LAPPEENRANTA UNIVERSITY OF TECHNOLOGY

School of Engineering Science

Erasmus Mundus Degree Program - PERCCOM

GreenInn Hotels

Home Automation CodeCamp

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LIST OF SYMBOLS AND ABBREVIATIONS

HM	HomeMatic
RF	Radio Frequency
VR	Virtual Reality

1 INTRODUCTION

Background

Hotel guest rooms account for 40 to 80 percent of energy use in the hospitality industry, with high-end guest rooms consuming 50 to 70 kW and luxury guest rooms consuming more than 80 kW per day [1]. Meanwhile, introducing home automation techniques in a hotel environment represents a niche for increasing energy efficiency of living environment for several reasons. Firstly, the hotel air conditioning and resources supply could be automatically measured and controlled, which has a potential to reduce the hotel's energy consumption. Secondly, the automation advertised in a shared living environment will encourage visitors to act green not only in the hotel, but also incorporate automation ideas into their personal living conditions.

Aims & Objectives

The aim of the project is to pave the way towards a smart hotel industry which cuts costs, is greener and provides comfort and leisure with the technology of the future. In order to reach this goal and create the overall concept of a green hotel with prototyping its part, the following objectives are considered:

1. Identifying short-term goals for implementation through a research of existing technologies.
2. Defining long-term implementation scenarios.
3. Estimating monetary benefits of proposed innovations.
4. Creating a working prototype corresponding to short-term scenarios.
5. Analyzing the technologies use.
6. Drawing conclusions of the work.

Structure of the report

Section 2 of this report contains an overview of the GreenInn concept developed by the group for the purposes of this codecamp. Following that, Section 3 will deal with monetization of the idea behind the GreenInn concept hotel. Section 4 will offer insights into the implementation of our prototype while Section 5 will contain a brief overview of the FHEM home automation server package and its core logic. Section 6 will offer a brief introduction to the EnOcean concept and this work is concluded in Section 7.

2 GREENINN CONCEPT

Concept for the Short-Term Implementation

The short-term goals lie within the scope of one year of implementation efforts and include responsive smart metering and automation systems. Table 2.1 lists main metering systems and automatization perspectives as well as their estimated effect on the system. The short period of their integration is determined by the current presence of such systems in the market. In this context, sources [1-5] give overview of opportunities to increase room and overall hotel energy efficiency. They include ventilation and light adjustment to measurements of room ambience and also provide a user with a chance to make their stay in a living place greener by clicking only one button “Green”, which will think for the user about the energy consumption [2]. Moreover, food and water meters allow hotels make estimations on the amounts of resources they need to acquire monthly and annually and optimize their decisions [6]. Automation technologies are already present in a wide variety, including the drones which fly to the hotel rooms to deliver food for the guests [7].

Table 2.1. *Short-term improvements*

High granularity measurements	Effect
Temperature & humidity	Effective climate control with air conditioning, Heating, Ventilation power
Energy used by a room	Incentivize users to use energy efficiently Calculate the room price for check-out Calculate bonuses for guests and translate them into free bar drinks or similar benefits Translate energy used into CO_2 emissions for green audit
Electrical network load	Advize users to charge their devices at specific times to avoid peak loads
Water use	Calculate the room price for check-out
Food waste	Optimize resources supply
Outdoor light brightness	Shutter control to save lighting energy
Automation	**Effect**
Appliances power control: activate the outlets with guests' phones	Provide guests with an easy way of managing their power consumption of plugged in devices
Lock/unlock the door with smartphones	Guests' comfort & experience, less plastic is consumed if the cards are excluded
Smart elevator recognizing guests' destination	Optimize number of lifts and energy use
Automated assistant present for special orders	Avoid calling, optimize tasks stored in the system queue
Improved parking	Lighting control triggered by motion Customized lighting guidance for the guest to find their parking lot
Shared hybrid/electric cars	Reduce fuel consumption
Facilities activated upon users' presence or query	Efficient energy use (gym is powered on, swimming pool is heated only when visitors choose to come mentioning it in the hotel app
Robotization of simple tasks: cleaning, delivery (food, tea set, towels)	Reduce use of elevators and extra energy

Ideas for the Long-Term Implementation

Long-term results can be achieved upon technological readiness of devices, which are projected to be in place in 5-10 years in the needed amount. The ideas below are partly inspired by the report [8].

Table 2.2. *Long-term improvements*

Optimization	Example	Effect
Virtual reality for travelling	VR use for quick journeys	Reduced carbon footprint, since guests do not use transportation
Sightseeing with a robot	Drone accompanying hotel guests on a walk	Customized sightseeing can reduce the travel expenses, including CO2
3D printing of furniture and clothes with the use of biodegradable materials	Guests do not have to travel with large luggage, they print clothes instead	Reduced cost of travelling
Holographic projection for design purposes	Users can change holographic picture projected on their room setting to any pleasant environment (seaside, mountains)	Less materials are needed for different room designs
Cisco Meraki equipment for network devices	Manage the network of devices with a centralized dashboard	Monitoring energy consumption of the whole network, reducing the cost
Systematic green audit	Independent parties perform audit on the hotel chain and suggest improvements	Optimization of energy consumption
Advanced air sensors	Aromatherapy in the room	Saving space which was previously used for spa
Adjusting room walls	Shaping the suits for number of guests who would like to live together	Reduces construction cost

3 MONETIZATION

This section is dedicated to monetary benefits which can be provided by use of certain technological solutions from the tables in section 2.

Projected savings from incentivization of guests

One part of the GreenInn improvement involves multiple ways of motivating guests to act in a greener way. For example, guests are supposed to get bonuses for effective energy use following the guidelines proposed by advisory system. In addition, the rooms widows will be marked with green colour if low power consumption is registered, and with red for their counterparts.

Estimation of energy and cost savings are based on numbers of hotel rooms characteristic energy consumption made by one of the European hotel chains [9]. It is assumed that energy consumption in a medium hotel room is 715 kWh/m2. The GreenInn adds 5 cents for each kWh of difference between average energy consumption and a room's reduced consumption figure. From the one hand, in this case 10% energy savings will form 3.5 €/h for the most sustainable guests and 71 kWh less energy expense for a hotel. For the guest the savings may be converted to the use of hotel spa or bar special offers.

