TÉCNICO LISBOA

Energy Efficiency Optimization Through Occupancy Detection and User Preferences

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Thesis to obtain the Master of Science Degree in

Telecommunications and Informatics Engineering

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June 2014

I dedicate my dissertation work essentially to my parents, which despite of the distance, were at my side in all the difficult and successful moments.

Acknowledgments

First of all I would like to express my deepest gratitude to my advisor Prof. Paulo Carreira for his valuable help and continuous support of my research, for his patience, encouragement, enthusiasm, and immense knowledge. I must thank him for pushing me forward to discover and try new technologies and new areas of development. I would like to thank my second advisor Prof. Artur Arsenio for his willing to help, suggestions, support, guidance, advice throughout the research project. Without their guidance, this thesis would not be possible.

I also want to express my gratitude to Prof. Pedro Fazenda and Henrique Pombeiro for the availability and willing to help, on the development of this project.

To all my friends of the university, which together were succeeding the same challenges that made us better persons: Daniel Olim, João Prioste, João Rosa, Carlos Simões, Nadia Gonçalves and Gonçalo Pereira. Special thanks to Roberto Silva, João Cardoso, Lucca Mordente, Heitor Salazar, Tiago Edgar and Carina Queiroga for the availability on helping me on the development of his work.

To my friends Leandro Guerra, Rafael Amaral and Lorran Gabardo for providing such great moments together. And special thanks to Julio Viotti, Juliano Rodrigues and Cynthia Menezes for the great support and friendship that i couldn't have imagined having on this journey.

And finally but not least, to my father and mother, who supported me in all decisions and moments of my life, even being against them. They make possible for me to accomplish one of my dreams. If it wasn't for them, I surely would not be here writing this document. Thank you!

Resumo

Sistemas de Automação em edifícios são sistemas que visam controlar automaticamente dispositivos electrónicos em edifícios. Estes sistemas tem como objetivo proporcionar o controle de energia e gestão de conforto, controlando sistemas de AVAC. No entanto, esses sistemas utilizam configurações pré-definidas, que, geralmente não correspondem as preferências dos ocupantes. Além disso, não há nenhuma forma para que os ocupantes especifiquem suas preferências em um sistema de climatização. Isso é especialmente verdadeiro para espaços grandes. Os sistemas já existentes normalmente levam em conta o número de ocupantes e o consumo energético, sem levar em conta as preferências individuais dos ocupantes.

Um sistema que pode carregar automaticamente as preferências dos ocupantes e gerenciar automaticamente os níveis de ventilação e aquecimento de acordo com suas preferências, pode vir a ser uma inovação na gestão dos sistemas de climatização, permitindo-lhe reunir recursos para poupar energia, mantendo os níveis de conforto dos ocupantes.

Esta tese estuda o problema de encontrar automaticamente uma configuração adequada dos sistemas de climatização, tendo em conta as preferências dos ocupantes. Começa por realizar um estudo de soluções existentes para o problema, algoritmos para calcular as configurações mais apropriadas do sistema de climatização. Uma implementação de um protótipo é também descrito e validado.

Os resultados foram avaliados por simulação utilizando votos dos ocupantes. Portanto, espera-se melhorar a experiência dos ocupantes e reduzir o consumo de energia através da aplicação deste conceito em ambientes reais. Os resultados indicam que um dos algoritmos é capaz de manter com sucesso os níveis de conforto apropriadas ao mesmo tempo, reduzindo o consumo de energia em comparação com um cenário padrão.

Palavras-chave: Economia de energia, Preferencia de utilizadores, Sistema de RFID, Detecção de ocupantes, Sistema AVAC, Conforto térmico.

Abstract

Building Automation Systems (BASs) are distributed systems that aim at automatically controlling electronic devices on buildings. These systems aims to provide energy control and comfort management by controlling the Heating, Ventilation and Air Conditioning (HVAC) systems. However, these systems use pre-set configurations which usually do not correspond to occupants preferences. Moreover, there is no way for occupants to specify their preferences to HVAC system. This is especially true for large spaces. Indeed, existing systems take into account the number of occupants and the energy consumption, disregarding individual occupant preferences.

A system that can track the occupants preferences, and manage automatically the ventilation and heating levels accordingly to their preferences, should prove to be an innovation in the management of HVAC systems, allowing it to pool its resources for saving energy while maintaining user comfort levels.

This thesis studies the problem of automatically finding the appropriate set-point of HVAC systems taking into account user preferences. It starts by carrying out a study of existing solutions to the problem and distinct algorithms to compute the appropriate set-point configurations. A prototype solution implementation is also described and validated

The results were evaluated by simulation using occupant votes. Therefore, it is expected to improve the occupant experience and reduce the energy consumption by applying this concept into real environments. Our findings indicate that one of the algorithms is able to successfully maintain the appropriate comfort levels while also reducing energy consumption by comparing with a standard scenario.

Keywords: Energy Savings, Users Preferences, RFID System, Occupancy Detection, HVAC System, Thermal Comfort.

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List of acronyms

ACHE	Adaptive Control of Home Environments
AHU	Air Handler Units
AmI	Ambient Intelligence
ASHRAE	American Society of Heating and Air-Conditioning Engineers
BAS	Building Automation System
DB	Data Base
DHCP	Dynamic Host Configuration Protocol
EIBG	Europe Intelligent Building Group
FLEXOR	Flexible Localisation EXplOits Rfid
GGTS	Groovy Grails Tool Suite
HTML	HyperText Markup Language
HTTP	Hypertext Transfer Protocol
HVAC	Heating, Ventilation and Air Conditioning
IDE	Integrated Development Environment
ISES	Intelligent Services for Energy-Efficient Design and Life Cycle Simulation
JSON	JavaScript Object Notation
JVM	Java Virtual Machine
kNN	K-Nearest Neighbours
LAN	Local Area Network
LANDMARC	Location Identification based on Dynamic Active RFID Calibration
LCD	Liquid Crystal Display
MACES	Multi-Agent Comfort and Energy System

MASBO	Multi-Agent System for Building Control
ML	Maximum Likelihood
MVC	Model View Controller
NFC	Near Field Communication
OBSERVE	Occupancy-Based System for Efficient Reduction of HVAC Energy
PMV	Predicted Mean Vote
QEM	Quality Environment Modules
RAM	Random Access Memory
RFID	Radio Frequency Identification
ROCRSSI	Ring Overlapping Circle RSSI
RSSI	Relative Signal Strength Intensity
SOA	Service Oriented Architecture
UDP	User Datagram Protocol
VAV	Variable Air Units
XML	Extensible Markup Language

Chapter 1

Introduction

Heating, Ventilation and Air Conditioning (HVAC) systems account for up to 60% of the total energy consumption of commercial buildings [1]. Building Automation System (BAS) automate HVAC management, lighting and water heating subsystems in buildings and homes [2].

A BAS is used to save energy while maintaining user comfort. Since occupants cannot control the HVAC thermal settings, they may experience discomfort while the system is probably cooling or heating above what is required and wasting energy. Presumably if occupants were given the opportunity to control the HVAC system, situations of excessive service delivery, that spend more energy, would not be so frequent. Indeed, occupants are often in position to identify these situations and give critical feedback to the system. Consider that an occupant is feeling too cold because the set-point is set too low. In this case the occupant could indicate that he is feeling cold, causing the system to select a higher set-point, effectively spending less energy on cooling.

Occupancy detection by itself enables a a BAS to behave according to the number of occupants: when the system detects that there are no occupants in the environment, it triggers an energy saving policy, making it possible to turn off unused equipment such as the HVAC and water heating systems. A reasonable climate control solution employing intelligent systems is potentially able to minimize the energy consumption. This technique can be used to promote energy savings while maintaining the occupants comfort. However, it is important to note that the occupants opinion regarding comfort or discomfort, is typically not considered when controlling traditionally HVAC systems.

Studies show that the use of occupancy detection techniques with light and HVAC systems is beneficial to energy optimization, reaching savings values from 10% up to 50% [3, 4, 5]. However occupancy detection does not always have an acceptable accuracy rate. A promising approach is to use Radio Frequency Identification (RFID) systems to detect occupants with reliable accuracy, and retrieve occupants information such as their comfort preferences. This can lead to a higher occupancy detection accuracy and energy management control.

Using an RFID system, it is possible to obtain information regarding the occupants preferences, and, furthermore, their behaviour. A group of occupants may then have a set-point that the system can record. On a second moment. the system will automatically configure the set-point to match the occupants preferences, without needing to retrieve their feedback.

Energy management is concerned with finding sources of waste and act in order to improve the energy savings — a major problem on commercial buildings. Energy typically targets the HVAC system in order to reduce energy waste. However if the occupant is not in the loop, these improvements are under-optimal.

Energy consumption is influenced by many factors, such as weather and occupancy. The energy management system would benefit from a decision algorithm which could determine the most appropriate time to automatically change the configurations of HVAC. This would encourage energy savings. However, maximizing occupant comfort is a difficult task because preferences an be contradictory. Most existing systems only take into account a fixed mean temperature aiming at a comfortable ambient to the majority of occupants.

Even if the possibility to change HVAC system settings is given to occupants, probably it still would not be possible to reach a consensual set-point value that would make every single occupant feel comfortable. In a system in which all occupants could give their opinion about the climate comfort, it may be possible to compute a value of these opinions that minimizes the overall discomfort and configure the HVAC system for it.

This thesis explores how to merge technologies for occupancy detection and user feedback in order to improve the energy efficiency of an HVAC system.

1.1 Motivation

Consider a scenario where an automated program does all the calculations on the climate temperature and comfort and automatically configures the HVAC system to act accordingly to occupant preferences. Users could then use a smartphone or computer application to give feedback to the system regarding their comfort satisfaction. The HVAC system would then automatically configure itself to meet the occupant comfort value. After some time the system would be able to automatically configure itself based on the history of users preferences without the need to receive further feedback from them.

A system where an automated intelligent system configures the HVAC System could prove to be a better configuration approach for the HVAC system, in which users would need to use the system normally during some time and it would configure itself to match their preferences maximizing comfort.

It should be possible for the HVAC system to become completely ubiquitous to the occupants, where the system automatically loads its preferences and adjust itself to the occupants preferences when they enters a room.

1.2 Problem Statement

Energy Management Systems are mainly concerned on the energy consumption. Since occupant comfort can be contradictory, these systems typically have trouble on defining a optimal occupant comfort rate while minimizing the energy consumption. There are system which aims into solving this problem, however, there is still a lack of solutions based on occupant preferences. To date, there is no solution platform which **maximizes comfort** by collecting information on the occupant's preferences by giving a set-point based on their feedback. **Encourage occupants to save energy** by allowing them to see information on the other occupant's votes and actual inside and outside temperature of the room. **Store occupant preferences** in order to make decisions in the future, by storing information about the behaviour of the occupant. **Make automatic decisions** by using data on occupant's preferences which will enable an automatic configuration based on the data retrieved.

Considering that users are given the appropriate means to control the equipment and are provided with feedback on their actions in terms of energy and ambient variables. The underlying assumption is that users will react in a positive way determining the settings of the system and it will be possible to minimize energy consumption while maximizing comfort.

To validate this assumption, some questions needed to be raised: first, if a large group of occupants are given the possibility to control the HVAC set-point, will they collaborate to find out a set-point that is acceptable to everyone? second, if occupants are given feedback of the power consumption, would they be influenced to change their actions? third, ambient variables feedback such as temperature and CO levels, would also influence them to change their actions? and finally will these three assumptions be possible fulfill while maximizing user comfort and reducing energy consumption?

1.3 Goals and Contributions

This work develops a system which enables occupants of a given room to give their opinion on the configuration of the HVAC system. It calculates a set-point temperature which best fits their suggestions and find the most appropriate actuation to minimize energy consumption while, at the same time maximize comfort.

The proposed system incorporates dynamic user feedback control loops in order to optimize the energy/comfort trade-off. Furthermore, it provides a cooperative mechanism for users to agree on levels of comfort that decrease energy consumption. This system could expanded into a testing platform for validating different scenarios and algorithms related to the comfort and energy use. In particular the main contributions of this thesis are:

- A compilation of the existing projects regarding the energy consumption optimization with occupancy detection based solutions.
- The design and development of a prototype system that supports occupants votes and computes the set-point that maximizes their comfort.
- The design and development of an RFID-based occupancy detection system which can be used to enhance the occupant experience.
- Development and implementation of a learning algorithm capable of learning the occupant's behaviour and automatically configure the system.

– An evaluation of the solution by merging the previously mentioned prototype system with a energy simulation framework.

– A set of scenarios and simulation tests which demonstrate the use of the proposed solution with its validation on simulated results.

1.4 Document Organization

This document is organized into six chapters. Chapter 2 introduces concepts necessary to understand the technologies and systems underlying this work. It also presents the state of the art covering similar projects which try to solve related problems. Chapter 3 present the architecture of the proposed solution. The development of the solution with the corresponding algorithms is detailed on chapter 4. Chapter 5 presents the evaluation and, finally chapter 6 presents the conclusions.

Chapter 2

State-of-the-art

This project is focused on the area of Ambient Intelligence (AmI), HVAC systems and occupancy detection; and this area could have complex concepts, equipments and solutions. We will first introduce the fundamental concepts related to this project on section 2.1. Sections 2.2, 2.3 and 2.2.9 goes through the studies of the scientific community in order to promote energy savings, using AmI based solutions. Different approaches were done going through algorithms, simulations, neural networks and sensors for occupancy detection. These systems have a common goal that is use the AmI concepts to promote solutions that are able to turn possible energy savings.

RFID could be a viable solution to the occupancy detection problem, this section will also go through solutions proposed by the scientific community to promote occupancy detection through RFID systems.

2.1 Concepts

Section 2.1.1 introduces the concept of Ambient Intelligence in the realm of building operations automation using sensors. Section 2.1.2 introduces the HVAC systems and Energy Optimization, section 2.1.3 will introduce the concept of Occupancy Detection, finally RFID sensors which is used to track users preferences is presented in section 2.1.4

2.1.1 Ambient Intelligence

The Europe Intelligent Building Group (EIBG) defines an intelligent building as *"one that creates an environment which maximizes the effectiveness of the building's occupants, while at the same time enabling efficient management of resources with minimum life-time costs of hardware and facilities"* [6]. An intelligent building can be comprised in 10 Quality Environment Modules (QEM), such as environmental friendliness – health and energy conservation, space utilization and flexibility, cost effectiveness, human comfort and working efficiency.

AmI refers to the paradigm of environments that are able to automatically respond to users needs without the need to take orders from them. To this aim, environments are equipped with a network of small electronic devices with a minimum processing capability, that act as sensors or, as actuators, acting upon the environment, therefore changing it. The AmI is an area of study that makes possible the implementation of smart building systems, thus are used to give a better occupant experience and energy savings.

The effective planning and orchestration of the sensors and applications in AmI systems results in smart environments, characterized by systems and technologies that have the following features [7]: *(i)* embedded in the environment, in the sense that technology is ubiquitous and as undistinguishable from the surroundings as possible; *(ii)* context-aware, i.e., capable of obtaining information about the user and on-going activity to infer the current context; *(iii)* personalizable, in the sense that users can establish a set of preferences that tailor the system to their needs; *(iv)* adaptive to user and environment changes; *(v)* predictive, capable of anticipating of users' wishes based on their past behaviour, incorporating either implicit or explicit feedback.

A large variety of disciplines can be grouped under the umbrella of AmI: distributed intelligence, data and information communications, software and hardware design, robotics, information fusion, computer vision, speech recognition, social sciences, ethics and law [8].

AmI applications are concerned with optimizing the occupants experience in five aspects [9]: energy management; healthy living environment; personal safety and security; technical safety and entertainment.

The Energy Management and Healthy living environment promotes the possibility of energy saving, for example in HVAC systems, the use of ventilation on demand allows up to 70 % of energy savings [9]. Energy savings with HVAC systems are described in a more detailed format in section 2.1.2.

2.1.2 Heating, Ventilation and Air Conditioning

Heating, Ventilation and Air Conditioning (HVAC) systems, are designed to maintain good indoor air quality through adequate ventilation, and provide thermal comfort by supplying heated and cooled air as required. Air must be kept circulating in order to promote adequate temperature and comfort for occupants.

HVAC Basics

HVAC systems remove or supply heat and moisture from or to the environments, by using cooling or heating coils. An air cooling coil is called Evaporator, when a liquid refrigerant is fed through an expansion valve and evaporates completely before leaving as vapor, removing heat from the air stream in the process. An air heating coil is called condenser when the refrigerating is liquefied by removal of heat from the air stream [10]. These systems work in a closed circuit, in which the refrigerant will evaporate in the cooler and liquefy in the heater, circulating with the help of a compressor, thus promoting the exchange of heat between the two coils. The process can be reversed with the help of special actuated valves, so the coils can act as coolers or heaters as required. The air-handling unit can supply constant or variable air volume to the environments.

