Test data/p3hum0.csv")
p3h1 = pd.read_csv("Test data/p3hum1.csv")
p1h0p2 = pd.read_csv("Test data/p1hum0poging2.csv")
p1h0 = pd.concat([p1h01, p1h02], ignore_index = True)
data = [p1h0, p1h0p2, p2h0, p3h0, p3h1] #all dataframes

#function to calculate the passed time since the beginning
def calculatePassedTime(df):
    df['Time'] = pd.to_datetime(df['Time'], format='%H:%M:%S')
    starttime = df['Time'][0]
    for index, row in df.iterrows():
        df.loc[index, 'Passed'] = df.loc[index, 'Time'] - starttime
        stampie = df.loc[index, 'Passed']
        strStampie = str(stampie)
        df.loc[index, 'Passed'] = strStampie.split()[2];
```

```
#execute passed time function for all dataframes
for item in data:
    item['Passed'] = 0
    calculatePassedTime(item)

#Seperate plots of every dataframe, passed time vs temperature and humidity
values
plt1 = p1h0.plot(x='Passed', title='p1h0' )
plt2 = p1h0p2.plot(x='Passed', title='p1h0p2')
plt3 = p2h0.plot(x='Passed', title='p2h0')
plt4 = p3h0.plot(x='Passed', title='p3h0')
plt5 = p3h1.plot(x='Passed', title='p3h1')
plt1.set(xlabel='Passed time', ylabel='Values')
plt2.set(xlabel='Passed time', ylabel='Values')
plt3.set(xlabel='Passed time', ylabel='Values')
plt4.set(xlabel='Passed time', ylabel='Values')
plt5.set(xlabel='Passed time', ylabel='Values')

#All temperatrue and humidity measurements in one graph
ax = p1h0.plot(x='Passed', y='Temp', label='p1h0')
p1h0p2.plot(ax=ax, x='Passed', y='Temp', label='p1h0p2')
p2h0.plot(ax=ax, x='Passed', y='Temp', label='p2h0')
p3h0.plot(ax=ax, x='Passed', y='Temp', label='p3h0')
p3h1.plot(ax=ax, x='Passed', y='Temp', label='p3h1')
ax.set(xlabel='Passed time', ylabel='Temperature')

ax2 = p1h0.plot(x='Passed', y='Hum', label='p1h0')
p1h0p2.plot(ax=ax2, x='Passed', y='Hum', label='p1h0p2')
p2h0.plot(ax=ax2, x='Passed', y='Hum', label='p2h0')
p3h0.plot(ax=ax2, x='Passed', y='Hum', label='p3h0')
p3h1.plot(ax=ax2, x='Passed', y='Hum', label='p3h1')
ax2.set(xlabel='Passed time', ylabel='Humidity')

#make dataframe of all data
alldata = pd.DataFrame()
alldata = data[0]
alldata['Data'] = 'p1h0'
datastr = ['p1h0', 'p1h0p2', 'p2h0', 'p3h0', 'p3h1']
for i, item in enumerate(data):
    if i >= 1:
        alldata=alldata.append(item)
        alldata.Data = alldata.Data.fillna(datastr[i])
#plot the lowess of all data in one figure, temperature vs humidity
sns.set_style("whitegrid")
g = sns.lmplot(x='Temp', y='Hum', data=alldata, hue='Data', lowess=True,
scatter=False)
g.fig.axes[0].invert_xaxis()
```

Jupyter notebook Figure 4.4 to 4.12 (section 4.1.2)

```
#import libraries
import pandas as pd
import numpy as np
import seaborn as sns
```

```
import matplotlib.pyplot as plt
%matplotlib inline
import datetime

#read data
p1h0p2 = pd.read_csv("Test data/2addedp1h0p2.csv")
p1h0 = pd.read_csv("Test data/2addedp1hum0.csv")
p2h0 = pd.read_csv("Test data/2addedp2hum0.csv")
p3h0 = pd.read_csv("Test data/2addedp3hum0.csv")
p3h1 = pd.read_csv("Test data/2addedp3hum1.csv")