From the other hand, for a hotel of 1000 rooms with annual average energy consumption of $6200\ GWh = 715\ (kWh) \times 1000 \times (365 \times 24\ (h))$ with energy price of 0.2 €/kWh [10], if at least 50% of rooms follow the energy reduction guidelines, it will result in $6200 \times 0.5 \times 0.2 = 6,200,000,000$ €$/year$. With the estimation of [1] providing a figure of 70 kWh for hotels with smaller rooms, the same calculation will result in $70 \times 1000 \times 365 \times 24 \times 0.5 \times 0.2 = 455,200,000$ €$/year$. It is worth mentioning that the savings will be proportional to the hotel size and energy savings percentage, which is shown with these calculations.

3D-Printing of a Wardrobe

The futuristic scenario contains an idea of 3D-printing of clothes for the guests overnight. This will increase the comfort of users who will not be obliged to take large weighty suitcases while travelling. An idea of having a fresh shirt and a suit for the next-day business meeting may be appealing to those who travel a lot for job purposes. The textile for 3D-printing is being improved nowadays and allow particle decomposition of clothes and material reuse.

The monetary benefit calculation is based on nowadays price which has high probability of being decreased in the next 5-10 years a period of futuristic scenario implementation. One 23 kg bag on an airplane will cost a person around 22 €. It will increase fuel consumption of a plane by around 4,5 € for a 3000 km flight [12]. With the fuel cost ratio (1 litre of fuel costs 0,4 €) from [13] one can conclude that one bag requires $4,5 / 0,4 = 11,25$ extra litres of jet fuel for such a bag.

The same 22 € may be spent on 3D-printing of 5 T-shirts and one suit, if the hotel uses an average desktop printer of 1500 € [14] with average power consumption of 50 W [15] for 7 hours with electricity cost 0,2 €/kWh, with material cost of 2,3 € per meter [16] and its weight 150 g/m^2 [17]. The parameters were input in the online calculator [18-19] with some default assumptions that the printer is active 4 hours a day on average and requires 10% of repair costs.

Virtual Reality Integration: Virtual Travelling

Another futuristic scenario is that of virtual traveling. The technology for virtual reality is something which is constantly being developed. Nowadays we have a lot of devices from various manufacturers such as Samsung and HTC that give users an experience of living in a virtual world and interacting with various objects. The technology already available is pretty advanced but it has a lot of potential to grow in the future. And one of its use cases can be the hotel/leisure sector.

Traveling and seeing the world is a hobby taken up by many people. They go around all over the globe to experience the sights and structures human civilization has to offer. But all of this comes at a cost. The fuel consumed by the transportation industry is one of the leading causes of carbon emissions. In order to pave the way towards a more sustainable future, something needs to be done about this. And that is where virtual travel can play its part.

While there cannot be an alternative to traveling and its experience for some of the enthusiasts, most of the people do not have the time or resources to accomplish it. Consider, as an example, someone who is on a business trip and does not have time to spare to go around the city to see the sights. If they decide to prolong their trip to travel, it would cost more and the transportation would certainly add to the already excessive emissions. In such a scenario, the opportunity to enjoy a virtual traveling experience at the hotel would certainly add to the enjoyment of the users without costing them time in working hours and also allow them to be sustainable.

In order to highlight the savings in terms of carbon emissions enabled by virtual travel, consider the following scenario of a person arriving in Paris for a week for a business trip. At the end of their trip they decide to take a day off to see the city. They rent a car, a Renault Clio 1.2cc automatic (most popular car in France, 2017) and drive around for a distance of 10 kilometers. The emissions for this specific car amount to 137 grams of CO2 per kilometer [24]. Hence the total emissions for a one day travel around the city of paris for this person would be 1.37 kilograms of CO2.

Now consider the alternative of a virtual reality system that the same person can use at the end of the working day when they come back to their hotel room. Consider that the VR equipment used is an HTC Vive virtual reality headset, which is the most popular VR device currently in market, with a PC supporting a GTX 1060 GPU for running the simulations. The power consumption for the headset is 5.9W at maximum load [25]. And the maximum power supply unit (PSU) required for the PC is 750W. The total power consumption of the whole system is 756 W. Considering the person uses the system for an hour at the end of each day for five days, the total energy consumed by the system is 3.78 kWh. In order to calculate the emissions we use the conversion factor for France which is 0.056 [26]. Hence the total CO2 emissions for 5 hour use of this system are 211 grams or 0.211 kilograms. Hence there is 85% reduction in the CO2 emissions as compared to the case of actual travel.

Keep in mind that a laptop with considerably less power consumption and efficient GPU can be used instead of a PC. And the VR device i.e. HTC Vive considered in this scenario is a considerably cheaper one with a cost of approximately 600 euros. There is a high probability of more efficient and cheaper VR devices to be developed in the future. Hence, virtual traveling could be the next big alternative for cheap and sustainable entertainment and could be one of the main attractions offered by a smart hotel such as the GreenInn.

4 IMPLEMENTATION

In this section several ideas from the short-term scenario of technologies integration will be described.

Implementation Scenario 1

Temperature & Humidity Sensor , Philips Hue Iris Light, HomeMatic Switch Actuator (connecting a simple FAN for cooling/ventilation).

4.1.1 Scenario Definition

Hotel Automation technology will be present in every room of the hotel. Each bathroom of the hotel will have an automated ventilation system and a temperature and humidity sensor. Moreover, the hotel will possess a control room which will have leds that will represent the current state of each guests' bathroom in terms of room humidity. In our case, the Philips Hue Iris Light will represent the led in the control room. If the temperature or humidity surpass a certain threshold, the automated ventilation system will be triggered, and the corresponding change will be triggered to the respective led of the hotel's control room as well.

4.1.2 Philips Equipment Configuration

4.1.2.1 Pairing Philips Hue Bridge with Philips Iris Light

First, you connect the Philips Hue Bridge and Iris Light into the same network. You wait approximately 5 minutes for all the lights of the Hue Bridge to be active. Then, you connect to the same wireless network with your smartphone using the mobile app HUE. Within the mobile app, search for HUE Bridges, and after it has detected it, touch "set up" button. Immediately after, click the round button in the Phillips bridge to link it with your smartphone. If it is properly paired, then you should be able to see the information in Figure 4.1.

