Social Temperature Sensing

Master's Thesis

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Social Temperature Sensing

THESIS

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Social Temperature Sensing

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Abstract

Subjective well-being in an office space has been an important topic of discussion. While traditional companies focus on measuring the well-being of an employee by factors like one's salary and social standing, research has shown that factors like the office environment, work delegation and office ethics have more effect on an employee's well-being. Thus, this thesis focuses on the concept of facet well-being which deals with the comfort of an employee due to the change in physical environment. A literature study was done where it was found that thermal comfort has the most impact on the well-being of a person in the context of facet well-being. Also, various factors affecting thermal comfort was researched and narrowed down to age, gender, food, clothing and exercise. The aim of this thesis is to answer the main research question i.e., "How can a self-reporting mobile phone application be used to get a measure of perceived temperature?". To answer this research question, a self-reporting hybrid mobile phone application was developed using Apache Cordova and Bluemix, where the business logic of this mobile phone application involved asking questions based on the aforementioned influencing factors. An experiment was then conducted at IBM to get a measure of perceived temperature of their employees using this mobile phone application and verify it's relationship with the influencing factors. In addition, temperature sensors fitted on Arduino boards were used to measure indoor temperature. A novelty in this thesis is the development of a self-reporting mobile phone application which may be the first of it's kind solution to get a measure of thermal comfort of a person in a computer science domain. Also, the requirement of this thesis was that the experiment should be conducted in an uncontrolled environment which would give its results more credibility as it explores thermal comfort in a practical scenario. From the results obtained after the experiment, it was seen that a self-reporting mobile phone application can be used to get the information about the factors that influence perceived temperature of an employee and in the future it can be used to improve his/her well-being.

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Preface

This document is the result of my Master's thesis, which I did at the Web Information Systems (WIS) group at Delft University of Technology in collaboration with Centre for Advanced Studies (CAS) department at IBM, Benelux. First of all, I would like to thank Geert-Jan Houben, Alessandro Bozzon and Robert-Jan Sips for giving me an opportunity to work in a research lab and at the same time work in a professional environment. Dr. Alessandro Bozzon guided me through every step of my thesis making sure that my thesis was sound proof. I am grateful to Robert-Jan Sips for guiding me all the time and helping me to make sure that my work was always within the scope of the thesis. I would also like to thank Zoltan Szlavik (Researcher at CAS, IBM Benelux), for pushing me to work harder and listen to my thought process and help me align them in a proper way. Secondly, I would like to give a special thanks to Dr. Judith Redi (Faculty of EEMCS, TU Delft) for being my second university supervisor and helping me set up my experimental protocol and giving great inputs. Furthermore, I would like to thank Dr. Marco Zuniga for his participation in the thesis committee. And of course I am also grateful to all the employees of IBM, Netherlands who took part in the experiment and especially Sarah Bashirieh for helping me out in setting up the experiment. Lastly, I would like to thank my friends and family: Niké Jenny Bruinsma in helping me with UX for my mobile application; Livia Teerenstra during the analysis of my data; Sanket Suman Dash for proofreading my thesis; my sister Sharanya Ravindra for checking coding standards and peer-reviewing my code and my parents and grandparents for being my support system through the whole process of my Masters.

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Contents

List of Figures

Chapter 1

Introduction

1.1 Background

In this section, the context of the thesis is explained to give a better understanding of how the research question was framed.

1.1.1 Subjective Well-Being in an Office Environment

New age companies across the world are working on strategies for building and sustaining a talent pipeline, which is predominantly based on employees' well-being. Although traditional companies invest a lot in hiring and maintaining the talent crop of the company, organisational aspects such as working conditions, leadership and inclusion are often overlooked time and again leading to disengagement of the employee that lead to lower employee retention rates.

Research done by Zelenski et al. [27] has shown that user perceptions are integral component of workplace satisfaction. Furthermore, the organisations that are able to exploit this advantage and maintain long-term well-being at the workplace can increase and sustain productivity while reducing complaints and absenteeism. Hence, it is important to consider employees' well-being as a crucial factor along with good working environment being directly dependent on the profitability of the company.

Employee well-being in simpler terms can be referred to happiness of the employee. Since most researchers refrain from using the term happiness as it lacks scientific precision the term Subjective Well-Being (SWB) is preferred. SWB is an inclusive term that comprises of multiple empirically distinct constructs [27]. SWB refers to how people experience the quality of their lives which includes both emotional reactions and cognitive judgements. Psychologists have defined SWB as a combination of life satisfaction and the relative frequency of positive & negative effect.

According to Hsiao et al. [8] well-being of a person can be classified into three domains. The first, being context free which is related to person's chronic state of well-being, the second being domain specific well-being which covers feelings in a targeted domain and lastly facet specific well-being. This thesis addresses one specific area of employee's well-being in the context of subjective well-being(SWB) or happiness which is the facet specific well-being.

As defined by Sharif et al. [24], facet specific well-being of an employee at the workplace refers to; how satisfied employees are with their work. Facet specific well-being of an employee can be categorised in two ways: first being well-being due to change in physical environment and second being social well-being. Social well-being refers to factors like one's social standing, designation and one's salary, which are variables easy to quantify and control as mentioned earlier. On the other hand, well-being due to change in physical environment can be categorised into sub-factors such as thermal comfort, acoustic comfort and lighting comfort. However, these variables are hard to quantify and control.

To further narrow down the scope of this thesis, emphasis is given on well-being affected due to changes in physical environment such has thermal, acoustic and light comfort. A literature survey conducted by Frontczak and Wargocki [5] has identified that thermal comfort is the most influential factor for human comfort when compared with other aforementioned factors. Which is in line with other publications such as [21] which have concluded that outdoor climatic variations including seasonal changes have greater importance when compared with visual and acoustic comfort or good air quality. Thus, the thesis focuses on thermal comfort as part of evaluating SWB of an employee in an inclusive enterprise.

1.2 Motivation

In a competing job market, employers try to retain the best talent pool by providing them with 'incentive'. As argued in [25] factors such as employee's well-being and inclusion are more important than variables such as designation, size, and even pay though these variables are easy to quantify and control.

From the previous section it can be deduced that the most important type of well-being affected due to change in physical environment is thermal comfort in the context of facet well-being. Although research in this field has been done by social scientists, an effective thermal comfort system is still lacking in many office spaces around the world. This is substantiated by a case study done in the Amsterdam office of IBM, Benelux where the complaint database of the company was analysed and search query performed to identify the problems faced by the employees. The results of the search are shown in figure 1.1.

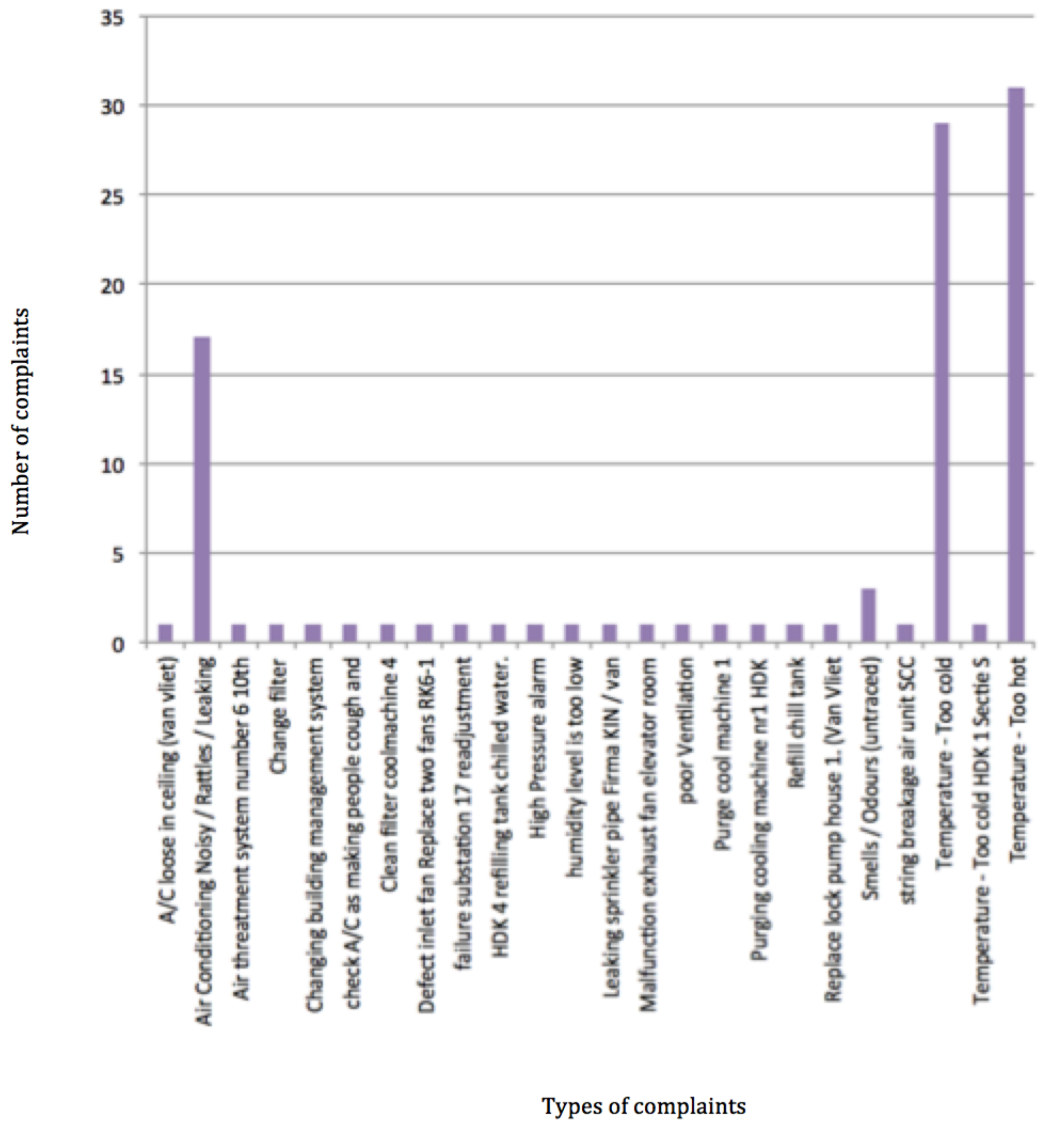

Figure 1.1: Complaints of IBM employees

It can be seen in the figure 1.1 that most of the complaints are related to thermal comfort. If we combine the two categories of "Temperature-Too hot" and "Temperature-Too cold", we get more than 50% of complaints just on thermal comfort (see Appendix A). So, based on the literature study[5, 7, 21] done and the above case study it can be concluded that thermal comfort is an important issue and has to be investigated in detail to reduce the inconvenience caused to employees in a office space.

With the aim to find a solution to this issue the common approach has been a social science way. Instead, it is the goal of this thesis to find a solution using a computer science approach. This approach allows us to have a measure of the perceived temperature from each individual at different times during the day, which would give us an idea about their thermal comfort. Also, it could be used to verify if a person can reasonably self-report his/her perceived temperature. To demonstrate this a self-reporting mobile application is developed and the data gathered by using this mobile application during an experiment is used to test different hypothesis. Although, this approach has not yet been explored, it has the potential to be more practical and realistic in solving the issue.

1.3 Research Objective

The main research question through out this thesis is "How can a self-reporting mobile phone application be used to get a measure of perceived temperature?"

To answer this main research question, using the novel approach of applying computer science means, a self-reporting hybrid mobile phone application was built. The aim of this application is to provide questions based on the factors that influence the user's thermal comfort. These influential factors will be introduced and discussed in Chapter 2: related work. The next chapter covers the details of how the mobile phone application is built and how the questions based on the influential factors are incorporated in it's business logic. The application allows each individual to report their perceived temperature and their activities during the data. This application can then be used in an experiment to test the thermal comfort of employees in a workspace as shown in Chapter 4.

For this thesis, the experiment was conducted in an IBM office where the employees who participated were asked to download the mobile phone application through which they were asked questions during the course of the day at fixed intervals. The data collected from the experiment was to form a data set for analysis by different statistical tools to arrive at conclusions based on the relationship between perceived temperature and it's influencing factors to answer the main research question. These conclusions help not only in improving building management systems but also increasing the overall well-being of an employee.

1.4 Outline

This thesis is outlined in five chapters, including this first introductory chapter. Chapter 2 then focuses on exploring the related work performed in the scope of thermal comfort by looking into different experiments conducted in this domain and finding out the influencing factors for thermal comfort in an office space. Next, Chapter 3 covers in detail about the design and building of the self-reporting mobile phone application. Chapter 4 consists of methodology to design and implement a suitable experiment in IBM workplace and the findings of this experiment along with the analysis. The final chapter, Chapter 5 concludes the thesis with discussion and future work.

Chapter 2

Related Work

2.1 Introduction

This chapter is divided into three sections. Section 2.2 focuses on discussing previous works that were done to identify; thermal comfort as the most influencing type of facet well-being. Followed by section 2.3 which covers the related experiments performed in the field of thermal comfort and finally section 2.4 discusses the factors that have been identified to influence thermal comfort or perception of temperature of a person.

Few of the experiments discussed in the section 2.3, have similar objectives to the experiment conducted as part of this thesis. During the discussion of the previously conducted experiments, the topics covered are: aim of the experiment, experimental protocol and results of the experiment. These topics are covered to assure that the experiment conducted as a part of this thesis is unique yet inspired from previously conducted experiments.

2.2 Thermal Comfort

In the paper by Frontczak and Wargocki [5] includes a literature survey aiming at exploring how the indoor environment in buildings affect human comfort. The indoor environmental conditions that were surveyed by them which had influence on human comfort were thermal, visual, acoustic and air quality comfort. In this literature survey one of their aims was to determine which of the above conditions were ranked by building users as being the most important determinant of comfort. This literature survey was therefore an important starting point to further narrow down the focus of the thesis. The results of the survey showed that building users considered thermal comfort to be the most important parameter influencing indoor comfort.

This survey [5] also tried to find out to which extent other factors unrelated to the indoor environment have an influence on human comfort in an indoor environment, such as: individual characteristics of building occupants, building-related factors and outdoor climate including seasonal changes. Also it was found that factors such as age, gender and country of origin had an influence on indoor thermal comfort even though they were unrelated to the indoor environment. Throughout this thesis thermal comfort is defined as "that condition of mind which expresses satisfaction with the thermal environment" which means that when a person is thermally comfortable, the person will wish to feel neither warmer nor cooler when asked about thermal state and preference. Visual comfort is defined as "a subjective condition of visual well-being induced by the visual environment". This visual comfort is characterised by other parameters also such as: luminance distribution, luminance and its uniformity, glare, colour of light, colour rendering, flicker rate and amount of daylight. Acoustic comfort is defined as "a state of contentment with acoustic conditions". The quality of the sound environment is linked to numerous physical parameters, which include both the physical properties of sound itself and the physical properties of a room.

Similar to the above survey, a study was conducted in the year 1988 by Höppe [7], which also concluded that among different indoor environmental conditions/factors thermal comfort is preferred/given greater importance compared to visual, acoustic and air quality. Yet another literature study conducted by Rothe et al. [21] which was aimed on understanding user needs and preferences with regard to their physical work environment and how to steer on employee satisfaction and labour productivity in workplace change process. In this study they compared employees of two different countries. They explored similarities and dissimilarities in work environment priorities of Finnish and Dutch office users. As with globalisation, workplaces today have a very diverse set of employees with different nationalities and cultures. So, when this study was conducted, cultural differences and their impact on user needs in the decision making process.

During this study [7] which was conducted in the year 2009, web questionnaires were used to collect data. The survey assessed the perceived importance of various work environmental attributes, including location of the workplace, services, characteristics of the building and the work space. In Finland the data was gathered in spring 2009 and in Netherlands in January 2009 until December 2010. In Finland around 4275 employees took part, from 21 organisations in the Helsinki Metropolitan Area. In Netherlands 9 organisations took part and near about 3393 participants took part.

The results of the survey can be seen in the bar graph shown in figure 2.1.

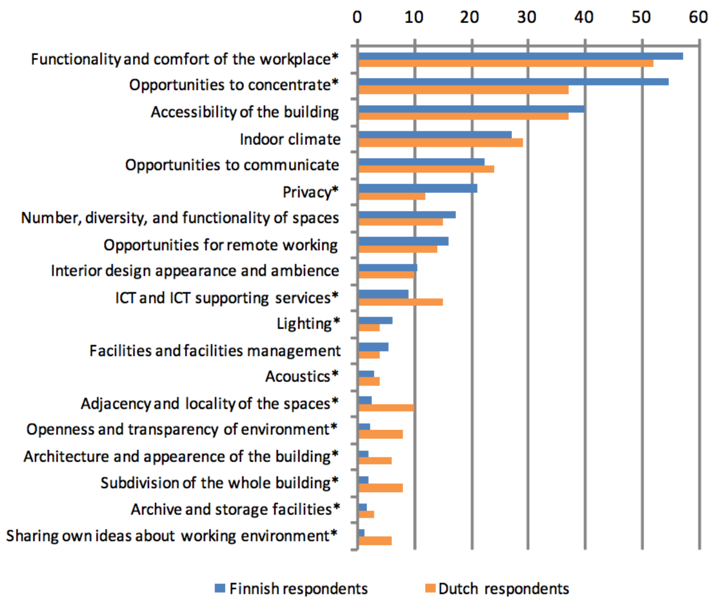

Figure 2.1: Comparison of attributes between Finnish and Dutch users

In figure 2.1 one can see that out of 19 attributes compared between Finnish users and Dutch users, indoor climate ranked 4^{th} in most important attribute in a work environment.