#make plots of temperature vs humidity
g = sns.lmplot(x="Temp", y="Hum", hue="Sensation", col="Comfort", data=p1h0,
aspect=.4, x_jitter=.1,fit_reg=False )
g.fig.axes[0].invert_xaxis()
g.fig.suptitle('p1h0', fontsize=16, y=1.1)
g = sns.lmplot(x="Temp", y="Hum", hue="Sensation", col="Comfort", data=p1h0p2,
aspect=.4, x_jitter=.1,fit_reg=False )
g.fig.axes[0].invert_xaxis()
g.fig.suptitle('p1h0p2', fontsize=16, y=1.1)

g = sns.lmplot(x="Temp", y="Hum", hue="Sensation", col="Comfort", data=p2h0,
aspect=.4, x_jitter=.1,fit_reg=False )
g.fig.axes[0].invert_xaxis()
g.fig.suptitle('p2h0', fontsize=16, y=1.1)
g = sns.lmplot(x="Temp", y="Hum", hue="Sensation", col="Comfort", data=p3h0,
aspect=.4, x_jitter=.1,fit_reg=False )
g.fig.axes[0].invert_xaxis()
g.fig.suptitle('p3h0', fontsize=16, y=1.1)
g = sns.lmplot(x="Temp", y="Hum", hue="Sensation", col="Comfort", data=p3h1,
aspect=.4, x_jitter=.1,fit_reg=False )
g.fig.axes[0].invert_xaxis()
g.fig.suptitle('p3h1', fontsize=16, y=1.1)

#make plots of temperature vs comfort
plt.subplots(figsize=(11,6))
g = sns.stripplot(x="Comfort", y="Temp", hue="Sensation", data=p1h0, size=4)
g.set_title('p1h0', fontsize=16)
g.set(xlabel='Comfort level', ylabel='Temperature (°C)')

plt.subplots(figsize=(11,6))
g = sns.stripplot(x="Comfort", y="Temp", hue="Sensation", data=p2h0, size=4)
g.set_title('p2h0', fontsize=16)
g.set(xlabel='Comfort level', ylabel='Temperature (°C)')

plt.subplots(figsize=(11,6))
g = sns.stripplot(x="Comfort", y="Temp", hue="Sensation", data=p3h0, size=4)
g.set_title('p3h0', fontsize=16)
g.set(xlabel='Comfort level', ylabel='Temperature (°C)')