Subsequently, with the mobile application within the Bridge Menu, touch on "+" sign in the "Light Settings" Menu. Then, touch on "Search" and wait for a few seconds, and then you will be able to find Philips Hue Lights in the network. Now, on the Home menu, you can control on or off, change color, choose a color loop, or choose the lamp mode as shown in Figure 4.3 If you have managed to control the lights from your smartphone, then you have confirmed that there’s connectivity between the Philips Hue Bridge and the Philips Hue Iris.

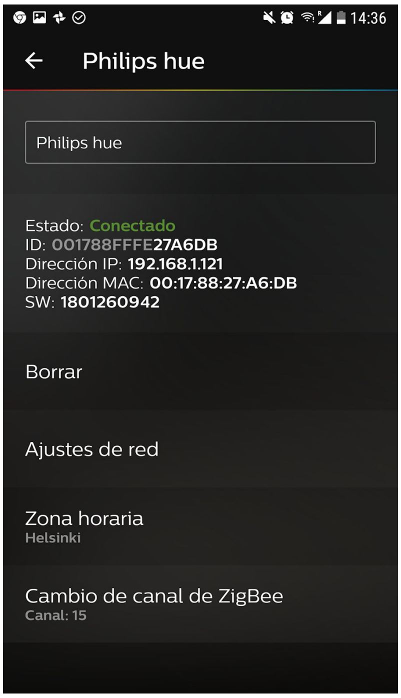


Figure 4.1

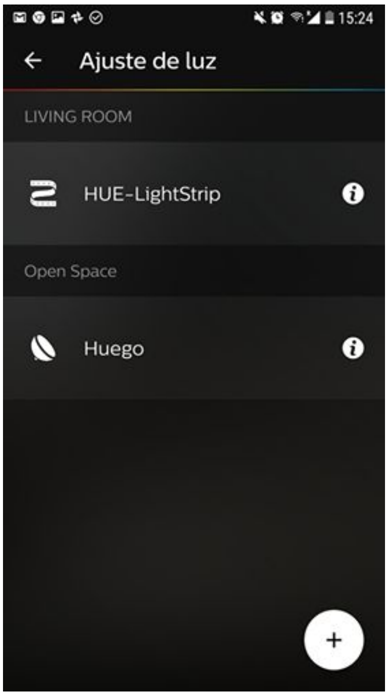


Figure 4.2

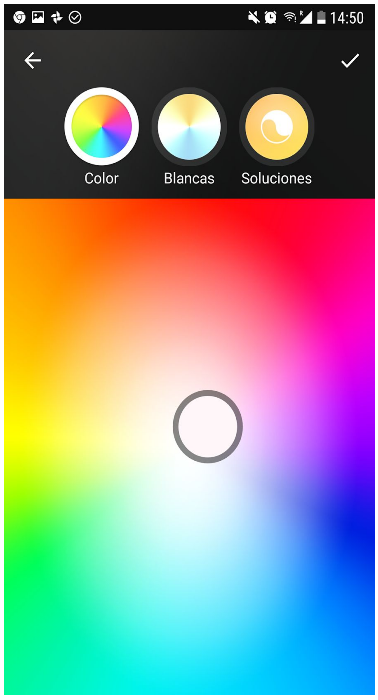


Figure 4.3

4.1.2.2 Pairing FHEM Server with Hue Bridge

After you have validated the connection between the Philips equipment, then now it’s time to provide it connectivity with the FHEM Server. First, you define the HUE Bridge in the FHEM server with the following command:

> define *PhilipsBridge* HUEBridge 192.168.1.141

Subsequently, you should see a device “Philips Device” in the unsorted list. Click on it, and in order to be fully connected with the bridge execute the following set command, as shown below and on Figure 4.4.

set *PhilipsBridge* active

After successfully connecting with the Philips Bridge, it's time to connect with the philips smart lights. You will have to execute the following set commands as shown below, and in Figure 4.4

set *PhilipsBridge* autodetect

set *PhilipsBridge* autocreate

Now, you should be able to execute a complex set of instructions from the FHEM server to the smart lights using the philips bridge as an intermediary. Figure 4.5 shows some simple commands you can directly command to the Hue Lights.