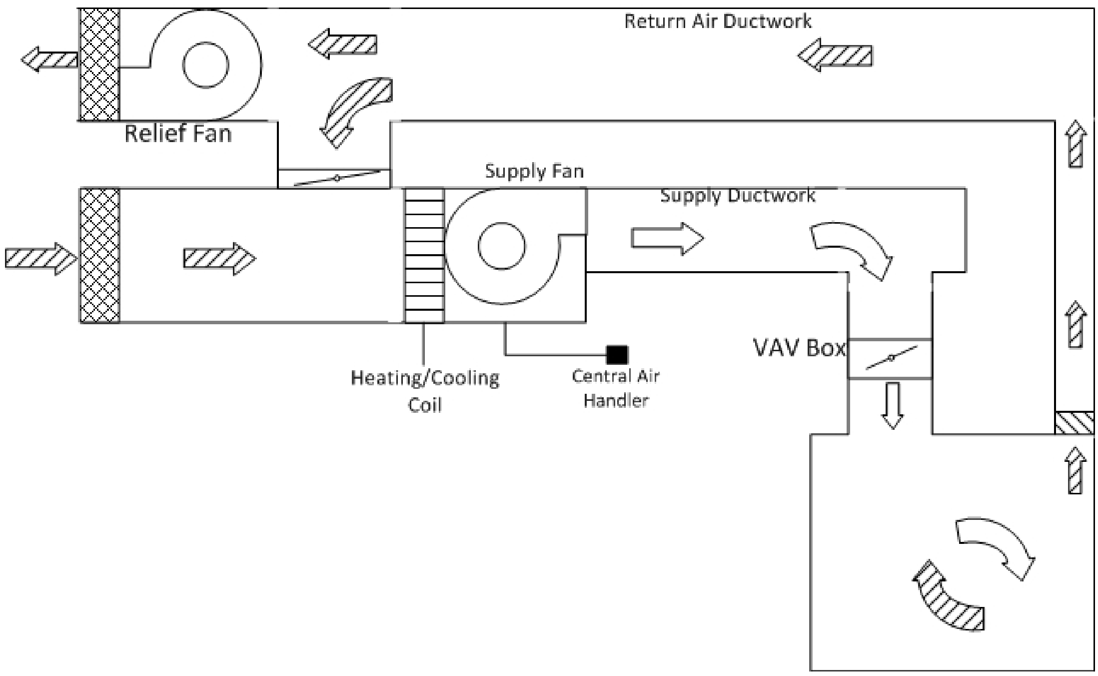

Figure 2.1: Typical VAV System: The air is recirculated through a cooling coil and then supplied to the room at a given constant temperature. The terminal VAV Box will vary the volume of supplied air according to the room load, which is sensed by an ambient thermostat.

The Air Handler Units (AHU) are HVAC equipments where the recirculated air is treated with a number of processes such as: cooling, heating, humidifying and filtrating. The air-handling equipment is usually custom-designed and fabricated to suit a particular application. Air-handling units may be either centrally or remotely located [11].

Variable Air Units (VAV) systems control temperature in the spaces by varying the quantity of supply air keeping its temperature relatively constant. The supply air temperature must always be low enough to meet the cooling load in the most demanding zone of the building. The figure 2.1 depicts a basic schema of a typical VAV system.

HVAC Energy Optimization

HVAC systems are among the largest energy consumers in buildings. Up to 60% of the buildings energy consumption are related to HVAC systems [1] Some simulation-based results show that estimated energy savings from HVAC systems may vary between 10% and 60% [12]. This analysis emphasizes the need for intelligent controlled systems, that allow for custom configurations, or that otherwise react dynamically to environment changes. A common example is to turn off the heating system when the zone is unoccupied.

The energy consumers of a HVAC system are chillers, refrigerant compressors, fans and pumps [13]. In order to efficiently control these components, the HVAC system relies their configurations in sensors. These sensors can be grouped into the following types [9]: temperature and humidity, pressure, air flow rate, comfort, and indoor air quality. The HVAC system adjusts itself accordingly to the readings of these sensors. The sensors must be specified with performance, practical and economic factors such as: range, accuracy, sensitivity, linearity, response time, cost, maintenance and interference. It is recommended by the manufacturer to maintain these sensors correctly calibrated in order to receive good readings from them.

Despite of their sensors, the HVAC systems are usually large energy consumers in buildings due to bad system management. Usually the system is kept cooling air when there are no occupants, it can even stay all night long if someone forgets to turn it off. Sometimes occupants do not have the ability to configure the temperature accordingly to its needs, then the system cools the ambient more than is necessary. This bad management of the system is responsible for inefficient energy savings, one solution for this problem is the use of occupancy detection, that will configure the HVAC system to behave accordingly to the presence of occupants

HVAC systems are driven by electronic and computerized controllers that adjust air flow and temperature according to a number of factors measured by their sensors. These controllers can be controlled by BAS systems. BAS are control systems installed in intelligent buildings which controls and monitors building's mechanical and electrical equipments such as lighting and HVAC systems. These systems, try to be energy efficient and they are integrated with control, monitoring, heating and ventilation systems. They try to optimize the energy savings without reducing user individual comfort [14]. There is, however, a trade-off between indoor thermal comfort and energy consumption. The aim of an intelligent control system is to maintain occupants comfortable while saving the maximum energy as possible.

Energy efficiency is an important issue related to HVAC systems due to the growing energy costs and environmental concerns. Over the last 25 years, the annual global energy consumption has increased by 66% with 51% subsequent increase in energy-related carbon emissions [15].

Due to the high potential of energy savings in intelligent HVAC systems, the interest of researching new ways to reduce the energy savings is growing fast. Research studies aiming to optimize energy savings are usually focused in specific topics, such as: optimizing HVAC algorithms, occupancy detection, occupancy simulation and occupancy prediction.

Occupant Comfort

One important parameter measured is the comfort value. It is based on six parameters such as: metabolic rate of occupants, clothing insulation of occupants, dry bulb temperature, moisture content, wind speed and mean radiant temperature. All these parameters estimates the Predicted Mean Vote (PMV) [16], this value is one manner to estimate a sense of comfort of most human beings [9]. The PMV was first calculated through surveys where occupants vote for their comfort sensation in a indoor space. This study leaded into a complex equation based on the previously mentioned parameters that can calculate the PMV. The PMV equation only applies to humans exposed for a long period to constant conditions at a constant metabolic rate. Conservation of energy leads to the heat balance equation 2.1 [16]:

$$H - Ed - Esw - Ere - L = R + C \tag{2.1}$$

Where:

– H = internal heat production

– Ed = heat loss due to water vapour diffusion through the skin

– Esw = heat loss due to sweating

– Ere = latent heat loss due to respiration

– L = dry respiration heat loss

– R = heat loss by radiation from the surface of the clothed body

– C = heat loss by convection from the surface of the clothed body

Nowadays the PMV is a pattern that can be calculated through the sensor's readings and the equation previously mentioned. Since more energy is spent when optimizing the occupant comfort, maintaining user comfort using a minimum energy possible can be a tricky task.

2.1.3 Occupancy Detection

Occupancy Detection refers to automated systems that can automatically detect people in environments through various types of sensors. The main goal is to know when and how many occupants are located in a given space, and then take decisions based on this information. In energy management applications, the occupancy sensor sends a signal that is used to reduce de energy consumption in case detects an empty room (e.g., switch lights off when the space has been unoccupied for 5 min).

Occupancy detection is achieved through a sensor network, commonly consisting of Infrared Motion sensors, Infrared-Based People Counter, CO2 analyzer, Ultrasonic Motion, and RFID sensors [1]. Many real applications of these systems even use a mix of sensors to improve the effectiveness of occupancy detection, because some sensors cannot single-handedly differentiate between one and multiple occupants in a space [17].

There are different occupancy detection strategies such as using simple infra-red sensors or RFID systems in doors to count the number of persons entering and exiting a space; use data from sensors to count exactly the number of persons in a space using ultrasonic tracking systems or video cameras; or using the both techniques in order to maximize the accuracy of the system.

Energy management occupancy detection usually distinguish three modes of operation: User-presence, On-demand and User-absence mode [1]. When the systems acts on user-presence mode, most of them are configured to load user preferences despite of energy savings. The On-demand mode forces the system to detect the occupants and automatically calculate how much energy can be spent to grant a satisfactory user commodity consuming the less possible energy. Finally the User-absence mode is concerned with the case when there are no occupants in the environment, therefore a "stand-by" or power savings mode are enabled.

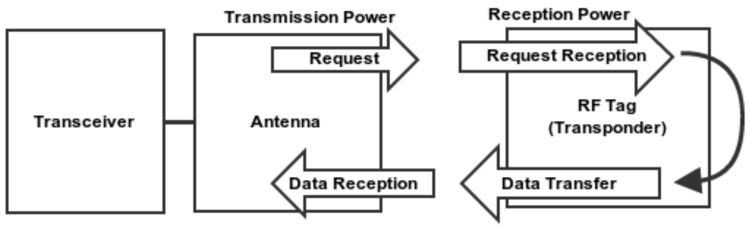

Figure 2.2: Typical RFID system. The transceiver makes as request and the antenna retrieves the information stored on the tag

2.1.4 Radio Frequency Identification (RFID)

Radio Frequency Identification (RFID) is a technology used to store information about physical objects. It allows for information retrieval through the use of a reader and a tag, in a similar fashion to that of bar code systems. Unlike bar code systems, the RFID technology can dynamically transmit and receive information within a wider range of up to 100 meters [18].

Sensing systems based on RFIDs use typically readers and transponders (commonly referred as tags) (see Figure 2.2). The tags are affixed to the physical objects to be tracked. The transponder is electronically programmed with a unique identification, and may also have other information about the object. The readers and the tags do not transmit at the same time. First, the transceiver queries tags by transmitting a query on the system's operating frequency, and then the tag replies by transmitting data stored on the tag, as depicted in Figure 2.2. The reader may be linked to a database, which stores the information received from the tag. There is also a anti-collision protocol that ensures that the shared communication channel is exclusively allocated to the transmitting transponder, avoiding more than one transponder to communicate at the same time to avoid communication collisions.

There are two most common types of RFID tags: passive tags and active tags [19]. The passive tags are the most common ones. They do not contain battery, and the power is supplied by the reader [20]. Their read range are up to 12 meters. The tag remains readable for a minimum period of 10 years. Passive tags are more often used for inventory assets, and on disposable consumer goods [21]. Typically the passive tags have a cost range between USD 0,07 and 0,15, depending upon quantity, durability and manufacturer [22]. Active tags are equipped with a battery that can be used as a total or partial source of power for the tag's circuitry and antenna. The RFID active tags are commonly used to perform real-time asset monitoring. As they can provide a better layer of security than passive tags. It is usually possible to read an active tag within a range of up to 100 meters. The price of these tags is in a range of USD 15,00 and 100,00 depending on the quantity, options (motion sensor, tamper detection, temperature sensor), and form factor [19].

2.1.5 HVAC Simulation Systems

Simulation is a replica operation of a real-world process over time. In order to simulate something, it first requires a model which represents the behaviours and functions of the selected physical and abstract processes [23]. The HVAC simulation system follows the same concept, which given circumstances such as weather, location and a building layout, will simulate the behaviour of an HVAC system over time.

The concept of building energy simulation systems, refers to programs which are capable of evaluating energy efficiency by means of simulations. These systems create virtual environments and tries to simulate all the possible variables on the environment such as indoor/outdoor temperature, solar radiance, window reflex, human heat, energy consumption among many others [24].

These virtual simulated environments are used by engineers, architects and researchers to model energy and water use in buildings, with the main goal to model the performance and optimize the model in order to use less energy and water. An example of a energy simulation system is the Energy Plus software [25] which is developed by the Department of Energy of the United States.

2.2 Intelligent Energy Savings Approaches

Since the major energy consumer in a building is the HVAC system, most of these approaches focus on intelligently managing the HVAC system's energy. This section will go through multi-agent systems, adaptive control systems, fuzzy logic control systems, probabilistic model systems, pattern mining, sensor-based and image acquisition sensors. The multi-agent systems are equipped with logical intelligent agents that are used with the purpose of solving problems that are difficult to individual agents to solve. Artificial intelligence systems are able to make decisions from patterns learned from different inputs and outputs. Artificial intelligence systems imbued may be with the Neural Networks concept. It learns patterns and uses the statistical information to make decisions on inputs.

2.2.1 Multi-Agent Systems

Multi-agent systems consists of a collection of communicating software agents that monitor and control a building systems such as lighting and HVAC. Multi-agent systems can be used to reduce energy in a building while maintaining user comfort.

Three projects were analysed, Intelligent Services for Energy-Efficient Design and Life Cycle Simulation (ISES), Multi-Agent System for Building Control (MASBO) and Multi-Agent Comfort and Energy System (MACES). The ISES was able to show that the multi-agent system controller is able to reduce energy consumption by 40% while keeping occupant satisfaction similar values to traditional control methods [3, 26, 27]. The MASBO records the personal preferences of each user separately and passively through wireless sensors. Each agent in the system is responsible for a different aspect of the environment [28, 29]. MACES uses a multi-agent system to control HVAC system according to two strategies: reactive, that automatically adjust itself according to real time occupancy; and predictive that predicts the occupancy [4].

The ISES system uses temperature, light and active badge sensors for occupancy detection. The active badge system makes it possible to know which persons are in each room. The multi-agent system uses four agents to control the light and HVAC system, these agents are: Personal Comfort Agents, Room Agents, Environmental Parameters Agents and Badge System Agents. The Personal Agents are responsible to store the personal preferences, the Room Agents controls particular rooms light and HVAC system, Environmental Parameter Agents monitors and controls a particular environmental parameter in a particular room, finally the Badge System Agents are responsible to track the position of the occupants in the building and stores it in a database.

The MASBO system consists of four agents: the Local Agent, the Monitor and Control Agent, the Personal Agent and the Central Agent. The Local Agent main function is to monitor a given room, acting as a mediator between different user preferences. The Monitor and Control Agent sets the temperature configuration regarding to the Local Agent's decisions. The Personal Agent is responsible for recording the user's preferences passively by monitoring the user's interactions with the environment. Finally, the Central Agent has two main functions: acting both as a decision aggregator and as an interface to the internal and external services required by the agents. The project also provides a feedback mechanism, that shows information about the ambient variables to the occupants foe information purposes.

MACES was tested by simulating the behaviour of humans inside a university building. The system labels the occupants in four different activities: attending classes, teaching, in a meeting or studying. Predictive and reactive control was used to reach their results. In ISES solution, the occupant satisfaction value is measured based on a simple linear model, where 16°C or less corresponds to 0% satisfaction, and 22°C corresponds to 100%. Their results may not reflect reality because they are only based on simulations. The method of testing the occupant satisfaction may be reductive, for it uses a sliding scale to represent the user satisfaction. The system has a simple architecture and it also stores individual user preferences.

Unfortunately MACES has only been tested through simulation, and results showed that using predictive user occupancy control proved to be a better solution and can reduce energy consumption up to 12.17%. This solution reached levels of comfort between 90% and 95% regarding the PMV index of the American Society of Heating and Air-Conditioning Engineers (ASHRAE). If these results could be achieved in a real test bed this system could be a successful solution to occupancy prediction based systems in intelligent buildings.

2.2.2 Adaptive Control-Based Systems

Adaptive Control systems adapt a controlled system through variable parameters in real time, usually by means of parameter estimation. An example of an Adaptive Control system can be a control system that adapts the HVAC temperature regarding occupants preferences that may vary over time.

Adaptive Control of Home Environments (ACHE) uses a neural network to learn how to control the lighting, HVAC and water heating systems of a house [30, 31]. The project was developed with two main goals: first, to foresee the inhabitants needs, and the second is to ensure energy savings. This system learns the comfort patterns of the user by analysing its manual adjustments. In a way, ACHE learns from user-triggered events.

When the user is not present, the lights and the water heater are set to a minimum in order to save energy. Occasionally despite of user presence, the system lowers the energy required to maintain the temperature, or lighting levels. This is intended to elicit a user response if the comfort levels drop below what is acceptable by the user. The ACHE uses neural network, as previously hinted, learns from the event and applies the new knowledge to optimize energy consumption. The system does not provide any feedback on ambient variables to the user.

The system tests were made during a three-month period, but none of the results show a quantified value representing the energy saved. The comfort settings do not distinguish between user classes and, therefore, there are no individual user configurations.

Other project also uses artificial intelligence system to promote a minimum energy consumption whilst maximizing user comfort [32]. This system consists of a differential: a negotiation agent. Occupants can adjust the temperature and humidity settings using input panels located in various rooms throughout the building. The neural network has pre-defined energy savings rules, to ensure energy optimization.

The system tries to reduce energy consumption by acting upon the occupants preferences. This implies applying energy savings rules that best match the occupants needs. However the application of an energy saving rule may change the comfort conditions. It is then up to the negotiation agent to determine whether the application of the new rules will fall under one of three states regarding the current comfort conditions. It can either affect, partially affect, or totally affect the current comfort conditions. If the new rule affects the comfort conditions, it will not be applied.

The satisfaction survey showed that 75% of users were very satisfied, 20% satisfied and 5% not satisfied. There was neither a mention quantifying the energy saved, nor as to if the system stores users individual comfort settings. This kind of system shows that it is important to analyse information before making changes on the system, even if the system is based on responding to users requests.

2.2.3 Fuzzy Logic Based Control

Fuzzy control systems are logic systems that basically provides effective means of capturing or approximate the inexact nature of the real world. They are used when the sources of information are interpreted qualitatively, inexactly or uncertainly. Thus the Fuzzy Logic Controllers may be viewed as a rapprochement between conventional precise mathematical control and human-like decision making [33].

The iDorm project uses fuzzy logic controllers to control a typical dorm room [34, 35]. The focus of the project is to learn user preferences and generate rules based on the user's behavioural history. The system database also contains preprogrammed conditions to save energy when there are no occupants in the rooms. This system is controlled by a hand held device where the user's preferences can be adjusted.