Another study was conducted way back in 1989 by Mølhave [17] on sick buildings and other buildings with indoor climate problems. In this study the conclusion that was drawn is that the temperature is the biggest factor among all the other environmental conditions.

A paper by Sanjog et al. [22] on the indoor physical environment evaluated from an ergonomic perspective was also found to be related. In this paper ergonomics is defined as "the scientific discipline concerned with the understanding of the interactions among humans and other elements of a system and the profession that applies theoretical principles, data and methods to design in order to optimise human well-being and overall system performance". And the ergonomic design of work place/environmental ergonomics of the physical workplace refers to the creation of ambient conditions that are appropriate, acceptable and does not compromise on work performance or worker's health. Acceptability and performance of the occupants are affected by various factors such as light, noise, air quality and thermal environment. The conclusion drawn from the study was similar to all other previous studies, i.e., with an ergonomic perspective, thermal comfort is the most preferred parameter amongst the employees.

Lastly, in a recent study by Maastricht university [15] it was identified that most of the building management systems are gender biased, which means the they are built considering male metabolism rate. Metabolism rate of an employee is directly proportional to his/her thermal comfort which is one of the main factors in indoor environment. In the following chapter we illustrate the fact that males and females have different perception of indoor environment, thereby making the aforementioned assumption by building management systems invalid.

Hereby the literature study concludes that thermal comfort is the most important factor to judge subjective well-being.

2.3 Temperature Perception

From the previous section it was identified that thermal comfort is the most important factor in indoor environment and has a strong influence on subjective well-being. This section covers previously conducted experiments in the field of thermal comfort. The point of focus is on the: aim of the experiment, experimental protocol and results of the experiment.

2.3.1 Effect on Productivity

In the experiment conducted by Lan et al. [12] they tested the effect of indoor air temperature at 17 °C, 21°C and 28°C on the productivity of 21 participants who voluntarily took part in an laboratory experiment. Among the 21 participants that volunteered for the experiment 6 of them were female and rest of them were male. The experiment was conducted in a low-polluting ordinary office, where the participants were asked to sit at seven separate workstations where each workstation consisted of a table, a chair and a personal computer. The temperature of the room was controlled during the experiment with the help of an air-conditioner. The experiment was conducted on three different air temperatures i.e., 17°C, 21°C and 28°C. In these three different air temperatures the productivity of the volunteers was studied. The experiment was performed only for three days. Each day the experiment was conducted for 8.5 hrs from morning to afternoon.

The 21 volunteered participants were separated into 3 groups, where each group had 7 participants. Each group was exposed to all the three temperature conditions in one day. Two pauses were given between the three temperature conditions one was from 11:00 - 12:30, which was during lunch time, and the other being from 14:30 - 15:30. During the lunch hour the participants were given Chinese food which was same for all the days. During the second break the participants were asked to go out of the office and were allowed to consume non-carbonated water and biscuits which was for free. During the experiment each temperature condition was maintained for a period of 120 min. At first, the participants entered the office reading book or playing games for near about 40 min to adapt to the indoor environment. During this 40 min period, physical parameters of the volunteers were measured in the office space. After the exposure, participants spent about 60 mins on performing various computerised neuro-behavioural tests and assessing the workload. After completing the tests, participants were asked to assess their general perception towards the environment, emotions, well-being and their motivation towards work. They were given a questionnaires to assess the above values, which took near about 10 mins to fill in. After this the physiological parameters of one of the seven participants was measured for 10 mins. During the experiment the participants were instructed not to leave the room until the 120 mins session was over. Prior to taking part in the experiment, participants were asked to participate in the neurobehavioral test battery for 1 hour. In this session they were instructed on how to fill out the answers to the questionnaires.

After the experiment was completed following conclusions were drawn: Participants showed low motivation to work and their EEG decreased when the environment became moderately uncomfortable. Warm discomfort led to increase in LF/HF value of heart, which negatively affected participants' well-being. The added workload due to neurobehavioral tests increased in the moderately uncomfortable environment and participants had to exert more effort to maintain their performance with the increase of workload. Thermal discomfort caused by high or low air temperature had negative influence on office workers' productivity and the subjective well-being.

On similar lines one more experiment was conducted by McCartney and Humphreys [16]. Their aim was to establish a link between thermal comfort and productivity of office workers and present some limited conclusion based on a European field study of office buildings.

In this experiment, the occupants were asked to assess their own "perceived" productivity on a subjective rating scale. The results that were obtained from these votes were then compared to measurements of indoor environmental conditions to establish a link to thermal comfort. According to the previous studies conducted by this paper they have shown that the perceived level of productivity tends to fall as the perceived environmental conditions tend to move away from an "optimum" value. The strength of this approach is that it is not task dependent and is relevant to everyday office practice. As long as all occupants assessed in the same study vote on the same scale, results can be compared directly. However, the weakness is that this method is not an unbiased, objective measurement and therefore any conclusions that drawn are somewhat tenuous.

The results of the experiment showed that perceived productivity does not vary with indoor air temperature. This is contrary to some research views that suggest that either a substantial increase or decrease in temperature will result in a fall in productivity. It could be seen that whilst perceived productivity is not influenced by actual temperature itself, it is influenced by "perception" of temperature, i.e. thermal comfort. The results add some weight to Adaptive Comfort Theory as they suggest that people may report no change in productivity at high or low temperatures providing they have adapted sufficiently to maintain comfort levels.

In this section we address one final experiment conducted by Cui et al. [3] on influence of indoor air temperature on human thermal comfort, motivation and performance.

The experiment was carried out in an artificial climate chamber, in which participants sat at four workstations, each consisting of a table, a chair and a computer. The air was supplied through perforated ceiling and returned from the floor.

A total of 36 Chinese adults (18 males and 18 females) were recruited to participate in the experiment. The participants were all university students (average age 22.3). Before entering the chamber, subjects were required to wear uniform clothes, containing long-sleeved shirt, long thin trousers, underwear, socks and slippers. All subjects were healthy and they were required to have a good rest before the experiment. The participants were paid a salary for participation in the experiment at a fixed rate per hour with no additional bonus. All subjects successfully completed experimental sessions.

A total of five conditions were designed and they were all steady-state conditions (22°C, 24°C, 26°C, 29°C, 32°C). The subjects were divided into Group A and Group B. Group A contained 20 subjects and Group B contained 16 subjects. The number of male and female was equal in both groups. Subjects in Group A participated in all five conditions and for comparison Group B was exposed to only one condition (26°C). The purpose was to find out whether learning effect would be affected by temperature

Each subject had to participate for five times under the same temperature condition (26°C). The subgroup sequence of first experiment was randomly arranged and this sequence remained the same in the following four experiments conducted. In both Group A and Group B, the experiment time and the interval between two experiments for each subgroup was the same, in order to reduce the influencing factors as much as possible. If a subgroup was arranged for the first experiment from 9:00 to 11:30 in the morning, they would always had experiment in the same time period in the following four experiments. The exposure interval for Group B was one day and two day for Group A because one day interval was not enough for all five subgroups to take experiments.

The results of the experiment showed that temperature had a significant effect on learning. The participants felt a certain amount of discomfort due to frequent change of temperature and thermal discomfort slowed down their learning speed. It was also seen that warm discomfort environments were more harmful than to cold discomfort environments to both motivation and performance of the participants. An environment between slightly cold to neutral was recommended because the performance change was not that significant. The final conclusion drawn was that the improvement in thermal comfort made people more motivated and performance would increase due to higher motivation.

2.3.2 Effect of Age and Gender

The aim of the experiment conducted by Schellen et al. [23] was to test the effect of a moderate temperature drift on physiological responses, thermal comfort and productivity between eight young adults between age 22-25 year and eight older adults between the age group 67-73 years. This experiment was conducted in a special room called climate room at the laboratory of the unit Building of Physics and Systems at TU Eindhoven, Eindhoven. It was conducted in this room because of the possibility to control air temperature and relative humidity of the room accurately. The room consisted of well-insulated walls with a low thermal mass; which meant that that wall temperatures of the room followed the air temperature near instantly. To further add the mixing of the air, a ceiling fan was also installed during the experiment.

The temperature of the supplied air was controlled through a PID controller. Sixteen volunteers were recruited to participate in the experiment. All the recruited volunteers were men, healthy and were under no medication as it might alter the cardiovascular or thermo-regulatory responses to the temperature changes. The participants were made to sit in the climate room in two conditions S1 and S2 that differed in indoor climate condition. The order of visiting the room was altered between the participants. Which means if participant 1 first went to S1 and then to S2, then participant 2 first went to S2 and then to S1 and similarly participant 3 first went to S1 and then to S2.

S1: In session S1, a steady temperature of 21.5°C was maintained. The session S1 was conducted for 8 hrs. The temperature at 21.5°C corresponds to a neutral thermal sensation.

S2: In session S2, a transient condition was maintained. The duration of this session was also 8 hrs, but temperature range was between: 17°C - 25°C.

Most of the experiments conducted before this experiment focused on the effects of temperatures warmer than neutral. But in this experiment the study focused on temperatures colder than neutral as well. The minimum temperature of 17°C was set to avoid shivering to any of the participants.

Prior to the measurements, the participants were asked to perform light exercise until skin vasodilatation occurred, to ensure all participants entered the climate room in an equal thermal state. Vasodilatation was assessed by the skin temperature difference between forearm and top of the forefinger. After entering the climate room, the experiment was started with an acclimatization period of 30 mins. During this period, the skin temperature sensors were attached, and their characteristics (height, weight, and fat percentage) were determined. Furthermore, they received an instruction regarding the use of the questionnaires that they had to fill in two times per hour. During the experiments, the participants were instructed to wear standardised clothing, consisting of a cardigan, jogging pants, thin T-shirt, underpants, and socks and shoes. Two times per hour, the volunteers were asked to fill in a questionnaire that included a continuous 7-point thermal sensation interval scale, scales to assess the acceptability of the thermal environment, and visual analog scales (VAS) to assess adverse perceptions and the perceived indoor environment. There were two types of questionnaire one was to assess self-estimated performance and another one was to assess perceived stress. The tasks that the participants were asked to perform were very similar to typical office tasks such as: text typing and addition. The questionnaires and the office tasks were both presented in Dutch language to the participants, which they were asked to do fill in online.

For all three different skin temperatures, the difference between young and elderly was quite significant. The majority of the local skin temperatures of the elderly were significantly lower than the skin temperature of the young adults. During a constant temperature level and equal clothing level, elderly prefer a higher ambient temperature in comparison with their younger counterparts, which was in line with previous studies.

Another field study was conducted by Indraganti and Rao [9] on effect of age, gender, economic group and tenure on thermal comfort. The field study was conducted with Indian standards of thermal comfort which was between the temperature of 23°C and 26°C for all types of buildings across the nation. The field study was conducted in naturally ventilated apartments in the year of 2008, where over 100 subjects. The research was conducted in the summer month of May and monsoon months of June and July. The dataset constituted of 35 male subjects and 64 female subjects. Which were in the age group of 17 - 69 years with males, average age being 40.14 and for females, average age being 42 years. The subjects were handed out an questionnaire which had six sections: apartment building and flat identification; background information; current clothing; activity level; thermal comfort responses and adaptation methods. Thermal acceptance was measured by asking the people following question "Can you accept the present hot environment or not?" and to measure the indoor environment a set of calibrated digital hand held instruments were used.

When the effect of age on thermal comfort was tested it was seen that thermal sensation of older people was slightly lower than that of the young, with a lower mean preference vote. It was seen that smaller percentage of older subjects did not accept the environment, despite voting on the warmer side of sensation scale. Older subjects were more tolerant of the thermal environment. Next test was conducted to see the effect of thermal sensation on gender. It was seen that the results showed a weak correlation and a higher percentage of women 74% had voted that they were uncomfortable with the environment, where as only 69% of the men considered the same conditions comfortable. However, overall it was seen that women preferred a warmer environment than men. On the lines of gender difference in thermal comfort, Karjalainen [11] conducted a study on the topic of gender differences in thermal comfort and use of thermostats in everyday thermal environments. In the study a quantitative interview survey was conducted on a total of 3094 respondents in a controlled environment. The study was carried out in Finland and they considered thermal environments: homes, offices and a university. The interviews were performed in early wintertime, in the month of November and December. The controlled environment which was created for the experiment simulated real use of thermostats. The user interfaces were given on a printed sheet which was similar to those of any normal room thermostats. Two types of papers were given to each user. The temperature scale was relative, so the user marked the changes they preferred to make in the current room temperature. Along with the temperature preference the participants also wrote their age and gender. During the experiment, the room air temperature was measured with a Fluke 52 digital thermometer just before the papers were given out to the participants. The participants in the tests were university students. Most of whom were in the age between 19 and 25 years of age and were made to sit in an auditorium.

In the interview survey, it was found that males are more satisfied with room temperatures. Statistical analysis showed statistically significant differences between the genders. The difference between males and females was more remarkable in the office environment than the home environment. It was observed that females feel uncomfortably cold and uncomfortably hot more often than males.

2.4 Influencing Factors

After identifying that temperature is the factor which has the most impact on employee's well-being in office space, a deeper analysis was needed to find out the factors which affect thermal comfort of an employee in a work-space.

The first step in identifying the factors that have an influence on temperature perception was by considering all the daily activities that an employee participates in before coming to office and also during office hours. To accomplish this goal, a story-line was drawn for all the daily activities performed by the employee. Then a survey was done to see what factors and activities have an observable and proven impact on perceived temperature, which is explained in detail below.

The following factors were found to have an impact on perceived temperature:

1. Gender
2. Age
3. Food
4. Exercise
5. Clothing
6. Caffeine

Below we will discuss how each factor individually influences human perception towards temperature and how the related study conducted for each factors has been used as the basis for the experiment conducted in IBM. In the previous section we have already discussed on the experiments conducted on how different genders and age group feel a given temperature. So, we focus on rest of the factors which are food, exercise, clothing and caffeine.

2.4.1 Food

Brobeck [2] conducted studies on regulation of energy exchange based on two hypotheses. The two hypotheses are: the two important sources of heat for an organism are food and work, and the amount of food eaten or muscular activity undertaken is determined in part by the need for heat and the ability to lose heat to the environment. Even though this experiment was conducted on male rats, the same experiment was conducted by Johnson and Kark [10] concluding that the same behaviour is applied for humans also.

In the experiment conducted by Brobeck [2] they considered sixty male rats from the age of 4 months to the age of 2. These rats were classified according to body weight into groups of 6 and then were housed for 17 days in community cages at a temperature of 82-84°F. Constant supply of food and water was provided to the rats. Each group was subsequently used for 1 to 3 experiments involving exposure for 18 hours to a controlled environmental temperature. The range of temperature chosen for the experiments was from 65 to 97 °F. At 11:00 AM the next day, the rats were weighed, their body temperature was again measured and food and water intakes were also determined.

The results of the experiment showed that food intake varied with the environmental temperature; it was low at high temperatures and high at low temperatures, while during exposure to cold.

Based on the results of this paper in our experiment we try to see how eating habits of a person is related to their temperature perception. In the experiment, we ask people what did they eat for breakfast and lunch and then ask how to do they feel about the temperature. For example, when we ask them about breakfast we give them 4 options to choose which are: just Coffee, light breakfast(consisting of fruits), normal breakfast(which comprises of sandwich) and heavy breakfast same goes for lunch also.

Also, in our experiment we would like to see if we can replicate the observations using a self-reporting mobile phone application; made by Johnson and Kark [10], which is, does our food intake influence our perception towards thermal comfort .

2.4.2 Exercise

In this section we show the research work that has been done in establishing a relationship between exercise and core body temperature. We would like to establish a hypothesis based on the existing research work that when a person does any exercise his perception towards temperature is influenced.

In the paper by ÖConnor et al. [19] they show that because of doing exercise there is an increase in core temperature. But the main focus of the experiment was to prove that because of this increase in core temperature results in a disruption of a behavioural measure of sleep. In the experiment they recruited college students to participate. The experimental protocol included that the participants should be between the ages of 18 to 35, they should be moderately physical active as determined by a standardised interview, no physical contraindications to completing a maximal exercise test as determined from a written medical history, freedom from major physical or mental health problems as determined from the medical history, freedom from the use of medications as determined from the medical history and freedom from major sleep problems.

During the experiment it was found that after conducting any form of exercise, there was an increase in core body temperature and it was independent on the time period of the exercise being performed. The exercise intensity by time interaction was not significant.

In another experiment conducted by Febbraio et al. [4] they tested the effect of blunting the rise in body temperature on exercise metabolism. For the experiment they choose seven endurance-trained men who cycled for 40 min in an environmental chamber at either 20°C and 20% relative humidity. Trails of the experiment were conducted in random order which were at least 1 week apart from each other.

The results of the experiment were similar to the experiment conducted by ÖConnor et al. [19] which is, any form of exercise results in increase in core body temperature and metabolism rate which in turn is directly proportional to perceived temperature.

Based on the experiments conducted by ÖConnor et al. [19], Febbraio et al. [4], Lim et al. [14] we can say that exercise has a big influence on core body temperature, metabolic rate and perception towards temperature. From the above mentioned experiments we can establish that irrespective of type of exercise or duration of the exercise it has an influence on perception towards temperature. Type of exercise is only required when we want to know by how much the core body temperature has increased and by how much factor the persons affinity towards temperature has increased, which is beyond the scope of the experiment conducted by us. We just want to know if the persons perception towards temperature is influenced because of exercise or not. Hence, in our experiment we just ask our participants that if they performed any form of exercise before coming to office.

2.4.3 Clothing

In an experiment conducted by Morgan and de Dear [18], to test the adaptive thermal comfort model which links indoor comfort temperatures to prevailing weather outdoors, shifting them higher in warm weather and lower in cool weather. Here they examined clothing behaviour and its relationship with thermal environments in 2 different indoor settings located in Sydney, Australia.