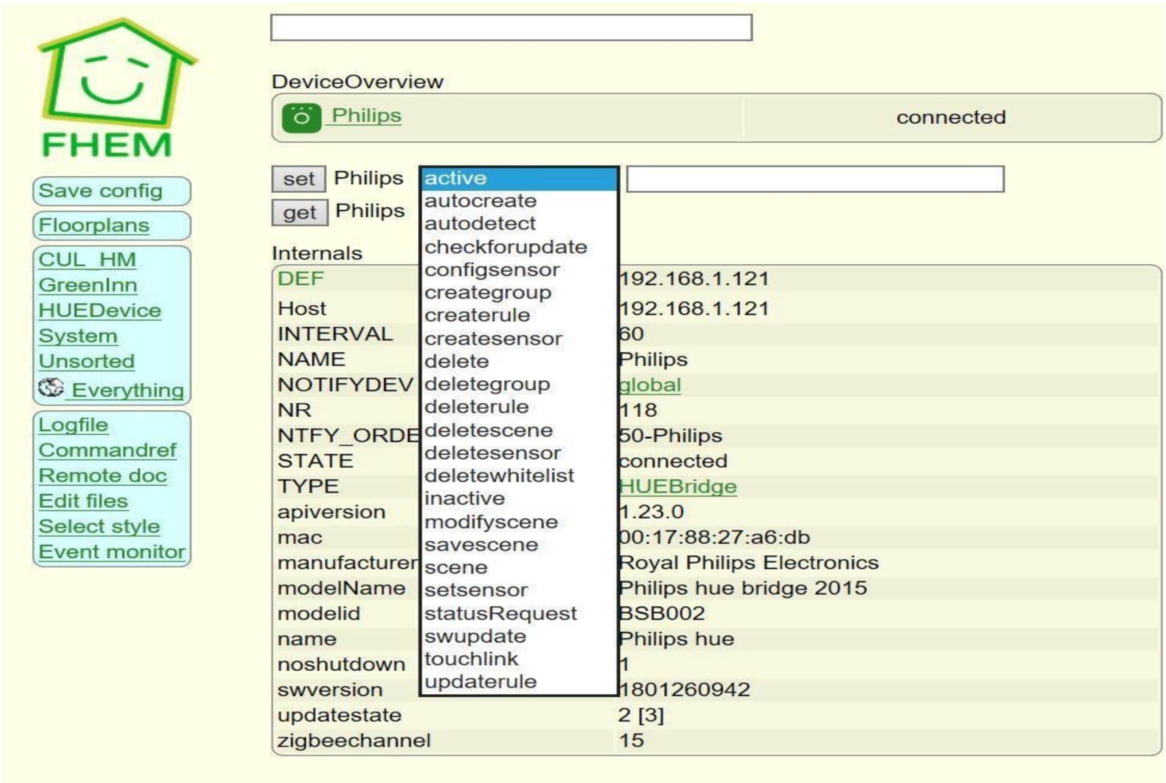


Figure 4.4

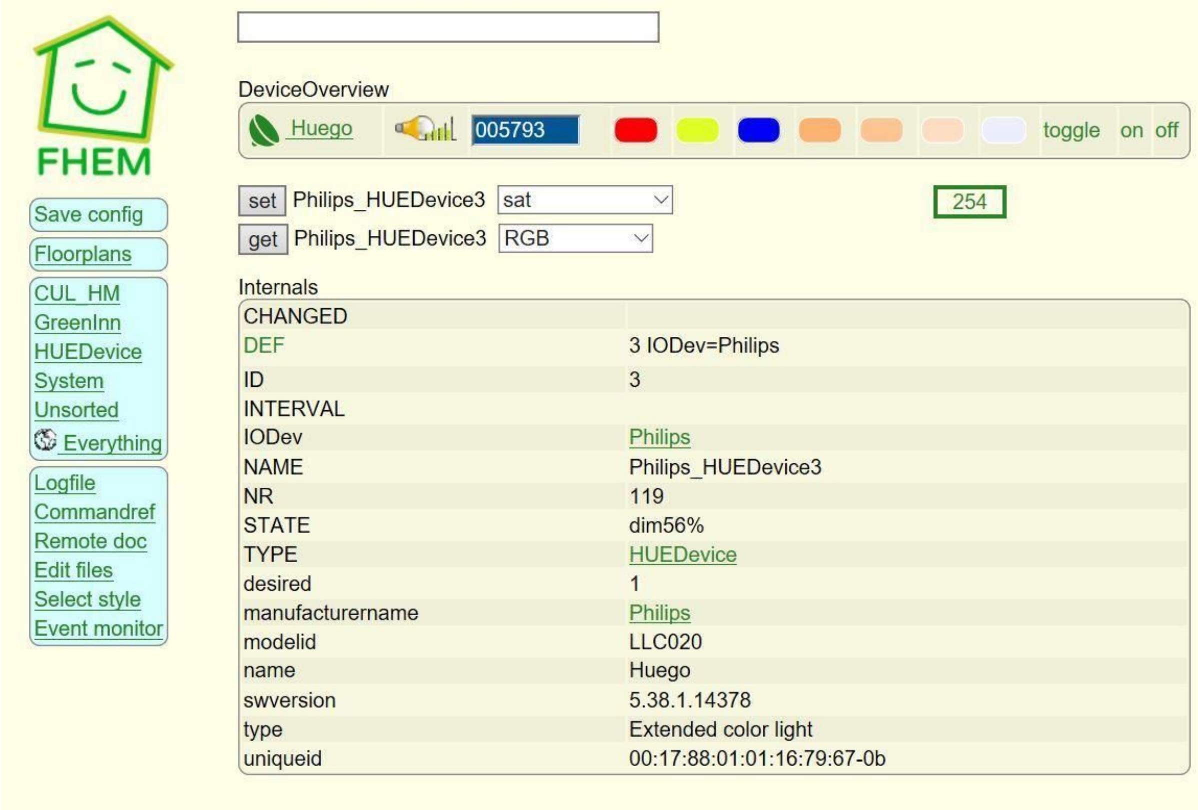


Figure 4.5

4.1.3 HomeMatic Wireless Switch Actuator Configuration

In order to cool the bathroom when the temperature or humidity are not at appropriate levels, it is necessary to use HomeMatic Wireless Switch Actuator to power on/off the fan. To pair the wireless switch actuator, it is necessary to change the RF mode of the FHEM server's air interface to Home Matic 843 MHZ as shown in Figure 4.6. Afterwards, you must change set HMPairForSec for a specific amount of seconds in order for the FHEM Server to listen for HomeMatic messages from the nearby HomeMatic devices.This is shown in Figure 4.6.

```
attr CSM rfmode HomeMatic
set CSM HMPairForSec 360
```