The evaluation of the system consisted in having a test subject living in the room for 5 days. The results show that the system was able to adjust itself meeting the subject preferences within the first 3 days, after this the generation of rules reduced considerably as most of the subject's behaviours had already been captured by the system. Feedback was also given to the occupants even though it was not one of the main project goals.

This research did not present a result showing the amount of energy that was saved during the testing period. However the tests showed that it is possible to learn user preferences, and optimize the environment to improve the occupant experience through behavioural analysis.

2.2.4 Probabilistic Models of Occupancy

A Belief Network is based on probabilistic graphical models that represents a set of random variables and their conditional dependencies. A common example is a belief network that represents the probabilistic relationships between occupancy detection through various simple sensors. If one sensor has a reading about one occupant, the belief network will calculate the probability of having an occupant in the room in that moment. A decision will be taken regarding the sensor reading and the probabilities. In that case, to increase the accuracy is possible to put more than a simple occupancy sensor.

The studied Sensor Belief Network, strives to develop appropriate models of sensor networks. The authors propose an occupancy sensor belief network. The belief network is capable of providing information regarding building occupancy, both in individual and aggregate space [17].

The system makes use of sensors to determine occupancy, in which triggering of sensors provides information regarding occupancy. However the information originated by the triggering of a single sensor is not enough to assure that there is in fact an occupant. It is only by resorting to the belief network—which has the ultimate decision on the occupancy state—that the system assure the de facto occupancy within the room. The belief network uses information on the actual state (occupied or unoccupied) to calculate probabilities on a possible future state; if the room is empty now, is likely that it will remain empty in the near future; if the room has an occupant now, it is also likely that the occupant will remain there.

The testing was made in two private offices, they had tree passive infra-red occupancy sensors and a telephone sensor which senses when the telephone is off hook; each of these sensors provides an independent measure of occupancy. All the sensors were connected to a data acquisition system, and the belief network handle the data to decide and made the decisions regarding occupancy.

2.2.5 Pattern Mining Approaches

Data mining is a process used commonly to extract information from a data set and translate it into organized and understandable information, normally these processes are done by means of artificial intelligence. Pattern mining is a data mining approach optimized to find existing patterns in data. In this context the system learns the occupants common behaviour by determining patterns in their actions.

The EcoSense Project, was created with the intention of developing a mining method that can automatically discover behavioural patterns of a house's resident activities [36]. The experiments resulted in the system being able to acknowledge a total of ten activities, i.e. bathing, entering or leaving house, bed to toilet transition, cooking, eating and sleeping. Later the EcoSense Project was used to promote energy savings resorting to occupancy information in order to control an HVAC system [37].

Only a simplified version of the project was tested. Information from the sensors was only gathered into the database system, without incorporating the HVAC system control. No results in energy savings were mentioned although this system propose a solution that could acknowledge different actions of the occupants.

Other solution, has focused mainly on estimate the impact of occupancy information on climate control by means of simulations [38]. Predictive control models make predictions on occupancy information. Occupancy was generated randomly through geometric distributions. The system then tries to predict the occupation in order to verify the possibility to reduce HVAC system use if there was no occupant.

Simulations showed a savings potential of 34%. However, if the lighting and ventilation used were adjusted with predictive occupancy information, there would still be significant savings. The conclusions of this work show that occupancy information in building control has a significant energy savings potential, but predicting the occupancy may not be the best approach. Large part of the savings potential can be achieved using the instantaneous occupancy information.

Other system, uses artificial intelligence based solution to optimize the energy efficiency and user comfort through advanced control strategies [39]. The studies of this project suggest that they could use RFID tags to track the occupants position and that information would be stored to compute and predict the user occupancy data [40, 41]. This way, using this information with the neuronal network it would be possible to have considerable energy savings. However they did not make use of RFID tags to track occupant's position.

This system combines data from a sensor network with acoustics, lighting, temperature, motion and CO sensors. It resorts to an event based pattern algorithm for predict of user behaviour patterns [42] which then controls the HVAC is set to to minimize the energy consumption while there is no occupant detected.

The tests were made by HVAC simulation, by using the data collected from the sensor network. The results suggest potential energy savings of 30% while maintaining an indoor comfort level.

iSense aims at recognizing the status of a meeting room [5] using light, passive infra-red, temperature and microphone sensors to define if there is a meeting in a room. Tests show that the room was not being used correctly, because the occupants always forget to turn off the HVAC which translated into an energy waste. The system has been optimized to automatically turn the lights and HVAC system on and off.

Their results indicate that it is possible to reach savings up to 13% in electricity based on tests made in three meeting rooms of different sizes. However the room still spends some energy while unoccupied because the system uses the information about light, occupation and air conditioning to define if there is a meeting or not, and sometimes it triggers the occupied behaviour erroneously.

2.2.6 Image Acquisition For Occupancy Detection

Instead of using sensors or predicting occupancy, Occupancy-Based System for Efficient Reduction of HVAC Energy (OBSERVE) project [43] makes use of a wireless camera sensor network for tracing human mobility patterns in buildings, with a 84% of accuracy of occupancy detection [44].

By using the HVAC system with a optimal control strategy, their simulations showed that it is possible to achieve a reduction up to 14% of the annual HVAC energy consumption [43]. On the project's second year new strategies were used, and the savings simulations could reach up to 20% [45] and the third year they used Markov Chain estimation from occupancy data retrieved from the wireless camera sensor network and the achieved results are up to 42% of annual energy savings [46].

These results show a considerable quantity of energy savings potential, but none of these innovations were tested under real life conditions. Only the occupation data was obtained by effectively using a test bed system, other results only were possible through simulations.

2.2.7 Sensor-Based Occupancy Prediction

Wireless sensor networks are networks of small, low-cost sensors, which collect and disseminate environmental data. Wireless sensor networks facilitate monitoring and control of physical environments from remote locations with a high relative accuracy [47]. These solutions can increase the energy efficiency by using low-cost and simple sensors.

The solutions analysed were: one based in wireless sensor networks technology, aims to analyse and evaluate the energy-efficiency of an existing lighting control system [48]. Another project intended to demonstrate the benefits of the occupancy control [49]. The SpotLight project [50], aimed at giving people the possibility to monitor their own resource consumption with an easy installation method. And finally a more expensive system used ultrasonic fine-tracking systems that provides three-dimensional tracking accuracy of approximately 3 cm 95% of the time [51].

The solution based on Wireless sensor networks retrieves the information of the sensors ans use it to quantify the amount of energy savings that could be possible by replacing the lighting control system with an alternative solution. Passive infra-red sensors were used for occupancy detection and light detectors for detecting ambient and luminaries light state.

The solution that intended to demonstrate the benefits of the occupancy control, made tests with passive infra-red sensors and magnetic reed switch door sensors to detect occupancy. After two weeks collecting data on occupancy, simulations with this data were made to estimate the energy consumption of a HVAC system.

The SpotLight project monitors energy consumption by using proximity sensors, the occupant should carry an active RFID tag to be detected by the antennas, that way it is possible to know the location of the occupants. The goal of this project was to determinate that occupancy control information alongside with the HVAC system makes it possible to save a considerable amount of energy.

While the ultrasonic tracking-based solution is in fact regarding the analysis of how people work and which energy savings might be possible to achieve if they were able to shut down the non-using devices.

The test was made through collecting occupancy information data over 60 randomly chosen days, and it involved around 40 people with various roles.

The wireless sensor network-based system make tests in an office space collecting data on occupancy and daylight. It was concluded that it is possible to optimize the energy savings of the lighting system in 50% by installing an alternative lighting control system.

The results achieved by the SpotLight presented potential energy savings from 10% to 15%. The ultrasonic tracking-based solution suggest that the energy expended on light and fast-response systems could have been cut by 50% and that around 140Wh per PC per day could have been saved. The last solution, indicate that it is possible to reach savings up to 15% only by lowering the cooling when a room is not occupied.

The occupancy information is important not only to drive HVAC energy savings, but also for example, for the lighting system of a house. These systems achieved considerable energy savings, unfortunately since it was only tested through simulations, no guarantees can be given as to its real life performance.

2.2.8 Smart Thermostat Solutions

A thermostat is a thermal control system equipped with temperature sensors, which automatically senses the temperature of an ambient and adjusts itself to maintain the temperature near a desired set-point.

Using thermostat solutions with the concepts of Smart Buildings, proved to be a viable solution to promote energy savings. The Self Programming Thermostat automatically creates a optimal set-point schedule based on user occupancy data statistics, but the occupancy is limited only by a binary mode of occupancy *at home* or *not at home* obtained with passive infra-red sensors. The thermostat uses an algorithm to configure itself into predicting when there will be occupants at home and save energy while there are not [52].

No results are available but, using simple passive infra-red sensors, it was possible to get preliminary results that point to and energy waste reduction of 15%. There may be a potential increase in energy savings if the thermostat could predict the occupants behavioural patterns.

Another idea is to use simple and cheap sensing technologies to manage occupancy detection, while using these informations to control the HVAC system [53]. The sensors were deployed in 8 different homes, and the authors propose a model to estimate the probability of being home using passive infra-red sensors and contact switches on doors. The data collected was used to simulate results through a simulation framework.

The results showed that the initial cost is less than USD 25,00 and by using the proposed model, it is possible to achieve up to 28% of energy savings while still not sacrificing user comfort. Smart thermostat solutions with occupancy information can be a good alternative to control the HVAC system while saving energy through smart environment solutions.

2.2.9 Feedback-based System

Some of the previously mentioned projects gave the user the opportunity to control the HVAC system and receive a direct feedback from it, allowing users to change their actions according to the feedback they were given.

Murakami et al. [54] proposed a study to conceal the controls of the HVAC system to occupants' requests. The system collects the occupants requests from their own personal computer, and a logic system controls the balancing of the occupants' requests and the energy consumption.

Murakami use the feedback system to motivates occupants to cooperate with energy-saving initiatives. The occupants can check the system at any time for the feedback informations, these feedback informations are: control history, requests and energy savings. The control history shows the occupants the last time that there was a change in temperature, the requests shows the other occupants requests and finally the energy savings shows the actual amount of energy that is being saved in the actual state.

The experiment showed that the users changed their patterns every day, this shows that the occupants condition is not always consistent. All the participants were subjected to questionnaire surveys at the beginning and at the end of each day, to investigate the system satisfaction. These surveys showed that the occupant's did not feel too much affected with the feedback information, 43% did not hesitate to make their requests basing on the energy savings feedback, and 52% rarely hesitates.

This work demonstrates that it is possible to save energy with occupants cooperation while still saving energy, but the users do not feel intimidated to save energy when they are confronted with the feedback about energy savings; maybe a different approach to the feedback information could possibly increase the user's motivation to save energy.

2.2.10 Discussion

The common goal of these projects is to use Ambient Intelligence techniques to save energy while maintaining user comfort. Table 2.1 provides a comparison between the most relevant characteristics of the analysed projects.

The majority of the analysed projects use simulation based results and have a high margin of energy savings compared with iSense [5] which is the one that is not simulation based. Only the iSense presented results on energy savings obtained through the use of real test beds and its results show energy savings of up to 13%, much less than the other results obtained by other systems, which were based on simulations. The most common sensor used is the passive infra-red, this may be due to its ease of use and cost. None of the systems effectively used RFID to store user preferences. MACES [4] project stored their preferences, however its occupants and preferences are generated by simulations and it is not mentioned how it manage to store their preferences.

Some solutions presented systems that were able to predict the occupancy, these systems are: MACES [4], Pattern Recognition [42], Self Programming Thermostat [52], Smart thermostat [53] and the Occupant Information System [38], these solutions used occupancy prediction and reached a energy saving potential between 12.17% and 34%. However the Occupant Information System [38] reached

Solution	Evaluation	Energy savings	Learning
ISES [3]	Simulation based	40%	No
MASBO [28]	Gives feedback	N/A	Yes
ACHE [30]	Neural Network	N/A	Yes
iDorm [34]	Gives feedback	N/A	Yes
AI System [32]	Simulation and prediction-based	N/A	Yes
MACES [4]	Simulation and prediction based	12.17%	Yes
EcoSense [36]	Mining based	N/A	Yes
OBSERVE [43]	Simulation based	20%	No
Pattern Recognition [42]	Simulation and prediction based	30%	Yes
iSense [5]	Not simulation based	13%	No
Occupant Info System [38]	Simulation and prediction based	34%	Yes
Occupancy Control [50]	Simulation based	N/A	No

Table 2.1: Comparison of the intelligent energy efficient systems

almost the same results without occupancy prediction, suggesting that the efforts in making a prediction based solution are not worth. EcoSense Project [36] is a system that could discover behavioural patterns of occupants but did not present results, if this project was enriched with other AmI technologies, the energy saving potential could increase significantly.

Table 2.2 provides a comparison of the sensors used on sensor-based solutions and their respective energy savings. Is it possible to conclude that with simple sensors the solutions can manage to reach significant savings up to 50%, The SBAS [49] solution managed to save up to 15% only by turning off the HVAC system when the space was empty. Unfortunately all the results were based on simulations and their results may not reflect the reality.

Some of the solutions presented use feedback of ambient variables to notify the user, this is the case of the iDorm [28] and MASBO [34] projects. These only use feedback in order to notify the occupants, and this information is not intended to influence them to reduce the energy use. Other systems resort to the user preferences to reach a balanced set-point that could minimize the discomfort wile maximizing user comfort, these systems are: MACES [4], ACHE [30] and the AI System [32], but none of these solutions used RFID technology in order to store and retrieve user preferences.

2.3 Occupancy Information through RFID Sensors

The Radio Frequency Identification (RFID) technology has potential to promote various kind of user experiences, this section will go through user information and occupancy detection using this technology.

2.3.1 Simple Triangulation Based Solutions

Triangulation is a location process of radio transmitters that can be determined by measuring either the radial distance, or one direction of the received signal from two or three different points, in this case: antennas. Algorithms are used to get a better precision of the radio transmitter.

Solution	Sensors	Evaluation	Energy savings
Sensor Belief Network [17]	Infra-red	Prediction based	N/A
LighWise [48]	Infra-red and Lighting	Simulation based	50%
SBAS [49]	infra-red and magnetic reed switch door	Simulation based	15%
Self Prog. Thermostat [52]	Infra-red	Configures itself and prediction based	N/A
Smart Thermostat [53]	Infra-red and door contact switch	Simulation and prediction based	28%
Ultrasonic System [51]	Ultrasonic tracking	Simulation based	50%
SpotLight [50]	proximity	Simulation based	10 to 15%

Table 2.2: Comparison of the sensor-based energy efficient systems

A study aims to test triangulation methods with four different algorithms to demonstrate the difference and capabilities of each one. The algorithms studied are: Relative Signal Strength Intensity (RSSI) algorithm: *Ring Overlapping Circle RSSI (ROCRSSI)*, *K-Nearest Neighbours (kNN)*, *Maximum Likelihood (ML)* and *Min Max* [55].

Two main field tests were made, the first test bed in a 7 m x 6.4 m building and the second one on a 6.3 m x 5.1 m construction site. Results showed that the solutions work better on the first test bed. The best algorithm was the *Min Max*, for it reached an error of 1.22 m while *ROCRSSI* and *ML* reached an error of 1.69 m and 2.52 m respectively.

A solution that relies on triangulation methods is SpotOn, it uses the triangulation method to calculate target location [56]. The signal strength data is used to estimate the distance between a particular target and its nearby targets. SpotOn also relies on a client system for distance visualization. However achieved accuracy is not high enough to rely on these results.

Another triangulation method was used using a similar algorithm, using the signal strength to calculate the distance between the tracked objects and the antennas [57]. After obtaining the estimated distance between the tracked tag and the number of readers deployed in the sensing area, the solution estimates the target location. The authors reported that the accuracy increases when the tags are in a more centralized placement.

The triangulation method is difficult to use to locate targets, due to the fact that there is low signal information about the tracked tag, and when calculating its position, the error values are very high. Despite using this method to calculate the location, this simple method is enough to make a simple target-locator.

2.3.2 Location Identification based on Dynamic Active RFID Calibration (LANDMARC)

The Location Identification based on Dynamic Active RFID Calibration (LANDMARC) project [58], uses active RFID tags in two different roles: as tracking tags and as reference tags. The tracking tags are used in mobile traceable objects in an indoor environment, whilst the reference tags are fixed into the sensing area in known locations in order to provide reference locations.

Both the tracking and reference tags communicates with the antennas, then the system calculates the measurements values of the triangulation. The antennas transfer the collected data to a computer, which identifies the nearest reference tags to the target, and measures their distance. The neighbours locations and distance to the target are then used to calculate its location.

Field test showed that an accuracy up to 1 m is possible in 50% of times, and an accuracy up to 2 m is possible 90% of times, having an improvement when comparing to simple triangulation methods.

2.3.3 LANDMARC-based solutions

The satisfactory performance of the Location Identification based on Dynamic Active RFID Calibration (LANDMARC) lead the scientific community to grow an interest for improvements in the system's accuracy.

In 2006 a system based on the LANDMARC project, this system received the name Flexible Localisation EXplOits Rfid (FLEXOR) [59], the goal of this project was to introduce some improvements in the triangulation algorithm. The reference tag is divided in two types: boundary tags and cell tag; the boundary tags were used in a hexagon layout while the cell tag was in the center of the hexagon.