plt.subplots(figsize=(11,6))
g = sns.stripplot(x="Comfort", y="Temp", hue="Sensation", data=p3h1, size=4)
g.set_title('p3h1', fontsize=16)
g.set(xlabel='Comfort level', ylabel='Temperature (°C)')
```

Appendix D. Heat formula explanation.

The figures in this appendix show the difference between temperature and perceived temperature at three different relative humidity levels. The used formula is given by the USA National Weather Service [78]. For temperatures above and including 80°F, the used formula is:

$$HI = -42.379 + 2.04901523 * T + 10.14333127 * RH - .22475541 * T * RH - .00683783 * T * T - .05481717 * RH * RH + .00122874 * T * T * RH + .00085282 * T * RH * RH - .00000199 * T * T * RH * RH \quad [78]$$

For temperatures below 80°F a simplified version is used:

$$HI = 0.5 * \{T + 61.0 + [(T - 68.0) * 1.2] + (RH * 0.094)\} \quad [78]$$

HI = Heat index of apparent temperature in Fahrenheit

RH = Relative humidity in percent

T = Temperature in Fahrenheit

These two formulas are used with temperatures from 100°F down to 35°F, and with relative humidity of 90%, 50% and 10%. The results are shown in Figure D.1 to D.3.

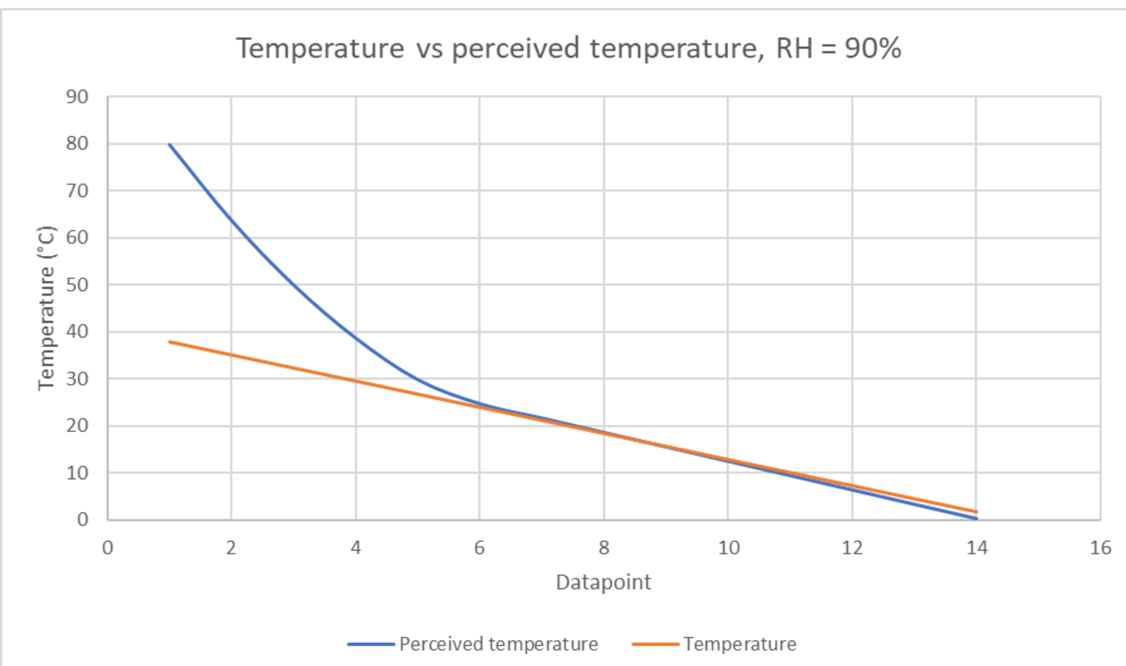


Figure D.1. Temperature vs perceived temperature with a relative humidity of 90%.

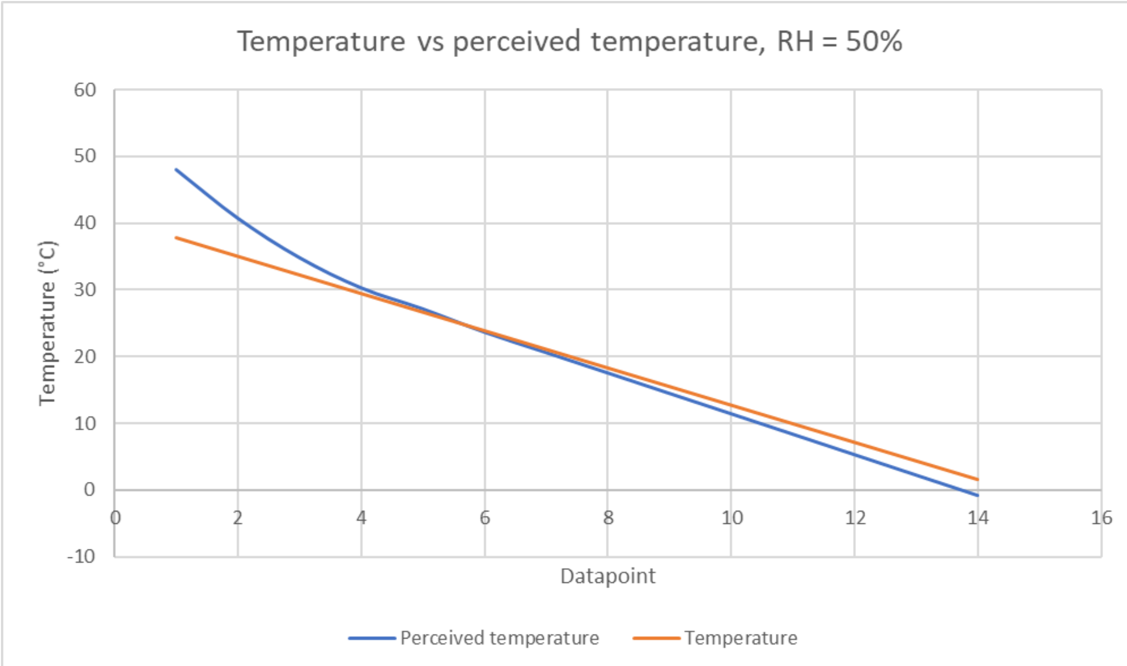


Figure D.2. Temperature vs perceived temperature with a relative humidity of 50%.

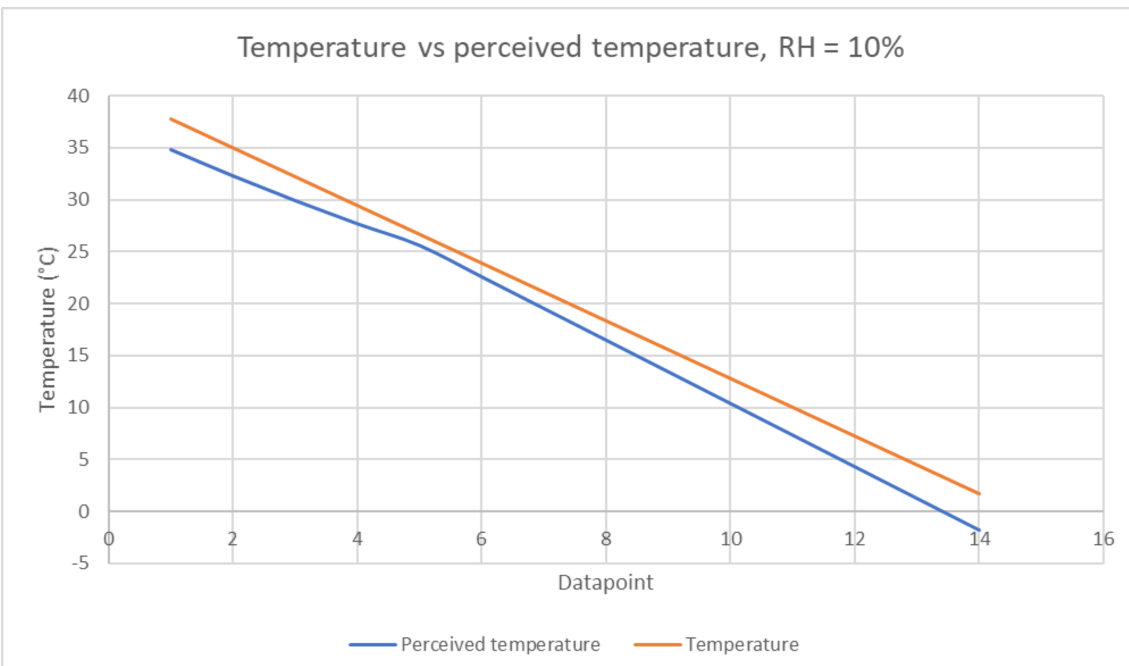


Figure D.3. Temperature vs perceived temperature with a relative humidity of 10%.

Appendix E. Final code of prototype.

The final code of the prototype is made and run in the Arduino IDE. The first four include statements include existing libraries. The last three include statements include the classes for filtering. The code for these classes is written in C++ and is also contained in this Appendix.

E.1 Arduino code