The first setting was of a suburban shopping mall, and the second setting was of a call-center office. In the second setting a strict business attire dress-code was followed from Monday to Thursday and on Fridays employees were free to wear casual clothes. One of the aspects of the experiment was to test how people change their way of clothing based on temperature and based on the observation a hybrid ventilation building was proposed. In this experiment they found that a key behavioural mechanism that increases thermal comfort indoors is by adjustment of clothing insulation levels.

Havenith et al. [6], collected data on the climate, clothing and metabolic heat production. This paper discusses the representation and measurement of clothing parameters and metabolic rate in the context of Predicted Mean Vote (PMV). Predicted Mean Vote (PMV) is a model which is very popular in building management systems for assessment of thermal comfort in buildings. In this paper they show that the effects of body motion and air movement are so big that they must be accounted in comfort prediction models to be physically accurate. However effects on the dry heat exchange are small for stationary, light work at low air movement. Although for metabolic heat production, it was concluded that for precise comfort assessment a precise measure of metabolic rate it needed.

Since the paper by [6] focuses on the physical thermal comfort system we are not going to describe in detail their whole model and calculations involved in the model. The important note we take from the model is that clothing and metabolic heat production are very crucial in understanding thermal comfort. If one wants to build any kind of system for thermal comfort they have to consider persons clothing and their metabolic heat production.

From the above experiments one important conclusion that can be drawn is that when trying to understand or calculate thermal comfort we have to consider what a person is wearing.

For that matter in our experiment, we ask people what kind of clothing they are wearing inside the office space. We want to know how a given temperature is perceived between people wearing thermal clothes and people who are not wearing thermal clothes. When we ask the question to participants we give them two choices as answer, one with no thermal clothes and the other one with thermal clothing.

2.4.4 Caffeine

In this paper by Vallerand et al. [26] they conducted an experiment with an objective to see if caffeine content in humans shows any impact on cold-tolerance.

The experiment tested the influence of caffeine on cold tolerance in nine healthy young male subjects who were subjected to exposure to cold air for 3hrs at 10°C. It is generally considered that humans are tropical animals who have relatively poor resistance to cold. In this study nine healthy young male volunteers took part in the study. Each of the participant was studied by a physician and once they were approved by the physician, the participant was allowed to take part in the study. As a mandatory part of every experiment the participants were clearly explained the nature and purpose of the experiment. Since a part of the experiment was to expose yourself to cold air, before the actual experiment the participants were allowed to familiarise themselves to 1h of cold air.

The experimental protocol that was followed was: Two cold exposure tests were conducted that was 3h at 10°C. These two tests were performed with a gap time of 1 week. During the test, participants were asked to wear bathing suit. As part of the protocol the participants were asked to refrain from alcohol and exercise, also fast for at least 12-14hrs before the test and also caffeine for 24hrs before the test. After the test it was concluded that that ingestion of caffeine improves cold tolerance in humans, resulting in significantly warmer body temperature as well as a significantly lower body heat. Another paper by [1], inspected the effect of caffeine on metabolism which in-turn influences core body temperature. The experiment concluded that the caffeine increases resting metabolic rate in individuals, which increases heat storage and internal body temperature which in short affects in thermal comfort.

2.5 Findings and Discussion

To summarise the chapter, from first section we can conclude that in indoor environment the three main components are thermal comfort, acoustic comfort and visual comfort. Amongst the three, thermal comfort stands out the most. By this, we mean people are more concerned with thermal comfort over other factors in an indoor environment. From the second section, where we discuss about the experiments, one conclusion can be drawn is that all the experiments conducted so far have been executed in a controlled environment and the final section gives us an idea about what factors would contribute to thermal comfort of people in an indoor environment. However all these experiments were conducted in the sphere of social science.

As computer scientists, we decided to take a novel approach for this thesis which would include designing a self-reporting mobile phone application which would work as a medium for participants to report their thermal comfort in an office space. This self-reporting mobile phone application would include questions based on the factors influencing the thermal comfort of an employee. This brings a novelty to this thesis. Another novelty in the experiment conducted in this thesis is that experiment was conducted in an **uncontrolled corporate environment** in other words **measurement was done in the wild**. Such a setup would give more credibility to the results as it is done in a practical scenario where there are no restrictions on the participants or the environment.

The next chapter deals with the design and build of the mobile phone application and the sensors.

Chapter 3

Implementation

3.1 Introduction

To analyse if the factors identified in the previous chapter have an influence on perception of temperature of an employee in an office space, an experiment was conducted using a mobile phone application. A mobile phone application was built because of its ease of usability from the point of view of the participants and also because it is less obtrusive. It was necessary for this mobile phone application to be a self-reporting application because, this allows participants to report the answers themselves to the questions provided in the application, which have an influence on their own thermal comfort.

Based on the type of developmental method of building the mobile phone application, applications are divided into two types: either Native mobile phone application or Hybrid mobile phone application. The native mobile applications are written for a single type of operating system (OS), while hybrid mobile application allows deployment on all types of OS. A hybrid mobile phone application was thus chosen to build as it would allow more employees with any type of smart-phones to take part in this experiment. The hybrid application for this thesis was build using: Cordova Framework for front-end, IBM Bluemix for back-end and postreSQL as the database.

Based on the conclusions made in the previous chapter, this chapter covers the implementation and design choices involved in building the mobile phone application. After which the following chapter will discuss the details and results of the experiment in which the mobile phone application was used.

3.2 Mobile Phone Application

This section covers the topic of: system architecture, design choices, frontend of the application, backend to the application, business logic, user interface and challenges. To thereby discuss and describe the decision process behind the resulting mobile phone application.

3.2.1 System Architecture

The mobile phone application is structured as a multi-layered application consisting of three layers: presentation layer, business logic layer, and data layer as shown in the figure 3.1 [13].

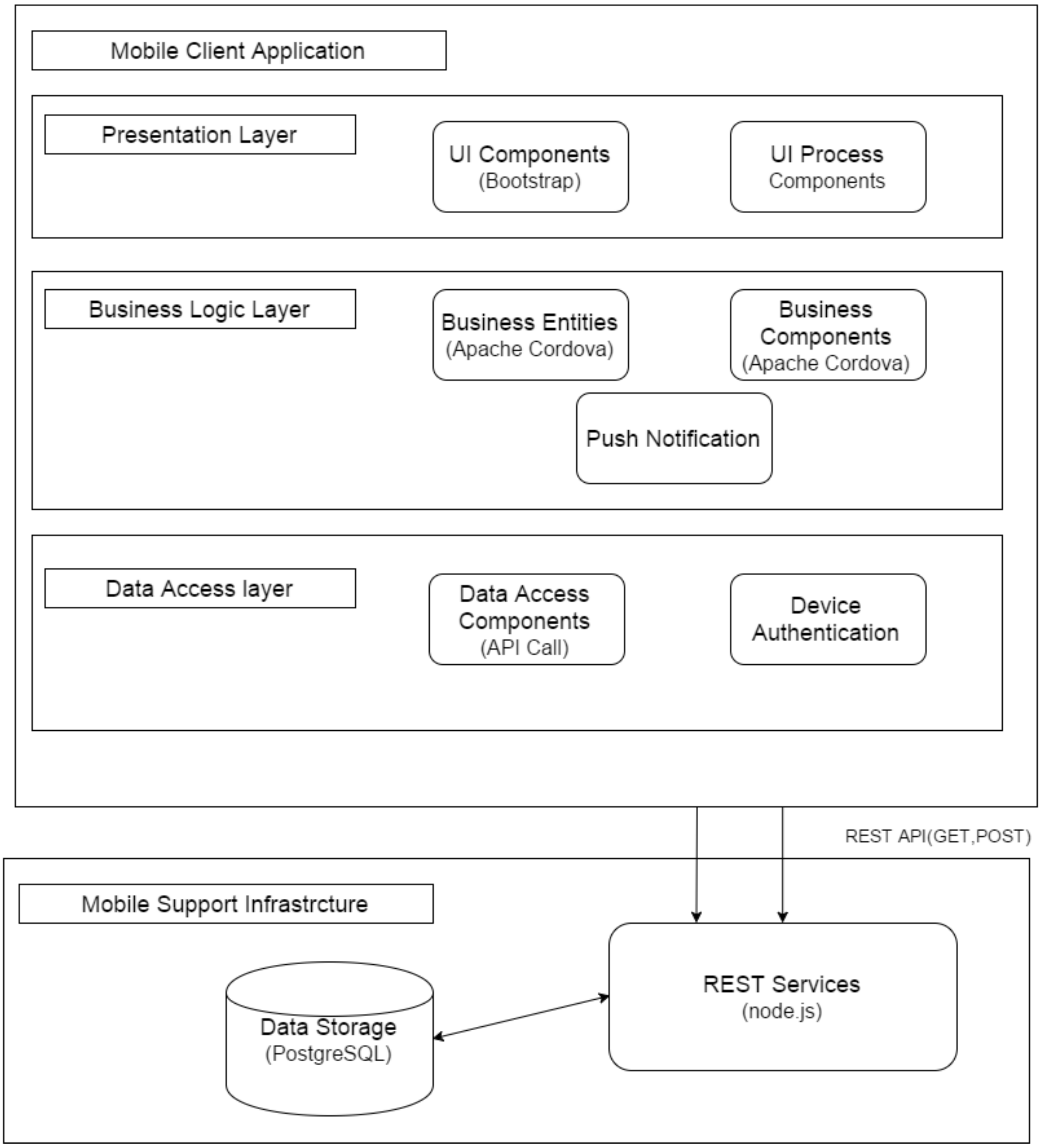

Figure 3.1: Mobile Application Architecture

The presentation layer consists of building the user interface (UI) components and task flow. A Bootstrap 3 framework was used to design this, because of its responsive feature[1].

The business logic layer consists of all the questions that are to be asked to the participants of the experiment. It also consists of a feature to unlock some questions only after a given time. To identify each user of the application, the participant's smart-phone device id was used. And to properly track their process of completing the questions within the application a record was kept at all times including the information of, which questions were answered and what is the next question for them.

The data access layer consisted of the components that were used to connect to the backend. The database was accessed using REST API calls.

3.2.2 Design Choices

The system architecture was designed in such a way that the application can be extended easily according to the requirements. Following paragraphs describe the design choices that were made when building in the application.

Extensibility

Extensibility refers to the ability of the existing system to extend the number of questions asked, make changes in available themes, implement new strategies to ask questions etc. Extensibility would allow a future developer to introduce new features and improve the current implementation. This approach thus saves effort and time for a future developer, who otherwise would have to implement the application from scratch. The chosen solution for achieving extensibility was by providing the business entities open for extension but closed for modification, which is based on open/closed principle (OCP) of programing, which was followed during development of the mobile phone application.

Scalability

Scalability can be defined as the ability of the application to be able to be used by multiple participants at the same time. This feature ensures that participants can concurrently use the application. Also, another way of defining scalability can be the ability of the application to be available on-demand. In other words, if during the initial experiment the target group had 20 participants, in future it should be able to handle more than 20 participants at the same time. It was therefore seen as a requirement for the application to be able

[1] http://bootstrapdocs.com/v3.0.3/docs/css/

to scale according to the number of participants. This was achieved by using Bluemix backend which has a feature of auto-scaling policy.

3.2.3 Frontend of the Application

For the frontend development of the application the Apache Cordova framework and the Bootstrap 3 was used, for the following reasons.

Apache Cordova

Apache Cordova is an open-source mobile development framework. It allows one to use standard web technologies such as HTML5, CSS3, and JavaScript for cross-platform development. Applications execute within wrappers targeted to each platform, and rely on standards-compliant application programming interface(API) bindings to access each device's sensors, data and network status [2].

Various plugin interface are available for Cordova, which would help in communication between native components and to the backend. This enabled us to invoke native code from JavaScript. The plugins used for this mobile phone application are:

```
com.ibm.mobile.cordova.ibmbluemix 1.0.0-20150311-1224 "IBMBluemix Hybrid"
com.ibm.mobile.cordova.ibmpush 1.0.0-20150311-1224 "IBMPush Hybrid"
cordova-plugin-device 1.0.1 "Device"
cordova-plugin-whitelist 1.0.0 "Whitelist"
```

The first plugin is used to communicate with the backend which is deployed on IBM Bluemix like the name specifies. The second plugin is used to enable the feature of push notification. The third plugin enables us to add devices for debugging purposes and also to install applications on devices. Finally, "whitelisting" is a security model that controls access to external domains over which the application has no control. Cordova's default security policy allows access to any site. This last plugin thus ensures that the AJAX calls made to the Bluemix Sever are not blocked by the application.

Bootstrap 3

For building the UI of the application Bootstrap 3 was used[3]. Bootstrap is a free and open-source collection of tools for creating websites and web applications. It contains HTML5 and CSS based design templates for typography,

[2] https://cordova.apache.org/
[3] http://getbootstrap.com/

forms, buttons, navigation and other interface components, as well as optional JavaScript extensions. It thereby aims to ease the development of dynamic websites and web applications. However, the most important feature of Bootstrap is its responsiveness. Thanks to responsiveness one can ensure that the display of the application remains the same across different platforms and different screen sizes. Which is important for the design of the mobile phone application to be used as it is assumed that there will be a wide variety in screen sizes amongst the participants of our experiment.

3.2.4 Backend of the Application

For the development of the backend of the application Node.js environment, PostgreSQL database and Bluemix service was used.

Node.js

Node.js is an open-source, cross-platform runtime environment for developing server-side web applications. Node.js applications are written in JavaScript. The advantage of Node.js is that it provides an event-driven architecture and a non-blocking I/O API designed to optimise an application's throughput and scalability for real-time web applications. Node.js contains a built-in library to allow applications to act as a web server without software such as Apache HTTP Server, Nginx or IIS.

PostgreSQL Database

PostgreSQL, is an object-relational database management system (ORDBMS) with an emphasis on extensibility and on standards-compliance [4]. As a database server, its primary function are to store data securely, support best practises and to allow for retrieval at the request of other software applications. The best feature of PostgreSQL is that, it can handle workloads ranging from small single-machine applications to large Internet-facing applications with many concurrent users and also it is compliant with IBM privacy policies.

Bluemix

IBM Bluemix is a cloud platform as a service (PaaS) developed by IBM. It supports several programming languages and services as well as integrated DevOps to build, run, deploy and manage applications on the cloud. DevOps thereby

[4] http://www.postgresql.org/

enables the developer to automatically increase or decrease the compute capacity of the application. The number of application instances are adjusted dynamically based on the Auto-Scaling policy defined[5].

Now that the design choices for the building of the mobile phone application has been discussed and motivated, the following section serves to describe how the influential factors of thermal comfort (as concluded in Chapter 2) were measured using the mobile phone application.

3.2.5 Business Logic

The framework of the mobile phone application was divided into 5 sets of questions based on the time of the day. A push notification was sent to remind the participants to answer the upcoming set. In each set some questions were asked to the participants. The first push notification was sent at 9 am, which was a reminder for set 1. In set 1 the first question asked was related to breakfast. In figure 3.2 one can see the 4 options that were given to the participants to answer this first question. As you can see visual aids were given to the participants to thereby help them to relate to the kind of breakfast they had and to ensure that they would make a proper choice when answering.

The next question in set 1 was on exercise. As mentioned in the previous Chapter, we are interested in knowing if exercise is a factor that has influenced participants perception towards thermal comfort. So, as it can be seen in figure 3.3, two options were given for the question "Did you exercise before coming to office?". However, we do not ask them how long did they exercise or what kind of exercise they did before coming to office, for the reasons that were given in section 2.4.2.

The next question asked to the participants was on clothing. For this question we again gave visual aid to the participants, as seen in figure 3.5. Similar to the exercise question, this was again to know if one's perception towards temperature was biased because of warm clothing or not.

Finally, in set 1 the last question asked was on how they were feeling, in terms of thermal comfort. Three options were given, as seen in figure 3.4. This was again represented in ordinal scale based on previous experiments conducted in this field. This question is asked repeatedly in each set to uncover if there is a relationship between the time of the day and perceived temperature. The next set, which is set 2 was at 11 am. In this set participants were asked if they had any caffeine intake or not. Since, caffeine intake can be in two forms of warm or cold, both options were given. In figure 3.6 it can be seen that in

[5] http://www.ibm.com/developerworks/cloud/library/cl-bluemixfoundry/

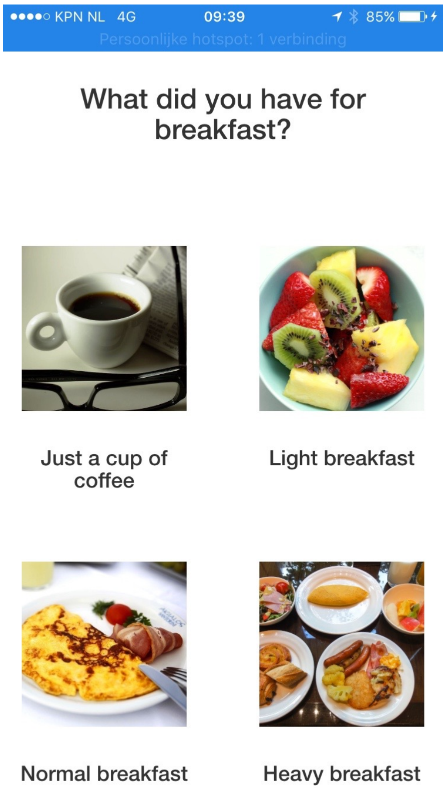

Figure 3.2: Breakfast Question

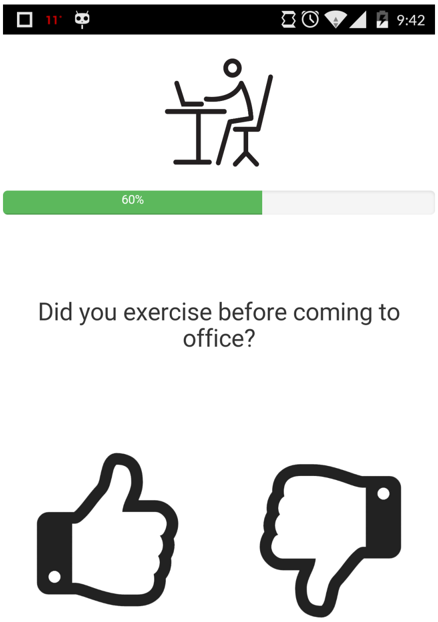

Figure 3.3: Exercise Question

total three options were given to participants representing caffeine in hot form, caffeine in cold form and finally nothing.