Still in 2006, a research project focused in calibrating the LANDMARC error value. The proposed solution was to identify the *k* nearest neighbours based on signal strength, their locations are estimated with triangulation method [60]. Since the actual location of the neighbours is known, the estimated errors can be calculated, then the mean error is added to the estimated location of the target, which is calculated using the proximity method. Test proved that the accuracy was improved to a minimum distance of 0.7 m.

Later in 2009, a LANDMARC based solution received the name of LANDMARC+, due to an improvement on a problem in the original LANDMARC. The problem consists in a lack of accuracy in the tracking system when trying to detect the room where the tracked object is. The solution was to add a secondary-possible room to the results, this way it is possible to improve the accuracy of the system. Simulation results showed that an improvement of 96.66% in the original LANDMARC in terms of reporting the correct room location.

An error value calculation method to improve the location accuracy is also used to improve the original LANDMARC project [61]. It puts a reference tag in a known location and calculates the estimate location, then calculates the location error of the known *k* nearest tags. The error is then compared with the actual location of the tracking test and it's recorded, then the error for all reference tags in the set is averaged and added to the estimated location of the tracking tag for a final estimation. Tests were done in a room of 5 m x 10 m with four readers and 16 active tags, which reported an accuracy within 1 m over 90% of the time.

Finally in 2011, a solution was presented with the goal to reduce the energy consumption by integrating HVAC systems with occupancy detection, using the *k* nearest neighbour algorithm also based on the LANDMARC solution [62]. Tests were made in a floor of an educational building. The project was also trying to detect in which room each occupant was, and the results showed that mean occupancy detection rate was 88% in the best case that is stationary occupants, and 62% in the worst case, that is mobile occupants. Nonetheless the occupancy presence detection was at a rate of 100%. These results define the possibility to use these information with the HVAC settings and adjust the set-points accordingly to user preferences.

Chapter 3

Solution Proposal

This chapter covers the architecture, the requirements and features of the system to be developed. The chapter is organized in 3 sections. Section 3.1 focuses on requirement analysis. Section 3.2 details the use cases. The solution's architecture is detailed in section 3.3.

3.1 Requirements Analysis

The requirement analysis focuses on establishing the project's features in terms of users needs. Requirements can be organized in two main different categories: functional requirements, which are detailed on section 3.1.1, and non-functional requirements which are detailed on section 3.1.2.

3.1.1 Functional Requirements

Functional requirements are technical details that define what the system is supposed to accomplish. In this particular scenario, the users, teachers and administrators needs, were taken into account. Briefly the system requirements are:

- **Automatic detection of occupants:** The system should detect occupants, automatically recognise them, and allow them to vote in order to change the indoor temperature.
- **Distinction of Occupants:** The system should be able to distinguish between occupants.
- **Occupancy detection through student card:** The occupancy detection system should detect occupants by reading their student cards. The user will only be able to vote if the Occupancy Detection System detects his/her presence.
- **Occupant's can vote to configure the HVAC System:** The system must have an interface which allows users to vote and calculates a set-point which maximizes their comfort.
- **Validation:** An administrator should be able to manipulate the way that the system works by generating different scenarios and retrieving different information of the system use. More specifically, the way that users behave according to the information shown to them.

- **Calculate the new set-point:** The system should refresh its set-point from time to time, without any need for user interaction with the application.
- **Store User Preferences:** The system should store all the information related to the user's votes.

3.1.2 Non-Functional Requirements

Non-Functional requirements specify criteria that the system needs to comply, but which are not functionalities. They are usually used to describe system's characteristics that users might not be aware.

- **Provide the feedback of the system to users:** Users should have a interface which shows the actual status of the Ambient Variables, which includes: Indoor Temperature, Outdoor Temperature, Indoor CO Level, Energy Spent, Air Humidity and the Actual Votes Status.
- **The main system should have an universal communication system:** It should have an architecture that allows for universal communication. The system will receive requests from various types of applications, such as web browsers, the occupancy detection system and smartphones.
- **Invisible to User:** The system should hide all calculations from the user. The only interaction that the user will have with the system is make requests.
- **Availability:** It should be available to the users that are inside the room. It should behave as a service, since the users need to use it whenever they want to.
- **Network Topology:** It should have his own Local Area Network (LAN) in order to exchange information between the nodes.
- **Response Time:** The system should have a response time that is tolerable to the user.
- **Price:** The system should be created as cheap as possible.

3.2 Use Cases

This solution will be validated at an university. This section describes the interactions of this system with different actors and systems. Users can be classified into three different types: User, Teacher and Administrator. The user is supposed to be either a student or a visitor, both without administration rights. A teacher is an extension of the user but has more functionalities available, while the administrator has full management rights of the application.

- **User perspective:** The user is able to log in the system, he is presented with a screen showing the Ambient Variables that are pre-configured by the administrator. The user is only allowed to make requests for temperature changes. After the request, the user is redirected to the Ambient Variables screen with his request computed.

– **Teacher perspective:** As the teacher logs in the system, he is presented with a similar screen to the one viewed by a user. However a teacher is allowed to change the value of the HVAC set-point without the need for a request.

– **Administrator perspective:** The administrator is allowed to add/remove all types of users, manage which are the Ambient Variables that visible to users, and it can also force a set-point calculation at any time.

3.3 System Architecture

This section explains the architecture and interactions of the system. The system's overview is described on section 3.3.1, the web server and web application, the Data Base (DB) System, the RFID System and its application in sections 3.3.2, 3.3.3 and 3.3.4 respectively.

3.3.1 Overview

Since the users should be able to access the system in any device, and at any time, it was necessary to devise a solution with a programming language independent architecture, which should also be available whenever the user requests so. In order to make it available for users, it is appropriate to use a web server which accepts requests from users and is available on the network, concentrating all the relevant and complex processes into it. It was necessary to develop a simple system which could detect the occupants, and read the student's card. A solution using Arduino and a Near Field Communication (NFC) module could retrieve the users informations, read the student's card, communicate on the network with a web server and could also be useful in other situations.

The architecture of the solution is of a certain complexity due to the various types of different technologies and systems used during the development. It is composed by a Web Server, a RFID System, a Database server and an interface to communicate with the HVAC system. The Web Server is responsible for user interactions with the all the system functions. The Web Application runs within the Web Server, and it is divided into two main layers: the presentation layer and the core application as can be seen in figure 3.1.

3.3.2 Backend

An backend application which can abstract the access to the database, could make possible the development of a Service Oriented Architecture (SOA) [63] where any desired client should be able to request information on the database. Clients are able to make these requests using Hypertext Transfer Protocol (HTTP)[1].

Several advantages could be attained by using this application, among them: The creation of abstraction layers simplifies the users interactions with the DB. The client application is independent from

[1] http://www.w3.org/Protocols/

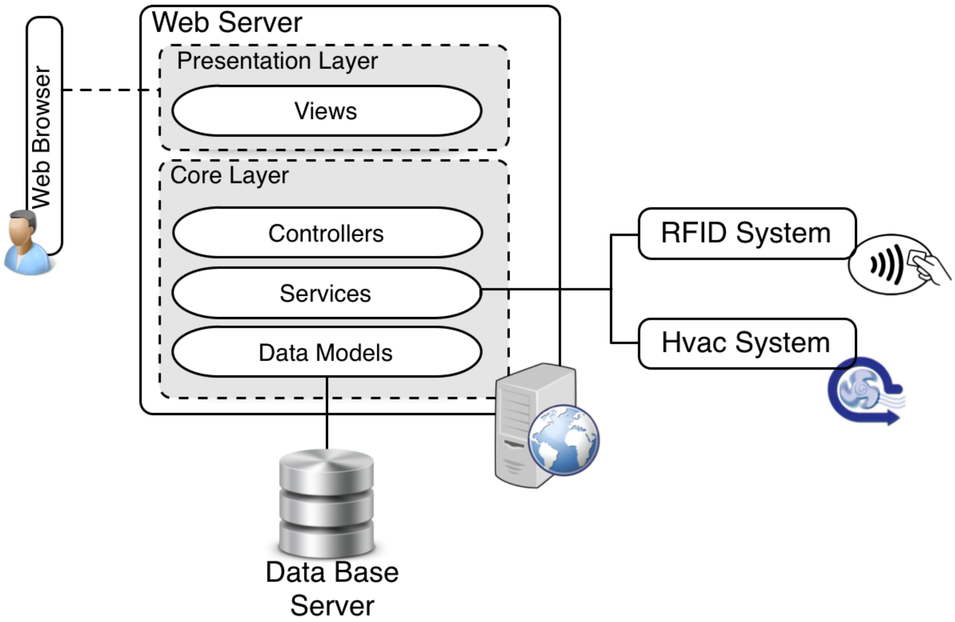

Figure 3.1: System's architecture, consisting on a web server with two layers, the presentation one which will be used by the web browser. The core layer will be used to interact with external systems such as the RFID, data base and HVAC.

the backend, allowing for a client application to be developed in other programming languages. Only client applications can start interactions by making requests, and so the application will be simpler since it only has to provide answers to requests.

In order to make a user-friendly SOA where an abstraction of the system's layers would be created, the user interface is developed using the Model View Controller (MVC) software architectural pattern, where the application is divided into three interconnected main parts, as the name suggests: Models, Views and Controllers. The Models are the representation of all the data on the system, i.e. the DB, the Views are those information displayed for the users, such as the layout, HTTP and JavaScript code, and the Controllers are used to manipulate the Models [64]. The MVC architecture was adapted to this solution so as to simplify it. Figure 3.2 shows the architecture of the Web Server, the presentation layer is composed by the Views, and the Core is composed by the Controllers, Services and the Model Layer. On that particular case, the Services are responsible for managing the data generated by the system, the complex algorithms, the security, and the Learning algorithm.

The Learning Algorithm is a module which does not interact with users, as it can be seen on figure 3.2, it is used by the services. The services calls the Learning Algorithm and it will automatically load the preferences from the Models and return its decision to the Controllers.

Users interacts directly with the Presentation Layer. They can see all the information available trough the Views and make requests to Controllers, which establish the communication between the external and internal architecture. Through this architecture, users can also make inputs in the HVAC system and see other information about the environments and other user's inputs, because all of this data is stored in the DB. Inputs are taken by the controllers and redirected to the corresponding service which

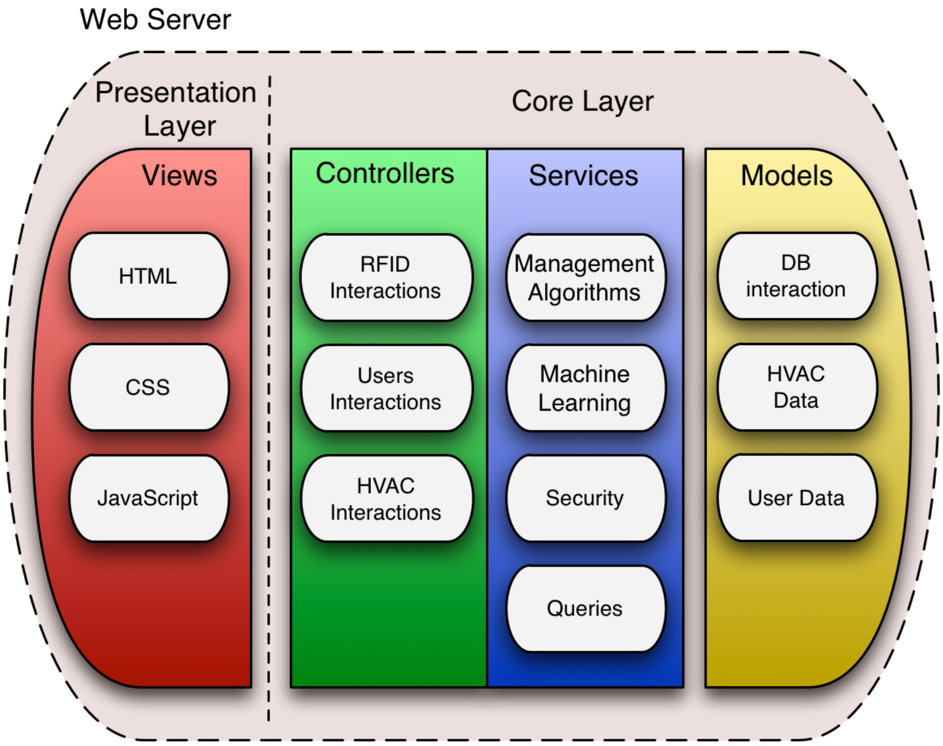

Figure 3.2: Web Server architecture, where the presentation layer is responsible for interacting with the user with the views and the core layer is responsible for the controllers, services and models.

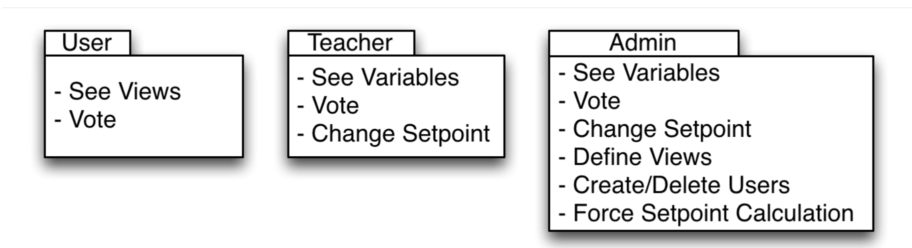

Figure 3.3: Web Application Areas, shows the User, Teacher and Admin users and its respective permissions.

stores the data in the Database, and recalculates the new set-point to update the HVAC system (see section 4.6 for information on the set-point calculation algorithm).

There are three areas that the users can access through the Web Application: user, teacher, and admin. Figure 3.3 depicts the architecture of the main areas. The User area is designed for the students. It is possible to see the HVAC variables and to vote for changing the set-point configuration. The teacher's area allows to change the HVAC set-point at any time, vote as a simple user and it is also possible to see the information about all the HVAC variables and users requests. Finally the admin can add and remove users, vote for set-point chance, force an instant set-point change. It can also add or remove the HVAC information available to users.

3.3.3 Database

The storage, manipulation, and usage of users related information demand a system which provides these processes. A DB System is an appropriate solution which will store and manage the data as intended by the solution main system. As described on section 3.3.2, a DB system fits on the SOA and MVC architectures.

The Data Base server is located in the same LAN as the Web Server and includes the PostgreSQL DB System[2]. This system was chosen because the Middleware which controls the HVAC System also uses PostgreSQL. Since the main system's database is in the same Data Base Server of the middleware's, it was decided then to use the PostgreSQL in order to avoid possible incompatibilities with the DB language. This results on the homogeneity of the Data Bases avoiding the installation of new databases in the same server, which may cause conflicts.

3.3.4 RFID System

It was planned to use a low cost occupancy detection system, which has a user-friendly interface. Another interesting system feature would be the capability for reading the student card. The RFID system is able to fulfill these problems and has many other advantages, among them:

– There is no need for users to buy tags, the student card will do.

– The student card does not need a battery, so that it can be used without restrictions.

– There is no need for training the occupants to use the system, since the system is very user friendly.

– Easy user detection mechanism which the students would not bother to use.

– The RFID could be used on other situations, e.g.: replace the presence list.

Among many other systems, the Arduino could use a NFC and a Ethernet module to read the students card and to communicate with the Web Application. The advantage for using the arduino is that it is possible to develop a lot of different systems using other shields[3]. This system could be improved in the future by using other types of sensors.

The room where it is intended to install the occupancy detection system has two doors, and so two Arduinos were employed. Each Arduino system has three shields: the first one is a ethernet shield, responsible to connect the Arduino into the LAN through a wired router. The second shield is the NFC antenna responsible to read information of the RFID tags and the student's card. Finally, the last shield is an LCD screen which is used to give feedback for users, indicating that the system added them to the room.

Since there are two Arduino systems, there is the need for another system to aggregate the information of these systems and send it to the Web Application. To solve this problem, a Raspberry Pi, which is

[2] http://www.postgresql.org/docs/9.3/interactive/protocol.html
[3] http://www.arduino.cc/

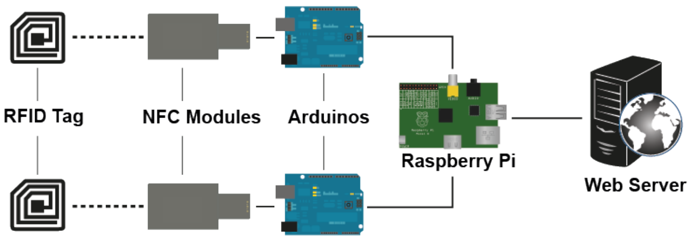

Figure 3.4: The RFID System Logical architecture containing two Arduinos and a Raspberry Pi logically connected with the Web Server.

also connected into the same LAN, was used. The Raspberry Pi and the Arduino are connected through Ethernet into a wired router. The logical architecture of the system is depicted in figure 3.4.

The basic functionality of the RFID system is to read the occupant's tags and send the information to the Raspberry Pi, which receives it and sends a request to the Web Server indicating that the tag was read. The web server verifies the user related to that specific tag and adds a flag to it indicating that this user entered the room.

The Arduinos and the Raspberry have the role to transfer the tag information to the Web Server and give the server's response feedback to user on the Liquid Crystal Display (LCD) screen. In order to have their tags read, the users need to put their student card near the Arduino, since the read range of this system is only 6 centimetres.

