A home automation system using EnOcean wireless technology and Beckhoff Automation

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ABSTRACT

Energy renovation of existing old detached houses and designing a new home automation system for them induce a huge potential for energy efficiency increase in Northern European countries. In Finland, there are more than a million of such wooden traditional houses, which could make a vast energy saving in general.

This paper is a follow-up of the research work, which focused on energy renovation of an old, wood-framed, and poorly insulated house in Finland. Having a mindset that the house was fully refurbished, this project targeted to level up the plus energy concept and to bring in a smart home system. After having completed a profound analysis of the current energy situation of the house and reviewed literature concerning the common technologies, the hardware and software elements for this project were selected. The Beckhoff Automation was chosen to be a base framework of the system, whereas EnOcean's wireless technology acted as a main device.

The focus of the system fell on the lighting control since it had a capability for great energy savings and was easy to handle. The project resulted in a small home automation prototype with a visualization board for a user.

Keywords Beckhoff, Energy efficiency, EnOcean, Lighting control, Smart Home

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LIST OF ABBREVIATIONS

ARIB	Association of Radio Industries and Businesses
ASK	Amplitude Shift Keying
BACnet	Building Automation and Control network
CO_2	Carbon Dioxide
CFR	Code of Federal Regulations
CNC	Computer Numerical Control
DALI	Digital Addressable Lighting Interface
DC	Direct Current
DECT	Digitally Enhanced Cordless Telecommunications
DMX	Digital MultipleX
EEP	EnOcean Equipment Profile
EIB/KNX	European Installation Bus/Konnex
EIRP	Effective Isotropic Radiated Power
EN	European Norm
EU	European Union
FCC/IC	Federal Communications Commission/Industry Canada
FSK	Frequency Shift Keying
HVAC	Heating, Ventilation, Air Conditioning
IEEE	Institute of Electrical and Electronics Engineers
ISO/IEC	International Organization for Standardization and International Electrotechnical Commission
LED	Light Emitting Diode
LON	Local Operating Network
M-bus	Meter-bus
MCI	Media Control Interface
MODBUS	Modicon Bus
MP-bus	Multi Point - bus
MVHR	Mechanical Ventilation system with a Heat Recovery
NC	Network Computing
OPC UA	Open Platform Communications Unified Architecture
OSI	Open Systems Interconnection
PLC	Programmable Logic Controller
PMR	Personal Mobile Radio
PV	Photovoltaic
P2P	Peer to Peer
R&TTE	Radio and telecommunications terminal equipment
RF	Radio Frequency
SCADA	Supervisory Control and Data Acquisition
SMI	Standard Motor Interface
TCP/IP	Transmission Control Protocol / Internet Protocol
UDP	User Datagram Protocol
WLAN	Wireless Local Area Network

1 INTRODUCTION

Today's futuristic world of technology highlights the importance of automating as many things as possible to ameliorate an everyday life quality. The greatest example of emerging automation system variety is Home Automation, also known as domotics (from Latin word "domus", house). The main idea of such houses is a utilization of computers, information technology, electrotechnics and electronics to control home appliances and features with the help of various control systems (Easydom, 2019). That makes the home "smart". In smart home, home appliances are used only if they are needed and if energy is cheap at this time. The home automation systems are applied for controlling lights, heat, ventilation, air conditioning system, door entry and security cases, as well as electronic home appliances by using smart home automation systems, which consist of various modules (Agarwal, n.d.).

Devices are connected to a network and interact with each other to manage various tasks. The user can control devices all over the house from a central location, for example a touch terminal, personal computer, or remotely via a smartphone. Such systems can vary in complexity level. It can be a simple lighting control via your mobile phone or an intricate microcontroller-based smart home structure with infinite competences to use. By virtue of the assimilation of modern technologies with building structures, it is possible to establish a strong communication between them, which would result in many great assets, such as energy savings, comfort, and safety. So far, automation of a building was mainly used for industrial and public buildings, but although home automation is a relatively new occurrence, it is becoming widely used among users who seek for engaging automation solutions into their daily lives, as the concept of smart homes is getting more and more efficient and available (Hicks, 2019).

This chapter contains information regarding the project background, aims to be achieved, as well as a motivation behind the work. In addition to that, the project methodology is discussed and outlined to show what kind of research methods were selected to accomplish the project targets. Research questions are also described in this chapter.

1.1 Project background

This project is a follow-up of pilot study on the energy renovation of an old detached house in Finland. The project was executed under the course "Specialization 1: Building energy design" at University of Applied Sciences Wien Technikum and focused on refurbishing the case study house by:

i. Improving the building envelope, thus reducing heat losses.

ii. Introducing a brand-new mechanical ventilation system with heat recovery.
iii. Supplying the energy demand for hot water and heating with solar thermal collectors, a pellet furnace, and active energy gain via Photovoltaic for electricity.

As a case study, an old, wood-framed, and poorly insulated house, built in 1954, and located in Valkeakoski, Central Finland was examined under this project. Innovative home automation systems are also a part of energy efficiency-oriented buildings; however, due to the project scope's limitations, nothing concerning this issue was done here. Therefore, this project was focused on examining existing smart home systems and designing a prototype of a home automation system with focus on lighting control for the above-discussed case study house.

The parts with planning, researching, building hardware design, and writing the software were carried out at UAS Wien Technikum in Austria, whereas testing with already built-in hardware and finalizing sections were completed at the home university in Finland.

1.2 **Project objectives**

Once again, home automation is not a super recent technology, but there are inventions and concepts created regularly. For instance, wireless data transmission, which has become a thing among building owners only recently, can be considered as an innovative solution. There have been many discussions about positive and negative sides of wired and wireless systems, but since wireless technology seems to be more relevant nowadays, and receives a lot of successful outcomes, it was decided to examine wireless systems in this project. Therefore, the purpose of this project was to come up with a concept for a simple and cost-efficient home automation system for the case study house by implementing wireless technology. The system should meet the following major requirements: energy efficiency, comfort, flexibility, low installation costs, low maintenance costs, a simple configuration, and easy expandability. The focal point of the system was lighting control, as it is the essential part of any smart home projects.

1.3 **Motivation behind project**

There are many reasons why it is important to renovate old houses and incorporate home automation system in the refurbishment procedure. An energy renovation of such houses entails a great potential for the development of energy efficiency concept in general. In Finland, there are more than a million old wooden traditional houses, which are no longer in line with the current energy standards in Europe. According to the European Union's (EU) 2020 Energy strategy, the EU targets these three

aspirations: to reduce the greenhouse gas emissions in the EU by at least 20%, to increase the share of renewable energy to at least 20% of consumption, and to achieve energy savings of 20% or more (European Commission, 2008). A plus-energy concept building, which generates more energy than it needs for heating, preparation of hot water, and electricity, has a capability to cover all of the above mentioned targets; and thus, it is of a high importance how the refurbishment of existing house is designed and executed. Plus-energy houses in general make an active contribution to the issues of energy efficiency, climate protection and fossil fuel dependency, along with economical and living comfort-related advantages for an owner. The author personally feels an urge to address this issue, since a promiscuous use of energy is a matter to be amended and to be aware of.