In set 3, for which the push notification was sent at 1 pm; the participants were asked what they had for lunch. Just like in breakfast question, for lunch the participants were also given four options with visual aids to answer the question. This visual representation was based on the type of lunch provided in the cafeteria of IBM.

In set 4 and 5, the only question asked to the participants was regarding their perception towards the temperature and comfort around them or how they were feeling. The responses were recorded in three categories as " It's cold", "It's just about right" and "It's warm" to judge their affinity of thermal comfort at the recorded time. This wraps up the whole experimental setup for the day. In total the experiment was recorded over 6 days, asking the same 3 sets of questions each day.

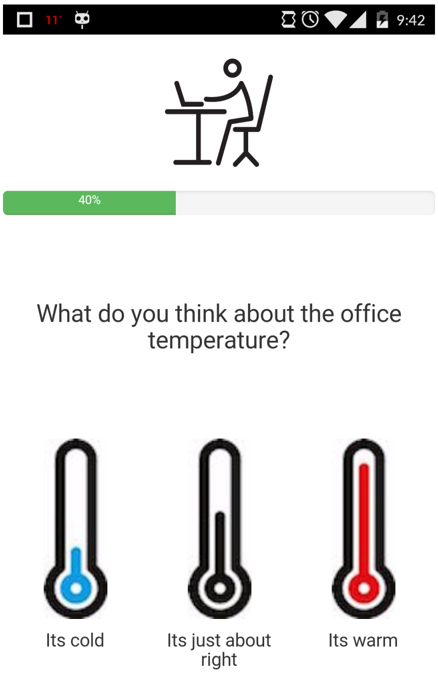

Figure 3.4: Perceived Temperature Question

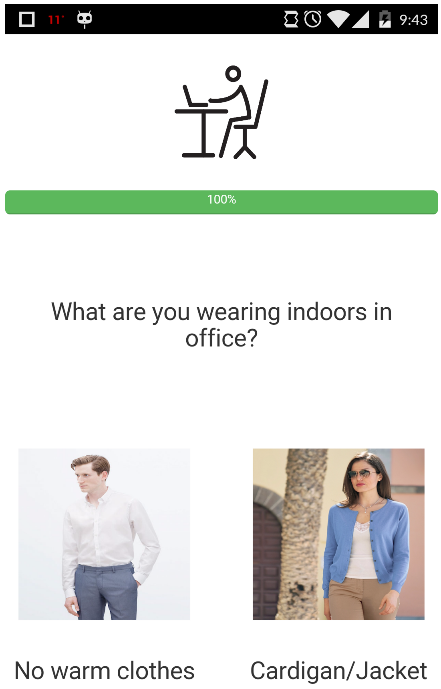

Figure 3.5: Warm Clothing Question

3.2.6 User Interface

There are three important features in the user interface (UI) of the application which were purposely implemented to thereby improve the usability and user experience of the mobile phone application. Those three features are:

1. To let the participants know how far they are from completing the set, a progress bar is given.

2. For each set a different icon is shown at the top of the screen. These icons are representative of the type of questions being asked in the set.

3. At the end of each set there is a thank you page. This thank you page lets the participants know when the next set will be available to answer or if it's the end of the day.

3.2.7 Challenges

The following four decisions had to be made due to challenges that arose during the development process of the mobile phone application. Each of these four

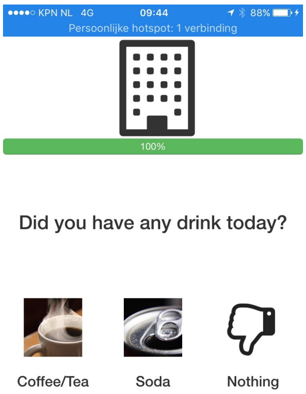

Figure 3.6: Caffeine Intake

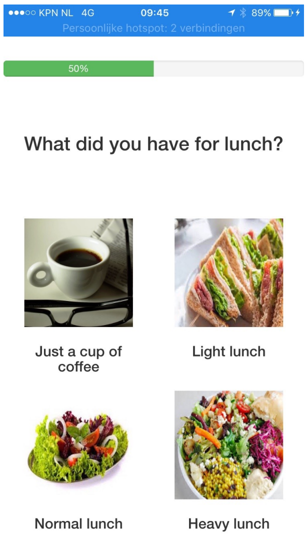

Figure 3.7: Lunch Question

unforeseen challenges and the consequential decisions are discussed one by one in the following paragraphs.

1. Initially, to build the hybrid mobile phone application IBM's MobileFirst framework was chosen as frontend and for the backend IBM Bluemix was chosen. However, later it was seen that the services provided by IBM Bluemix only supported native iOS mobile phone applications and had no support for hybrid applications made with MobileFirst framework. So, the combination of MobileFirst and Bluemix was not possible. Thereby a choice had to be made to either use a different framework for frontend other than MobileFirst or use a separate server space to run the backend. Since, it was necessary to have a stable and auto-scaling backend, it was chosen to retain Bluemix as the backend and a new frontend framework was used namely: Apache Cordova.

2. In the experiment it was necessary to have anonymized data to thereby protect the privacy of the participants. Therefore, it was not possible to use participant profiling to know which question has to be asked to which participant in the application. So, to overcome this issue, the device id of the smartphones was chosen as a means of user authentication.

3. As mentioned in the above bullet point, it was important to keep track of the next question to be asked to each participant. This could be done in two ways. Either by maintaining sessions or by using the database to keep track of previous questions that were answered. However, problem

with the session based method is that, the user could delete unwanted cookies to save memory space and to increase mobile performance and thereby deleting the session information. So to avoid this complication the second option of using the database for keeping track of the previous question was chosen. Thus every time a user answered a question, a field was maintained in the database, which would tell what the next question is to be asked.

4. During the implementation of push notification service, it was seen that devices with Android 5 could only register to the push notification. But unfortunately it was later found out that there was an incompatibility with Cordova 5 and Bluemix push service. So, to ensure that all android devices could still register, the Cordova version had to be downgraded from Cordova 5 to Cordova 4.3.

3.3 Temperature Sensors

With the design chooses made and the faced challenges solved the development of the mobile phone application was all figured out. What remained however were the sensors, which were another important part of the social temperature sensing experiment of this thesis.

The sensors to measure the indoor temperature were built by two Bachelor Students from TU Delft, as a part of the Bachelor Thesis using Arduino Boards. The sensors could measure the temperature and humidity of their location [20]. The sensors would connect with a windows laptop and send data to the database which was deployed on IBM Bluemix[6]. The connection between the sensors and the laptop was established using a bluetooth connection. The system architecture of the sensors is shown in figure 3.8.

As you can see in the figure 3.8, mobile phones can also be used to measure the temperature value. However, mobile phone devices were not used during the experiment because the application developed to extract the temperature data from the phone was a native application and specific only to Android users. This would have caused problem in having a uniformity in experimental setup. Thus, a decision was made to only use the Arduino sensors as the baseline for indoor temperature measurements for this experiment.

[6] https://console.ng.bluemix.net/

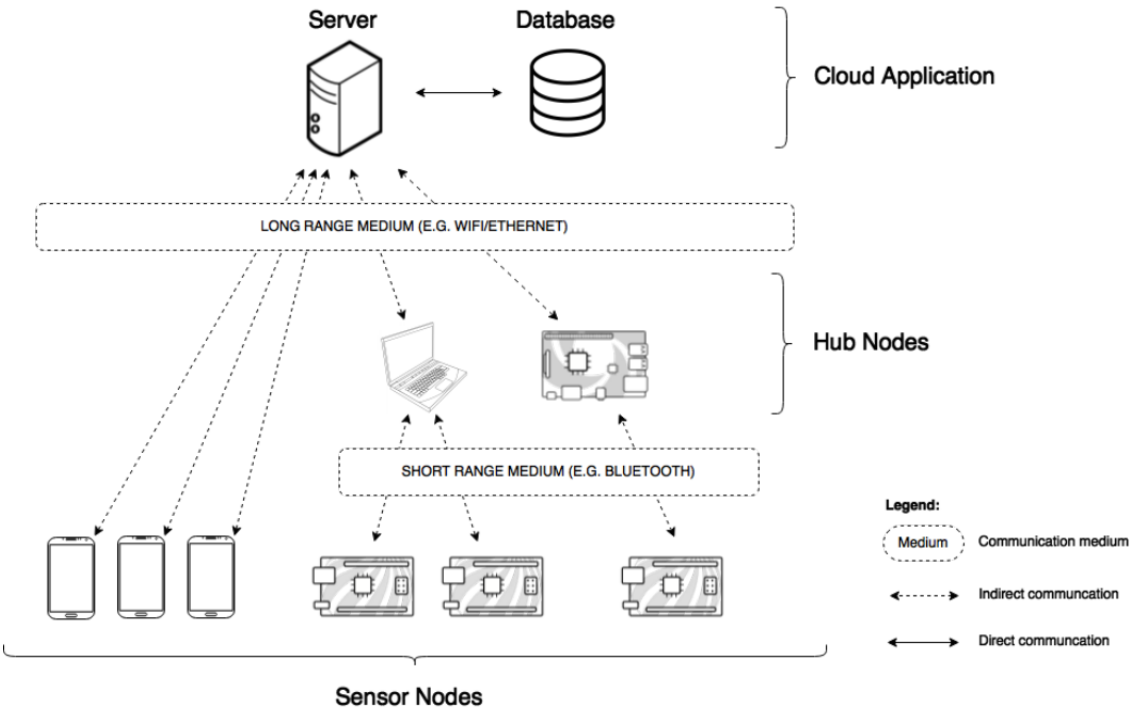

Figure 3.8: Sensor Architecture

Chapter 4

Experiment and Results

This fourth chapter discusses the decided methodology of the experiment that was conducted to answer the main research question. As a reminder the main research question is: "How can a self-reporting mobile phone application be used to get a measure of perceived temperature?". The experiment thus included gathering of self-reported values on perceived temperature of an employee and the verification of it's relationship with the influencing factors that were identified in chapter 3.

This chapter is organized in the following way: section 4.1 gives an elaborate description of the experimental setup, section 4.2 describes different phases of the experiment, then section 4.3 evaluates how robust the experiment is, section 4.4 discusses the results of the experiment and finally section 4.5 concludes the results of the experiment.

4.1 Experimental Setup

Generally, an experiment consists of independent and dependent variables where, independent variables are variables that are measured during the experiment and dependent variables are the variables which are equivalent to the conditions that we are going to measure.

The independent variables in this experiment are:

- Gender
- Age group
- Time
- Eating Habits
- Caffeine intake

- Clothing
- Physical exercise and
- Physical temperature

And the only dependent variable of this experiment is:

- Perceived temperature

The experimental setup consists of two main components, the first being measurement of physical temperature using temperature sensors and the second being measurement of perceived temperature of the participant with the help of a self-reporting mobile phone application which would be used by the participants. How these two components were deployed in the experiment is discussed below.

4.1.1 Sensor Setup

During the experiment, 10 of the Arduino boards developed by Bachelor students (Section 3.3) were used to measure the physical temperature. Since, the IBM desk plan is in such a way that 4 people sit at four different corners of a table, for each table a sensor was placed and a laptop was connected with the sensor to get the temperature reading. During the experiment, the sensor placement was changed everyday. This was done to check if the device is constantly showing the same value or does it change based on a different location. The sensors send readings to the connected laptop at an interval of 5 seconds. This ensures a higher granularity of the reading.

The connected laptop acted as a hub and sends out readings to the database. As each sensor had an unique number assigned to it, it was easy to know the temperature reading and where it corresponded to, in the floor plan. Also, when a laptop was connected to a sensor to access the data, an unique identifier was generated for each laptop which remained the same even if a new sensor was attached to it. For example on day 1 if sensor number 14 and sensor number 15 are both connected to the same laptop which has a device id 50, then in the database the values for both the sensors will be recorded with the device number 50.

This gave us a freedom to attach different sensors at the same location to check if two sensors are giving the same value or not and if not then by how much are they varying. It was done to make sure we can rely on all sensors and average out the values at each location and avoid faulty sensor values for

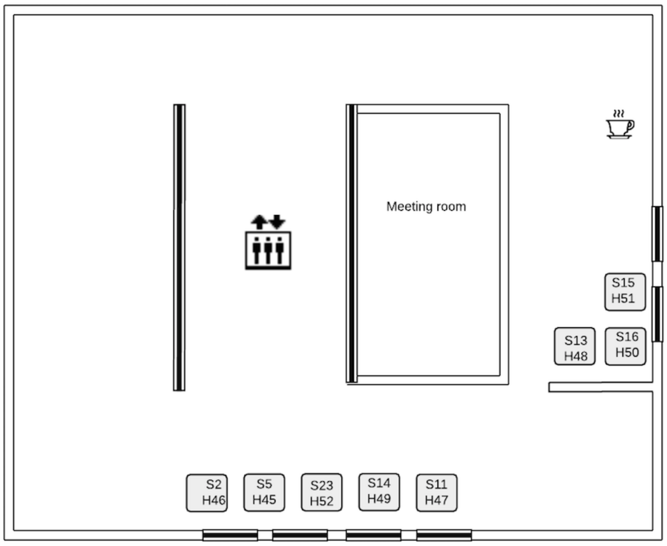

Figure 4.1: Floor Plan and sensor placements of day 1

a particular location. In figure 4.1 one can see where each sensor is placed on a desk and identified with an unique identifier.

To make sure that the values of the sensors can be trusted, another instrument called Netatmo weather station, a temperature measuring instrument was used to verify the values. Netatmo was chosen based on its reviews [1] and ranking, which is in the list of top 3 weather measuring instruments [2] .

4.1.2 Mobile Application Setup

As the self-reporting mobile phone application was developed for research purposes and not for commercial use the application was not deployed on any of the Appstores. Instead, the mobile phone application was installed by connecting the participants' smart-phones to my laptop and thereby launch the application on their phones. During this installation process, the participants were given a brief description about the questions that they could expect in the experiment and what does it exactly mean. When the application was launched for the first time, the participants could read a set of instructions and guidelines to be followed during the experiment. After the application was installed participants were asked some basic questions and were asked to fill in the sensor number of the nearest sensor they were sitting to.

[1] http://www.wired.com/2015/03/put-4-home-weather-stations-test/
[2] http://top10bestpro.com/top-10-best-wireless-weather-stations/

4.2 Experiment Procedure

The experiment was conduced in two phases: the pilot phase and the experiment phase.

A pilot phase of the experiment was conducted with the following four objectives:

1. To make people aware about the experiment and thereby recruit the required participants for the following experiment phase.

2. To identify the optimal locations for the sensors.

3. To check the stability and usability of the application on multiple versions of OS.

4. To check if the push notifications worked properly in all the registered devices.

The findings from the pilot phase were then taken into consideration for the following experiment phase by making; improvements in the experimental design.

Details on the methodology and procedures used in both of the two phases are discussed in the following two sections.

4.2.1 Pilot Phase

It was important to conduct the Pilot phase to do a user testing of the application as it provided us insights into the scalability and stability of the mobile phone application. By stability we mean if the application was compatible with multiple versions of OS.

The Pilot phase of the experiment was conducted on the following dates: 21st September (day 1), 22nd September (day 2) and on 23rd September (day 3).

On day 1 the number of participants was just 5, on day 2 more people joined in and by the end of day 3 a database of 25 interested participants was available.

To start the pilot phase, an invite was sent out to the employees working at IBM, Dynatos Building 5 and people who showed interest in taking part in the experiment were asked to download the application in their smart-phone.

Once the pilot phase was completed a preliminary analysis was done on sensor data and the user responses. In this analysis, we could identify how data clean up should be performed to get a clean data-set for final analysis.

Some important lessons learnt from the pilot phase were :

- In pilot phase, it was identified that all the sensors would toggle between two values at a given time of the day. For example, sensor number 15 would give temperature readings 23°C and 31°C in an interval of 5 seconds. Due to this reason, it was decided to recalibrate all the sensors to thereby ensure that this would not happen with the temperature reading in the Experiment phase. After the calibration, the sensors did not toggle between two values.

- In the user response data set it was seen that because of poor internet connection most of the users answered the same question multiple times thinking that their answer was not logged. In addition, some bugs with push notification was also identified in iOS devices. For instance, we could identify that most of the iOS 9 devices failed to register for the push notification. This problem was solved for the Experiment phase by doing minor changes in the mobile phone application code.

- We were happy to see that the pilot phase created a buzz amongst the employees. For instance, it was seen that it was also posted in IBMs internal Connections page (see figure 4.2). IBMs Connection is something which employees in IBM use to communicate with everyone about various events that are going on inside IBM, give updates on their project etc.