Arduino

The Arduino is an Uno[4] model, with a ATmega328[5] micro-controller. It has 14 digital input/output pins, 6 analog inputs, a 16 MHz ceramic resonator, a USB connection, a power jack, an ICSP header, a reset button and its equipped with Ethernet, NFC and LCD shields.

The NFC/RFID shield contains a 13.56MHz capable antenna. The RFID Antenna, serves in standby mode until a tag is read. The read tag information is routed through the Ethernet interface, which reaches the router and then the Raspberry Pi.

The Ethernet shield is plug and play, and the NFC module is connected through the Ethernet shield. Figure 3.5 shows the schematics depicting the connections of the NFC module and the Arduino. The TX-1 pin of the Arduino is connected on the RX pin of the NFC module, and the RX-0 pin is connected on the TX pin of the NFC. Both have GND and 3.3V pins, and the GND is connected with the GND and 3.3V with the 3.3V on each shield. Whenever a tag approaches the NFC module, it reads the tag's information and sends in a plain text format through the Ethernet module, which encapsulates the text into a User Datagram Protocol (UDP) packet and sends it to the Raspberry Pi.

Raspberry Pi

The Raspberry Pi[6] should need to work as a gateway between the Arduinos and the Web Server, so that this component system would receive the information from the Arduinos, filter and sends it to the web

[4]More information at Arduino Uno Official Website: http://arduino.cc/en/Main/arduinoBoardUno
[5]Datasheet: http://www.atmel.com/Images/doc8161.pdf
[6]http://www.raspberrypi.org/

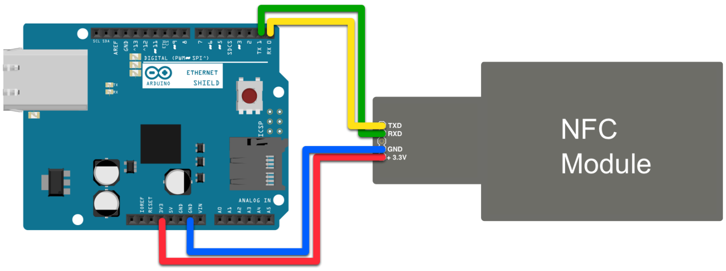

Figure 3.5: Arduino Schematics, Demonstrating where each pin on the NFC module is connected on the Arduino.

server. This information is then sent trough a HTTP Request, with the tag information within a JavaScript Object Notation (JSON) format. Afterwards it receives a HTTP Response which will reply to the Arduino.

The Raspberry Pi application is developed in Java[7], and it is divided in three parts: The first one is responsible to exchange information with the Arduinos. The second one is responsible to parse and filter the information received from the Arduinos and send it to the Web Server in the JSON format. The last part is responsible to send the data to the Web Server.

[7]http://www.oracle.com/technetwork/Java/index.html

Chapter 4

Implementation

This chapter goes through all the development phase of the solution, going through the used hardware on section 4.1, the development environment on section 4.2. The Database, Web Server functions and the Application Core are described on sections 4.3, 4.4, and 4.5 respectively. Finally to conclude the chapter, the used algorithms and the simulations interactions are described on section 4.6 and 4.7 respectively.

4.1 Hardware

Since it is not necessary a very powerful machine to run the application described on chapter 3, to run the Web Server and the DB system it is necessary a server computer which is able to run the Java Virtual Machine and The PostgreSQL.

The Raspberry Pi is used as a gateway between the Arduino and the web server, it runs in standby mode waiting for a UDP requests. It counts with a ARM with a 700MHz clock processor and 512 MB of Random Access Memory (RAM) memory.

The Arduino programming language is an implementation of Wiring, which is very similar to the C programming language. The NFC module sends the information through the transmission jumper, the Arduino then resends it to the Ethernet shield, which encapsulates on a UDP packet and send to the Raspberry Pi. The UDP method is used since the LAN which connects all nodes, its a cabbed network, and the probability of loosing a packet due to collisions is very low.

The router is configured as a Dynamic Host Configuration Protocol (DHCP) client which will automatically assign IP addresses to all the equipments of the LAN, this way is possible to establish communication between all the nodes. It is used to improve the communication in between the network nodes.

4.2 Development Environment

Before defining the development environment it is first necessary to define a programming language to use. Since the Java Virtual Machine (JVM) has a great community and it is world wide used to develop all kind of applications, it is appropriate to use the Java language to develop the solution. However, the Java language does not implement the SOA or the MVC architecture as default. In that case, a framework which works on the Java language could do this task.

The Grails[1] framework is used over the Groovy language which is dynamically compiled to JVM bytecode, and interoperates with other Java code and libraries [65]. It uses the Spring MVC under de hood [66], making it a faster and easy development of web application over the Java Language. The Groovy language also interprets the Pure Java Language. Considering that the Grails Framework is an complete framework which helps on the development on an MVC and SOA Application.

Since it is decided which is the language used, it needs a web server which will deploy the developed software. It turns that the Apache Tomcat[2] is the most traditionally used web server to deploy Java and grails web applications.

The development environment is a Eclipse-powered tool that provides the support for the Groovy and Grails. The Groovy Grails Tool Suite (GGTS) includes all the Eclipse functions, integration with the Apache Tomcat, the Spring Insight Console and is compatible with all the eclipse plugins [65]. The Java application developed for the Raspberry Pi was also developed under the GGTS environment.

The Arduino Integrated Development Environment (IDE) used was the provided by the official Arduino web page[3]. It is an open source development tool, which runs on Windows, Linux and Mac OS. It has functions with pre-defined codes to test the equipment, and a tool which uploads code on the board.

4.3 DataBase

As mentioned on section 3.3.3, the project will collect large amount of data that will need to be retrieved to the learning algorithm in the future, this way the Data Base system is located on the same server as the Web Application, this improves the performance speed on retrieving and storing data. It stores information about: Users, Roles, HVAC variables, User's Inputs and the RFID tags. In particular:

- **Users:** The user information is consisted of an unique identification number, full name, last time he logged in, if the user is present in the room, username, password, and the RFID tag associated with the username.
- **Roles:** The role information is responsible to give permissions to the users, This information is needed to identify the Users, Teachers and Administrators, giving them their right permissions.
- **HVAC Variables:** The HVAC Variables represents all the variables that is possible to retrieve from the HVAC System, such as: Indoor Temperature, CO Level, Outdoor Temperature, Air Humidity

[1] http://grails.org/
[2] http://tomcat.apache.org/
[3] http://www.arduino.cc/

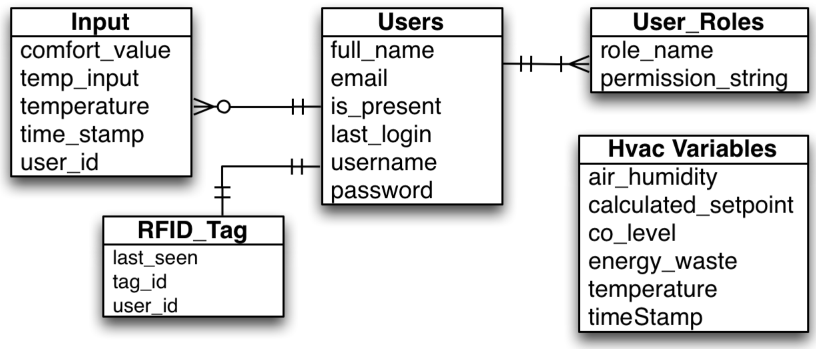

Figure 4.1: Database Model. Stores the information about the users, their inputs, their tag and their permissions(Roles). The HVAC Variables are not related to the user, however, they are still stored on the database

Level. This data has a timestamp in order to give context to the data gathered.

- **User's Inputs:** The inputs information are relevant information about the user inputs, such as: the actual temperature, the user vote, the user who made it, and finally the time which the feedback was given. This information will be used to load the Users preferences and predicting an ideal set-point.

- **RFID Tags:** The RFID tag information holds the information about the tag reads and the time when it was read. For instance, it is possible to merge data in order to know when were the users inside the room and who were they.

Figure 4.1 illustrates the structure of the Database, and demonstrate the informations contained in the database as aforementioned.

4.4 Web Services

In order to develop a system which could integrate with other systems in such way that they should be independent from the programmed language the system needed to have a Web Service which as mentioned on section 3.3.2, will only take requests as a service.

The Web Service is invisible to users, its main function is to provide intercommunication among all applications and users such as the RFID system, HVAC services and all other third party software. It takes responsibility of Views of the Web Server. As it can be seen on Figure 3.2, it is responsible for all the interactions among the systems which are also part of the solution.

The functionalities provided, can be accessed by either using a web browser, accessing common HyperText Markup Language (HTML) pages, that can be accessed through any device with a installed web browser, or through other applications, or smartphones apps.

In order to do it, it could be used Extensible Markup Language (XML)[4] or JSON[5], the first one is

[4] http://www.w3.org/XML/
[5] http://www.json.org/

more robust, but it requires more data to be transferred and it is needed to build a parser in order to retrieve the information. The JSON is lightweight and can be sent faster on the network, does not need to build any parser in order to retrieve its information. Due to the low amount of data to be transferred from the Web Service to the client applications, the chosen method was the JSON format.

4.4.1 Views

The views are responsible for showing the state of the system. Such as the ambient variables, number of people which voted and give means to user's to vote. The views are the main interaction that the users have with the system.

There are many ways to develop a view, the most common is through an HTML page which contains functions that makes possible to make requests to the Application Core, and display the server response on a web browser.

The views are divided on three main pages. The first one is used for authentication purposes, while the second one shows the users the ambient variables information. The last page is the one that allows the users to vote.

4.4.2 Interactions

The Web Service takes place between all the communication among the external system's and the Core Layer of the Web Server (see Figure 3.2). All the data flow between the layers, first needs to be processed by the Web Service, and only after, the data is submitted to the core layer. The Web Service retrieves the relevant information that comes from these requests, and send the information to the Application Core, which will process the information and return the answer to the Web Service, which in turn will send the response to the entity whom made the request.

4.4.3 User Interface

The user interface hides all the system complexity, making easier for users to receive the ambient variables information and on the voting phase. The system starts by showing to users the ambient variables, the other users votes, the actual set-point and temperature. Figure 4.2 is a screenshot of this variables, and it is also possible to see the button that allow the users to vote on the temperature.

4.5 Application Core

The Application Core acts as the brain of the system. It is responsible for computing all the complex algorithms including the simulation and the learning algorithm. Some of the main functions are:

– **User vote and feedback:** Accept user's votes and send them the ambient variables.

– **Occupancy detection:** The task of knowing and deciding if a user is on the room or not, based on the information that is received from the RFID System.

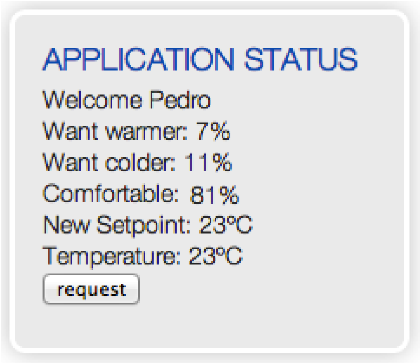

Figure 4.2: Ambient Variables from the Home Page, containing the percentage of other votes, the new calculated set-point and the temperature on the room.

- **Set-point calculation:** Collecting the occupant's votes, validate them and calculate a new set-point which minimize discomfort.
- **Learning algorithm:** Learn information about occupant's behaviour and predict a best decision to make.
- **Interact with HVAC System:** Send information about the new set-point and receive information about the ambient variables.

In order to access the user preferences, the Application Core is directly connected to the DB service. Only the Application Core has permissions to access and alter the data contained on it, for security reasons. The next sections will describe in more detail the algorithm and other functionalities of the Application core.

4.6 Algorithms

The solution contains functions and complex algorithms that need to be discussed. This section will enter in detail all the important algorithms that were implemented on the development of a solution. All the algorithms are processed by the Application Core.

4.6.1 Basic Services

This algorithm can be divided in two steps, the first one is the process of providing to users the ambient variables, and collecting occupant's vote. The second step can be defined on the process that occurs on the Application Core which is the submission of the vote and the management of the queue.

On the first step, the system stands by waiting for a user to login, when it receives a user request, it starts by loading ambient variables from the DB system and returning this information. At this point, users are allowed to vote if they judge necessary. The vote will be sent to the Application Core which will deal with the process of submitting the vote. Figure 4.3 depicts this process.

There are two ways to submitting a vote. The first one by accessing the application directly through a web browser. The user can browse to the vote section and place a vote. The second way is by

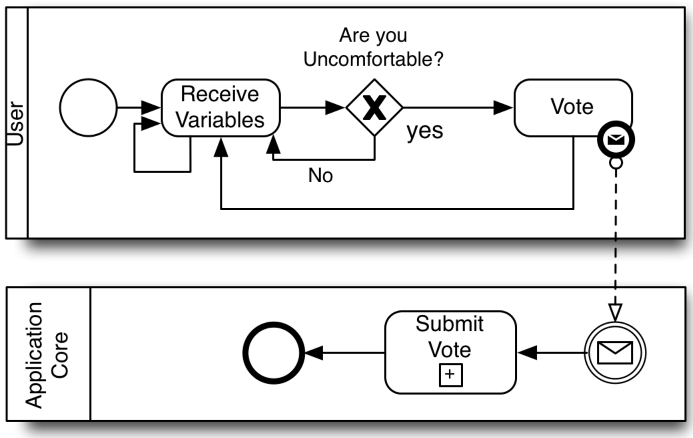

Figure 4.3: Users Interactions with Main Application. The users receive the variables and are able to vote. The Application Core receives the vote, compute it and finishes the process

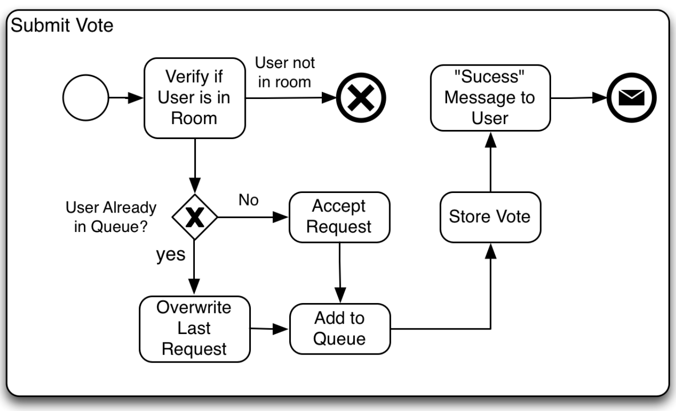

Figure 4.4: Process of storing vote. The system first verifies if the user is on the room, and then verifies if he is already on the queue. Store the vote and respond to the user.

applications. Since the Web Server also receive connections from other applications and smartphones apps, it is possible to send information relative to the Web Server sending a JSON object through HTTP request. The Web Server does the same process after receiving either of these requests.

After the user vote, the Core starts by verifying if the user is in the room, if it is not present, the process ends with an error message. Next it verifies if the user has already voted, if yes, it automatically overwrites the last request, adds it to the queue and stores it on the DB with all the relevant information of the status of the room. This process is depicted on figure 4.4.

The ambient variables which are on the DB are inserted by a routine process which sends the variables to the Application Core and then stores the received information. The set-point calculation algorithm is described on section 4.6.2.

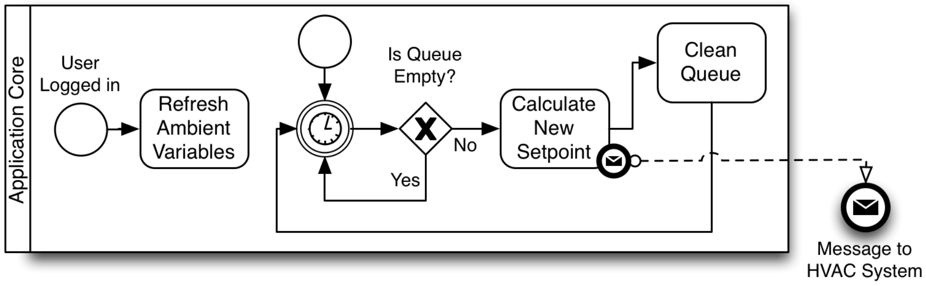

Figure 4.5: Main functions of the Application Core. Refresh ambient variables, calculates the set-point periodically and cleans queue.

4.6.2 Set-point Calculation

The set-point calculation algorithm is responsible for gathering the occupants votes and calculate a set-point which tries to minimize the probability of votes occurrence, thus maximizing overall comfort on the room.

On a specific interval, the system verifies the queue, if it is not empty, it calculates the new set-point, cleans the queued requests and send the new set-point to the HVAC system. After this process, returns to the state where it waits again for recalculating the new set-point. Figure 4.5 illustrates the basic process of the requests.

This algorithm uses a equation to validate the proof of concept. If the system calculates the set-point based always on the majority of votes, it is natural that eventually it will reach a medium value where the majority of occupant's will feel comfortable.

It is assumed that a vote is a proof that a person is unsatisfied with the current temperature and wants to change it, then he can vote to increase or decrease the temperature. The vote calculation starts on the second part of the set-point calculation algorithm. Starts by collecting all the queued votes and calculating the number of people in the room. Then it verifies the percentage of votes relatively to the number of people in the room, if more than 10% of the present users has voted, it means that more than 90% of occupants are unsatisfied, then the system starts by calculating the percentages of votes. The difference between the votes that want to increase and decrease the temperature should be greater than 10%, if its not, then it only cleans the queue and do not change the set-point. The calculation decides if the set-point should increase or decrease the temperature considering the majority of the votes changing it from 1ºC.