1.4 **Project methodology**

In order to accomplish project goals, the project methodology was determined. It consists of four key procedures, which include scrutinizing available data, applying calculation files, designing the optimized system, and setting feedback about the project results. More information in details is given in Figure 1:

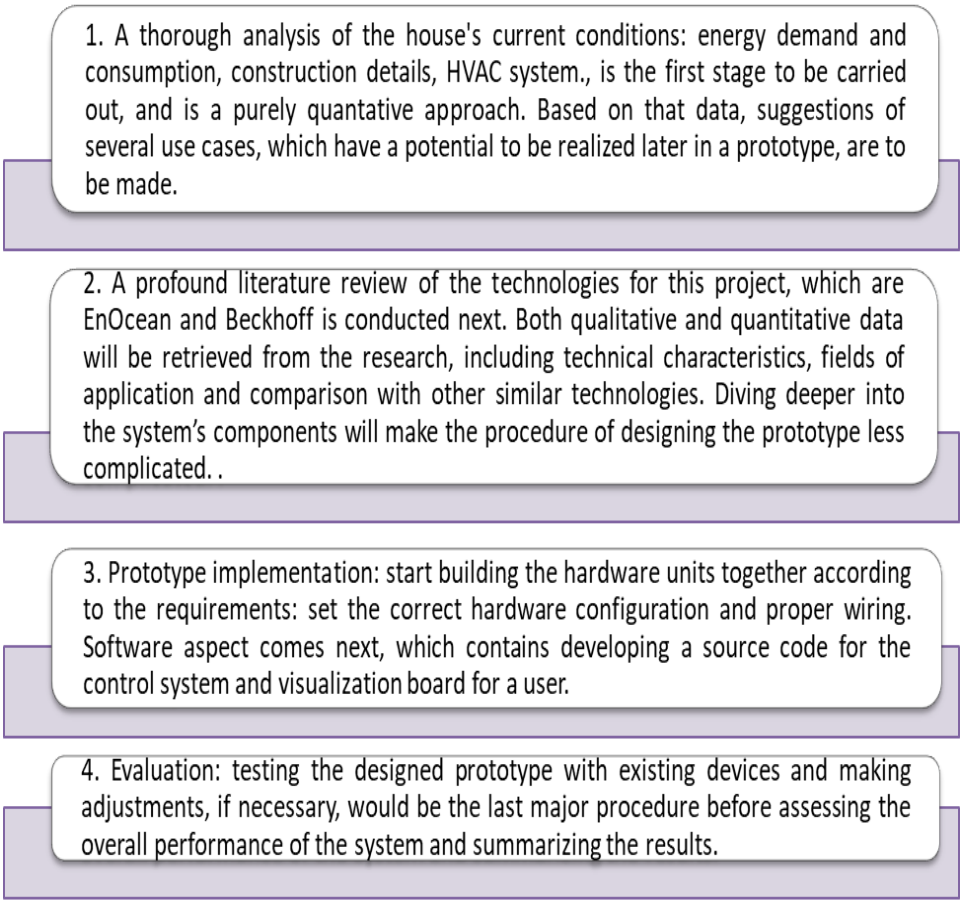


Figure 1. Project methodology

1.5 Research questions

A plus-energy house with home automation system of its own is not a conventional phenomenon in Finland because of the country's relatively severe climate conditions and the high cost of technologies and services for smart home buildings. In most of the cases, the renovations of buildings achieve only very low energy or passive house requirements. Having that piece of information on mind, the following research questions were outlined:

1. What are the highlights of a home automation system for a plus-energy concept house peculiarly in Finland?
2. How to maintain the project scope without heavy constructions?
3. What would be the estimated cost of a designed prototype?
4. Is it possible to integrate other existing home automation technologies into the system and expand its intelligence capabilities?

2 CASE STUDY HOUSE

2.1 Overview of house before renovation

The data below illustrates the details of the house (see Figure 2) even before the renovation design was introduced in the pilot study:

- Location: Valkeakoski, 37630, Finland.
- Type: Detached wooden house.
- Room plan description: 7 rooms + 2 kitchens + 3 bathrooms + sauna
- Living area: 178 m² and basement 100 m², the total area of the house is about 270 m², excluding stairs.
- Floors: 2 + basement (sauna, bathroom, storage room and garage)
- Construction finished in 1954 with some small internal renovation afterwards
- Orientation: South-West
- Heating: district heating
- Ventilation: Gravity ventilation system (Buoyancy pressure natural ventilation)

Figure 2. Case study house

In the following some general features of the house with the energy consumption data:

- Total heat consumption in 2018 was 37.7 MWh/a - note! includes heating of hot water.
- Electricity consumption for the period 04/2018 - 03/2019 totalled 6.868 MWh/a.
- Water consumption in 2018 was 82.9 m³. This figure includes both cold water and hot water since there are no separate meters for cold and hot water.
- Since there is no specific data for the energy demand for hot water, an estimated hot water consumption and overall heating load calculation is shown in Figure 3:

$$Total\ water\ consumption: 82.9\ m^3/year\ =\ 227\ l/day;$$

$$For\ one\ person:$$

$$76\ l/day\ with\ approximately\ 55°C\ hot\ water\ demand\ and\ 7°C\ of\ cold\ water\ supply$$

$$=\ 76\ l/day\ \times\ (55°C - 7°C) \times 1{,}16\ Wh/lK\ =\ 4.2\ kWh/day;$$

$$3\ people\ per\ year\ =\ 4.2\ kWh/day\ \times\ 3\ \times\ 365\ days\ =\ 4.6\ MWh/a;$$

$$Total\ hot\ water\ consumption\ =\ 25.8\ kWh/m^2a;$$

- $Total\ hot\ water\ consumption\ = 4.6\ MWh/a;$

$$Total\ space\ heating\ consumption\ =\ 33.1\ MWh/a;$$

$$Heating\ load = \frac{33.1\ MWh/a}{2000\ (heating\ season\ full\ operaton)} = 16.5kW$$

Figure 3. Heating load calculation

Considering the information regarding construction and building details from the owner, Table 1 was created with the help of special Excel Calculation Sheet. This tool takes into consideration building's technical specifications and weather conditions of the building location and generates the thermal energy concept indexes:

Table 1. Demand for heating energy before renovation

	Results	WBF	Location	
1	Conductances (Leitwerte) $L_e + L_u + L_g$		145,94	W/K
2	Added conductances $L_\psi + L_\chi$		8,98	W/K
3	Transmission conductance L_T		154,92	W/K
4	Ventilation conductance L_V		70,27	W/K
5	Heating load P_{tot}		8 557	W
6	Transmission losses Q_T		17 531	kWh/a
7	Ventilation losses Q_V		7 952	kWh/a
8	Passive solar gains $\eta \times Q_s$		4 715	kWh/a
9	Internal heat gains $\eta \times Q_i$		3 278	kWh/a
10	**Heating energy demand (Heizwärmebedarf) Q_h**		**17 490**	**kWh/a**
11	Ratio of heat gains and heat losses γ		32	%

2.2 **Renovation results**

In order to tackle the issue of high heating energy consumption, air leakage and poor insulation, the envelope of the building was covered by an additional insulation layer, and new special low energy windows were installed. All the draught points were fully filled up and concealed with an extra airtight layer. The major improvements were achieved by virtue of the new Mechanical Ventilation system with Heat Recovery (MVHR). Floor plans in Figure 4 and 5 demonstrate the renovation schemes:

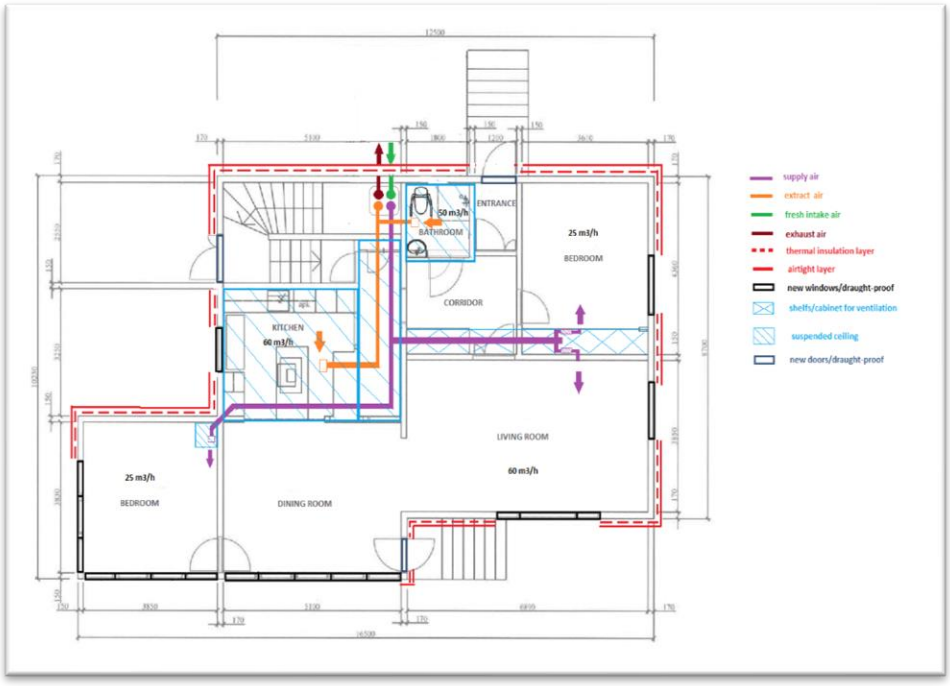


Figure 4. 1st floor plan with MVHR and thermal insulation

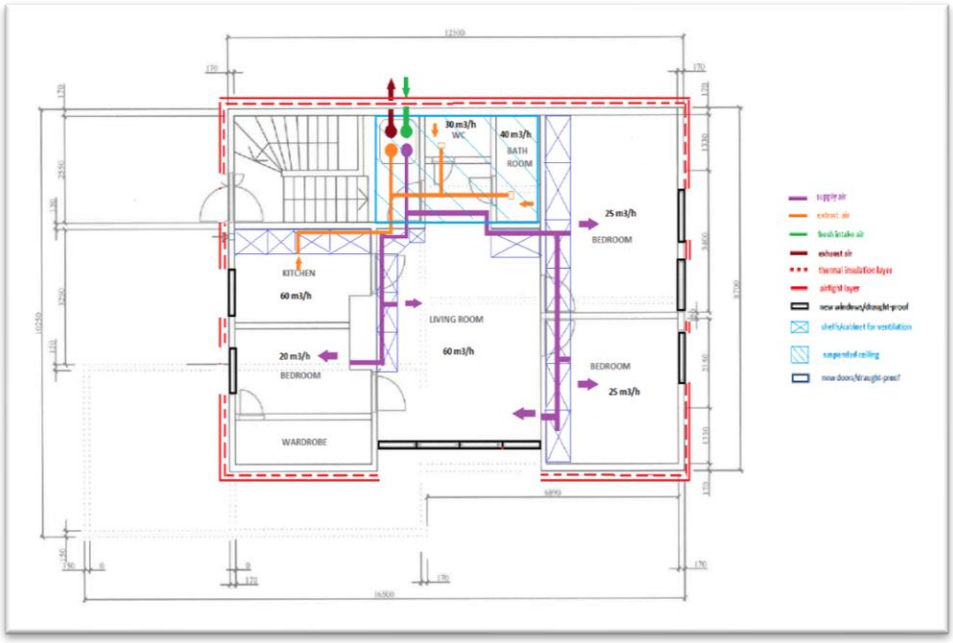


Figure 5. 2nd floor plan with MVHR and thermal insulation

As a result, the heating demand value reduced drastically, from 17490 kWh/a to 2790 kWh/a and it is given in Figure 6:

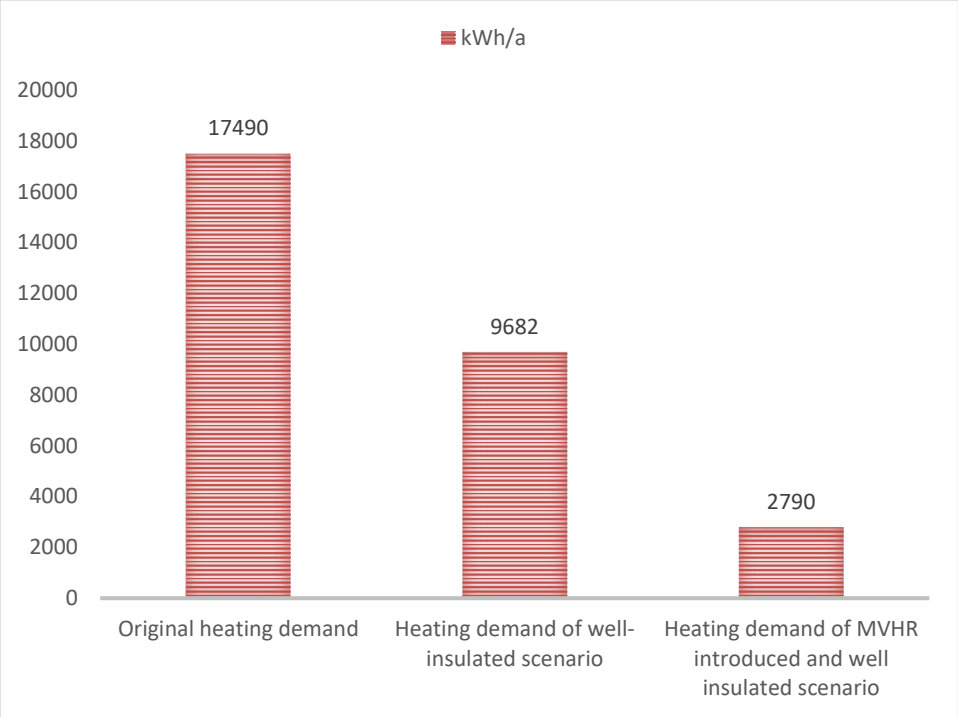


Figure 6. Heating demand comparison

When it comes to renewable energy utilization, the rest of the energy demand for domestic hot water preparation is supplied with the help of solar thermal collector system. Calculations reveal that four of such collectors would be enough to fully cover hot water consumption during summertime and up to 80% during wintertime. Pellet furnace is chosen as a space-heating source due to its efficiency and very little emissions. Active electrical energy gain via Photovoltaic (PV) will be collected as well using 50 m^2 of the roof, which is more than sufficient to cover all the electricity consumption. As it is about this project, from now on the renovated adaptation of the case study will be under the research.

3 CASES OF USE

In the following Table 2-6 are listed cases of use, which are the most common for the house under this project. They can also be attributed to the most prevalent practices among home automation users. Due to the project's limitations as to the hardware and complexity of some cases of use, they were not implemented in a practical setting.

3.1 Description of cases of use

Table 2. Case of use №1

Case name	Lighting control
User	Residents
Details	1. A user enters a dark room. The system detects the presence. 2. Another trigger, which initiates the use case, could be using a control cabinet on Personal Computer (PC) or smartphone, or a light switch.
Precondition	1. The control system should be running
Postcondition	1. In case of an occupancy sensor, lights will automatically turn on in that certain room. It will switch off after 5 seconds with no presence. 2. Using a control system will allow a user to turn on/off the lights in any room desired.

Table 3. Case of use №2

Case name	HVAC control
User	Residents
Details	1. The system detects no presence in all rooms. 2. Windows or balcony doors are left opened. 3. The room temperature, humidity level or Carbon Dioxide (CO_2) amount is higher/lower than the set values.
Precondition	-
Postcondition	1. If an occupancy sensor detects nobody at home, then heating valve will activate and reduce the heat. 2. When windows or balcony doors are left opened, window contacts setback HVAC not to lose any heat and fresh indoor air. 3. HVAC units and devices will work accordingly. For example, if the room temperature is too high because of heating gains, heating valve will setback and vice versa.

Table 4. Case of use №3

Case name	Device control
User	Residents
Details	All the electronic devices should be controlled by using a control panel on PC or smartphone.
Precondition	The control system should be running
Postcondition	A control system will allow a user to turn on/off all the electronics that are plugged in through Wi-Fi socket outlet.