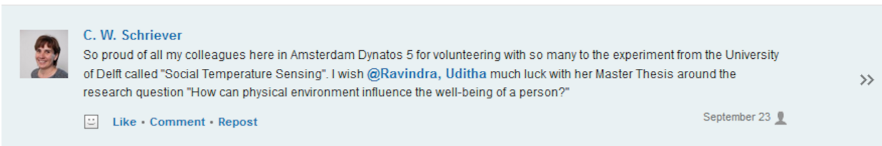

Figure 4.2: Office Chatter

A small feedback session was also conducted with the employees' asking if they could understand properly what they were asked to do, did they understand all the questions or not.

After identifying flaws and limitations in the pilot phase, necessary changes were made in the experimental protocol of the actual experiment and the experiment was conducted.

4.2.2 Experiment Phase

The experiment phase was conducted for a total of 6 days. To be precise, the experiment was conducted on the following dates: 30th September, 1st October, 2nd October, 5th October, 6th October and finally on the 7th of

October. The experiment was not conducted on the 3rd and 4th of October as it was a weekend. On the first day of the Experiment phase an updated version of the application (in comparison to the Pilot phase) was installed in the participants,Äô smart-phones. At the end of each day of the experiment a backup of user's self-reported value was taken and was stored locally.

To properly gather the required data, for the experiment phase, full participation of each participant was required. However, based on previous experiments conducted in the domain of temperature sensing and based on the observations made in pilot phase, it has been noticed that most people are not motivated enough to fully take part in the experiment. For this reason a special effort was made to encourage more participants, an invite was again sent to the participants who participated in the pilot phase requesting them to ask their friends and colleagues within IBM Dynatos to take part in the experiment.

As a result of the measures to increase awareness through the Pilot phase as well as word to mouth it could be seen that during this experimental phase an average of 15 participants actively took part during the 6 day period of experimental phase. Unfortunately the number of participants could not be increased, because most of the employees who worked on the chosen floor have one or two days at which they work from home and some of them did not own a smart-phone.

4.2.3 Data Aggregation

During the course of the experiment the self-reported values were collected from the participants over a period of 6 days. Overall the number of registered participants were 23 out of which 16 were male and 7 were female. The participants age and gender distribution were a representative of IBM's demographics in Amsterdam. However, the exact distribution is not mentioned due to IBM's privacy policy.

A day wise breakdown of the participants is given below:

Day	Number of Participants
Day 1	16
Day 2	16
Day 3	7
Day 4	17
Day 5	15
Day 6	11

It was seen that by the end of the 6^{th} day a total of 889 responses were obtained. After all the responses were recorded, a data clean up was done to remove noisy data points. The reason behind noisy data is given here: *It was seen that sometimes because of poor internet connection the API call made to the server to record the user response would take time, which would eventually result in slower response time from the application to move to the next question. During this period the participant might think that his/her response is not recorded and makes one more API call to the server to record the response. This results in duplicate responses.* So, during the data clean up, the first response is taken only and the other duplicate responses are removed.

So, after the data clean up process, the number of responses was reduced from 889 to 812. After that tests were performed on the data points.

4.3 Robustness of the Experiment

To verify the robustness of the sensor values and check the variation of indoor temperature values over the course of the experiment, a second instrument known as Netatmo Weather Station was used. It was seen that values given by the Arduino sensor and the Weather Station were same.

A second test was done to verify if the fluctuations observed in the indoor temperature values collected from the Sensors were comparable to the outdoor temperature values over the period of the day. A graph was plotted where the average indoor temperature and the outdoor temperature were varied over the course of the day. A close relationship can be observed between the indoor and outdoor temperatures for all the six days as shown below. However, as the building temperature is set to a comfortable value throughout the day, care should be only given to notice the fluctuations and not compare the values linearly.

As seen in figure 4.3 during a certain time of the day, the room temperature value rose upto 31°C. A deeper investigation was done on this reading because it seemed odd to have a room temperature this high. Few possible reasons for this anomaly could be that:

- Since all the tables were close to the window, sun-rays were falling on the sensor directly which resulted in a higher temperature value or,
- When more people were around the sensor the temperature value would increase because of the exposure to body heat and other electrical appliances like desktops, laptops etc.

However, as it was previously verified with the use of the Netatmo Weather station that the Arduino sensor values are valid, it was decided to thus con-

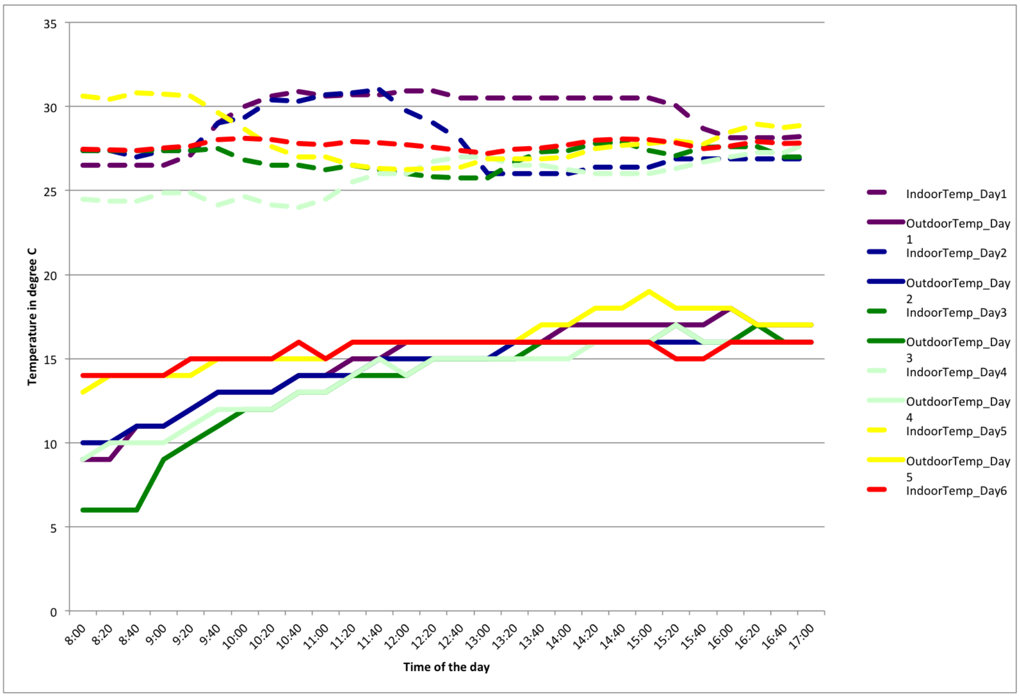

Figure 4.3: Indoor-Outdoor Temperature variation

sider this high temperature reading as a true outlier and thus not take it into consideration when drawing conclusions on the acquired results

4.4 Results

In this section, we discuss the statistical tests used to analyse the data set. IBM SPSS (Statistical Package for the Social Sciences) software package was used to run these tests. At first, a short study was done on various statistical techniques as it was necessary to identify the right test to be conducted on the variables to obtain accurate results. Here a brief description is given about each of the test that was performed and what does the test signify.

1. **Chi-square test for independence** was conducted to see if there was a relationship between the dependent and the independent variables. It is used to determine whether there is a significant association between the two variables or not. The null H_0 hypothesis of the chi-square test for independence states that the two variables A and B are independent of each other and the alternative hypothesis H_a states that variables A and B are not independent and are related but are not causal [3]. Here

[3]http://stattrek.com/chi-square-test/independence.aspx?Tutorial=AP

causality is not shown but with this test relationships can be established and predicted how strong the relationship is between the two variables. *In the test results if the p value is less than* 0.05 *then null hypothesis is rejected and accept the alternative hypothesis.* When the null hypothesis is rejected Cramer's V value is checked which tells how strong or weak is the relationship between the dependent and independent variable. If the Cramer's V value is less than 0.10 then it is said that the relationship is weak, if the value is between 0.11 and 0.30 then moderate and when it's greater than 0.31, then strong.

2. **Kruskal-Wallis Test** also known as one-way ANOVA on ranks is a rank-based nonparametric test that can be used to determine if there is statistical difference between two or more groups of an independent variable [4]. In cases where there are only two groups on which this test is performed, the test tells if the two groups are different or not. In cases where there are more than two groups, the test cannot tell which specific groups of the independent variable are statistically significant from each other. The null hypothesis H_0 assumes that the samples are from identical populations and the alternative hypothesis H_a assumes that the samples come from different populations. Similar to chi-square test, a null hypothesis is rejected when the statistical significance p value is lower than 0.05 and the alternative hypothesis is accepted.

3. **Friedman Test** is performed when there is repeated measurement of an independent variable. It is a non-parametric alternative to the one-way ANOVA with repeated measures. It is used to test the differences between groups when the dependent variable is ordinal. The null hypothesis for the Friedman test is that there are no differences between the repeatedly measured variables and the alternative hypothesis that there is a difference between the repeatedly measured variables. Here also a null hypothesis is rejected when the statistical significance p value is lower than 0.05.

4. **Linear regression** is used when we want to predict the value of variable based on the value of another variable. Here the variable that is to be predicted is called the dependent variable and the variable which is being used to predict the dependent variable is called the independent variable. The null hypothesis for linear regression is that there is no significant relationship between independent and dependent variable and the alternative hypothesis states that there is a significant relationship between

[4] https://statistics.laerd.com/stata-tutorials/kruskal-wallis-h-test-using-stata.php

the independent and dependent variables. Here also a null hypothesis is rejected when the statistical significance p value is lower than 0.05.

The type of test to be conducted was based on the type of the independent variable. All the analysis conducted below are to see if these independent variables have a relationship with perceived temperature or not. In all the analysis the common variable is "perceived temperature". For analysis purpose each option of the question on perceived temperature was given a numeric value. The option of "It's cold" was given a numeric value of 1, "It's just about right" was assigned with 2 and finally "It's warm" with 3.

4.4.1 Gender

On gender Kruskal-Wallis test was performed. As mentioned in the previous section it is very, similar to one way ANOVA and is performed to see if there is statistical significant difference between two or more groups of an independent variable. In the kruskal-wallis test some assumptions are made as shown below:

- The first assumption that the dependent variable should be measured at the ordinal or continuous level
- The second assumption is that the independent variable should consists of two or more categorical, independent groups, which is true in this case.

The results of this test as seen in figure 4.4 show that the p value is less than 0.05 and the chi-square value is 5.420, which implies that the null hypothesis is rejected. By rejecting the null hypothesis it can be said that the two populations are different and do not behave the same way. Here the two populations are male and female.

	Perceived Temperature
Chi-Square	5.420
df	1
Asymp. Sig.	.020

Figure 4.4: Kruskal-Wallis p significance

Now to see which one has a higher perception of temperature, the mean scores are checked. In figure 4.5 it is seen that mean score of male perceived temperature is 418.16 and the mean score of female perceived temperature is 386.56. Thus, it may be inferred that females feel colder than men in the same given room temperature.

	Gender	N	Mean Rank
Perceived Temperature	Male	499	418.16
	Female	312	386.56
	Total	811	

Figure 4.5: Mean Ranks for Gender

To confirm if females generally feel colder than men in the same given room temperature, a t-Test between the gender and actual room temperature was conducted. Since, the p value is greater than 0.05 we can say that they are not significantly different as seen in figure 4.6, thus it can concluded that females generally feel colder than men given the same room temperature.

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference Lower	Upper
Temperature	Equal variances assumed	,005	,945	1,692	810	,091	,2758	,1631	-,0442	,5959
	Equal variances not assumed			1,684	653,714	,093	,2758	,1637	-,0457	,5974

Figure 4.6: Independent t Test between Actual Temperature and Gender

4.4.2 Age

The next analysis was conducted to check if there is relationship between age and perceived temperature. Since, age is a ratio scale and perceived temperature is an ordinal scale a linear regression was performed. To see if there is a linear relationship between age and perceived temperature the most appropriate test to be performed was Linear regression. In figure 4.7 it can been seen that p is not less than 0.05. Hence the null hypothesis is accepted and it can be said that statistically there is no linear relationship between age and perceived temperature.

Model		Sum of Squares	df	Mean Square	F	Sig.
	Regression	.006	1	.006	.040	.844[b]
1	Residual	3.298	21	.157		
	Total	3.304	22			

Figure 4.7: Linear regression p significance for Age

4.4.3 Actual Temperature

The next test conducted was to verify if there is a relationship between perceived temperature and actual temperature. When we say perceived temperature we mean the responses given by participants in the form of "It's cold", "It's just about right" or "It's warm" which were given numerical value as mentioned earlier. Since actual temperature is in interval scale and perceived temperature is in ordinal scale, the appropriate test to be performed here is linear regression. This is to see if there is a linear relationship between the independent and dependent variable (actual temperature being independent variable and perceived temperature being dependent variable). In figure 4.8 it can been seen that p is not less than 0.05. Hence the null hypothesis is accepted and it can be said that statistically there is no linear relationship between actual temperature and perceived temperature.

4.4.4 Time of the day

The next test we conduct was to test if there is a relationship between the time of the day and perceived temperature. In our experiment we asked people in an

Model		Sum of Squares	df	Mean Square	F	Sig.
	Regression	.851	1	.851	3.089	.079[b]
1	Residual	222.883	809	.276		
	Total	223.734	810			

Figure 4.8: Linear regressions p significance for Actual temperature

intervals of 2 hours between 9 am to 5 pm about how they were feeling, which was in compliance with the working hour of the company.

Friedman test is used here to test if there is relationship between time and perceived temperature as time is a repeated measure. After the analysis it can be seen in figure 4.9 that $p < 0.05$. Hence, the null hypothesis is rejected and it can be said that there is statistical difference between different groups of measurement which means that time of the day has a statistical significance on perceived temperature. Figure 4.10 gives the distribution of self-reported perceived temperature values against the time of the day which, indicates that the participants felt less colder in the morning after arriving to office and more colder while leaving the office in the evening.

N	811
Chi-Square	4.769
df	1
Asymp. Sig.	.029

Figure 4.9: Friedman test for Time of the day

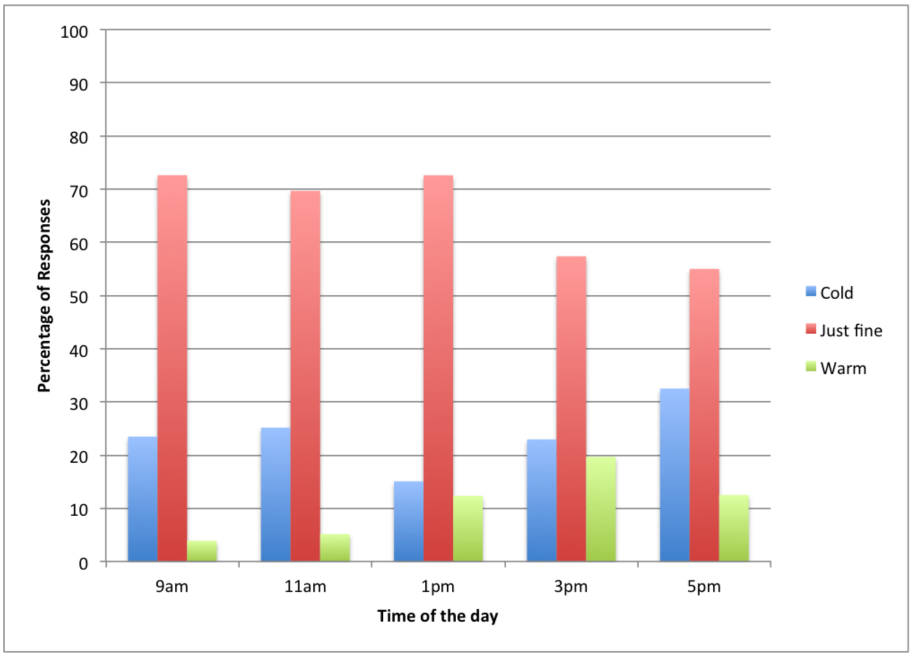

Figure 4.10: Percentage of responses Vs Time of the day

4.4.5 Clothing

The next test performed was to see if there is a relationship between type of clothing and perceived temperature. In chapter 3 it was mentioned that for clothing only two options were given to participants, i.e., if they wore warm clothing or not. Chi-square test for independence was performed here. In figure 4.11 it can be seen that p is not less than 0.05, which implies that the null hypothesis is accepted. This means that there is no relationship between type of clothes worn and perceived temperature.

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	2.507[a]	2	.285
Likelihood Ratio	3.270	2	.195
Linear-by-Linear Association	.754	1	.385
N of Valid Cases	82		

Figure 4.11: Chi square test for clothing

4.4.6 Breakfast

Next, we check if there is a relationship between breakfast and perceived temperature. Note that, the perceived temperature here refers to the question asked in set 1 in the morning during the experiment. According to the literature study we found out that, food intake suggests an influence on how one's metabolism work which in turn influence perception towards temperature. However, in our experiment we could not prove this result. In figure 4.12 you can see that $\chi^2 = 1.833$ and the value of $p > 0.05$ which means that there is no relationship between breakfast and perceived temperature.

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	1.833[a]	4	.766
Likelihood Ratio	2.770	4	.597
Linear-by-Linear Association	.007	1	.935
N of Valid Cases	83		

Figure 4.12: Chi square test for breakfast

4.4.7 Lunch

Next analysis was done to check if there is a relationship between lunch and perceived temperature. Note that, the perceived temperature here refers to the question asked in set 3 in the afternoon during the experiment. Unlike breakfast, here we could prove the results obtained from the literature study. In figure 4.13 one can see that the value of $\chi^2 = 16.328$ and $p = 0.012$ which is less that 0.05. Hence we can say that there is a positive relationship between lunch and perceived temperature.

To see how strong the relationship is, we again check the Cramer's V value. In figure 4.14 we can see that the value is 0.337, which is falls under the category of strong relationship. In other words, lunch and perceived are strongly related.