```
/*
   Final code
   Daniëlle Kwakkel
   Graduation Project Creative Technology
   University of Twente
   February - July 2018
   Based on code from Hinke Bosch
*/
#include <math.h>
#include "arduinoFFT.h"
#include <toneAC.h>
#include <SHT1X.h>
//Classes used for the filtering of the accelerometer data
#include <FilterBuBp2.h>
#include <FilterBuLp2.h>
#include <Acc_hin.h>


int count;
int countM;
int riskLevel;

bool moving;
bool shivering;
bool noValue;

//Values for the position changing and filters
int pNew;
int pOld;
int minV;
int minMaxY;
arduinoFFT FFT = arduinoFFT();
const uint16_t samples = 64; //This value MUST ALWAYS be a power of 2
const double samplingFrequency = 50;

//Sensor objects
Accelerometer accel1(A0, A1, A2);
SHT1x sht15(A4, A5);//Data, SCK

//These are the input and output vectors. Input vectors receive computed
results from FFT
double vReal[samples];
double vImag[samples];
float maxFFT;
#define SCL_INDEX 0x00
#define SCL_TIME 0x01
#define SCL_FREQUENCY 0x02
```

```
void setup()
{
  Serial.begin(115200);
  //Counts for time Movement / Shivering
  count = 0;
  countM = 0;
  riskLevel = 0;
  //Variables to load in position sitting or laying, and corresponding filter
values.
  pNew = 0;
  pOld = 0;
  minV = 0;
  minMaxY = 0;