Table 5. Case of use №4

Case name	Shading control
User	Residents
Details	1. Blinds' performance is dependent on the sunlight level falling on the windows. 2. Another trigger, which initiates the use case, could be using a control cabinet on PC or smartphone.
Precondition	1. The control system should be running
Postcondition	1. Blind will adjust to an appropriate angle and position by utilizing a shutter drive and actuators. 2. Using a control system will allow a user to open/close the shutters.

Table 6. Case of use №5

Case name	Scenario mode
User	Residents
Details	There is a special mode for the whole system, when the residents are not at home for a long time
Precondition	-
Postcondition	It can be achieved by implementing a specific button for such case. It will include following: all the lights are off, HVAC system is not active, and blinds are shut down.

3.2 Requirements for implementation of cases of use

As it was noted above, due to the paucity in hardware and time limit, it is decided to implement only two of the use cases partially. However, a brief commentary regarding requirements on not implemented use cases is presented below:

i. For presence detection, a great solution for new constructions could be installing lamps with an embedded occupancy sensor. When it comes to renovation occasions, wireless wall mounted occupancy sensors are perfect match, i.e. EnOcean Wall Mounted Occupancy sensor.

ii. HVAC can be controlled based on window position. A suitable device in this case would be Wireless Window/Door handles and contacts.

iii. Controlling electronic appliances can be fulfilled via Smart Wi-Fi outlets. The trick is to integrate it to the Beckhoff and EnOcean system, since EnOcean does not produce such outlets yet. However, the integration can be done by virtue of OpenHAB implementation.

iv. Controlling window blinds can easily be integrated into the system by applying shutter drives and actuators, for instance, by SMI and KNX, respectively. Easysens offer endless types of blind switches,

where it is possible to control the speed, operation and angle of rollers. In addition, they all are compatible with Beckhoff technology.

v. Setting a scenario mode is not uncommon in the smart building world. If all the elements are already realized, it is just a matter of programming.

4 DEEP DIVE INTO THEORY

There are several reasons why specifically EnOcean and Beckhoff out of many other systems available were selected. Firstly, EnOcean offers battery less, maintenance free and wireless data transmission solutions. It also gives an easy accessibility to be installed on any surface. Since this project is related to refurbishment of the old house, this matter should be taken into account, too. EnOcean is ideal for both new and renovated buildings. When it comes to the framework, EnOcean's interoperability with other systems contributed to choosing Beckhoff, since all Beckhoff controllers support EnOcean communication. There is even a library "TcEnOcean" in TwinCAT, which is used explicitly for EnOcean terminals' application. In addition, a similar university project made under the course "Automation Application in Smart Home" at HAMK was a driving force for deciding on the systems.

This chapter contains detailed information on EnOcean and Beckhoff technologies: technical specifications, fields of application, and comparison analysis with other similar systems.

4.1 EnOcean Technology

The EnOcean is an energy harvesting technology that perfectly combines micro-energy converters with ultra-low power electronics and radio technology, which enables innovative maintenance-free wireless sensor solutions. Since the EnOcean sensors, switches, controllers, and gateways do not require any wires or batteries, it adds unparalleled flexibility to time savings and energy efficiency, while minimizing investment and operating costs. Wireless systems by EnOcean have been introduced in over a million building structures around the world, making it the most across the board and most field-tried building automation standard available in the scene. (EnOcean Alliance Inc., 2020). The EnOcean innovation is utilized essentially in building automation frameworks, however beside that, it is applicable to other different areas, for example, in manufacturing, transportation, and intelligent homes (EnOcean Alliance Inc., 2016, p. 3).

According to the innovation description by EnOcean GmbH (2020), the main sources of energy used by EnOcean are movement, light, or

temperature changes. The main principal behind this innovation is based on a sorely basic perception: a module activation brings alterations in energy, which is sufficient to transmit remote signals. Driven by movement, light, and temperature, no wires, or batteries are needed for exchanging or obtaining of data from any sensor (EnOcean Alliance Inc., 2020).

The technology is always advancing, so it is important to consider an issue of interoperability, especially for sensor solutions. For this reason, a special communication protocol called EnOcean Equipment Profiles - EEPs was developed by EnOcean Alliance in order to assure a stable and easy communication bridge between modules of different manufacturing origins (EnOcean Alliance Inc., 2020).

Ultimate features of EnOcean in a brief:

i. Wireless sensor networks usually consist of these: no battery and line powered wireless nodes and wired bus systems.
ii. Energy management: the way energy is used and managed has intelligent features, and thus it causes a cost-effectiveness of components and systems.
iii. Software concept: EnOcean's software is quite straightforward and extremely specialized that there is no need in executing any sorts of modifications and complicated configurations unless it is required for special applications. The aim is easy use of the technology without advanced knowledge and experience (Anders, 2011, p. 6).

Overall, after reviewing the basic of EnOcean technology, several advantages are delineated. To start with, no wiring, uncomplicated installation and simple configuration make the system more flexible for a user, alongside with its time benefits. As it was mentioned before, the technology is energy harvesting, maintenance free and battery free, which gives a great environmentally friendly perspective because of existing energy use and a small fraction of raw materials utilized for modules and cabling. In both long and short run, the system is very beneficial in terms of cost due to reasons noted earlier (Anders, 2011, p. 2)

4.1.1 Technical specifications

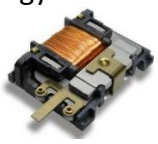
System Features:

- All kill technical solution: energy converting system, energy management, radio technology, convenient software.
- Radio devices with no batteries: The required operating energy for radio telegram transmission is very low.
- Energy emanation level is at its lowest. A great comparison example would be that emission index of energy from EnOcean is less than a start radiation from an ordinary light switch and far less than the one from a mobile phone (Anders, 2011, p. 1).

Energy converter:

EnOcean sensors can gather minor sums of energy from their environment, empowering them to process various signals and send them in a wireless way. That means EnOcean devices are run on energy that is basically created out of sources shown in Table 7:

Table 7. Various energy converter characteristics (EnOcean GmbH, 2020).

Technology principle	Energy converter model	Technical features
Linear motion/pressure: A button switching operation activates electromechanical or electrodynamical converter, which is in turn would generate energy enough to transmit a signal data for any smart home segment, but in most cases, lighting control.	ECO 200 - Kinetic Energy Harvesting  	Generally, there are over a million switching cycles at the temperature of 25 °C. This model is mainly for little and level switch structures.
Light: A minimum level of 200 lux can ensure solar cells to convert the light into energy that can be used for sensors' operation, for instance, temperature, humidity, CO_2, and motion detector sensors, along with window and door contacts.	ECS 300 - Solar cell for self-powered wireless sensors  	Typically, the size of this model would be 35.0 × 12.8 × 1.1 mm. There is smaller versions as well, which are mainly designated for unidirectional sensor applications.
Temperature change: The main concept behind this technology is that even a 2 °C temperature change can be satisfactory to operate some modules as heating valves. Such valves can utilize the inner and outer temperature change of a radiator to grant energy for a successful transmitting data to a gateway.	ECT 310 Perpetuum - Thermo Energy Harvesting  	This model follows a similar pattern as Peltier element, obtains its application at very tiny temperature differences and supports self-powered actuators.