4.6.3 RFID System

To detect the user presence, the data base has an information field which indicates if the user is or not present. When the RFID system detects a tag, the information reaches the Web Server adding a flag on the information field which means that the user is present.

The RFID System interacts with the Web Service as soon as a tag is read. Figure 4.6 depicts the flow of interactions that are triggered when a tag is read. The RFID System sends the information to

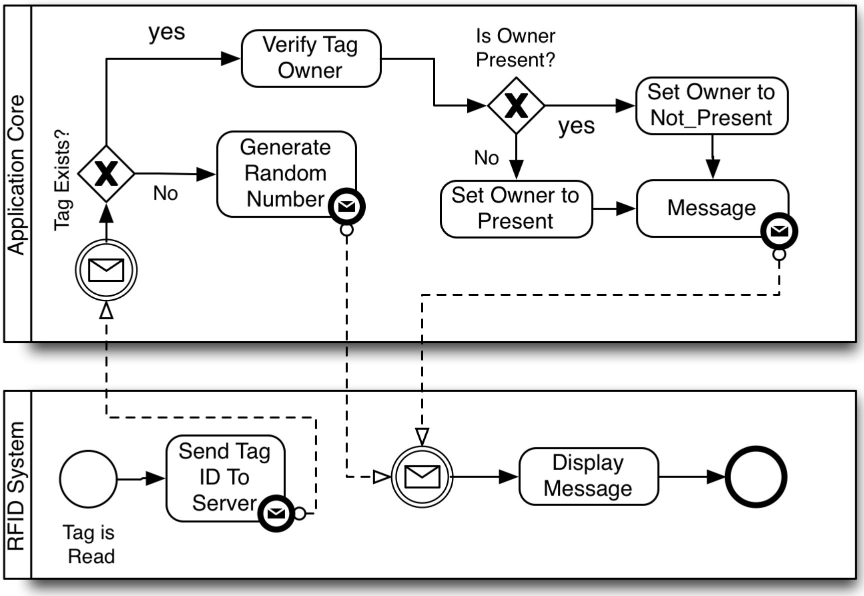

Figure 4.6: RFID System's interaction with the Main Application. It starts by sending the read tag ID to the Core, which verifies if the owner exists and defines it as present or absent.

the Web Service which will verify if the tag exists. If it does, the system will set the user present or not present depending on the current status of the tag owner.

The algorithm goal is to control the flow of people in the room, thus recording the historical behaviour of occupants and making possible for other algorithms that needs the number of people in the room as a variable to be calculated. The main algorithm consists in three stages, which are: the first one is to detect the RFID tag (or student card), the second one is to route this information through a Raspberry Pi and add a simple security layer to the information. Finally the last stage consists in the Web Server receive the information, adds a flag on the user database indicating that he is present, save the date time and hour that the user entered the room and return the response to the Arduino's LCD.

The Arduino has a Ethernet Module which communicates with the Raspberry Pi on the LAN, whose is also connected with the Web Server. The algorithm receives the 25 hexadecimal codes which each tag contains, since the Arduino has a very limited amount of RAM memory, the parsing and security functions are made by the Raspberry Pi on the second part of the Arduino. The hexadecimal codes are sent to the Raspberry Pi through a UDP channel then the Arduino waits for an answer, marking an end to the first step.

The second step starts with the Raspberry receiving the datagram and verifying its size, if the size is less than 25 it discards it, because it means that the datagram came with an error, or the message sent by the Arduino may not be of a tag reading. The parsing phase eliminates the first 17 hex codes and creates a string object containing the 8 important hex codes whose is encapsulated on a JSON object and sent to the Web Server as a HTTP request. Finally the last step of the process is to verify the tag received, compare the string with the one contained on the database. The system can identify three different types of action on this step:

– **Tag was never seen before:** The system does not find the tag on the database, then it is added without a user registered to it. A random and unique integer number from 0000 to 9999 is generated and associated to this tag. The Web Service then responds the random generated number to the HTTP request made on the second step whose responds to the Arduino's LCD screen to inform the user its number.

– **User has never registered its tag:** The system finds the tag on the database, but it does not have any user registered. Then the system does as the fist action and respond the random generated number that was already created to the user.

  Whenever a user that does not have a registered tag logs in the system, the system automatically requests the user to input the random generated number that the Arduino showed him. The system searches the database for the corresponding tag that have the number entered, and register the user to the found tag.

– **Registered User:** The last action is when the tag is found, and it has a user associated with it. Then the system adds a flag which means that the user is inside the room and responds with a welcome message to the user, to inform that his tag was successfully been read.

4.6.4 HVAC System Interactions

The Application Core is prepared to receive information of the HVAC System and its variables. It has the DB system equipped to receive its relevant information and the Application Core will read it from time to time to become always up to date. These informations are seen by users which are logged on the system. The Application Core make its calculations on set-point based on votes and on these informations, then it returns the new calculated set-point to the HVAC system.

4.6.5 Learning Algorithm

The idea to make the users configure the HVAC System with votes, can be improved in order to it to automatically configure itself. First it is needed to the system to gather all the votes, identify patterns into it and learn them to take decisions in the future.

A common learning algorithm is able to identify patterns among thousands of input data. In this particular case, the system will not have this amount of data to identify patterns. And the data analysed will probably have three different types of input data: the ones who want to raise the temperature, the ones who does not want to change and the ones which wants to lower the temperature. After this analysis, a learning algorithm which could separate these data into clusters accordingly to their similarity is the K-means algorithm [67]. Using this algorithm makes possible the auto configuration of the room's set-point without needing the occupants to vote.

The learning algorithm has as a goal to configure the set-point accordingly to a prediction based on the actual status of the room. The Web Server manages to do that by loading the information about the room and comparing it to a set of previously calculated scenarios. Then it has a decision algorithm that defines which set-point is the most indicated.

This algorithm is intended to provide more comfort to users, since they are detected as inside the room, it should be possible to automatically calculate the most appropriate set-point which will minimize the occupants discomfort. This is possible through a unsupervised learning algorithm which uses the clustering technique.

The k-means algorithm is a method of cluster analysis which divides into k clusters a set of n observations, each cluster S are associated with a centroid C. Each observation should belong to the cluster with the nearest mean. Considering a set of data points $S = \{X\}$, letting $d(X, Y)$ be the distance between two vectors X and Y.

The k-means algorithm can be divided in two main phases, the first once consists in mapping the clusters and the second one is the computing of the new centroid. First, the algorithm starts by mapping the clusters by choosing *k* random values and define them as the new centroids, then it iterates and calculate a new centroid, the iteration method is given as follows [68]

Mapping Phase: Given a set of cluster centres $SC_p = \{C_i\}$, find the partition of S; that is divided into k clusters S_i where $S_j = \{X|d(X, C_j) \leq d(X, C_i)$ for all $i \neq j\}$. Compute the centroid of each cluster to obtain a new set of clusters SC_{p+1}

Iteration Phase: Begin with the initial set of cluster centres SC_0. Set $p = 0$. the second step start by performing an iteration on the set of cluster centres SC_p generating the new set of clusters centroids SC_{p+1}. Finally compute the average distortion for SC_{p+1}. If it is changed by a small enough amount since last iteration then it has achieved convergence and the algorithm stops. Otherwise set $p + 1 = p$ and repeat the second step.

The nearest cluster centre is determnined by computing the euclidean distances between a data point $X = (x_1, x_2, ..., x_d)^t$ and cluster centre $C = (c_1, c_2, ..., c_d)^t$ is defined below on equation 4.1 [67, 68]:

$$d(X, C) = \left[\sum_{i=1}^{d} |x_i - c_i|^2\right]^{0,5} \tag{4.1}$$

4.7 Simulations

For a better understanding of the system's functionality and a pre-validation of the project's objectives, a low cost solution which imitates the user's and temperature behaviour can give preliminary results to ensure that the system works as intended and verify if the results are similar to the ones expected. Among various simulations system, the chosen one is the Energy Plus simulation software. Energy Plus is a simulation software designed to engineers and architect to size HVAC equipments in order to optimize energy performance [69]. This software can be powered with the Ptolemy II framework [70] , it is a open-source framework which allows the use of Java developed actor to interact with the Energy Plus simulation as it goes. Actors are able to change variables on the running simulation, such as

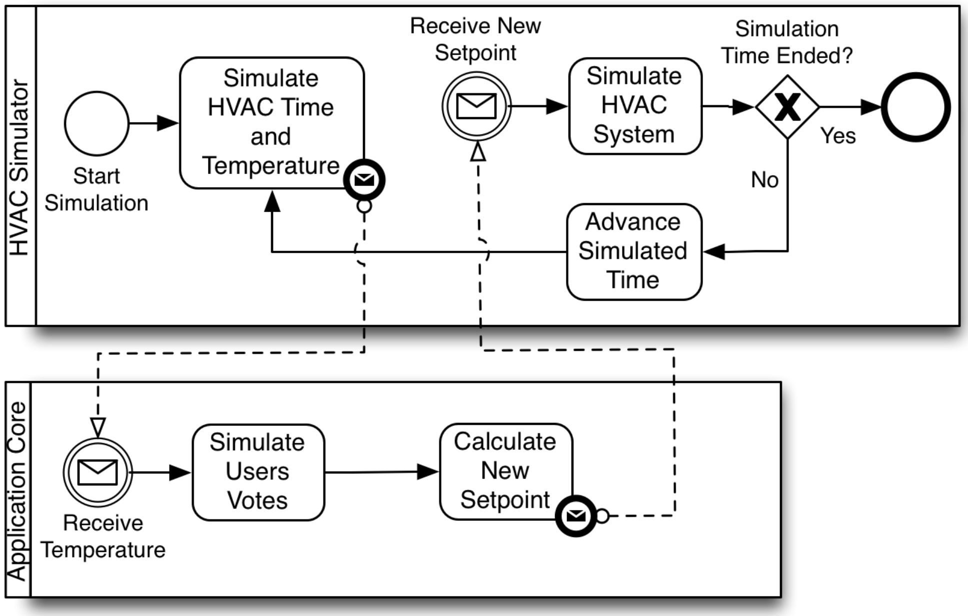

Figure 4.7: Overview of Simulation Process. The simulation framework starts by simulating temperature, sends the data to the Core which will simulate votes and calculate a new set-point, responding the new value to the HVAC simulation again. This process happens until the simulation time is over.

number of people in room, set-point and turn on or off the HVAC System. With this powerful framework it is possible to communicate with the Web Server on the simulation run. This section will explain each step of the simulation process among with the results.

4.7.1 Overview

The project's goal is to define a set-point which minimize the occupants discomfort and validate the possibility to save energy using this method. The simulated environment is set within a room of 144 square meters with four windows and one door. The time zone and weather used is on the Lisbon city in Portugal. The month chosen was January, in the winter.

The simulations takes on account that occupants arrive at 8:00h and leave for lunch at 12:00h returning at 13:00h. Then they leave at 18:00h. Each occupant has a unique comfort interval and can be absent. These equations used will be explained furthermore in this section.

The Energy Plus takes the same role as the HVAC System described on section 4.6.4, and the process uses the same principle, first it starts by simulating outdoor and indoor temperatures and adding it to the DB notifying the Application Core that is has been updated. The Application Core will verify the indoor temperature and simulate the discomfort among occupants to retrieve voting results and storing it. The next step is to calculate the new set-point based on the votes, the result will be sent back to the Energy Plus software. At this point, the system will simulate the temperature according to the new set-point received from the Application Core. Each of these sub processes are described in detail on section 4.7.2, and the overall procedure is depicted on Figure 4.7.

4.7.2 Role of the Application Core

It was necessary the development of a interface which would make possible the communication of the Application Core and the simulation software, this process will be explained on section 4.7.3. While the Application Core takes on the simulation of users and vote, the other softwares are used only to provide simulated information about the HVAC system and room temperature.

User comfort range: Each time the system restarts, it counts with a tool which will create up to 40 unique users. Each user have a comfort interval which means that is the best comfort value that this user will have. Every user will eventually vote to reach the values in their comfort range.

The comfort range of each unique user is defined based on the equality from Humphreys and Nicol [71] defined on equation 4.2 where T_c is the comfort temperature and T_{out} is defined by the average outdoor temperature from the previous 30 days, in that case 13ºC.

$$T_c = 24.2 + 0.43(T_{out} - 22) \times e^{(\frac{T_{out}-22}{24\sqrt{2}})^2} \tag{4.2}$$

In order to make a unique comfort range to each occupant, the result value is added to the equation 4.3 where r_i is the result from the equation 4.2 and r_f the lower value of the comfort range, where it subtracts 2ºC and adds a random number which goes through 0 and 4. The comfort range should be from 1ºC, then is just add 1 to r_f in order to retrieve the upper limit of the comfort range.

$$r_f = (r_i - 2) + rand(0..4) \tag{4.3}$$

Day simulation: In order to simulate days, the application provides a simple mechanism which introduce a date on the end of each day simulation. It will not only update the days, but some other important functions as removing all the occupants, and calculating a probability of the users to be present on the next day. Using this system, it is possible to simulate a entire month.

User presence simulation: To make the simulations with a reasonable resemblance to the reality, the number of occupants in a room are are also simulated. Each time that the system resets the days, unique users are inserted in the room, but each user has a probability of not being in the room. This calculation tries to simulate people which by any reason does not attend to classes.

The simulation occurs on the beginning of each day, it verifies all the possible present students, and for each, a poisson distribution occurrence is thrown to the probability of the student to become away from class. The result defines if the person is or not present in the room.

This will influence the set-point calculation, strictly on each vote, considering that each person has a unique comfort range and who is not present does not vote. In order to simplify this calculations, it is assumed that every person arrives and leaves at the same time.

User probability of vote: To simulate a user voting, each time that the indoor temperature goes different from the user's comfort interval, it votes. But a user would not vote every time it feels uncomfortable, it should have a probability of voting. This probability is calculated using the Poisson discrete probability distribution with mean 4 times a day.

New Set-point Calculation: There is no need to simulate the set-point, since the algorithm which will calculate the set-point is exactly the same as the one that will be used to calculate the true set-point on a production stage. The main difference is that this function will return the set-point to the Ptolemy II framework instead of returning it to the framework which controls the HVAC system.

4.7.3 Energy Plus

The Energy Plus software is the base system which simulates a room, and the temperature inside and outside the room. It takes on account the temperature that the human bodies irradiates inside the room, the sun's temperature, and a 12000W heater.

The Ptolemy II framework uses a simplified interface to work with the Energy Plus simulations, but it has the power to add complexity to the simulation, as to put and remove people from the room or turning the heating system on and off while the simulation is running.

The Ptolemy II framework is used to interact with the simulation as it runs by means of programming. The Ptolemy II framework, calculates all the temperature and HVAC related data. While the Application Core will only simulate users entering the room, voting and calculate the best set-point while trying to minimize the occupants discomfort.

The framework uses Actors to automate and change variables whilst the Energy Plus simulation is running. The base simulation uses two actors, the first one to turn on and off the heating system, and the second one to add people to the room. The simulation starts at 0:00h, and starts the heating system at 7:00h, people are set to arrive at 8:00h. Lunch time is set between 12:00h and 13:00h. The people leave the room at 18:00h and the heating system goes off at the same time.

The Application Core is responsible to create users, simulate votes and calculate an optimal set-point, the Ptolemy II framework will work as a interface to connect both softwares. It starts by calculating a base temperature for a common winter day on Lisbon, then calculates the inside temperature and sends it to the Application Core, which will receive the internal temperature as an input parameter.

The Application Core will simulate the people feeling uncomfortable and voting as described in section 4.7.2, then it will calculate the new set-point and send the response to Ptolemy II, which will then calculate again the temperature of the room based on the new set-point. This cycle repeats itself on a time period of 10 minutes, and it will end once the simulated time reaches the 0:00h again.

4.7.4 Integration with Energy Plus

The Application Core and the Ptolemy II framework are both developed on a Java environment and there is no tool to assemble them. All the Ptolemy's actors are developed in Java language. Then an intercommunication interface should be made in order to make the integration of both systems.

The first step was to develop an Actor compatible with the Ptolemy II framework. A reverse engineering was made in order to develop an Actor which will receive the room's temperature as a input and return the new set-point as an output.

The first step is to define the input and output ports, and their function. The first input port is able to receive the simulated indoor temperature. The Actor then opens a socket connection to communicate with the Application Core, this communications calls the simulation algorithm which will receive as a parameter the temperature and waits for the response.

At this moment, the users are already created and they receive the temperature as a input and each user has a probability of voting as was explained on section 4.7.2. After collecting all the votes the system calculates the new set-point and returns it to the Ptolemy II Actor which at this moment is still waiting for a response in order to close the socket connection. The return message is the newest calculated set-point which will be the output of the Actor and input for the next iteration of the simulation which will be 10 minutes later..

4.7.5 The Role of the Learning Algorithm

The Learning Algorithm is needed on a post phase of the simulations, withdrawing the results of the simulations, and it defines the next decision of the new set-point. This step is important to validate if the k-means algorithm proposed on section 4.6.5 is a valid solution on the learning and decision making phase of the solution.

The algorithm retrieves the information on each vote made and save on the DB during the submission of a user request. The information retrieved by the k-means algorithm is calculated and returns different centroids. Each centroid is related to a system decision. When it activates, it calculates once per day the new centroids updating all the new requests and labelling each one of them.