In figure 4.15 one can see the number of responses for each type of lunch and how they perceive temperature. Therefore, a normal or light lunch was correlated with temperature being perceived as 'fine' as seen from the graph below.

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	16.328[a]	6	.012
Likelihood Ratio	15.942	6	.014
Linear-by-Linear Association	7.133	1	.008
N of Valid Cases	72		

Figure 4.13: Chi square test for Lunch

Symmetric Measures

		Value	Approx. Sig.
Nominal by Nominal	Phi	.476	.012
	Cramer's V	.337	.012
N of Valid Cases		72	

Figure 4.14: Symmetric measures for Lunch

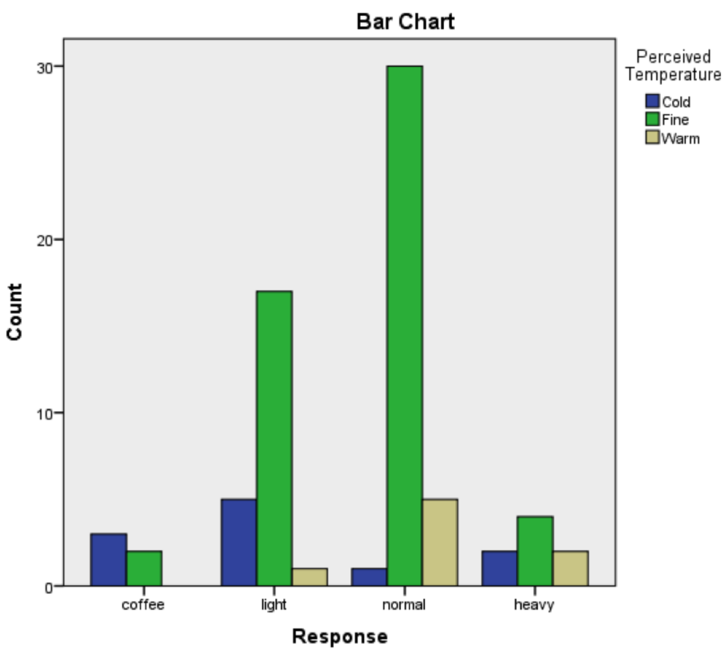

Figure 4.15: Lunch vs Perceived Temperature

4.4.8 Caffeine

In our literature study we had found out that caffeine also has an influence on perceived temperature. In our experiment we try to see if we can re-establish those results or not. Unfortunately, we could not re-establish those results. As one can see in the figure 4.16 that $\chi^2 = 5.77$ and $p = 0.195$.

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	6.055[a]	4	.195
Likelihood Ratio	5.763	4	.218
Linear-by-Linear Association	4.525	1	.033
N of Valid Cases	77		

Figure 4.16: Chi square test for caffeine

4.4.9 Exercise

We conducted a chi square test to see if there is relationship between exercise and perceived temperature or not. In our experiment we see that the number of cases where people responded with the option that they did exercise before coming to office was too low. The result for this test is seen in figure 4.17 that $p = 0.056$ which is very close to 0.05. It can be concluded that the effect of having exercise done on perceived temperature is borderline significant.

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	5.774[a]	2	.056
Likelihood Ratio	9.133	2	.010
Linear-by-Linear Association	2.566	1	.109
N of Valid Cases	81		

Figure 4.17: Chi square test for exercise

In figure 4.18 one can see that all the people who responded with an yes to exercise felt just fine to the temperature where as people who did not exercise complained about being cold.

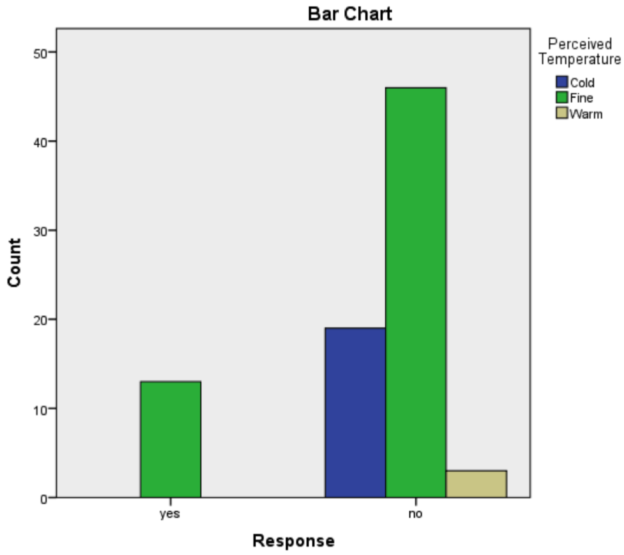

Figure 4.18: Exercise Response

4.5 Conclusion

All the above results that have been shown were aggregated over the responses gathered during the experiment. In the table below a check-mark in the box indicates there is a relationship between the two variables on which the test was conducted, it is indicated when the p value was less than 0.05. This is supported by conclusive evidence generated by all the tests performed. In the table 4.5 a cross mark means there is no relationship between the two variables. The reasons for this are:

1. $p > 0.05$ and the two variables are independent of each other
2. The test could not be conducted at all because of low N value i.e low number of responses.

	Day1	Day2	Day3	Day4	Day5	Day6	Overall
Number of Responses	182	175	80	188	143	121	889
Time Vs Perceived Temperature	✓	✓	✗	✓	✗	✗	✓
Actual Temp Vs Perceived Temperature	✓	✗	✗	✓	✗	✗	✗
Age Vs Perceived Temperature	✗	✗	✗	✗	✗	✗	✗
Gender Vs Perceived Temperature	✗	✓	✗	✓	✗	✓	✓
Caffeine Vs Perceived Temperature	✓	✓	✗	✗	✗	✗	✗
Breakfast Vs Perceived Temperature	✗	✗	✗	✗	✗	✗	✗
Lunch Vs Perceived Temperature	✗	✓	✓	✗	✗	✗	✓
Exercise Vs Perceived Temperature	✗	✗	✗	✗	✗	✗	✗

From the table 4.5 it is seen that on an overall basis there is a positive relationship between the following:

1. Gender and perceived temperature: Females feel colder than males at the same room temperature.

2. Time and perceived temperature: A significant effect was found of time of day on perceived temperature. It can be seen that the participants felt less colder in the morning after arriving to office and more colder while leaving the office in the evening.

3. Lunch and perceived temperature: A normal or light lunch was shown to have perceived temperature to be 'It's just about right' for the participants.

Another conclusion drawn from the results was that the relationship between exercise and perceived temperature was borderline significant.

Chapter 5

Conclusion and Future Work

This chapter gives an overview of the project's contributions and future work.

5.1 Conclusion

To the best of our knowledge this is one of the first experiments to be conducted in the domain of thermal comfort using a self-reporting mobile phone application, in an uncontrolled office space or in other words it can be said that the experiment was conducted "in the wild". The novelty which is brought through this experiment is that it was conducted "in the wild", which was representative of real world scenario and using a self-reporting mobile phone application. Also, by making the experiment as unobtrusive as possible, the 'comfort' of the employee participating in the experiment was judged practically. Although similar experiments have been conducted in the past in the domain of social sciences, a lot of restrictions are placed during the course of these experiments such as recruitment of participants from outside, experiment monitored in a closed room etc.

This thesis provides a novel approach to explore factors influencing thermal comfort and it's relation with physical environment, in the context of an office space using a self-reporting mobile phone application. During this thesis, at first it was needed to know the physical factors influencing the subjective well being of an employee. This was done by performing a literature study of the research concerning this domain and also taking IBM as a case study. During the first phase of the literature study, where research was to find which kind of facet well-being caused by change in physical environment factors influences people more, was done. Among those factors, thermal comfort was considered to have the maximum impact on subjective well-being of a person.

After identifying that thermal comfort has the maximum influence on subjective well-being of employees in an office space, an analysis of the building management system complaint database of IBM (International Business Machines), Amsterdam office was done as a case study.

After analysing database, it was seen that more than 50% of the complaints was related to thermal comfort. Most of the complaints lodged stated that the office space was too hot or too warm. All other complaints were on reporting things that were broken and had to be fixed. So, the findings from the literature study and the case study at IBM were coherent, we decided on addressing the issue of thermal comfort.

The next goal was to see how this thermal comfort can be measured and which factors have an influence on perception towards temperature. For that an extensive research as part of the second phase during the literature survey was done to identify the significant factors that have an influence on perception towards temperature. The following factors were found to have the maximum impact on perceived temperature.

1. Age
2. Gender
3. Food (which included both breakfast and lunch)
4. Caffeine (Hot and cold)
5. Exercise

It was then decided to conduct an experiment to verify if there is any relationship between perceived temperature (thermal comfort) and the above mentioned factors using a self-reporting mobile phone application. Alongside the aforementioned factors, two more factors i.e time of the day and actual room temperature were added. A self-reporting hybrid mobile phone application was developed which was used during the experiment by the participants for self-reporting. Along with calibrated temperature sensors and the mobile phone application this experiment was conducted for six days. From the experiment it was concluded that the following have a relationship:

1. Gender and perceived temperature: Females feel colder than males at the same room temperature.
2. Time and perceived temperature: A significant effect was found of time of day on perceived temperature. It can be seen that the participants felt less colder in the morning after arriving to office and more colder while leaving the office in the evening.

3. Lunch and perceived temperature: A normal or light lunch was shown to have perceived temperature to be 'just about right' for the participants.

From the statistical results, it can be said that a self-reporting mobile phone application can be used to get the information about the factors that influence perceived temperature and in future it can be used to improve the well-being of an employee.

5.2 Future work

From the literature study we had identified that the current building management systems are sexist i.e., they are designed considering male metabolism rate. An important finding of this thesis is that females usually feel colder than the male population at the given room temperature. It would be interesting to see in the future if the building management systems incorporates these findings and ensures a better thermal comfort for employees irrespective of their gender.

Another important finding of this thesis showed that people having a 'light' lunch, consisting of healthy food, usually have a higher thermal comfort level than the people who either under-eat or over-eat during lunch. So, in future a food recommendation system could be designed in order to advise the users' on the type of meal he/she should take during lunch to have a better thermal comfort. Also, with the development of Internet of things (IOT) it would be interesting to develop sensors to control thermal comfort of a person individually independent of building management systems.

Bibliography

[1] Lawrence E Armstrong, Douglas J Casa, Carl M Maresh, and Matthew S Ganio. Caffeine, fluid-electrolyte balance, temperature regulation, and exercise-heat tolerance. *Exercise and sport sciences reviews*, 35(3):135–140, 2007.

[2] John R Brobeck. Food intake as a mechanism of temperature regulation. *The Yale journal of biology and medicine*, 20(6):545, 1948.

[3] Weilin Cui, Guoguang Cao, Jung Ho Park, Qin Ouyang, and Yingxin Zhu. Influence of indoor air temperature on human thermal comfort, motivation and performance. *Building and Environment*, 68:114–122, 2013.

[4] Mark A Febbraio, Rodney J Snow, Christos G Stathis, Mark Hargreaves, and Michael F Carey. Blunting the rise in body temperature reduces muscle glycogenolysis during exercise in humans. *Experimental physiology*, 81(4):685–693, 1996.

[5] Monika Frontczak and Pawel Wargocki. Literature survey on how different factors influence human comfort in indoor environments. *Building and Environment*, 46(4):922–937, 2011.

[6] George Havenith, Ingvar Holmér, and Ken Parsons. Personal factors in thermal comfort assessment: clothing properties and metabolic heat production. *Energy and buildings*, 34(6):581–591, 2002.

[7] Peter Höppe. Comfort requirements in indoor climate. *Energy and Buildings*, 11(1):249–257, 1988.

[8] James Po-Hsun Hsiao, Chyi Jaw, TCT Huan, and Arch G Woodside. How algorithms with happiness-at-work identify high (low) performing hospitality frontline-employees: Transcending variable and cases-based analyses. 2013.

[9] Madhavi Indraganti and Kavita Daryani Rao. Effect of age, gender, economic group and tenure on thermal comfort: a field study in residential buildings in hot and dry climate with seasonal variations. *Energy and buildings*, 42(3):273–281, 2010.

[10] Robert E Johnson and Robert M Kark. Environment and food intake in man. *Science*, 105(2728):378–379, 1947.

[11] Sami Karjalainen. Gender differences in thermal comfort and use of thermostats in everyday thermal environments. *Building and environment*, 42 (4):1594–1603, 2007.

[12] Li Lan, Zhiwei Lian, and Li Pan. The effects of air temperature on office workers,Äô well-being, workload and productivity-evaluated with subjective ratings. *Applied ergonomics*, 42(1):29–36, 2010.

[13] Valentino Lee, Heather Schneider, and Robbie Schell. *Mobile applications: architecture, design, and development*. Prentice Hall PTR, 2004.

[14] Chin Leong Lim, Chris Byrne, and Jason KW Lee. Human thermoregulation and measurement of body temperature in exercise and clinical settings. *Annals Academy of Medicine Singapore*, 37(4):347, 2008.

[15] Maastrichtuniversity.nl. Energy-efficient buildings by taking into account female metabolism - maastricht university, 2015. URL `http://www.maastrichtuniversity.nl/web/Main/Sitewide/News1/EnergyefficientBuildingsByTakingIntoAccountFemaleMetabolism1.htm`.

[16] KJ McCartney and MA Humphreys. Thermal comfort and productivity. *Proceeding of Indoor Air*, pages 822–827, 2002.

[17] L Mølhave. The sick buildings and other buildings with indoor climate problems. *Environment International*, 15(1):65–74, 1989.

[18] Craig Morgan and Richard de Dear. Weather, clothing and thermal adaptation to indoor climate. *Climate Research*, 24(3):267–284, 2003.

[19] Patrick J ÖConnor, Michael J Breus, and Shawn D Youngstedt. Exercise-induced increase in core temperature does not disrupt a behavioral measure of sleep. *Physiology & behavior*, 64(3):213–217, 1998.

[20] DJA Rennings and SA Kassing. The sensitive office: A demonstrator for sensing the enterprise environment. 2015.

[21] Peggie M Rothe, Marion Beijer, and Theo JM Van der Voordt. Most important aspects of the work environment: a comparison between two countries. In *EFMC2011: Proceedings of the 10th EuroFM research symposium: Cracking the productivity nut, Vienna, Austria, 24-25 May, 2011*. EuroFM, 2011.

[22] J Sanjog, Thaneswer Patel, and Sougata Karmakar. Indoor physical work environment: An ergonomics perspective. *International Journal of Science, Engineering and Technology Research*, 2(3):507–513, 2013.

[23] Lisje Schellen, WD van Marken Lichtenbelt, MGLC Loomans, Jørn Toftum, and MH De Wit. Differences between young adults and elderly in thermal comfort, productivity, and thermal physiology in response to a moderate temperature drift and a steady-state condition. *Indoor air*, 20 (4):273–283, 2010.

[24] Mohmad Yazam Sharif, Abdul Halim Abdul Majid, et al. A conceptual framework of happiness at the workplace. *Asian Social Science*, 11(2):p78, 2014.

[25] Robert-Jan Sips, Alessandro Bozzon, Gerard Smit, and Geert-Jan Houben. The inclusive enterprise: Vision and roadmap. In *Engineering the Web in the Big Data Era*, pages 621–624. Springer, 2015.

[26] ANDRE L Vallerand, I Jacobs, and MARGARET F Kavanagh. Mechanism of enhanced cold tolerance by an ephedrine-caffeine mixture in humans. *Journal of Applied Physiology*, 67(1):438–444, 1989.

[27] John M Zelenski, Steven A Murphy, and David A Jenkins. The happy-productive worker thesis revisited. *Journal of Happiness Studies*, 9(4): 521–537, 2008.

Appendix A

Appendix A

In this appendix we have the list of complaints that we extracted from the complaint database of employees at IBM Amsterdam. The names of the employees have been removed for privacy reasons. We can see nearly 50 % of the complaints are based on temperature.