  //Booleans for movement
  moving = false;
  shivering = false;
}

void loop() {
  //Reset values
  moving = false;
  shivering = false;
  noValue = false;
  maxFFT = 0;

  for (uint16_t i = 0; i < samples; i++) {
    accel1.aloop();
    //accel1.dump();
    position_changing(i); //Change minV and minMaxY according to the position
of a full cycle
    if (accel1.getVectorLP2() >= minV && moving == false && noValue == false)
{ // detects if a filtered value of the 64 samples passes the threshold
      moving = true;
      Serial.println("Moving is true");
    }
    //output vectors
    vReal[i] = double(accel1.getVectorBP());
    vImag[i] = 0;
    // Serial.print("Temperature =  ");
    //Serial.println(sht15.readTemperatureC());
    //delay(16); // +/- 50Hz with printing values
    delay(19); // +/- 50Hz without printing values
  }

  maxFFT = FFT_value(); //Compute the FFT value of the accelerometer data

  if (moving == true && maxFFT > minMaxY) { // if moving is detected and
frequency amplitude has the right value, then it is registered as moving
    Serial.print("maxFFT: ");
    Serial.println(maxFFT);
    countM = countM + 1;
    Serial.println("CountM");
  }
  count ++;
```

```
  if (count == 13) { // after 13 rounds, around 20 sec, the amount of
movements are counted, if higher then 4 and temperature is low enough,
shivering is detected
    if (countM >= 4 ) { //if moving 4 times out of 13 measurements, shivering
is true
      shivering = true;
    }

    String toPrint = (String("countM") + countM + String("count") + count);
    Serial.println(toPrint);

    count = 0;
    countM = 0;

    riskLevel = Risk_level(shivering);
    String printStuff = (String("Shivering: ") + shivering + String(" Risk: ")
+ riskLevel + String(" Count: ") + count);
    Serial.println(printStuff);
    Play_notification(Risk_level(shivering));
  }
}


void position_changing(int i) {
  pNew = accel1.getPosition();
  if ((pOld != pNew && i > 1) || pNew == 2) { // detect if values do not
correlate with only one position for one session of 64 values
    Serial.println("NO POSTURE");
    //digitalWrite(ledPin, LOW);
    noValue = true; // only if no change of position is measured in the 64
samples, the sample can be determined as shivering
  }
  else if (pNew == 0) { //sitting
    //Serial.println("sitting");
    minV = 12;
    minMaxY = 3000; //prev. 250
  }
  else if (pNew = 1) { // laying
    //Serial.println("laying");
    minV = 5;
    minMaxY = 3000; //prev. 125
  }
  pOld = pNew;
}

//Function to compute the FFT value of the accelerometer data
float FFT_value() {
  //COMPUTE FFT
  FFT.Windowing(vReal, samples, FFT_WIN_TYP_RECTANGLE, FFT_FORWARD); /* Weigh
data */
  FFT.Compute(vReal, vImag, samples, FFT_FORWARD); /* Compute FFT */
  FFT.ComplexToMagnitude(vReal, vImag, samples); /* Compute magnitudes */
  //PrintVector(vReal, (samples >> 1), SCL_FREQUENCY);
  double x = FFT.MajorPeak(vReal, samples, samplingFrequency);
  // DETECT WHAT THE HIGHEST VALUE IS OF THE FFT
  double maxY = 0;
  for (uint16_t i = 1; i < ((samples >> 1) - 1); i++) {
```

```
      if ((vReal[i - 1] < vReal[i]) && (vReal[i] > vReal[i + 1])) {
        if (vReal[i] > maxY) {
          maxY = vReal[i];
        }
      }
    }
    return float(maxY);
  }

//Function to find the comfort level derived from the measured temperature
int Comfort_level() {
  int comfort = 3; //Very high comfort
  float temp = sht15.readTemperatureC();
  if (temp < 19.00) {
    comfort = 0; //Very low comfort
  } else if (temp < 22.50) {
    comfort = 1; //Low comfort
  } else if (temp < 25.5) {
    comfort = 2; //High comfort
  }
  return comfort;
}

//Function to find the risk level by combining the comfort level and the
shivering boolean
int Risk_level(bool shivering) {
  int comfort = Comfort_level();
  int risk = 0;
  if (shivering == false) { //if shivering is not detected
    if (comfort == 0) { //Very low comfort
      risk = 2; //High risk
    } else if (comfort == 1) { //Low comfort
      risk = 1; //Low risk
    } else if (comfort == 2) { //High comfort
      risk = 0; //No risk
    }
  } else { //if shivering is detected
    if (comfort == 0) { //Very low comfort
      risk = 3; //Very high risk
    } else if (comfort == 1) { //Low comfort
      risk = 2; //High risk
    } else if (comfort == 2) { //High comfort
      risk = 1; //Low risk
    }
  }
  return risk;
}