Ultra-low Power Management:

The way converted energy is managed and stored has an undeniable vitality in EnOcean wireless systems. Because of the circumstance of energy harvesting's exceptionally limited quantities of intensity, it is important to save it up during the periods when the framework is resting and to lose just a little part of it all the while. In this way, the energy accumulation process makes EnOcean sensors possess an incredibly short idle current, and that is why a miniscule measure of energy is devoured while the framework is resting. The most recent age of EnOcean modules requires a fall-back current amounting to just 100 nanoamperes or even less (EnOcean GmbH, 2020)

Radio technology:

What makes EnOcean even more astounding is that not only it is energy harvesting technology, but it can also transmit data at a relatively grand range. A typical EnOcean wireless device can without much of a stretch send a telegram up to 300 meters outdoors in a free area and 30 meters indoors. The vital reason behind such accomplishment is the duration of signal. It is stated that the total time of whole procedure's beginning, fulfilment, and finish is accounting for approximately only thousandth of one second (Anders, 2011, p. 4). What should not be neglected in this discussion is how EnOcean is evolving the standardization of all energy converting wireless systems to make one of a kind prospects of this innovation accessible for every single wireless protocols, including the EnOcean Alliance, Bluetooth SIG and Zigbee Alliance. The concealed goal is to enhance these wireless network standards for the sustainable development purposes. In general, EnOcean's radio system is arranged like in Figure 7 (EnOcean GmbH, 2020):

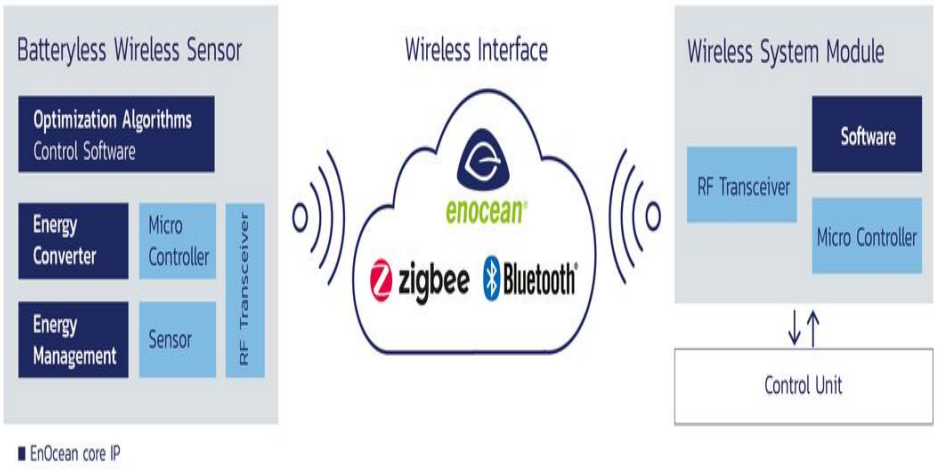


Figure 7. EnOcean system architecture (EnOcean GmbH, 2020)

EnOcean's radio protocol is acknowledged as reliable and interoperable. There are a few technical characteristics which would make it right. To begin with, EnOcean uses most of worldwide frequency ranges: 868 MHz – RED regulations in Europe and China, 902 MHz - FCC/IC-specification in North America and 928 MHz - ARIB specification in Japan. There is also a possibility to send multiple signals with checksums and 8-bit CRCs and very short signals if a large sensor network is needed, with a repeater to prolong the range in access. It is crucial to note that the security issues are also reflected, hence 128 AES encryption is presented. Additionally, there is no disturbance with DECT, WLAN, PMR systems and so on and the data transmission speed is 125 Kbit/s, which can be attributed to high rate in wireless system category. Most importantly, the percentage of data being overhead is infinitesimal with appropriate Amplitude and Frequency Shift Keying modulations (EnOcean GmbH, 2020).

Network topology is demonstrated in Figure 8:
There are several major bus systems that EnOcean can communicate with: KNX, LON, DALI, BACnet or TCP/IP. As for the network topology, a point-to-point, star and mesh topologies are usable, however P2P network topology is the most widespread one, where each wireless module can build a network with any other module in the communication system.

- Battery-less, energy converting transmitters, which are sensors and switches, can have unidirectional communication with both receivers and transceivers.
- Actuators or receivers often come as battery or main powered and have double communication ways: receiving data from transceivers or directly from sensors and switches.
- Room controllers and gateways are also known as transceivers due to their bidirectionality, which implies being able to both send and receive telegrams (Richter, 2012, p. 38).

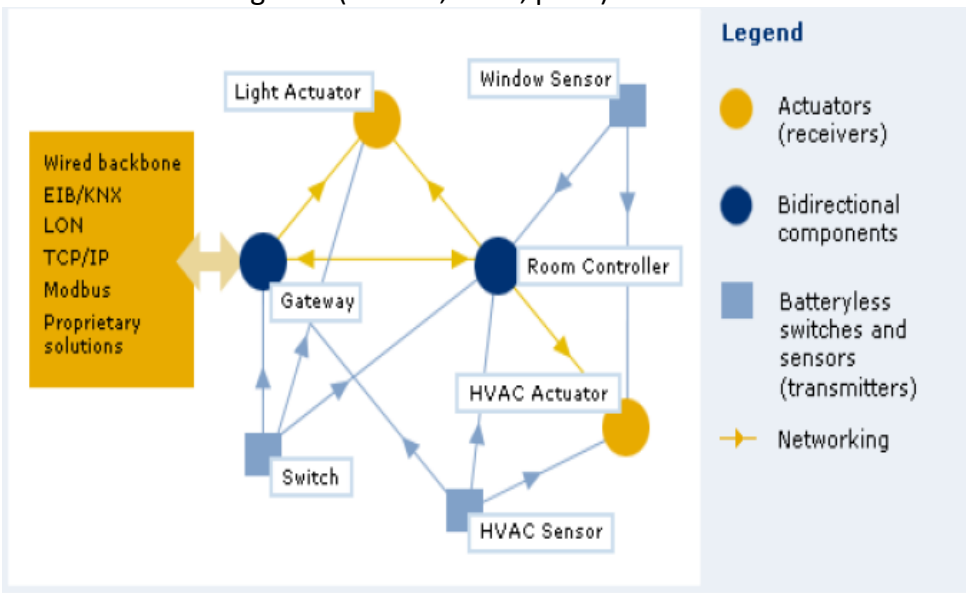


Figure 8. Topology of EnOcean network (Anders, 2011, p. 4)

Layer model, as it is given in Figure 9:
The standard covers the OSI (Open Systems Interconnection) layers 1-3, which are the physical, data link and networking layers, and application for EEP:

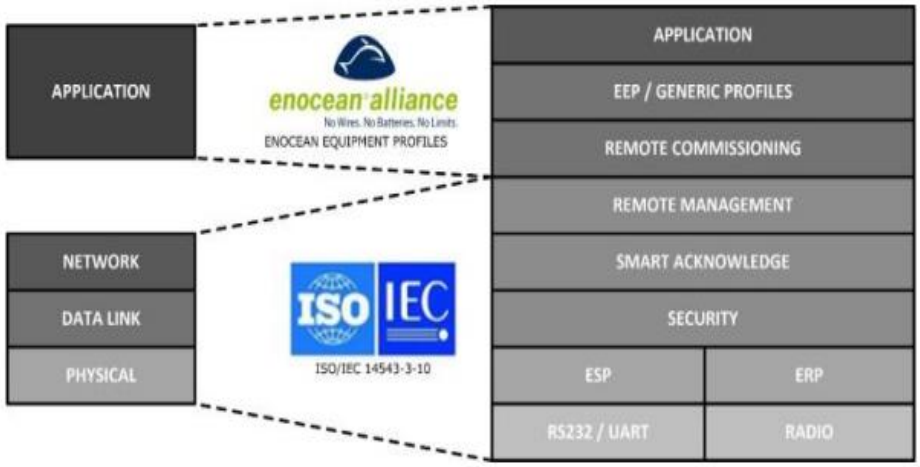


Figure 9. OSI model of the EnOcean standard (EnOcean Alliance Inc., 2016, p. 24)

4.1.2 Fields of application

The coverage of EnOcean technology in departments of utilization is certainly diverse. Starting from a simple home automation right to multilevel process automation. By virtue of a great balance between costs, know-how technology and flexibility, EnOcean offers solutions across the globe. Figure 10 and 11 demonstrate EnOcean's most predominant building and home automation system proposals.

Figure 10. Building automation example (EnOcean GmbH, 2020)

Figure 11. Home Automation example (EnOcean GmbH, 2020)

Not only conquering the building side, but also reaching to industrial automation (see Figure 12), EnOcean ensures high quality operation in manufacturing chains in a sense of resource savings, in transportation as a quality assurance, in automotive as a process optimizer and safety provider, and in medicine field by developing more precise diagnosis identification, more intelligent patient's health supervising and better system management (Richter, 2012, p. 43).