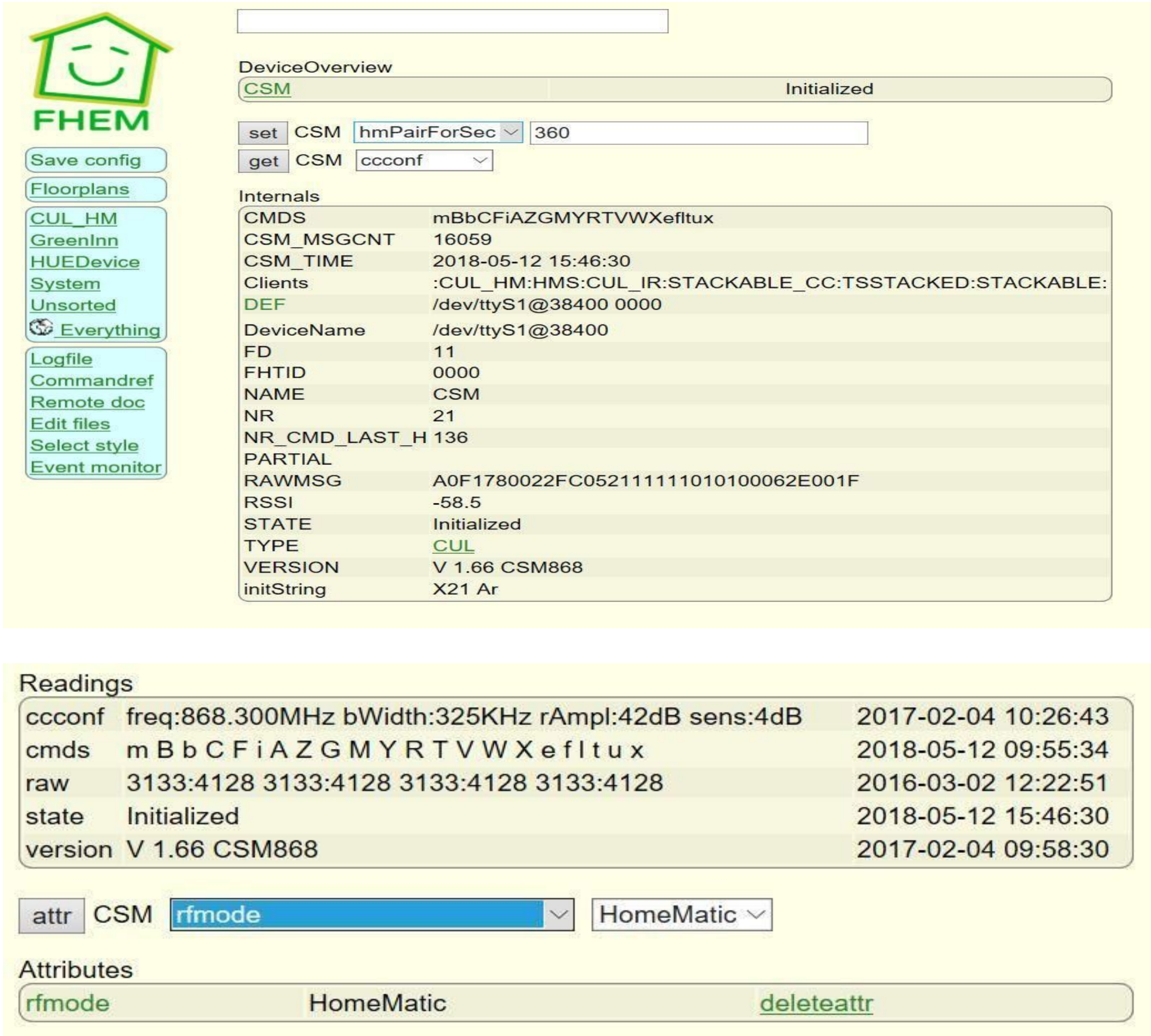


Figure 4.6

After you have set the FHEM server to listen HomeMatic protocol messages, click on the pairing button on the HomeMatic device. This information may be found on the respective device's manual. Generally, this process is done to pair all HomeMatic devices. Best case scenario, the HomeMatic devices will be paired. When the device is successfully paired, you should be able to control the wireless switch from the FHEM server.

4.1.4 HomeMatic Temperature & Humidity Sensor - HM-WDS40-TH-I-2 Configuration

To pair the temperature and humidity sensor the procedure explained in the previous section is used since it's a HomeMatic device. Subsequently, you should be able to see temperature and humidity readings from the Unsorted section in the FHEM server.

4.1.5 Scenario Coding

After all the devices in the present scenario are paired, it is time to code the logic that will trigger the actuators. In order to do that, it is necessary to create a notification that turns the Iris light green and then turns on the fan on the bathroom. First, a generic notification is created using the following syntax:

```
define  <name> notify <name> <command>
```

Then, clicking on DEF will give you the ability to modify the logic behind the trigger. This is the code used for this trigger:

```
HM_341B72 {
    my $temp = ReadingsVal("HM_341B72","temperature",0);
    my $humi = ReadingsVal("HM_341B72","humidity",0);
    if ($temp > 27 or $humi > 35) {
        fhem "set HM_3F88A7 on";
        fhem "set Philips_HUEDevice3 hue 65324";
    } else {
        fhem "set HM_3F88A7 off";
        fhem "set Philips_HUEDevice3 hue 37243";
    }
}
```

Implementation Scenario 2

Philips Hue LightStrip , Three-State Door Sensor, Resource Usage Signaling - A

4.1.6 Scenario Definition

The hotel automation technology will manage to influence user's behavior. Sensors and actuators will be embedded throughout the guests' rooms in the hotel and will be able to provide resource accounting at a user level. Each guest will have a Philips Hue Lightstrip outside of their respective room. These lights will change color depending on the amount of resources , i.e. energy, water, etc…, the guests have used. The light strip will display green, if they maintained an acceptable level of resource consumption, red, if they surpassed their allocated resources for the day. People outside of the hotel will be able to see whether the guests of GreenInn are being resource efficient (i.e. green) or not. If the green light is maintained during the whole day, guests will be able to gain "carbon" bonuses that can be exchanged for drinks and food. Moreover, this same idea could be applied at a hotel level. The different branches of the hotel chain will be able to compare their resource consumption with other branches….

4.1.7 Philips Hue LightStrip Configuration

These device's configuration can be found on the previous section. The procedure is the same as the Philips Iris Hue light.

4.1.8 HomeMatic Three-State Door Sensor Configuration:

The configuration of this device is explained in the previous section. The procedure is the same as any other HomeMatic device. It differs on the placement of the button on the HomeMatic device as such.