//Function to play the notification using the risk level
void Play_notification(int risk) {
  int notification = 0;
  if (risk == 3) {
    notification = 10;
  } else if (risk == 2) {
    notification = 8;
  } else if (risk == 1) {
    notification = 6;
```

```
  }
  if (notification != 0) {
    //Play five times the notification. The frequency, volume, duration, and
inter-pulse delay change with the notificatoin level.
    for (int i = 0; i < 5; i++) {
      toneAC(notification * 50, notification, 1500 - (notification * 100),
true);
      delay(2 * (1500 - (notification * 100)));
    }
  }
}

//Function to print the calculated vector
void PrintVector(double * vData, uint16_t bufferSize, uint8_t scaleType) {
  for (uint16_t i = 0; i < bufferSize; i++) {
    double abscissa;
    /* Print abscissa value */
    switch (scaleType) {
      case SCL_INDEX:
        abscissa = (i * 1.0);
        break;
      case SCL_TIME:
        abscissa = ((i * 1.0) / samplingFrequency);
        break;
      case SCL_FREQUENCY:
        abscissa = ((i * 1.0 * samplingFrequency) / samples);
        break;
    }
    if (abscissa > 1) {
      Serial.print("Abscissa");
      Serial.print(abscissa, 2);
      Serial.print("\t");
      Serial.print(vData[i], 2);
      Serial.println();
    }
  }
  Serial.println();
}
```

E.2 Accelerometer class

Header code

```
/*
   Accelerometer class
   Daniëlle Kwakkel
   Graduation Project Creative Technology
   University of Twente
   February - July 2018
   Based on code from Hinke Bosch
*/
#ifndef Acc_hin_h
#define Acc_hin_h

#include "Arduino.h"
#include "FilterBuBp2.h"
#include "FilterBuLp2.h"
class Accelerometer
```

```
{
    public:
        int pins[3]; // which analog pins
        float data[3]; // acceleration, mapped
        float vector; //calculating vector from incoming data
        int scale; // scaling factor between ADC and gravity
        float vectorFiltBP; //vector after bandpass filter
        float vectorFiltLP; //vector after lowpass filter
        float absVector; //absolute values vector after lowpass filter
        //FilterBuBp2 filterBP = FilterBuBp2(); //bandpass filter
        FilterBuBp2 filterBP;
        FilterBuLp2 filterLP;
        //FilterBuLp2 filterLP = FilterBuLp2(); //lowpass filter
        int pos; // position of user, laying or sitting
        Accelerometer(int pinX, int pinY, int pinZ);
        void update();
        float getVector();
        float getVectorBP();
        float getVectorLP2();
        int getPosition();
        float mapf(float x, float in_min, float in_max, float out_min, float
out_max);
        void dump();
        void aloop();
};

#endif
```

CPP code

```
/*
   Accelerometer class
   Daniëlle Kwakkel
   Graduation Project Creative Technology
   University of Twente
   February - July 2018
   Based on code from Hinke Bosch
*/
#include "Arduino.h"
#include "Acc_hin.h"

Accelerometer::Accelerometer(int pinX, int pinY, int pinZ){
      pinMode((pins[0] = pinX), INPUT);
      pinMode((pins[1] = pinY), INPUT);
      pinMode((pins[2] = pinZ), INPUT);
      for (int i = 0; i < 3; i++) {
        data[i] = 0; // scaled data map
      }
      vector = 0;
      vectorFiltBP = 0;
      vectorFiltLP = 0;
      absVector = 0;
      scale = 1500; // can be 1500 or 6000
      pos = 0;
    }
```