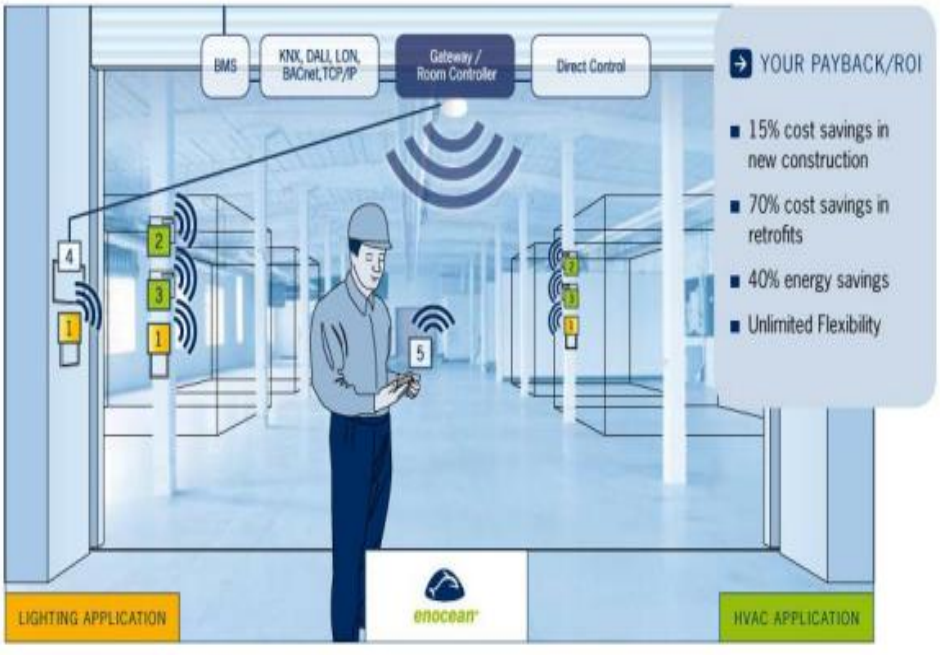


Figure 12. Industrial automation example (Richter, 2012, p. 43)

4.1.3 Comparison with another similar system

There are many wireless systems in the same area of utilization, offering similar solutions and product lines, as EnOcean: low power Wi-Fi, Bluetooth Smart, ZigBee and Z-Wave. As ZigBee is one of the most widespread technologies in smart home sector, the comparison is made with ZigBee. In general, the most tremendous difference that is commonly recognized is security matters. ZigBee technology's breakthrough was its encryption models that guaranteed a safety from potential cyber-attacks and malicious viruses to relatively large extent. Moreover, there is a belief that ZigBee is a better choice for home automation systems where only small quantity of modules are used, and thus maintenance and installation costs would be much lower (Richter, 2012, p. 47). Table 8 reflects on major technical differences between EnOcean and Zigbee.

Table 8. Technical comparison of EnOcean and ZigBee (Richter, 2012, p. 46)

	EnOcean	ZigBee
Standards	proprietary, EEP (EnOcean Equipment Profiles)	IEEE 802.15.4 + ZigBee standard + ZigBee Profiles
Standard status	closed	open
Offering	Complete Modules	Complete Software Stack for RF Chip
Battery & Maintenance free	Yes	No
Network Topology	P2P (Gessler & Krause, 2009)	Star network, P2P/Cluster tree network (IEEE-Std-802.15.4, 2006)
Frequency	868 (EU) /315 (US) MHz	868 (EU) /915 (US) MHz, 2.4GHz
Interference Risk	very low	very high (2,4GHz)
Minimum Telegram period	0.6ms	30ms (868MHz), 4ms (2.4GHz) (Anders & Schmidt)
Telegram length (max)	14 Bytes	133 Bytes (IEEE-Std-802.15.4, 2006)
Data Rate	125kb/s	20 - 250kb/s (IEEE-Std-802.15.4, 2006)
Range: Room/Line of Sight (LOS)	30/300m	30/30-100m
Sleep Current	0.08µA	1µA
Total System Energy Requirements	Factor 1	Factor 10-100
Security	NO	YES (ZigBee-Specification, 2007)
Live Cycle - Cost	Excellent	Good
Product Interoperability	Yes	Some profiles are not compatible with each other
OEM Products on Shelves	>265	<10
Target Market	Residential, Commercial, Industrial	Industry, Medical, Telecom, Consumer, Residential, Commercial,...

What stand out the most from the table are:

- Interference risk on signal is a lot lower in EnOcean.
- ZigBee can work with telegrams of bigger sizes.
- Date rate and range of signal of EnOcean is much higher.
- EnOcean modules are mostly compatible with other systems.

4.2 **Beckhoff automation system**

Beckhoff Automation is a company that manufactures all sorts of automation related technology based in Germany. Their product range covers both system solutions and technological equipment all oriented towards PC Control technology. When it comes to real products, Beckhoff focuses on production and offering solutions regarding Industrial and Embedded PCs, input and output terminal blocks and Fieldbus elements, Motor Technology, and automation software. One of their greatest achievements was in 2003, when they created and introduced EtherCAT for real-time system control by virtue of Ethernet network (Proskuriakov, 2018).

4.2.1 Technical specifications

PC-based control from Beckhoff empowers incorporated computerization of all structure frameworks in practical constructions and foundations – from single-room control to window control to concealing, lighting, HVAC MCI, smoke and warmth expulsion frameworks, get to control, energy observing and process representation. The Beckhoff I/O portfolio incorporates more than 400 signal types and 36 fieldbus frameworks and is perfect for controlling the full scope of sensors and actuators (Beckhoff Automation GmbH & Co. KG, 2018, p.11).

Beckhoff emphasizes 3 essential building automation systems:

i. Room Automation (Lighting, Occupancy sensor, Air quality, Temperature, Shading, HVAC)
ii. Media related automation (Audio and video installations and control, various presentation functions, and now lighting shows are getting popular due to its interior design perspective)
iii. Operating and Monitoring (Energy management, different maintenance methods, IoT-based control, Visualization, cloud implementation) (Beckhoff Automation GmbH & Co. KG, 2018, p. 8).

Open Communication systems:
For the coordination of controllers into a current computerization topology, Beckhoff underpins all the fundamental bus networks: for example:

- BACnet, OPC UA, Modbus TCP (automation level)

- DALI, DMX, EnOcean, LON, EIB/KNX, SMI MP-Bus, M-Bus (field level) (Beckhoff Automation GmbH & Co. KG, 2017, p. 13).

TwinCAT 3 – Automation Software:
A software developed by Beckhoff, TwinCAT, now generation 3, is a great tool for all kinds of controlling operations of different For PLCs, controlling positioning of various difficulty level, beginning from entry level to professional use. The main function of TwinCAT is to implementing automation programs and parameterizing required systems. IEC 61131-3 standard is considered as the programming protocol of Beckhoff as well, hence many universal automation software technologies follow the above-mentioned protocol. Delving deeper into key points, it is important to give TwinCAT 3 highlights. Firstly, it is all one embedded software for both programming and configuration. Secondly, TwinCAT can be integrated with Microsoft Visual Studio, which might come very convenient for many developers. The next standpoint to make is how runtime environment is arranged: almost 4 runtime systems per PC and 4 tasks per runtime system. With minor configurations, runtime mode is easily accessible. Other advantages would be a huge automation related library database for diverse applications, along with reusable software modules (Proskuriakov, 2018, p. 21). The interface of the main page of TwinCAT can be seen in Figure 13:

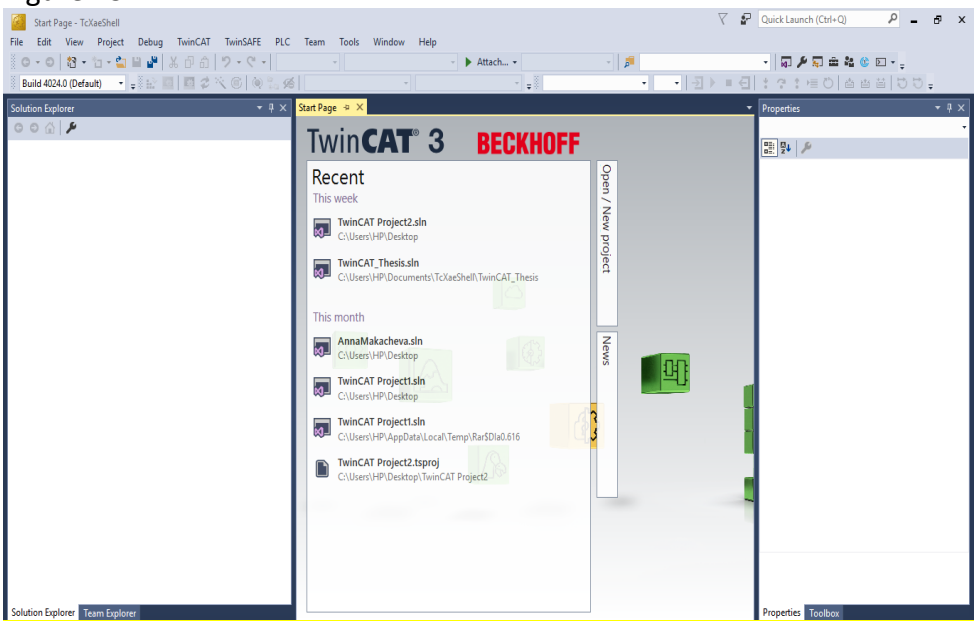


Figure 13. TwinCAT Software interface

4.2.2 Fields of application

Beckhoff's areas of application is quite diverse, covering almost all the crucial sectors of human's living. CNC-controlled machinery, automotive, production, service, smart buildings, interior design, etc. (Beckhoff Automation GmbH & Co. KG, 2017, p. 8). Beckhoff is a leading company in the advancement of numerous principals of current automation

technologies. The fundamental territories of use of Beckhoff items are power designing, process control frameworks in the oil, gas and synthetic businesses, transport frameworks, engine compartments, wind power, robotization of industrial facilities, plants, structures, and utilities (Proskuriakov, 2018, p. 16-17).

4.2.3 Comparison with another similar system

There are quite many automation-oriented companies, which have similar product range as Beckhoff. The most reasonable comparison would be PLC Automation by ABB due to the similarity in building infrastructure solutions. Although the product range of PLCs is relatively small, it has everything needed to develop a brand-new automation system. ABB's PLC systems are perfect for applications of all sizes. Their AC500 controllers and CP600 control panel units are admitted as being highly reliable, very compatible, and to execute a great automation performance. (ABB, 2019). An example of ABB's module is demonstrated in Figure 14:

Figure 14. PLCs by ABB (ABB, 2019, p. 2)

Another similarity with Beckhoff is that ABB's PLC Automation network is settled so, that the majority of communication standards are applicable for building any sort of system by ABB: BACnet, UDP, TCP/IP, OPC UA, SCADA and many more (see Figure 15) (ABB, 2019, p. 6). What needs to be mentioned next is the software area of the automation by ABB. Their software Automation Builder owns a perfect balance of machine building and system integration functions. Operations such as configuring, programming, debugging are executed in an efficient way and user-friendly interface. However, Automation Builder is predominantly designed for professional use (ABB, 2019).

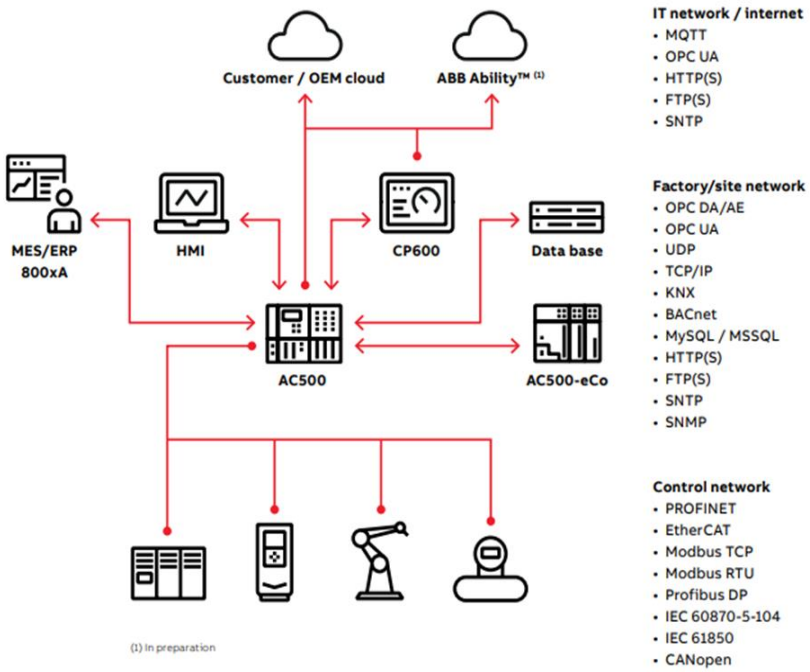


Figure 15. ABB PLC Automation product family connectivity (ABB, 2019, p. 6).

Apart from industrial automation, ABB also specializes in home automation. One of the most successful technologies they built is this innovative home automation technology named “ABB FREE@HOME”, which has wireless installation possibility as well. Here is a more thorough analysis of the system. ABB FREE@HOME offers light, blind, heating, and cooling control alongside with geofencing, safety and logic functions. Additionally, it gives the users access to remote control via already developed MyBuildings portal. What distinguishes ABB technology from Beckhoff automation is a better third-party products and services integration. For instance, ABB-FREE@HOME supports the integration of the Sonos wireless home and sound system, and Amazon’s cloud-based voice service Alexa.

As it can be indicated in Figure 16, the installation architecture of this innovation goes as follows: there can be both wired and wireless modules installed, each group’s device amount cannot exceed 64. The power supply for the bus system is two-wired bus cabled 230VAC and the system access point acts as a kind of heart of the organism (ABB, 2019):