4.1.9 Scenario Coding

ConsumptionAlarmOff

```
HM_30EA82:closed set HUEDevice4 hue 0
```

ConsumptionAlarmOn

```
HM_30EA82:closed set HUEDevice4 hue 19852
```

5 FHEM OVERVIEW

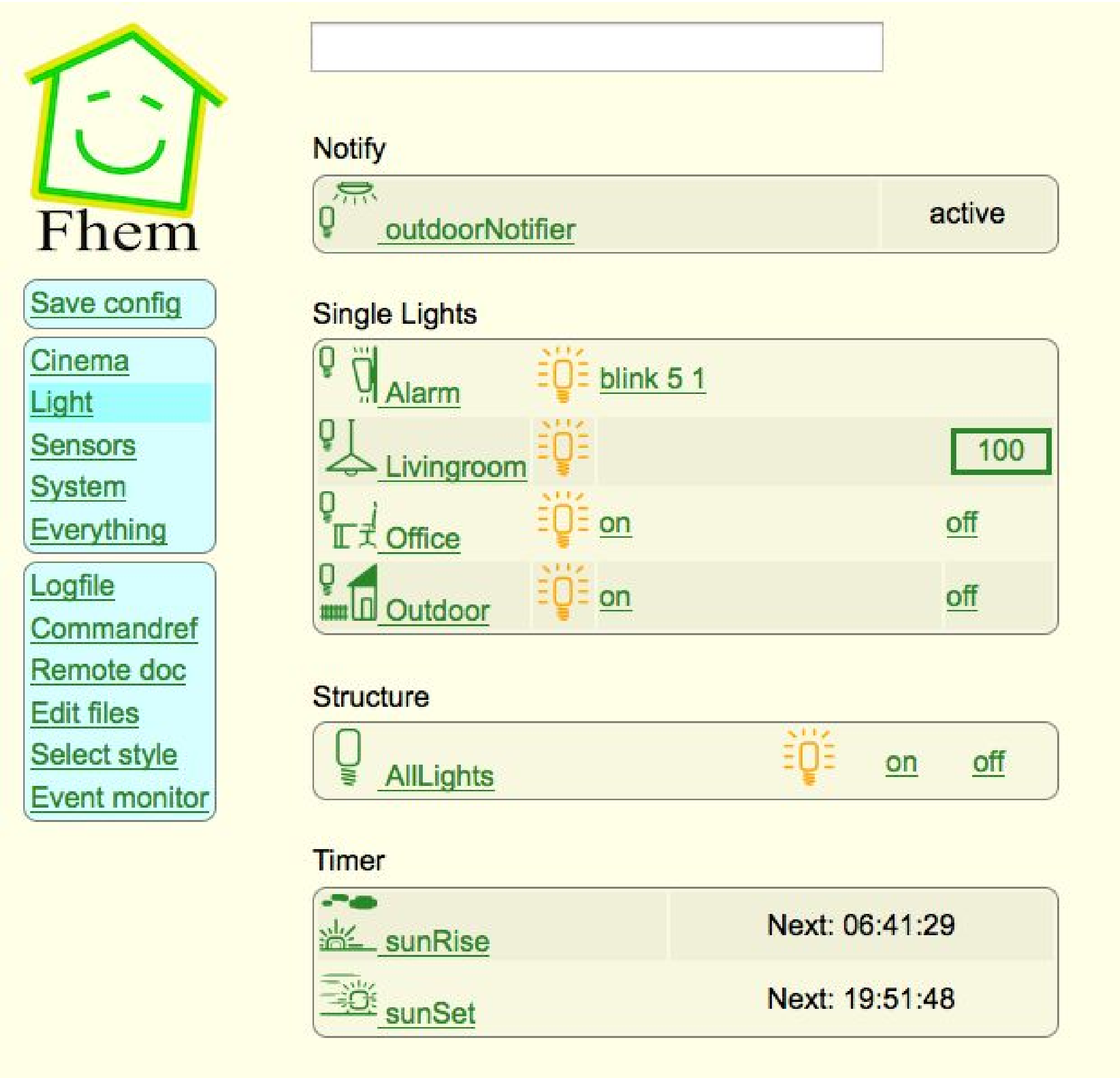
In this project we were introduced to the FHEM home automation server. It is an open source server implementation written in PERL for the purpose of integrating various home automation and IoT protocols and hardware to enable interoperability and integration.

FHEM itself originates from Germany, which is probably not surprising, given the fact that Germany is probably the biggest and most advanced market in the world for home automation products and projects.

The main use-case for FHEM is home automation, but it can enable various other scenarios as well. Currently there is a growing collection of modules that support various communication protocols and make the integration of these possible.

Modules are maintained by contributors and the FHEM forum is a great place to find additional help if one is stuck with some problem. The only drawback is that the forum is mainly in german, but the official documentation is well maintained and in English.

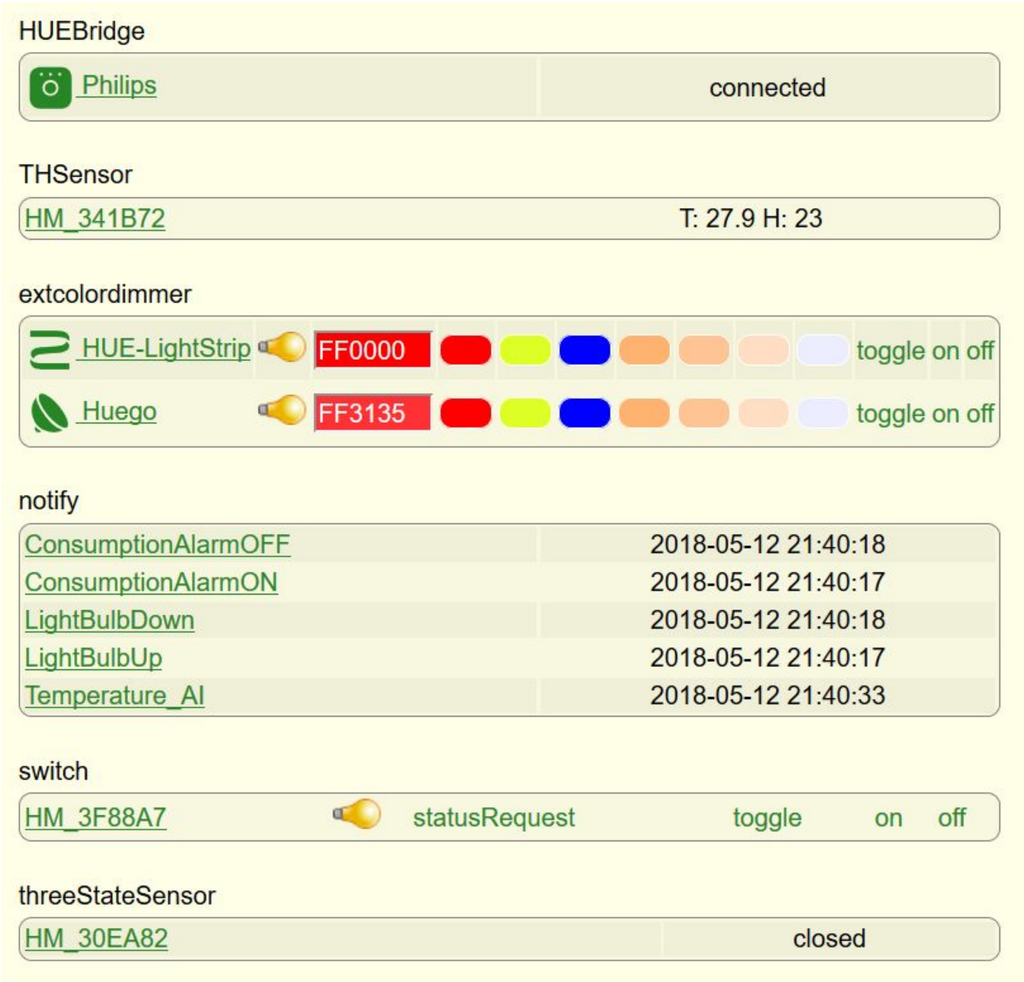
FHEM can connect sensors of different kind from various vendors using various protocols and tie them together with events that get triggered and define some action to execute on the actuators.