Once the system has the clusters calculated, it takes the information on current variables such as the indoor temperature, hour of day, number of occupants and calculates the cluster that fits better these variables. Then verifies which is the decision associated with the cluster and then decides it.

At the beginning of each day, the algorithm calculates again the new centroids based on all the previous votes and the now new ones made on the previous day, this methods makes possible of using the algorithm to calculate the set-point and at the same time using data to train it to achieve better results.

The k-means decision algorithm is adapted on the Ptolemy II Actor, which will take total control over the set-point calculation. The users are still able to vote, but at this point their vote will not interfere with the set-point calculation, it is only for the purpose of training the Learning Algorithm.

Chapter 5

Evaluation

This chapter details the outcome of the simulation of an application of the proposed solution to a real life scenario. The reason behind this simulation was solely to provide the means to evaluate the proposed solution, since a real testbed was not yet functional for this evaluation.

The solution should be able to validate if it is possible to calculate a set-point accordingly to user feedback and validate if it maximizes comfort, or at least maintains the same margin of comfort. It should also be able to learn the occupant's preferences and automatically configure the system using the learning algorithm. The chapter is structured as follows: Section 5.1 details the simulations procedures and their results, Section 5.2 presents the discussion about the achieved results, and section 5.3 details about the RFID System.

5.1 Methodology

In order to evaluate the proposed solution, a simulation of an application to a real life scenario was made. The real life scenario consisted of a room where occupants are using the proposed solution and were able to cast a vote with the intent of setting the temperature which best fitted their comfort. The system would calculate the new set-point and adjust the HVAC system accordingly. The data collected in order to evaluate the system corresponds to the overall daily comfort value, the daily mean energy consumption in KWh and the mean daily set-point.

Three variations of the main scenario were used. In the first scenario the temperature within the room did not vary throughout the day, independently on the occupant's votes. This scenario was used as baseline of comparison to the remaining scenarios. The other two scenarios were: A scenario where the system adjusts the room temperature based on the occupants votes and a scenario where the room temperature is adjusted based on the Learning Algorithm.

5.1.1 Baseline

As mentioned, in this scenario the room temperature does not vary throughout the day. In order to calculate the mean comfort temperature equation 4.2 was used. Where T_{out} was set at 13ºC and as

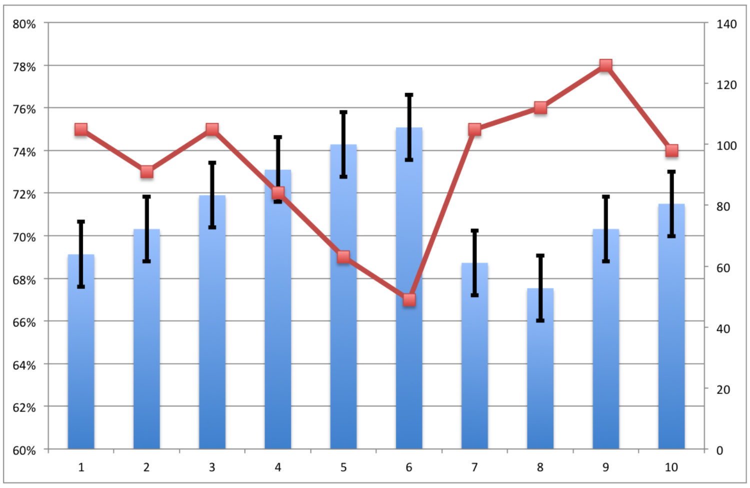

Figure 5.1: Baseline simulation results. The red line shows the percentage of the computed comfort, and the blue bars shows the energy consumption in KWh of each simulation.

a result T_c was nearly 21°C. Simulations were then made using fixed set-points on 20°C, 21°C, 22°C, 23°C and 24°C. In figure 5.1 the blue bars represent the mean energy waste, going on a total mean of 78,33KWh with a confidence interval of maximum 105,55 KWh and minimum of 52,78 KWh. The red line represents the mean daily comfort rate with total medium of 73,40%.

Analysing the results displayed in figure 5.1, it is possible to see that there is a high standard deviation (17,16KWh on energy spendings, and 3,31% on the mean comfort rate, see table 5.1). This is due to the fact that the occupants comfort values decreased on simulations where the set-point was fixed on 23°C and 24°C. In order to try to attain results where the comfort is maxed, other simulations were made using as a fixed set-point at 20°C, 21°C and 22°C, where the temperature will be near the mean comfort of the occupants. Figure 5.2 depicts the results of the second baseline simulations, where blue bars represent the electric consumption and the red line represents the comfort rate. Table 5.1 provide comparison of the results of both simulations. The results of the second simulation are slightly better, where the mean energy consumption is 67,89KWh with a 95 comfort interval from 61,54KWh to 74,25KWh compared with 67,69KWh and 88,96KWh on the first simulations. The standard deviation of 9,73KWh and 17,16KWh on the fist one.

	First Simulation		Second Simulation	
	Energy Use (KWh)	Comfort %	Energy Use (KWh)	Comfort %
Mean	78,33	73,40	67,89	75,67
Std Deviation	17,16	3,31	9,37	1,58
Superior CV	88,96	75,45	74,25	76,70
Inferior CV	67,69	71,35	61,54	64,96

Table 5.1: Comparison of the results of the two baseline simulations

5.1.2 Simulation Tests

With the informations gathered in section 5.1.1 it was possible to simulate the occupants votes, and evaluate the results in order to verify if they would behave as expected. As mentioned, this simulation

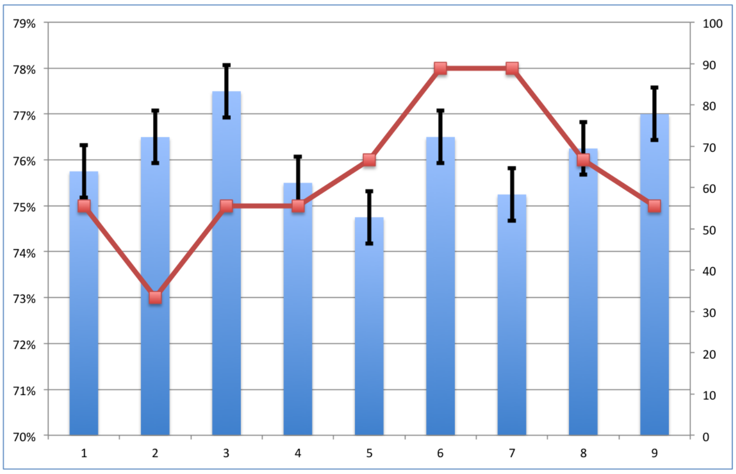

Figure 5.2: Second baseline simulation results. The red line shows the percentage of the computed comfort, and the blue bars shows the energy consumption in KWh of each simulation.

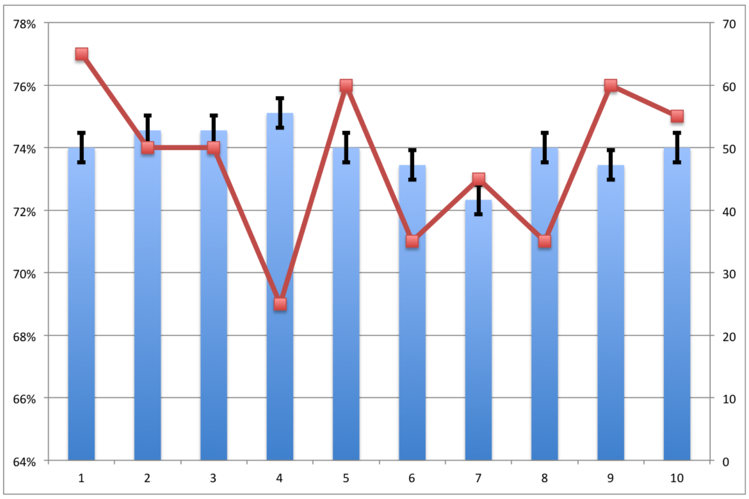

Figure 5.3: Simulation results using the occupant's votes to configure the set-point. The red line shows the percentage of the computed comfort, and the blue bars shows the energy consumption in KWh of each simulation.

would simulate the adjustment of temperature based on the occupants votes.

Figure 5.3 represents the results on the simulations and table 5.2 displays the same data, so as to facilitate a direct comparison with the data displayed in table 5.1. Figure 5.4 depicts the indoor temperature of one simulation. It is possible to confirm that occupants are voting and the mean comfort value is as expected, around 21°C. The comfort value has a 73,6%, which is almost 2% less than the second simulation made on section 5.1.1. This margin can be disregarded for being too low.

	Energy Use (KWh)	Comfort %	Mean Set-point
Mean	49,72	73,6	20,997
Std Deviation	3,81	2,59	0,35
Superior CV	52,08	75,21	21,21
Inferior CV	47,36	71,99	20,78

Table 5.2: Results on the simulations using occupants votes.

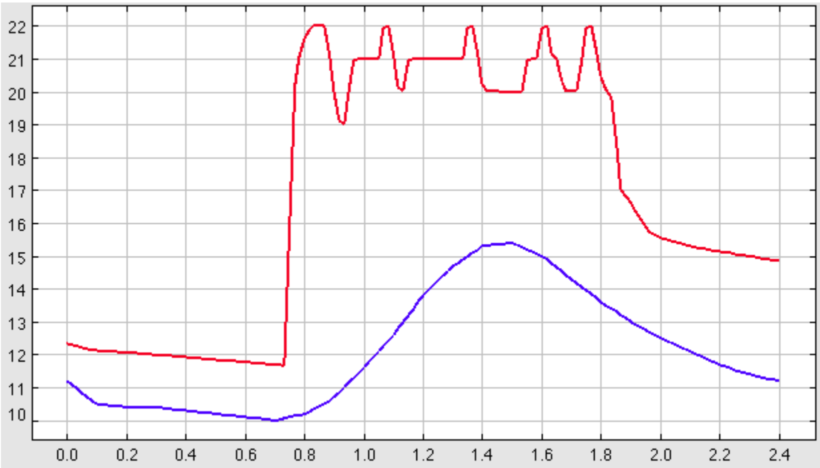

Figure 5.4: Simulation results using the occupant's votes to configure the set-point. The graphic shows the temperature over time. Where the red line shows the indoor temperature and the blue line the outdoor temperature.

5.1.3 Learning Algorithm

The Learning Algorithm was tested in three different scenarios. The first one was intended to test the k-means algorithm using 5 days simulations to train it and 9 centroids $(k = 9)$. The second one used 10 days to train it and 9 centroids$(k = 9)$. The last one also used 10 days to train it, but with only 3 centroids $(k = 3)$.

The results on the first two scenarios are presented in table 5.3. By analyzing the table it is possible to see that, the results slightly better than the baseline, but after analysing the standard deviation and confidence interval, it is notable that the achieved results are still heterogeneous in both tests. The mean energy waste has achieved a mean of 54,99KWh and 52,49KWh. This was due to the fact that the k-means decision algorithm was lowering the temperature, thus less energy was being used to warm the room, this explains the low comfort rate in both simulations.

	$k = 9$ and Days=5			$k = 9$ and Days=10		
	Energy Use (KWh)	Comfort %	Set-point	Energy Use (KWh)	Comfort %	Set-point
Mean	54,99	67,26	20,11	52,49	66,44	20,24
Std Deviation	28,72	2,27	2,84	39,74	2,38	4,45
Superior CV	72,79	68,66	21,87	77,12	67,91	22,99
Inferior CV	37,19	65,85	18,35	27,85	64,96	17,48

Table 5.3: Results on the simulations using K-means algorithm, with 5 and 10 days of training.

Since both results are equally heterogeneous, it can be deduced that using more days of training is not enough to achieve more homogeneous results. This problem could be due to the high number of clusters, since there are many clusters, the k-means may have trouble to identify clusters which are similar to each other.

One possible solution would be change the number of clusters. If the observations are too homogeneous, more clusters should solve the problem. However, if the observations are too homogeneous, probably using less clusters could divide them more precisely. Since 9 clusters is a relatively big number when compared to the total amount of data to analyse as input, it was decided to use less clusters, and

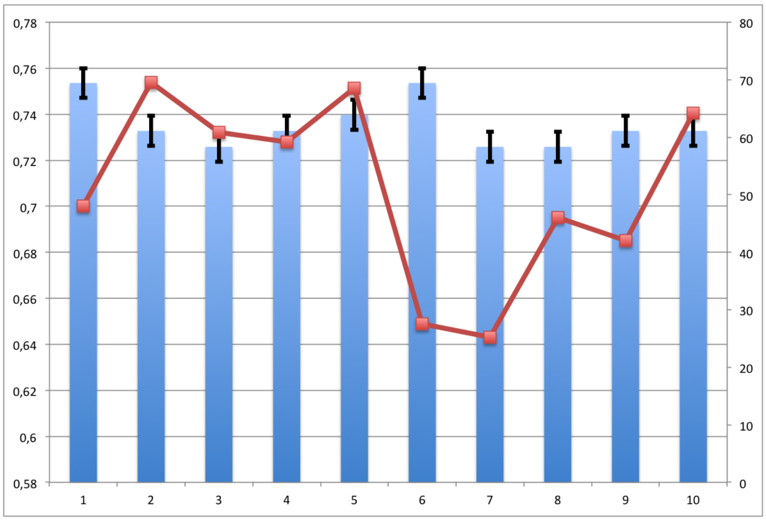

Figure 5.5: Second k-means simulation results, using $k = 3$. The red line shows the percentage of the computed comfort, and the blue bars shows the energy consumption in KWh of each simulation.

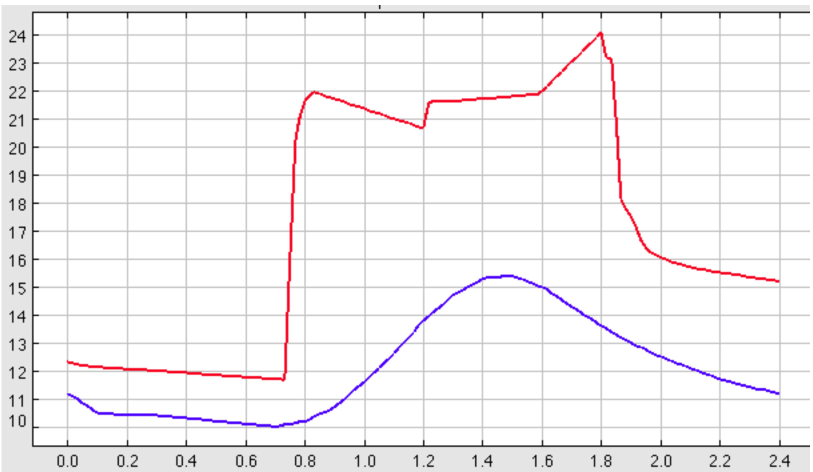

Figure 5.6: Second k-means simulation results, using $k = 3$. The graphic shows the temperature over time. Where the red line shows the indoor temperature and the blue line the outdoor temperature.

the number was reduced to 3.

For the last scenario, the same data was used as input, the results are depicted on figure 5.6 (a) depicts the result, which are more homogeneous than the other ones using the k-means algorithm, however the comfort values are still lower than the one displayed in figures 5.1 and 5.2 from the baseline simulations. Is also possible to confirm, by analysing figure 5.6 (b) that the temperature is configured almost as expected, maintaining the temperature around 22ºC. However at the end of the say the temperature raises to 24ºC, this suggests that more improvements still needs to be done. Through an analysis of table 5.4, the results prove to be near the expected but still needs some improvement. Comparing the data between tables 5.4 and 5.1, it is possible to determine that the mean energy use is slightly lower. This could mean that the system configured the HVAC System to be too cold, an assumption which can be confirmed by the lower value on the user comfort rate which is 70,78% against 75,67% on the fist baseline.

	$k = 3$, Days=10		
	Energy Use (KWh)	Comfort %	Set-point
Mean	62,22	70,78	21,67
Std Deviation	4,18	4,01	0,41
Superior CV	64,81	73,26	21,93
Inferior CV	59,63	68,29	64,96

Table 5.4: Results on the simulations using K-means algorithm, using $k = 3$.

5.2 Discussion

Considering that on a first moment, a baseline scenario was drawn in order to simulate an real life situation where the HVAC system is configured on a fixed temperature. The second baseline simulation is chosen to be the one to compare results, because this simulation was set a set-point which was near the user mean comfort value.

On the first scenario, the most relevant retrieved data is related to the energy spent, which is notably 18,19KWh less than the baseline, accounting for an energy reduction of 26,79%. This results suggests that it is possible to save energy only by allowing the occupants to vote on the temperature which more suits their needs.

The k-means algorithm has been used on three different configurations, the first and second simulations was intended to prove that the learning days could change the accuracy of the decisions. Even failing to prove this concept, the third scenario prove that in this particular case the accuracy is defined by the configuration variables used on this system. In this case, by using less number of clusters, the accuracy was increased. This is due to the data collected from the votes, the data probably is very heterogeneous, having a big distinction among each cluster, in that case, only three clusters could define more precisely a decision.

The results on the last scenario using the k-means algorithm suggest that it is possible to allow a room to configure the HVAC system based on a machine learning technique. Despite the comfort rate, which is approximately 5% lesser than the baseline, the energy consumption had a decrease of 5KWh on the mean consume. This suggests that there was a reduction on the energy consumption while abstaining from the occupant comfort rate.