```
void Accelerometer::update()
{
  for (int i = 0; i < 3; i++) {
    data[i] = mapf(analogRead(pins[i]), 0, 675.84, -scale, scale);
  }
  if (data[0] >= 300) { //sitting
    pos = 0;
  }
  else if (data[0] <= -200 ) { // laying
    pos = 1;
  }
  else {
    pos = 2;
  }
  vector = sqrt(sq(data[0]) + sq(data[1]) + sq(data[2]));
  vectorFiltBP = filterBP.step(vector, pos);
  absVector = abs(vectorFiltBP);
  vectorFiltLP = filterLP.step(absVector);
}

float Accelerometer::getVector() {
  return vector;
}
float Accelerometer::getVectorBP() {
  return vectorFiltBP;
}
float Accelerometer::getVectorLP2() {
  return vectorFiltLP;
}
int Accelerometer::getPosition() {
  return pos;
}
float Accelerometer::mapf(float x, float in_min, float in_max, float
out_min, float out_max)
{
  return (x - in_min) * (out_max - out_min) / (in_max - in_min) + out_min;
}
void Accelerometer::dump()
{
  Serial.println();
  Serial.print(data[0]); // mapped data x as
  Serial.print("\t"); Serial.print(data[1]); // y as
  Serial.print("\t"); Serial.print(data[2]); // z as
  /*Serial.print("\t"); Serial.print(vector); // vector
  Serial.print("\t"); Serial.print(vectorFiltBP);
  Serial.print("\t"); Serial.print(absVector);
  Serial.print("\t"); Serial.print(vectorFiltLP);
  Serial.print ("\t");*/
  // Serial.println();
}
void Accelerometer::aloop()
{
  update();
}
```

E.3 Band pass Butterworth filter

Header code

```
/*
   Band pass Butterworth filter
   Daniëlle Kwakkel
   Graduation Project Creative Technology
   University of Twente
   February - July 2018
   Based on code from Hinke Bosch
*/
#ifndef FilterBuBp2_h
#define FilterBuBp2_h

#include "Arduino.h"
//Band pass butterworth filter: sitting 8-10Hz alpha1=0.16 alpha2=0.2, laying 9-11Hz alpha1=0.18 alpha2=0.22, order=2
class FilterBuBp2
{
  public:
    FilterBuBp2();
    float step(float x, int p);
  private:
    float v[5];
};

#endif
```

CPP code

```
/*
   Band pass Butterworth filter
   Daniëlle Kwakkel
   Graduation Project Creative Technology
   University of Twente
   February - July 2018
   Based on code from Hinke Bosch
*/
#include "Arduino.h"
#include "FilterBuBp2.h"

FilterBuBp2::FilterBuBp2(){
    for (int i = 0; i <= 4; i++){
        v[i] = 0.0;
    }
}
float FilterBuBp2::step(float x, int p)
    {
      if (p == 0) { //sitting position, 8-10Hz
        v[0] = v[1];
        v[1] = v[2];
        v[2] = v[3];
        v[3] = v[4];
        v[4] = (1.335920515923225659e-2 * x)
             + (-0.70089678118840248455 * v[0])
             + (1.30862793567505475423 * v[1])
```

```
                + (-2.26416434984956360665 * v[2])
                + (1.56535622816321762230 * v[3]);
        return ((v[0] + v[4]) - 2 * v[2]);
      }
      else if (p == 1) { // laying position, 9-11Hz
        v[0] = v[1];
        v[1] = v[2];
        v[2] = v[3];
        v[3] = v[4];
        v[4] = (1.335920119429599012e-2 * x)
                + (-0.70089678118840237353 * v[0])
                + (0.94976030879978579069 * v[1])
                + (-1.97230236060631503037 * v[2])
                + (1.13608549390705593218 * v[3]);
        return ((v[0] + v[4]) - 2 * v[2]);
      }
      else {
        return 0;
      }
    }
```

E.4 Low pass Butterworth filter

Header code

```
/*
   Low pass Butterworth filter
   Daniëlle Kwakkel
   Graduation Project Creative Technology
   University of Twente
   February - July 2018
   Based on code from Hinke Bosch
*/
#ifndef FilterBuLp2_h
#define FilterBuLp2_h

#include "Arduino.h"

class FilterBuLp2
{
  public:
    FilterBuLp2();
    float step(float x);
  private:
    float v[3];
};

#endif
```

CPP code

```
/*
   Low pass Butterworth filter
   Daniëlle Kwakkel
   Graduation Project Creative Technology
   University of Twente
```

```
   February - July 2018
   Based on code from Hinke Bosch
*/
#include "Arduino.h"
#include "FilterBuLp2.h"