After installation, FHEM can be configured most conveniently through its web interface, which looks something like the below picture. In the top text-bar, commands can be entered which will be executed immediately and added to the config. To save the configuration to long-term storage (survives reboot) the "Save Config" button needs to be clicked regularly.

The left side contains 3 different panes. The middle one contains devices that are discovered via the installed HW and protocol modules and can be arranged into groups or left unsorted (not recommended for bigger projects).

For our GreenInn project we created a section called GreenInn in the middle section of the left pane and added all our sensors and actuators there for easier access. The actual sensors and actuators can be seen on the below picture.



The main logic is defined in the “Notify” constructs which run as part of an infinite loop in the PERL server. At the basic level, it is big collection of “if-then” constructs which enable the logic for automating various things and scenarios around the home.

Our FHEM server was running on a small linux machine provided by Prof. Drögehorn, which had pre-installed antenna modules and the FHEM server itself. We configured it to run with HomeMatic protocol and paired it with various home-matic devices.

Our experience with FHEM during these 4 days was that it is a platform with some challenges, but if one has dedication and is prepared to make an effort, the hurdles can be overcome and quite complex scenarios can be built for home-automation projects. Of course there were occasional hiccups, for example during the pairing process, and we had to go through the manual for every client device (sometimes only written in German), but in the end we managed quite well and implemented a small part of the GreenInn concept by the end of the week.

6 PROTOCOL: ENOCEAN

EnOcean is a wireless technology used for building and home automation. This technology is in use to make wireless sensors, gateways and other devices used in smart home systems. It is one of the technologies which are the most convenient to use and are increasing in popularity. This technology has three main features:

1. **Energy Harvesting:** This wireless technology is based on the concept of energy harvesting. The devices manufactured using this technology are battery less and do not need electrical power to function. Instead, they derive energy from their surroundings using physical phenomenon as a power source. Some of these phenomenon include motion, light and temperature. The devices are manufactured with micro energy converters to convert these physical energy sources to produce wireless signals.
2. **Ultra-Low Power Management:** The second important feature of EnOcean technology is its extremely low and efficient power management. In idle mode, the EnOcean devices conserve power. This is necessary as the power only comes through energy harvesting. Energy harvesting techniques provide very small amounts of energy and it is necessary for such devices to accumulate it overtime and not waste it. This is one of the main reasons the technology is based on power conservation. In the latest generation of EnOcean sensors the idle state current is only 100nA.
3. **Low Power Wireless Communication:** EnOcean combines energy harvesting and low power management with efficient and low power radio technology. With such a small amount of input energy, it is important for devices to not lose too much energy because of the radio transmission. As wireless communication is the fundamental part of automation services, EnOcean enables highly efficient and low powered communications. With a signal power as low as 50µW, a signal can be transmitted up to 30 meters indoors using an EnOcean device.

A Brief History

EnOcean technology was developed by a company which started as a spin off of Siemens and was founded in 2001. Since then, EnOcean has developed into a leading technology for home automation systems and has manufactured various devices including wireless sensors.

EnOcean Alliance

After the establishment of the technology there was a need to further promote it. A number of devices were being manufactured by different manufacturers and the technology was open source so a big community was adding to its development. In order to further promote it a group of companies including EnOcean, Texas Instruments, Omnio, Sylvania, Masco, and MK Electric formed the EnOcean Alliance in April 2008 as a non-profit, mutual benefit corporation. The purpose of this alliance was to create interoperability among the devices and standards built by different manufacturers. Working towards this goal, the EnOcean alliance successfully standardized the technology and it was ratified as international standard ISO/IEC 14543-3-10 in 2012. Currently the EnOcean alliance has more than 250 members including various well known companies and is based in San Ramon, California.

The EnOcean Standard

In order to produce a variety of products and to make them interoperable, the EnOcean standard was developed and later ratified as an ISO standard. This standard is built on top of the common OSI model and covers the first three layers of the OSI model. Higher layers of the OSI model are not covered as these are device specific. However, the EnOcean alliance specifies various application level protocols called the EnOcean Equipment Profiles (EEP's). Together with the three lower layers specified in the standard, the EEP's allow a fully interoperable open wireless technology.

ENOCEAN LAYER ARCHITECTURE			
LAYER	DATA ELEMENT	DETAILS	STANDARD
7. Application	Data		Not in standard
6. Presentation	Data		Not in standard
5. Session	Data		Not in standard
4. Transport	Segment		Not in standard
3. Network	Packet	Sub Telegram Timing, Media Access CSMA-CA (LBT)	Defined in standard
2. Data link	Frame	Sub-Telegram structure, Hash Algorithms, Header Compression	Defined in standard
1. Physical	Bit	Frequency, Modulation, Preamble, Sync, Coding, Length	Defined in standard

Technical Details

One of the advantages of EnOcean is that it uses a very simple radio transmission system with low power of transmissions and low levels of processing. This leads to much more efficient performance.

6.1.1 Modulation

The EnOcean radio interface uses GFSK: Gaussian Frequency Shift Keying. Frequency Shift Keying is a type of modulation where the signal frequency is changed between two frequencies. For and EnOcean radio signal the sift is ±62.5kHz of the central carrier position. The +62.5 kHz position is for the code used to indicate logical "1" and the -62.5 kHz position is the code used to indicate a logical "0".