Request title	Location	Report date
Air Conditioning Noisy / Rattles / Leaking	5th Floor	11May2015
Temperature - Too hot	6th Floor	7May2015
humidity level is too low	Ground Floor	5May2015
Vervangen Terugslagbeveiliging HDK 10 JC	Amsterdam HDK	29-Apr-15
Beg. Carrier Reiniging en Coaten Split HDK 2e	Amsterdam HDK	29-Apr-15
Temperature - Too cold	2nd Floor	22-Apr-15
Repareren aanzuig sectie (van vliet)	TR - Algemeen - 10e verdieping	16-Apr-15
Air Conditioning Noisy / Rattles / Leaking	1st Floor	26Mar2015
Temperature - Too cold	1st Floor	9Mar2015
Air Conditioning Noisy / Rattles / Leaking	6th Floor	24-Feb-15
Temperature - Too hot	9th Floor	18-Feb-15
SMC Sprinkler Meld Centrale was offline	Ground Floor	18-Feb-15
Temperature - Too hot	6th Floor	12-Feb-15
Temperature - Too cold	Ground Floor	11-Feb-15
Temperature - Too cold	1st Floor	2-Feb-15
Temperature - Too cold HDK 1 Sectie S	1st Floor	2-Feb-15
Temperature - Too cold	1st Floor	27-Jan-15
Temperature - Too cold	1st Floor	26-Jan-15
Air Conditioning Noisy / Rattles / Leaking	7th Floor	23-Jan-15
Temperature - Too cold	1st Floor	19-Jan-15
Temperature - Too cold	1st Floor	15-Jan-15
Temperature - Too cold	1st Floor	12-Jan-15
Temperature - Too cold	1st Floor	12-Jan-15
Temperature - Too cold	4th Floor	22-Dec-14
Temperature - Too cold	1st Floor	22-Dec-14
Temperature - Too cold	1st Floor	22-Dec-14
Temperature - Too cold	1st Floor	18-Dec-14
Temperature - Too cold	1st Floor	16-Dec-14
Air Conditioning Noisy / Rattles / Leaking	1st Floor	11-Dec-14
Temperature - Too hot	Ground Floor	10-Dec-14
Temperature - Too cold	Ground Floor	4-Dec-14
Temperature - Too cold	1st Floor	3-Dec-14
Temperature - Too cold	1st Floor	2-Dec-14
Replace lock pump house 1. (Van Vliet bv.)	Ground Floor	28-Nov-14
Temperature - Too hot	1st Floor	27-Nov-14
poor Ventilation	Ground Floor	27-Nov-14
Changing building management system operating hou	Ground Floor	18-Nov-14
Smells / Odours (untraced)	Ground Floor	17-Nov-14
Temperature - Too hot	4th Floor	13-Nov-14
Defect inlet fan Replace two fans RK6-1	6th Floor	7-Nov-14
Temperature - Too cold	2nd Floor	31Oct2014
Refill chill tank	10th Floor	31Oct2014
Malfunction exhaust fan elevator room	10th Floor	27Oct2014

Figure A.1: Complaint List part 1

Temperature - Too hot	Ground Floor	23Oct2014
Temperature - Too cold	4th Floor	14Oct2014
Temperature - Too cold	Ground Floor	8Oct2014
Air Conditioning Noisy / Rattles / Leaking	5th Floor	7Oct2014
failure substation 17 readjustment (replace coolin	4th Floor	6Oct2014
Temperature - Too hot	1st Floor	6Oct2014
Temperature - Too cold	1st Floor	2Oct2014
Air Conditioning Noisy / Rattles / Leaking	7th Floor	30-Sep-14
Temperature - Too cold	1st Floor	22-Sep-14
Temperature - Too hot	1st Floor	19-Sep-14
Air Conditioning Noisy / Rattles / Leaking	7th Floor	16-Sep-14
Carrier rep. off Condensor Fans tbv UPS koel HDK10	Amsterdam HDK	15-Sep-14
Temperature - Too cold	4th Floor	11-Sep-14
Temperature - Too hot	4th Floor	4-Aug-14
string breakage air unit SCC	5th Floor	30-Jul-14
HDK 4 refilling tank chilled water.	4th Floor	30-Jul-14
Air Conditioning Noisy / Rattles / Leaking	4th Floor	30-Jul-14
Air Conditioning Noisy / Rattles / Leaking	Ground Floor	28-Jul-14
Air Conditioning Noisy / Rattles / Leaking	3rd Floor	24-Jul-14
Temperature - Too cold	Ground Floor	24-Jul-14
Air Conditioning Noisy / Rattles / Leaking	7th Floor	22-Jul-14
Temperature - Too hot	1st Floor	18-Jul-14
Air Conditioning Noisy / Rattles / Leaking	5th Floor	16-Jul-14
Air Conditioning Noisy / Rattles / Leaking	9th Floor	11-Jul-14
Temperature - Too hot	5th Floor	9-Jul-14
Temperature - Too hot	5th Floor	4-Jul-14
Temperature - Too cold	5th Floor	20-Jun-14
Change filter	10th Floor	17-Jun-14
Temperature - Too hot	3rd Floor	16-Jun-14
Temperature - Too cold	5th Floor	16-Jun-14
Temperature - Too hot	6th Floor	12-Jun-14
Temperature - Too hot	7th Floor	11-Jun-14
Air Conditioning Noisy / Rattles / Leaking	7th Floor	11-Jun-14
Air Conditioning Noisy / Rattles / Leaking	6th Floor	11-Jun-14
Purge cool machine 1	Ground Floor	11-Jun-14
Air Conditioning Noisy / Rattles / Leaking	Ground Floor	10-Jun-14
Clean filter coolmachine 4	Ground Floor	20May2014
High Pressure alarm	10th Floor	29-Apr-14
A/C loose in ceiling (van vliet)	2nd Floor	28-Apr-14
Purging cooling machine nr1 HDK Amsterdam 10th flo	10th Floor	28-Apr-14
Temperature - Too hot	6th Floor	24-Apr-14
Temperature - Too hot	6th Floor	15-Apr-14
Temperature - Too hot	Ground Floor	15-Apr-14

Figure A.2: Complaint List part 2

check A/C as making people cough and they eyes	5th Floor	14-Apr-14
Temperature - Too hot	6th Floor	7-Apr-14
Temperature - Too cold	1st Floor	4-Apr-14
Temperature - Too hot	4th Floor	1-Apr-14
Temperature - Too hot	4th Floor	1-Apr-14
Temperature - Too hot	4th Floor	25Mar2014
Temperature - Too cold	4th Floor	20Mar2014
Temperature - Too hot	4th Floor	12Mar2014
Temperature - Too hot	Ground Floor	26-Feb-14
Temperature - Too hot	4th Floor	7-Feb-14
Temperature - Too hot	Ground Floor	6-Feb-14
Temperature - Too hot	4th Floor	30-Jan-14
Temperature - Too hot	Ground Floor	23-Jan-14
Temperature - Too hot	5th Floor	13-Dec-13

Figure A.3: Complaint List part 3

Appendix B

Appendix B

In this appendix, we show the different sensor placements varying over each day.

B.1 Sensor Placement and Floor Plan

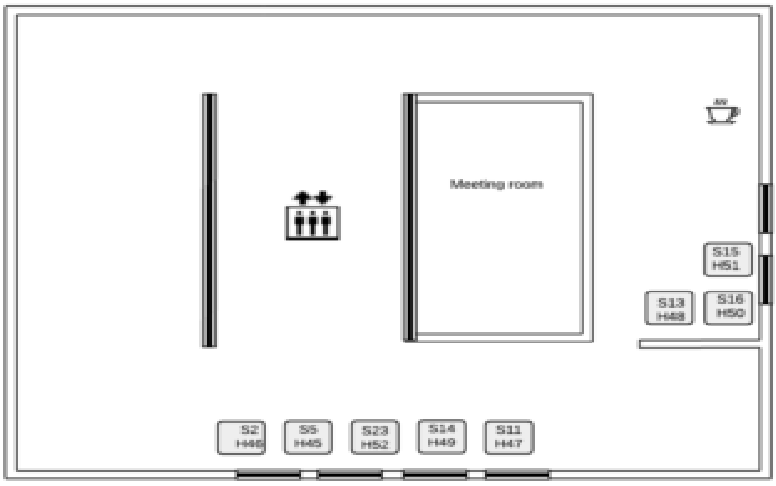

Figure B.1: Sensor Placement on day 1

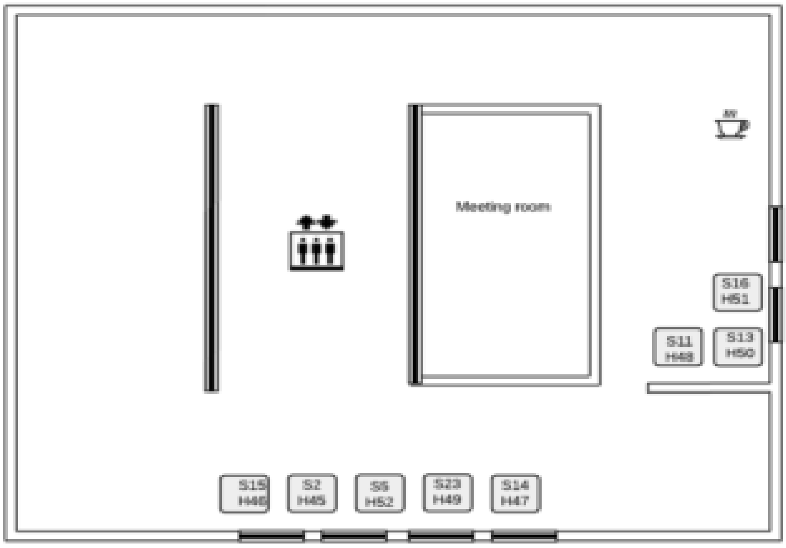

Figure B.2: Sensor Placement on day 2

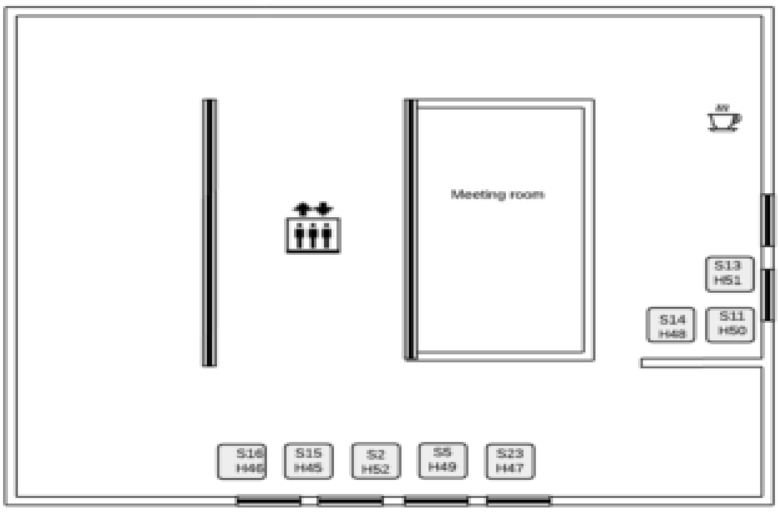

Figure B.3: Sensor Placement on day 3

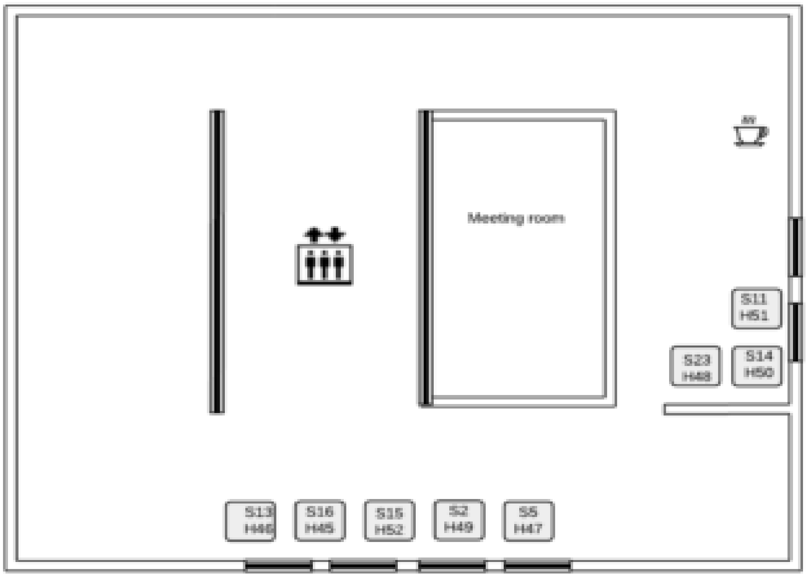

Figure B.4: Sensor Placement on day 4

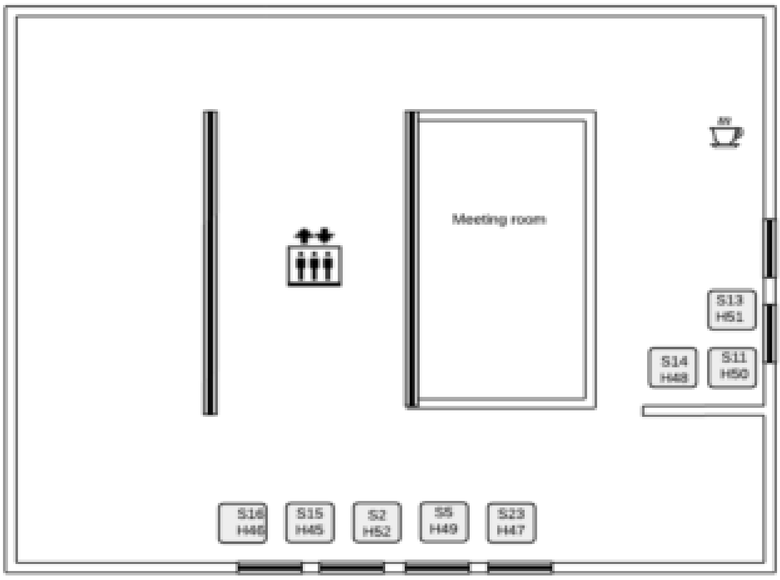

Figure B.5: Sensor Placement on day 5

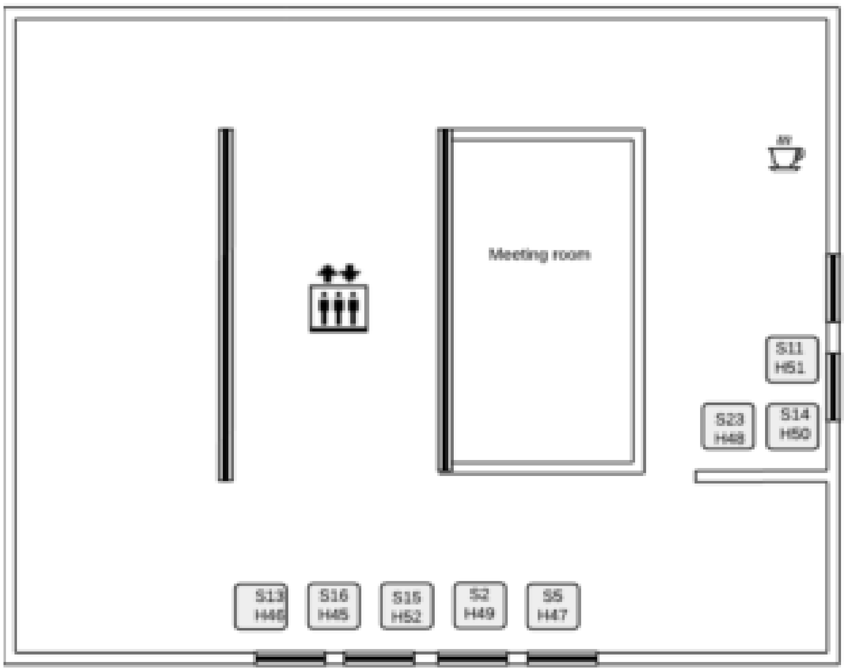

Figure B.6: Sensor Placement on day 6

Appendix C

Appendix C

In this appendix we show the temperature values measured by each sensor which were placed in the office space over the course of the experiment.

C.1 Sensor Readings from Arduino

DAY	TIME	HUB46	VALUE46	HUB45	VALUE45	HUB47	VALUE47	HUB48	VALUE48	HUB49	VALUE49	HUB51	VALUE51	HUB50	VALUE50	HUB52	VALUE52
30-Sep-15	8:00	46	27	45	26	47	26	48	27	49	26	51	26	50	27	52	27
30-Sep-15	8:20	46	27	45	26	47	26	48	27	49	26	51	26	50	27	52	27
30-Sep-15	8:40	46	27	45	26	47	26	48	27	49	26	51	26	50	27	52	27
30-Sep-15	9:00	46	27	45	26	47	26	48	27	49	26	51	26	50	27	52	27
30-Sep-15	9:20	46	27	45	27	47	27	48	27	49	27	51	28	50	27	52	27
30-Sep-15	9:40	46	30	45	30	47	27	48	30	49	27	51	28	50	30	52	30
30-Sep-15	10:00	46	30	45	30	47	30	48	30	49	30	51	30	50	30	52	30
30-Sep-15	10:20	46	31	45	31	47	30	48	31	49	30	51	30	50	31	52	31
30-Sep-15	10:40	46	31	45	31	47	30	48	31	49	31	51	31	50	31	52	31
30-Sep-15	11:00	46	31	45	31	47	30	48	31	49	31	51	29	50	31	52	31
30-Sep-15	11:20	46	30,5	45	30,5	47	30,5	48	31	49	30,5	51	30,5	50	31	52	31
30-Sep-15	11:40	46	30,5	45	30,5	47	30,5	48	31	49	30,5	51	30,5	50	31	52	31
30-Sep-15	12:00	46	31	45	31	47	31	48	31	49	30,5	51	31	50	31	52	31
30-Sep-15	12:20	46	31	45	31	47	31	48	31	49	30,5	51	31	50	31	52	31
30-Sep-15	12:40	46	30,5	45	30,5	47	30,5	48	30,5	49	30,5	51	30,5	50	30,5	52	30,5
30-Sep-15	13:00	46	30,5	45	30,5	47	30,5	48	30,5	49	30,5	51	30,5	50	30,5	52	30,5
30-Sep-15	13:20	46	30,5	45	30,5	47	30,5	48	30,5	49	30,5	51	30,5	50	30,5	52	30,5
30-Sep-15	13:40	46	30,5	45	30,5	47	30,5	48	30,5	49	30,5	51	30,5	50	30,5	52	30,5
30-Sep-15	14:00	46	30,5	45	30,5	47	30,5	48	30,5	49	30,5	51	30,5	50	30,5	52	30,5
30-Sep-15	14:20	46	30,5	45	30,5	47	30,5	48	30,5	49	30,5	51	30,5	50	30,5	52	30,5
30-Sep-15	14:40	46	30,5	45	30,5	47	30,5	48	30,5	49	30,5	51	30,5	50	30,5	52	30,5
30-Sep-15	15:00	46	30,5	45	30,5	47	30,5	48	30,5	49	30,5	51	30,5	50	30,5	52	30,5
30-Sep-15	15:20	46	30	45	30	47	30,5	48	30	49	30	51	30	50	30	52	30
30-Sep-15	15:40	46	29	45	28	47	30,5	48	29	49	28	51	29	50	28	52	28
30-Sep-15	16:00	46	28	45	28	47	29	48	28	49	28	51	28	50	28	52	28
30-Sep-15	16:20	46	28	45	28	47	29	48	28	49	28	51	28	50	28	52	28
30-Sep-15	16:40	46	28	45	28	47	29	48	28	49	28	51	28	50	28	52	28
30-Sep-15	17:00	46	28	45	28	47	30	48	28	49	28	51	28	50	28	52	28