5.3 RFID System

In order to evaluate the RFID System, it was necessary to install it on a real test bed which would be used by students and their feedback would be gathered. the intent was to make the installation on the amphitheatre A4 located on the IST - Taguspark University on Lisbon-Portugal. Making the students use it with their student's card. Unfortunately third party limitations on the physical installation of the system were encountered and unfortunately the system could not be tested on a real environment. Eventually it was not possible to gather information on the feedback on students use of the system.

Chapter 6

Conclusions

This work presented several contributions, of which it can be highlighted the creation of a prototype application which interacts with simulation applications and could be used in order to test various types of set-point calculation and learning algorithms. Our hypothesis was that developing a system which gives occupants the appropriate means to control the HVAC system, results in the minimization of the energy consumption while maximizing comfort.

6.1 Retrospective

The use of BAS systems are becoming everyday more common, since energy management is a major global concern, there is a raising interest in system which could promote energy savings.

Even with plenty of system which explores the same area of study, there still remains numerous questions yet to be answered. One of which is the possibility of allowing Ambient Intelligence Systems to control building's energy management system. This works proves to be possible to give the chance to occupants to give their opinion on a HVAC system and still provide reduction on the energy consumption. However, using a learning algorithm to control this category of system proved to be delicate, in which it is possible however, cautions and excessive testing needs to be taken, in order to start using in a real environment. This works also contains the development of a prototype system which makes possible the occupancy detection through a small electric boards which is able to read the university student card.

6.2 Achievements

This thesis contributed on the area of home and building automation systems with emphasis on energy management, with testing and validation based on simulations. It is addressed to the lack of system which could configure the HVAC system based on the preferences of the occupants. The main achievements of this work are:

– **A compilation on existing work** based on AmI system aiming on energy management and occupancy detection.

- **An Occupancy Detection system** based on the Arduino technology which is capable of reading the student card, thus could be used on many other practical applications.
- **The Development of an Platform** which could simulate users on a room, communicate with a HVAC simulation framework, and also can be upgraded to use machine learning algorithms to configure the HVAC system through simulations. And their results which suggests that it is possible to configure the HVAC system of a room by taking into account the occupants preferences, while consuming less energy.
- **The Machine Learning technique** applied on the platform, whose results suggests that is also possible to configure an HVAC system by loading the occupants preferences and deciding which is the best set-point that minimizes the energy consumption maximizing comfort.

6.3 Future Work

The implementation of this work involved several distinct technologies, making the main challenge for this project, to provide a simple and user-friendly interaction between them. However, it can be upgraded to be supported by new technologies. On the current implementation, the system uses a web server which is able respond inputs of all sorts of client applications; a relational DB model; an RFID system composed of Arduino and Raspberry Pi; interconnection with a simulation platform; and a learning algorithm capable of taking decisions.

- **Web Server:** The Web Server in this moment, is interconnected with an simulation application in which is the one responsible for providing all the presented results of this work. It could be enhanced by adding a connection with a real HVAC controller system. In which would provide the use of a real world testbed.
- **Architecture Expansion:** The actual architecture has been planned and developed for being used on an university. However, the presented architecture makes possible the expansion for other applications, such as meeting rooms, cinema and theatres, commercial centres among others.
- **Client Applications:** The solution was developed by using technologies which will allow support by any type of client applications. However, besides the RFID and Simulation systems, in the actual moment there is not any client application. Mobile application for users could be developed in order to make this system more user-friendly and more acceptable for occupants.
- **RFID System:** Taking in account that the RFID System has only been tested on labs, and it was still not been tested with real users. In the actual moment, to validate this system with real users, it needs to be installed and tested.
- **Arduino and Raspberry Pi:** These system are responsible to managing the occupancy detection on the room. However, there are many other means of detecting occupants in a room. These systems could be improved by the adding of new sensors in which would validate different occupancy detection means.

– **Simulations:** At this moment, the interconnection with the simulation framework is at a very initial state. The Energy Plus program is a very powerful tool to simulate various types of ambients, and this feature could be studied furthermore in order to improve the possible results on simulation that this application can provide.

– **Learning Algorithm:** Besides it was possible to prove the viability of using an learning algorithm to control the room's set-point, the tested learning algorithm had its results below expected. However, since there is of existence other learning algorithms, it would be interesting the results and comparison on various different learning algorithms and approaches using the simulation framework.

Bibliography

[1] Yang, R., Wang, L.: Development of multi-agent system for building energy and comfort management based on occupant behaviors. Energy and Buildings **56** (2013) 1 – 7

[2] Soucek, S., Zucker, G.: Current developments and challenges in building automation. e & i Elektrotechnik und Informationstechnik **129** (2012) 278–285

[3] Boman, M., Davidsson, P.: Energy saving and added customer value in intelligent buildings. International Conference on the Practical Application of Intelligent Agents and Multi-Agent Technology **1** (1998) 505 – 516

[4] Klein, L., Kwak, J.y., Kavulya, G., Jazizadeh, F., Becerik-Gerber, B., Varakantham, P., Tambe, M.: Coordinating occupant behavior for building energy and comfort management using multi-agent systems. Automation in Construction **22** (2012) 525–536

[5] Padmanabh, K., V, A.M.: iSense: a wireless sensor network based conference room management system. Proceedings of the First ACM Workshop on Embedded Sensing Systems for Energy-Efficiency in Buildings (2009) 37–42

[6] Wigginton, M., Harris, J.: Intelligent skins (2002)

[7] Resendes, S.: Automatic Conflict Resolution in Home and Building Automation Systems. Master's thesis, Instituto Superior Técnico (2012)

[8] Remagino, P., Foresti, G.: Ambient intelligence: A new multidisciplinary paradigm. Systems, Man and Cybernetics, Part A: Systems and Humans, IEEE Transactions on, **35** (2005) 1–6

[9] Hesse, J., Gardner, J.W., Göpel, W.: Sensors in Intelligent Buildings. Volume 2 of Sensors Applications. Wiley-VCH (2001)

[10] Swenson, D.: Hvac Heating, Ventilating, and Air Conditioning. American Technical Publishers, Inc., Homewood, Illinois (1995)

[11] Rezaie, B., Rosen, M.A.: District heating and cooling: Review of technology and potential enhancements. Applied Energy **93** (2012) 2 – 10 (1) Green Energy; (2)Special Section from papers presented at the 2nd International Enery 2030 Conf.

[12] Li, N., Calis, G., Becerik-Gerber, B.: Measuring and monitoring occupancy with an rfid based system for demand-driven hvac operations. Automation in Construction **24** (2012) 89 – 99

[13] Westphalen, D., Koszalinski, S.: Energy Consumption Characteristics of Commercial Building HVAC Systems. Volume II: Thermal Distribution, Auxiliary Equipment, and Ventilation. Arthur D. Little Inc (ADLI) **II** (1999)

[14] Freire, R.Z., Oliveira, G.H., Mendes, N.: Predictive controllers for thermal comfort optimization and energy savings. Energy and Buildings **40** (2008) 1353 – 1365

[15] Fasiuddin, M., Budaiwi, I.: Hvac system strategies for energy conservation in commercial buildings in saudi arabia. Energy and Buildings **43** (2011) 3457 – 3466

[16] ASHRAE: HVAC Applications. Si edn. ASHRAE Handbook. (2011)

[17] Dodier, R.H., Henze, G.P., Tiller, D.K., Guo, X.: Building occupancy detection through sensor belief networks. Energy and Buildings **38** (2006) 1033–1043

[18] Pardal, M.L.: Special topics in suply chain management (2010)

[19] inLogic, Inc: Passive RFID and Active RFID Tag. (`http://www.inlogic.com/rfid/passive_vs_active.aspx`) Accessed 11 Apr 2013.

[20] Technovelgy, L.: Passive RFID and Active RFID Tag. (`http://www.technovelgy.com/ct/technology-article.asp?artnum=47`) Accessed 11 Apr 2013.

[21] Bonsor, K., Fenion, W.: How RFID Works. `http://electronics.howstuffworks.com/gadgets/high-tech-gadgets/rfid.htm` (2007) Accessed 11 Apr 2013.

[22] Journal, R.: RFID Frequently Asked Questions. (`http://www.rfidjournal.com/faq/show?85`) Accessed 11 Apr 2014.

[23] Banks, J.: DISCRETE EVENT SIMULATION Jerry Banks Marietta, Georgia 30067. (1999) 7–13

[24] Uiuc, L.: EnergyPlus engineering reference: the reference to EnergyPlus calculations. US Department of Energy (2005)

[25] of Energy, U.D.: EnergyPlus. (`http://apps1.eere.energy.gov/buildings/energyplus/`) Accessed 11 Apr 2014.

[26] Davidsson, P., Boman, M.: Saving energy and providing value added services in intelligent buildings: A MAS approach. Agent Systems, Mobile Agents, and Applications (2000)

[27] Davidsson, P., Boman, M.: Distributed monitoring and control of office buildings by embedded agents. Information Sciences **171** (2005) 293–307

[28] Qiao, B., Liu, K., Guy, C.: A Multi-Agent System for Building Control. 2006 IEEE/WIC/ACM International Conference on Intelligent Agent Technology (2006) 653–659

[29] Booy, D., Liu, K., Qiao, B., Guy, C.: A Semiotic Multi-Agent System for Intelligent Building Control. Proceedings of the First International Conference on Ambient Media and Systems (2008)

[30] Mozer, M.C.: Lessions from an Adaptive House. Smart Environments (2005) 271–294

[31] Mozer, M.C.: The Neural Network House: An Environment that Adapts to its Inhabitants. Artificial Intelligence (1998) 110–114

[32] Sierra, E., Hossian, A., Rodriguéz, D., Britos, P.: Intelligent Systems Applied to Optimize Building's Environments Performance,. Sierra (**276**) 237–244

[33] Lee, C.: Fuzzy logic in control systems: fuzzy logic controller. I. Ieee Transactions On Systems Man And Cybernetic (1990)

[34] Doctor, F., Hagras, H., Callaghan, V.: A Fuzzy Embedded Agent-Based Approach for Realizing Ambient Intelligence in Intelligent Inhabited Environments. IEEE Transactions Systems **35** (2005) 55–65

[35] Hagras, H., Callaghan, V., Colley, M., Clake, G., Cornish, A.P., Duman, H.: Creating an ambient-intelligence environment using embedded agents. IEEE Intelligent Systems **19** (2004) 12–20

[36] Rashidi, P., Cook, D.J.: Mining and monitoring patterns of daily routines for assisted living in real world settings. Proceedings of the ACM international conference on Health informatics - IHI '10 (2010) 336

[37] Díaz, P., Olivares, T., Galindo, R., Ortiz, A., Royo, F., Clemente, T.: The ecosense project: An intelligent energy management system with a wireless sensor and actor network. **7** (2011) 237–245

[38] Oldewurtel, F., Sturzenegger, D., Morari, M.: Importance of occupancy information for building climate control. Applied Energy **101** (2013) 521 – 532 Sustainable Development of Energy, Water and Environment Systems.

[39] Kastner, W., Kofler, M., Reinisch, C.: Using AI to realize energy efficient yet comfortable smart homes. Factory Communication Systems (WFCS), 2010 8th IEEE International Workshop (2010)

[40] Reinisch, C., Kofler, M.J., Kastner, W.: ThinkHome: A smart home as digital ecosystem. 4th IEEE International Conference on Digital Ecosystems and Technologies (2010) 256–261

[41] Reinisch, C., Kofler, M., Iglesias, F., Kastner, W.: ThinkHome Energy Efficiency in Future Smart Homes. EURASIP Journal on Embedded Systems **2011** (2011) 104617

[42] Dong, B., Andrews, B.: Sensor-based occupancy behavioral pattern recognition for energy and comfort management in intelligent buildings. Proc. Int. IBPSA Conf (2009) 1444–1451

[43] Erickson, V.L., Lin, Y., Kamthe, A., Brahme, R., Surana, A., Cerpa, A.E., Sohn, M.D., Narayanan, S.: Energy efficient building environment control strategies using real-time occupancy measurements.

Proceedings of the First ACM Workshop on Embedded Sensing Systems for Energy-Efficiency in Buildings - BuildSys '09 (2009) 19

[44] Kamthe, A., Jiang, L., Dudys, M., Cerpa, A.: Scopes: Smart cameras object position estimation system. Wireless Sensor Networks (2009) 279–295

[45] Erickson, V.L., Cerpa, A.E.: Occupancy based demand response HVAC control strategy. Proceedings of the 2nd ACM Workshop on Embedded Sensing Systems for Energy-Efficiency in Building - BuildSys '10 (2010) 7

[46] Erickson, V.: OBSERVE: Occupancy-based system for efficient reduction of HVAC energy. Processing in Sensor (2011)

[47] Bharathidasan, A., Anand Sai Ponduru, V.: Sensor Networks: An Overview. (Department of Computer Science University of California) 1 – 24

[48] Delaney, D., O'Hare, G., Ruzzelli, A.: Evaluation of energy-efficiency in lighting systems using sensor networks. Proceedings of the First ACM Workshop on Embedded Sensing Systems for Energy-Efficiency in Buildings - BuildSys '09 (2009)

[49] Agarwal, Y., Balaji, B., Gupta, R., Lyles, J., Wei, M., Weng, T.: Occupancy-driven energy management for smart building automation. Proceedings of the 2nd ACM Workshop on Embedded Sensing Systems for Energy-Efficiency in Building - BuildSys '10 (2010) 1

[50] Kim, Y., Charbiwala, Z.: Spotlight: Personal natural resource consumption profiler. In Proceedings of the fifth workshop on Embedded Networked Sensors (HotEmNets) (2008)

[51] Harle, R.K., Hopper, a.: The potential for location-aware power management. Proceedings of the 10th international conference on Ubiquitous computing - UbiComp '08 (2008) 302

[52] Gao, G., Whitehouse, K.: The self-programming thermostat: optimizing setback schedules based on home occupancy patterns. Proceedings of the First ACM Workshop on Embedded Sensing Systems for Energy-Efficiency in Buildings (2009)

[53] Lu, J., Sookoor, T., Srinivasan, V.: The smart thermostat: using occupancy sensors to save energy in homes. Proceedings of the 8th ACM Conference on Embedded Networked Sensor Systems 8th ACM Conference on Embedded Networked Sensor Systems (2010)

[54] Murakami, Y., Terano, M., Mizutani, K., Harada, M., Kuno, S.: Field experiments on energy consumption and thermal comfort in the office environment controlled by occupants' requirements from PC terminal. Building and Environment **42** (2007) 4022–4027

[55] Luo, X., O'Brien, W.J., Julien, C.L.: Comparative evaluation of Received Signal-Strength Index (RSSI) based indoor localization techniques for construction jobsites. Advanced Engineering Informatics **25** (2011) 355–363

[56] Hightower, J., Want, R., Borriello, G.: SpotON: An indoor 3D location sensing technology based on RF signal strength. In Proceedings of the First ACM Workshop on Embedded Sensing Systems for Energy-Efficiency in Buildings (2000)

[57] Zhou, J., Shi, J.: A comprehensive multi-factor analysis on RFID localization capability. Advanced Engineering Informatics **25** (2011) 32–40

[58] Ni, L.M., Liu, Y., Lau, Y.C., Patil, A.P.: LANDMARC: Indoor Location Sensing Using Active RFID. Wireless Networks **10** (2004) 701–710

[59] Sue, K.L., Tsai, C.H., Lin, M.H.: Flexor: A flexible localization scheme based on rfid. **3961** (2006) 306–316

[60] Jin, G.y., Lu, X.y., Park, M.s.: An Indoor Localization Mechanism Using Active RFID Tag. IEEE International Conference on Sensor Networks, Ubiquitous, and Trustworthy Computing -Vol 1 (SUTC'06) **1** (2006) 40–43

[61] Jiang, X., Liu, Y., Wang, X.: An Enhanced Approach of Indoor Location Sensing Using Active RFID. 2009 WASE International Conference on Information Engineering **1** (2009) 169–172

[62] Li, N., Becerik-Gerber, B.: Performance-based evaluation of RFID-based indoor location sensing solutions for the built environment. Advanced Engineering Informatics **25** (2011) 535 – 546 Special Section: Engineering informatics in port operations and logistics.

[63] Group, T.O.: What is SOA? (`http://www.opengroup.org/soa/source-book/soa/soa.htm#soa_definition`) Accessed 04 May 2014.

[64] Avraham, L., Rayfield, T., J.: Web-Application Development Using the Model/View/Controller Design Pattern. IEEE Enterprise Distributed Object Computing Conference (2001) 118–127

[65] Grails: Grails website. (`http://grails.org/`) Accessed 12 Apr 2014.

[66] Grails: Grails Reference Documentation. (`http://grails.org/doc/latest/guide/spring.html`) Accessed 04 May 2014.

[67] MacKay, D.: Information theory, inference and learning algorithms. (2003) 316 – 322

[68] Sun, Z., Wun, Y.: Multispectral Image Compression Based on Fractal and K-Means Clustering. 2009 First International Conference on Information Science and Engineering (2009) 1341–1344

[69] of Energy, U.D.: EnergyPlus Energy Simulation Software. (`http://apps1.eere.energy.gov/buildings/energyplus`) Accessed 04 May 2014.

[70] Regents, U.: Ptolemy Project. (`http://ptolemy.eecs.berkeley.edu/ptolemyII/`) Accessed 04 May 2014.

[71] Humphreys, M., Nicol, J.: Understanding the adaptive approach to thermal comforts. Volume 14 of ASHRAE Technical Data Bulletin. (1998)