As with any signal, sidebands spread out either side when modulation is applied. In the case of a frequency shift keyed signal with sharp switching edges, sidebands could spread out over a wide bandwidth and therefore the signal is filtered at the transmitter to ensure only a narrow bandwidth is occupied. A Gaussian filter is used for this - hence the name Gaussian Filtered Frequency Shift Keying, GFSK.

ENOCEAN PHYSICAL LAYER PARAMETERS SUMMARY				
PARAMETER	MINIMUM	VALUE	MAXIMUM	UNIT
Frequency error	-18		+18	kHz
Modulation		FSK		
Frequency deviation	±55.0	±62.5	±70.0	kHz
Data rate		125		kbps
Data rate tolerance	-30		+30	ppm
PA ramp on time			40	μs
PA ramp off time			40	μs
Coding		NRZ		
Code for 1		+62.5		kHz
Code for 0		-62.5		kHz

6.1.2 Frequencies

The frequency ranges in which the EnOcean transmission is carried out are specified in the standard. These are 868 MHz for Europe and China, 902 MHz for North America and 928 MHz for Japan.

6.1.3 EnOcean Radio Protocol

The EnOcean Radio Protocol defines the way in which data is exchanged between devices using EnOcean technology. This protocol covers several layers of the OSI model to ensure correct and reliable delivery of data. The protocol is setup in such a way that it ensures the data is transmitted correctly but also with low power as the devices only use energy produced by energy harvesting techniques. The key areas for the EnOcean Radio Protocol are the data link and network layers.

6.1.4 Data unit description

The EnOcean radio protocol is a packet based protocol and depending upon OSI model layer, the data units can be of three different types:

1. **Frame:** A frame is the format of the physical layer encoding. The EnOcean frame includes control and synchronization information for the receiver. A frame is transmitted as a bit by bit serial sequence and has a distinct structure to enable the receiver to be able to receive and decode it correctly.

There are several sections within each EnOcean frame.

- **Preamble:** At the beginning of each EnOcean frame there is a preamble. This is used for bit synchronization and the generation of the data slicing thresholds.
- **Synchronisation Word:** A synchronisation word follows the preamble and this enables the receiver to synchronize to the data bytes.
- **Length:** The first byte transmitted after the synchronization word indicates the length of the data payload, **Data_PL**. Its value is the number of the bytes transmitted in the **Data_PL**.
- **Data Payload:** The data payload, Data_PL is transmitted after the length byte, and the end of the data is the end of the frame.

The length information and the data payload, Data_PL are transferred to the Data Link Layer up from the Physical Layer as defined by the EnOcean Radio Protocol. Vice versa the Length followed by the Data_PL, have to be transferred from the upper lying Data Link Layer.

ENOCEAN PROTOCOL FRAME PARAMETERS	
PARAMETER	VALUE
Endianness	The MSB is transmitted first, i.e. Big-Endian.
Preamble	16 bit 0b1010101010101010 (0xAAAA)
Synchronisation word	16 bit 0b1010100100111100 (0xA93C)
Length	1st Byte after the synchronisation word contains the number of data bytes to be transmitted
Data_PL	The data payload: the bytes containing the data for transmission,
Minimum number of data bytes	1
Maximum number of data bytes	255

2. **Subtelegram:** The EnOcean subtelegrams are the part of the protocol that are handled in the data link layer. This part gives the data being handled at the higher layers. To achieve the required performance, the ERP protocol is designed to work mostly as a unidirectional protocol without handshaking. This considerably reduces the amount of data needed to be transmitted in a basic subtelegram. However, to ensure transmission reliability, three identical subtelegrams are transmitted within a certain time range. Each transmitted subtelegram is a unit and contains all the information required.

There are several fields that are contained within the EnOcean subtelegram. The EnOcean radio protocol defines them as the following:

- **RORG/CHOICE:** This element of the subtelegram identifies the subtelegram type.
- **DATA:** This is the payload of the transmitted subtelegram.
- **TXID/SourceID:** This element of the subtelegram used within the EnOcean protocol identifies the transmitter, each having a unique 4 byte identity.
- **STATUS:** This identifies if the subtelegram is transmitted from a repeater and the type of integrity control mechanism used. This field is not present in a switch telegram.
- **HASH/Checksum:** This is used to check the data integrity. It is a check value of all the bytes.

The length of the subtelegram is not transmitted in the subtelegram structure. The length is determined by counting the number of bytes starting with RORG and ending with HASH.

3. **Telegram:** The telegram is used as a data format for the network layer.

ENOCEAN RADIO PROTOCOL PROTOCOL LAYERS		
LAYER	SERVICE ADDRESSED	DATA UNITS
7. Application (API)	EnOcean Equipment Profiles (EEP); RPC/RMCC handling	Data
6. Presentation	Radio Telegram Processing; Encryption	Data
5. Session	Not used	
4. Transport	Smart Ack; Remote Management	Telegram / message
3. Network	Addressing telegrams; (ADT Encapsulation/Decapsulation); Switch telegram conversion; (choice/status processing); Repeating (status processing)	Telegram
2. Data link	Subtelegram Structure; Control Sum Calculation Subtelegram; Timing; Listen before talk	Sub-Telegram
1. Physical	Encoding/Decoding (inverse bits) Radio reception/transmission	Bits; frame

6.1.5 Software Automation

EnOcean is newly supported by FHEM software suite which can be used to automate common tasks in households and buildings. FHEM runs as a server which can be controlled via a software front end.

CONCLUSION

Automation and granular measurements applied to a hotel following the GreenInn concept has been shown in the present report to result in certain cost savings for the hotel as well as increase the comfort level of guests. Suggested improvements were divided into two scenarios based on the time of their possible realization: short-term and futuristic ones. This report includes estimations on monetary savings from the short-term scenario when guests are encouraged to reduce their energy consumption by 10%. They are followed by approximate savings from 3D-printing of clothes and virtual travelling. Implementation covers parts of the short-term scenarios and includes automated air ventilation and visualization of power consumption rate of the room for psychological persuasion of guests to follow efficient rules of power consumption. The report also reveals the group's perception of the work with FHEM and EnOcean protocol overview. The GreenInn concept does not yet include optimization of swimming pools energy consumption or of towel cleaning. Nevertheless, it contains an overview of technologies that are advanced and currently in place in some of the hotels as well as futuristic ideas of pervasive technologies to be placed within hotel premises.

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