Figure C.1: Day 1 sensor values

DAY	TIME	HUB46	VALUE46	HUB45	VALUE45	HUB47	VALUE47	HUB48	VALUE48	HUB49	VALUE49	HUB51	VALUE51	HUB50	VALUE50	HUB52	VALUE52
1-Oct-15	8:00	46	27	45	27	47	28	48	28	49	27	51	28	50	27	52	27
1-Oct-15	8:20	46	27	45	27	47	28	48	28	49	27	51	28	50	27	52	27
1-Oct-15	8:40	46	27	45	27	47	27	48	27	49	27	51	27	50	27	52	27
1-Oct-15	9:00	46	28	45	28	47	27	48	27	49	27	51	27	50	27	52	28
1-Oct-15	9:20	46	28	45	28	47	27	48	27	49	27	51	27	50	27	52	28
1-Oct-15	9:40	46	28	45	28	47	30	48	30	49	29	51	30	50	29	52	28
1-Oct-15	10:00	46	29	45	29	47	30	48	30	49	29	51	30	50	29	52	29
1-Oct-15	10:20	46	30	45	30	47	31	48	31	49	30	51	31	50	30	52	30
1-Oct-15	10:40	46	30	45	30	47	30,5	48	30,5	49	30,5	51	30,5	50	30,5	52	30
1-Oct-15	11:00	46	31	45	31	47	30,5	48	30,5	49	30,5	51	30,5	50	30,5	52	31
1-Oct-15	11:20	46	31	45	31	47	30,5	48	30,5	49	31	51	30,5	50	31	52	31
1-Oct-15	11:40	46	31	45	31	47	31	48	31	49	31	51	31	50	31	52	31
1-Oct-15	12:00	46	31	45	31	47	29	48	29	49	29	51	29	50	29	52	31
1-Oct-15	12:20	46	29	45	29	47	29	48	29	49	29	51	29	50	29	52	29
1-Oct-15	12:40	46	28	45	28	47	28	48	28	49	28	51	28	50	28	52	28
1-Oct-15	13:00	46	26	45	26	47	26	48	26	49	26	51	26	50	26	52	26
1-Oct-15	13:20	46	26	45	26	47	26	48	26	49	26	51	26	50	26	52	26
1-Oct-15	13:40	46	26	45	26	47	26	48	26	49	26	51	26	50	26	52	26
1-Oct-15	14:00	46	26	45	26	47	26	48	26	49	26	51	26	50	26	52	26
1-Oct-15	14:20	46	27	45	26	47	27	48	26	49	26	51	26	50	27	52	26
1-Oct-15	14:40	46	27	45	26	47	27	48	26	49	26	51	26	50	27	52	26
1-Oct-15	15:00	46	27	45	26	47	27	48	26	49	26	51	26	50	27	52	26
1-Oct-15	15:20	46	27	45	27	47	27	48	27	49	27	51	27	50	27	52	26
1-Oct-15	15:40	46	27	45	27	47	27	48	27	49	27	51	27	50	27	52	26
1-Oct-15	16:00	46	27	45	27	47	27	48	27	49	27	51	27	50	27	52	26
1-Oct-15	16:20	46	27	45	27	47	27	48	27	49	27	51	27	50	27	52	26
1-Oct-15	16:40	46	27	45	27	47	27	48	27	49	27	51	27	50	27	52	26
1-Oct-15	17:00	46	27	45	27	47	27	48	27	49	27	51	27	50	27	52	26

Figure C.2: Day 2 sensor values

DAY	TIME	HUB46	VALUE46	HUB45	VALUE45	HUB47	VALUE47	HUB48	VALUE48	HUB49	VALUE49	HUB51	VALUE51	HUB50	VALUE50	HUB52	VALUE52
2-Oct-15	8:00	46	28	45	28	47	26	48	27	49	27	51	28	50	27	52	28
2-Oct-15	8:20	46	28	45	28	47	26	48	27	49	27	51	28	50	27	52	28
2-Oct-15	8:40	46	28	45	28	47	26	48	27	49	27	51	28	50	27	52	28
2-Oct-15	9:00	46	28	45	28	47	26	48	27	49	27	51	28	50	27	52	28
2-Oct-15	9:20	46	28	45	28	47	26	48	27	49	27	51	28	50	27	52	28
2-Oct-15	9:40	46	28	45	28	47	27	48	27	49	27	51	28	50	27	52	28
2-Oct-15	10:00	46	27	45	27	47	26,5	48	26,5	49	27	51	26,5	50	27	52	27
2-Oct-15	10:20	46	26,5	45	26,5	47	26,5	48	26,5	49	26,5	51	26,5	50	26,5	52	26,5
2-Oct-15	10:40	46	26,5	45	26,5	47	26,5	48	26,5	49	26,5	51	26,5	50	26,5	52	26,5
2-Oct-15	11:00	46	26	45	26	47	26,5	48	26,5	49	26	51	26,5	50	26,5	52	26
2-Oct-15	11:20	46	26	45	26	47	27	48	27	49	26	51	27	50	27	52	26
2-Oct-15	11:40	46	26	45	26	47	26,5	48	26.5	49	26	51	26,5	50	26,5	52	26
2-Oct-15	12:00	46	25	45	25	47	27	48	27	49	25	51	27	50	27	52	25
2-Oct-15	12:20	46	25	45	25	47	26,5	48	26,5	49	25	51	26,5	50	27	52	25
2-Oct-15	12:40	46	25	45	25	47	26,5	48	26,5	49	25	51	26,5	50	26,5	52	25
2-Oct-15	13:00	46	25	45	25	47	26,5	48	26,5	49	25	51	26,5	50	26,5	52	25
2-Oct-15	13:20	46	26,5	45	26,5	47	26,5	48	26,5	49	26,5	51	27	50	27	52	27
2-Oct-15	13:40	46	27	45	26,5	47	27	48	27	49	27	51	28	50	28	52	28
2-Oct-15	14:00	46	27	45	27	47	27	48	27	49	27	51	28	50	28	52	28
2-Oct-15	14:20	46	28	45	26,5	47	28	48	28	49	28	51	28	50	28	52	28
2-Oct-15	14:40	46	28	45	27	47	28	48	28	49	28	51	28	50	28	52	28
2-Oct-15	15:00	46	27	45	27	47	27	48	27	49	27	51	28	50	28	52	28
2-Oct-15	15:20	46	27	45	26,5	47	27	48	28	49	27	51	27	50	27	52	27
2-Oct-15	15:40	46	27	45	26.5	47	27	48	28	49	28	51	28	50	28	52	28
2-Oct-15	16:00	46	27	45	27	47	28	48	27	49	28	51	28	50	28	52	28
2-Oct-15	16:20	46	27	45	27	47	28	48	27	49	28	51	28	50	28	52	28
2-Oct-15	16:40	46	27	45	27	47	27	48	27	49	27	51	27	50	27	52	27
2-Oct-15	17:00	46	27	45	27	47	27	48	27	49	27	51	27	50	27	52	27

Figure C.3: Day 3 sensor values

DAY	TIME	HUB46	VALUE46	HUB45	VALUE45	HUB47	VALUE47	HUB48	VALUE48	HUB49	VALUE49	HUB51	VALUE51	HUB50	VALUE50	HUB52	VALUE52
5-Oct-15	8:00	46	25	45	24	47	25	48	24	49	24	51	25	50	25	52	24
5-Oct-15	8:20	46	25	45	24	47	24	48	24	49	24	51	25	50	25	52	24
5-Oct-15	8:40	46	25	45	24	47	24	48	24	49	24	51	25	50	25	52	24
5-Oct-15	9:00	46	25	45	25	47	24	48	25	49	25	51	25	50	25	52	25
5-Oct-15	9:20	46	25	45	25	47	24	48	25	49	25	51	25	50	25	52	25
5-Oct-15	9:40	46	24	45	24	47	25	48	24	49	24	51	24	50	24	52	24
5-Oct-15	10:00	46	24	45	25	47	25	48	25	49	25	51	24	50	24	52	25
5-Oct-15	10:20	46	24	45	24	47	25	48	24	49	24	51	24	50	24	52	24
5-Oct-15	10:40	46	24	45	24	47	24	48	24	49	24	51	24	50	24	52	24
5-Oct-15	11:00	46	24	45	25	47	24	48	25	49	25	51	24	50	24	52	25
5-Oct-15	11:20	46	25	45	26	47	25	48	26	49	25	51	26	50	26	52	25
5-Oct-15	11:40	46	26	45	26	47	26	48	26	49	26	51	26	50	26	52	26
5-Oct-15	12:00	46	26	45	26	47	26	48	26	49	26	51	26	50	26	52	26
5-Oct-15	12:20	46	27	45	26,5	47	27	48	26,5	49	27	51	26,5	50	26,5	52	27
5-Oct-15	12:40	46	27	45	27	47	27	48	27	49	27	51	27	50	27	52	27
5-Oct-15	13:00	46	27	45	27	47	27	48	27	49	27	51	27	50	27	52	27
5-Oct-15	13:20	46	26,5	45	26,5	47	26,5	48	26,5	49	26,5	51	26,5	50	26,5	52	26,5
5-Oct-15	13:40	46	26,5	45	26,5	47	26,5	48	26,5	49	26,5	51	26,5	50	26,5	52	26,5
5-Oct-15	14:00	46	26	45	26	47	26	48	26,5	49	26,5	51	26,5	50	26,5	52	26
5-Oct-15	14:20	46	25	45	25	47	25	48	27	49	27	51	27	50	27	52	25
5-Oct-15	14:40	46	25	45	25	47	25	48	27	49	27	51	27	50	27	52	25
5-Oct-15	15:00	46	25	45	25	47	25	48	27	49	27	51	27	50	27	52	25
5-Oct-15	15:20	46	26,5	45	26	47	26	48	26,5	49	26,5	51	26,5	50	26,5	52	26
5-Oct-15	15:40	46	26,5	45	27	47	27	48	26,5	49	26,5	51	26,5	50	26,5	52	27
5-Oct-15	16:00	46	27	45	27	47	27	48	27	49	27	51	27	50	27	52	27
5-Oct-15	16:20	46	27	45	27	47	28	48	27	49	27	51	27	50	27	52	28
5-Oct-15	16:40	46	27	45	27	47	28	48	27	49	27	51	27	50	27	52	28
5-Oct-15	17:00	46	28	45	27	47	28	48	28	49	28	51	28	50	28	52	28

Figure C.4: Day 4 sensor values

DAY	TIME	HUB46	VALUE46	HUB45	VALUE45	HUB47	VALUE47	HUB48	VALUE48	HUB49	VALUE49	HUB51	VALUE51	HUB50	VALUE50	HUB52	VALUE52
6-Oct-15	8:00	46	30	45	31	47	31	48	31	49	31	51	30	50	30	52	31
6-Oct-15	8:20	46	30,5	45	31	47	30	48	31	49	30	51	30,5	50	30,5	52	30
6-Oct-15	8:40	46	30,5	45	31	47	31	48	31	49	31	51	30,5	50	30,5	52	31
6-Oct-15	9:00	46	31	45	30,5	47	30,5	48	31	49	30,5	51	31	50	31	52	30,5
6-Oct-15	9:20	46	30	45	30,5	47	30,5	48	31	49	30,5	51	31	50	31	52	30,5
6-Oct-15	9:40	46	29	45	30	47	30	48	30	49	29	51	29	50	30	52	30
6-Oct-15	10:00	46	28	45	29	47	29	48	29	49	28	51	28	50	29	52	29
6-Oct-15	10:20	46	27	45	28	47	28	48	28	49	27	51	27	50	28	52	28
6-Oct-15	10:40	46	27	45	27	47	27	48	27	49	27	51	27	50	27	52	27
6-Oct-15	11:00	46	27	45	27	47	27	48	27	49	27	51	27	50	27	52	27
6-Oct-15	11:20	46	27	45	26	47	26	48	27	49	26	51	27	50	27	52	26
6-Oct-15	11:40	46	26	45	26	47	26	48	26	49	26	51	27	50	27	52	26,5
6-Oct-15	12:00	46	26	45	26	47	26	48	26	49	26	51	26	50	27	52	27
6-Oct-15	12:20	46	26	45	26	47	26	48	26	49	26	51	27	50	27	52	26,5
6-Oct-15	12:40	46	26	45	26	47	26	48	26	49	26	51	27	50	27	52	27
6-Oct-15	13:00	46	27	45	27	47	26	48	27	49	27	51	27	50	27	52	27
6-Oct-15	13:20	46	27	45	27	47	26	48	27	49	27	51	27	50	27	52	27
6-Oct-15	13:40	46	27	45	27	47	26	48	27	49	27	51	27	50	27	52	27
6-Oct-15	14:00	46	27	45	27	47	27	48	27	49	27	51	27	50	27	52	27
6-Oct-15	14:20	46	27	45	28	47	28	48	27	49	28	51	28	50	27	52	27
6-Oct-15	14:40	46	27	45	28,5	47	28	48	27	49	28,5	51	28,5	50	27	52	27
6-Oct-15	15:00	46	27	45	28,5	47	28	48	27	49	28,5	51	28,5	50	28	52	27
6-Oct-15	15:20	46	28	45	28	47	28	48	28	49	28	51	28	50	27,5	52	28
6-Oct-15	15:40	46	27,5	45	28	47	27,5	48	27,5	49	28	51	28	50	28	52	27,5
6-Oct-15	16:00	46	28	45	29	47	28	48	28	49	29	51	29	50	29	52	28
6-Oct-15	16:20	46	29	45	29	47	29	48	29	49	29	51	29	50	28,5	52	29
6-Oct-15	16:40	46	28,5	45	29	47	28,5	48	28,5	49	29	51	29	50	29	52	28,5
6-Oct-15	17:00	46	29	45	29	47	29	48	29	49	29	51	29	50	28,5	52	29

Figure C.5: Day 5 sensor values

DAY	TIME	HUB46	VALUE46	HUB45	VALUE45	HUB47	VALUE47	HUB48	VALUE48	HUB49	VALUE49	HUB51	VALUE51	HUB50	VALUE50	HUB52	VALUE52
7-Oct-15	8:00	46	23	45	23	47	23	48	23	49	23	51	23	50	23	52	23
7-Oct-15	8:20	46	23	45	23	47	23	48	23	49	23	51	23	50	23	52	23
7-Oct-15	8:40	46	23	45	23	47	23	48	23	49	23	51	23	50	23	52	23
7-Oct-15	9:00	46	24	45	24	47	24	48	24	49	24	51	24	50	24	52	24
7-Oct-15	9:20	46	24,5	45	24,5	47	24,5	48	24,5	49	24,5	51	24,5	50	24,5	52	24,5
7-Oct-15	9:40	46	24,5	45	24,5	47	24,5	48	24,5	49	24,5	51	24,5	50	24,5	52	24,5
7-Oct-15	10:00	46	25	45	25	47	25	48	25	49	25	51	25	50	25	52	25
7-Oct-15	10:20	46	25	45	25	47	25	48	25	49	25	51	25	50	25	52	25
7-Oct-15	10:40	46	26	45	26	47	26	48	26	49	26	51	26	50	26	52	26
7-Oct-15	11:00	46	26	45	26	47	26	48	26	49	26	51	26	50	26	52	26
7-Oct-15	11:20	46	26	45	26	47	26	48	26	49	26	51	26	50	26	52	26
7-Oct-15	11:40	46	25	45	25	47	25	48	25	49	25	51	25	50	25	52	25
7-Oct-15	12:00	46	25	45	25	47	25	48	25	49	25	51	25	50	25	52	25
7-Oct-15	12:20	46	25	45	25	47	25	48	25	49	25	51	25	50	25	52	25
7-Oct-15	12:40	46	25	45	25	47	25	48	25	49	25	51	25	50	25	52	25
7-Oct-15	13:00	46	26	45	26	47	26	48	26	49	26	51	26	50	26	52	26
7-Oct-15	13:20	46	27	45	27	47	27	48	27	49	26	51	27	50	27	52	26
7-Oct-15	13:40	46	27	45	27	47	27	48	27,5	49	27	51	27,5	50	27	52	27
7-Oct-15	14:00	46	27,5	45	27,5	47	27,5	48	27,5	49	27	51	27,5	50	27,5	52	27
7-Oct-15	14:20	46	28	45	28	47	28	48	28	49	28	51	28	50	28	52	28
7-Oct-15	14:40	46	28	45	27,5	47	27,5	48	28	49	28	51	28	50	27,5	52	28
7-Oct-15	15:00	46	28	45	27,5	47	27,5	48	27,5	49	27,5	51	27,5	50	28	52	27,5
7-Oct-15	15:20	46	27,5	45	27,5	47	27,5	48	27,5	49	27,5	51	27,5	50	27,5	52	27,5
7-Oct-15	15:40	46	27,5	45	27	47	27	48	27	49	27,5	51	27	50	28	52	27,5
7-Oct-15	16:00	46	27	45	27,5	47	27,5	48	27,5	49	28	51	27,5	50	27,5	52	28
7-Oct-15	16:20	46	27,5	45	27,5	47	27,5	48	27,5	49	27	51	27,5	50	27	52	27
7-Oct-15	16:40	46	27	45	27	47	27	48	27	49	27	51	27	50	27	52	27
7-Oct-15	17:00	46	27	45	27	47	27	48	27	49	27	51	27	50	27	52	27

Figure C.6: Day 6 sensor values