FilterBuLp2::FilterBuLp2(){
    v[0] = 0.0;
    v[1] = 0.0;
}
float FilterBuLp2::step(float x){
    v[0] = v[1];
    v[1] = v[2];
    v[2] = (1.820128711054497250e-3 * x)
           + (-0.88302608655343883814 * v[0])
           + (1.87574557170922084914 * v[1]);
    return ((v[0] + v[2]) + 2 * v[1]);
}
```

Appendix F. Evaluation test setup and execution.

Test set-up

The performance of the prototype was evaluated by testing it in a freezer. The prototype was placed inside the pocket and pinned inside the Sheltersuit at the left side of the chest. Various factors were measured and saved by the software:

- Position
- Movement
- Shivering
- FFT of movement
- Changes of position
- Temperature
- Risk level
- Comfort level
- Notification level

Also, the test subject inside the freezer provided feedback on the comfort and notification. The test lasted until the temperature has dropped to the highest notification level (below 19°C) and the test subject started to shiver lightly.

Execution

The test was done in a freezer of -20°C, and lasted 33 minutes. In this time the temperature in the Sheltersuit dropped 9.65°C, from 27.11°C to 18.46°C. From the evaluation test results, it can be concluded that the shivering function of the prototype does not work properly. When the test subject started to shiver, the prototype did not recognise it and thus did not adjust its notification level. To solve this problem, the right values should be found for the thresholds in the software. This could be done by executing the steps done by Bosch [1] again with multiple people wearing the Sheltersuit.

The notification output worked very well. When the subject felt more uncomfortable, the notification level changed. Thus, the temperature thresholds were for this test subject. Also, the different auditory signals were perceived as more urgent as the notification level increased. The notification could be heard well in the silent freezer. However, it was not loud enough to wake someone up. An improvement would be to increase the volume of the notification so it can also be heard with loud environmental noises or when sleeping.

Appendix G. Evaluation interview client 29-06-2018.

An evaluation interview was held with the contact person of the Sheltersuit Foundation. It was executed as a fully structured interview using a Likert scale.

What do you think of the final concept?

*Very bad – bad – reasonably – **good** – very good*

*Very dissatisfied – dissatisfied – neutral – satisfied – **very satisfied***

*(Heel slecht – slecht – redelijk – **goed** – heel goed)*

*(Heel ontevreden – ontevreden – neutraal – tevreden – **heel tevreden**)*

How do you think the final concept is worked out?

*Very bad – bad – reasonably – good – **very good***

*(Heel slecht – slecht – redelijk – goed – **heel goed**)*

Is the result of the worked-out concept what you expected of it?

*Much less than expected – less than expected – as expected – **more than expected** – much more than expected*

*(Veel minder dan verwacht – Minder dan verwacht – Zoals verwacht – **Meer dan verwacht** – Veel meer dan verwacht)*

What is your opinion about the experimental results?

Sufficient for the scope of this project. It would have been better to not only test on females, but include males in the test. We expect different temperatures for both sexes but we do not know if that is true. I would have liked to see that in the experiment. Also, the number of participants could have been higher.

Did you expect these experimental results?

*Very unexpected – **unexpected** – neutral – expected – very expected*

*(Helemaal niet verwacht – **niet verwacht** – neutraal – wel verwacht – helemaal wel verwacht)*

I did not expect the temperature to have different levels of risk. I also did not expect those temperatures to be very close together, just 3°C from each other.

What do you think about the prototype?

*Very bad – bad – reasonably – good – **very good***

*Much less than expected – less than expected – as expected – **more than expected** – much more than expected*

*(Heel slecht – slecht – redelijk – goed – **heel goed)***

*(Veel minder dan verwacht – Minder dan verwacht – Zoals verwacht – **Meer dan verwacht** – Veel meer dan verwacht)*

Is there anything you would improve?

No.

Are there things that I could have done better in the contact with Sheltersuit?

No

Do you have any other remarks?

You have done good research. You have done all the components that should be done in research. It's very good that you managed to get in contact with the final user of the product.

Other questions besides the evaluation:

What level of accuracy would you like the system to have for the temperature measurement?

Since the thresholds of the experimental results are very close together, the accuracy of the temperature is very important. Maybe the temperature sensor should be calibrated to be very accurate. Also, the accuracy of the sensor itself should be accurate on the 0.1°C -0.5°C between the 10°C and 35°C.

How hard is it to add this concept to the Sheltersuit production process?

It is not difficult to integrate an extra pocket in the production process. Also, the sewing of it is not difficult. It will be a challenge to make the design of the module better. Especially looking at making the module more robust, durable and ergonomic.