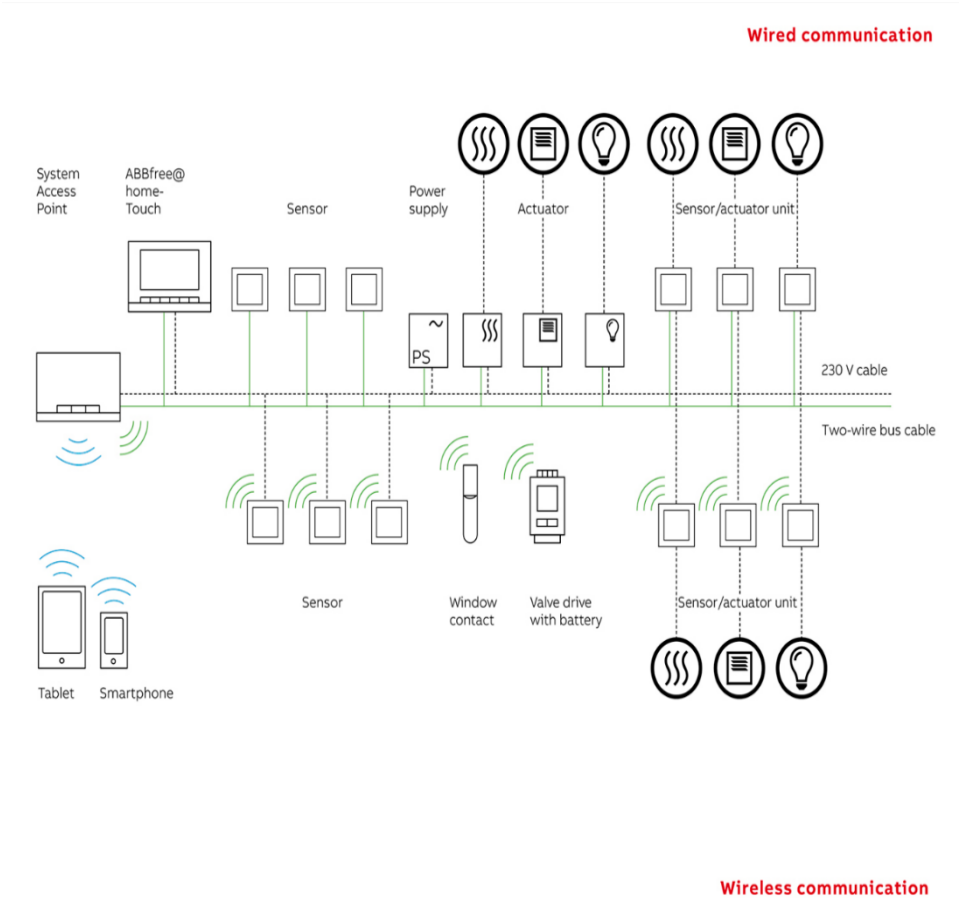


Figure 16. Installation structure of ABB FREE@HOME (ABB, 2019)

5 IMPLEMENTATION OF PROJECT

5.1 Planning of the project

As it was mentioned before, the project is a follow-up of a research project about the renovation of existing house. The project result needs to be in a form of a prototype with user-friendly visualization. By virtue of comprehensive literature review, it was decided to integrate EnOcean technology into Beckhoff automation system because of the low installation and maintenance costs, as well as simplicity and previous experience of an author. Since the size of living area in the house is quite huge, there is a necessity in many sensors to be installed; and thus, the chosen technologies would solve the issue of limitless wiring. The main software to be utilized during implementation stage is TwinCAT by Beckhoff. The latter's bus system, which was built as a hardware design of the project, plays a vital role in establishing a communication between wireless modules and the PC, where TwinCAT runs. The essential targets of the practical setting are to assemble Beckhoff bus system and configure it according to datasheet, to insert a software code based on EnOcean library specifications, and to do the program testing.

The practical part of this project is expected to be rather simple, so Figure 17 portrays the project layout of the system, that is to be built and tested, while in Figure 18 we can see the project layout as a real case, basically it shows how the system should have looked like if implemented.

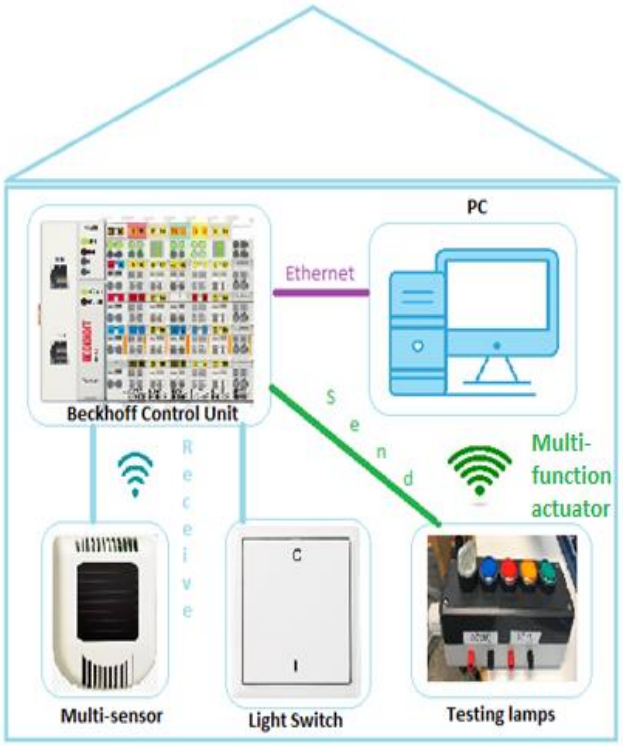


Figure 17. Project layout in practical terms

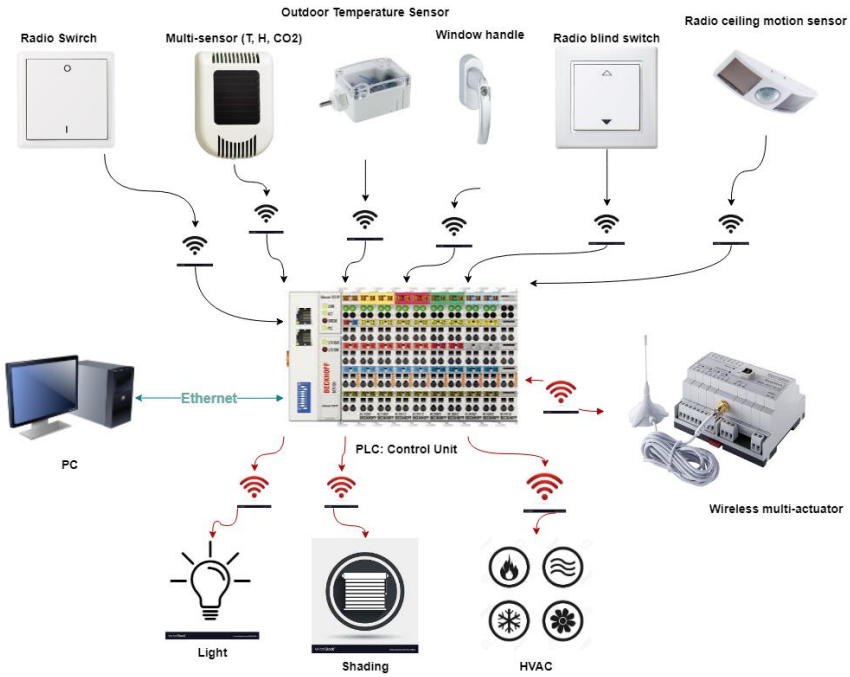


Figure 18. Project layout in real environment

5.2 **Hardware design**

5.2.1 Selection of hardware components

Table 9 is a list of hardware used in the practical part. Note: The cursive ones are certainly used. The date when the prizes were checked is May 17, 2020. The costs in some links are given in GBP, but they were converted in this table for convenience purposes, according to the exchange rate on the above-mentioned date.

Table 9. Hardware components description

Device code	Quantity	Description	Cost/EUR	Manufacturer: link
BK9050	*1*	*Ethernet TCP/IP Bus Coupler*	280	Beckhoff: https://www.radwell.co.uk/en-GB/Buy/BECKHOFF/BECKHOFF/BK9050/?redirect=true
KL9010	*1*	*Bus End Terminal*	16	Beckhoff: https://www.radwell.co.uk/en-GB/Buy/BECKHOFF/BECKHOFF/KL9010/?redirect=true
KL6581	*1*	*EnOcean Master Terminal*	313	Beckhoff: https://www.radwell.co.uk/en-GB/Buy/BECKHOFF/BECKHOFF/KL6581
KL6583	*1*	*EnOcean transmitter and receiver*	262	Beckhoff: https://www.radwell.co.uk/en-GB/Buy/BECKHOFF/BECKHOFF/KL6583
RSM 1	*1*	*Radio Switch Mini, 2 channel Light*	66	Thermokon: https://direct.thermokon.de/en/product-details/product/mini-2-kanal-licht-reinweiss-glaenzend/
60.CO2 SLR TMP HUM	*1*	*Wireless CO2, Temperature and Humidity Sensor*	n.d.	Pressac: https://www.enocean-alliance.org/product/pressac_co2_temperature_humidity_sensor/
SRC-ADO 1	1	Multi-function actuator	347	Thermokon: https://direct.thermokon.de/en/product-details/product/src-ado-4aa4do-100240-v-typ-dimmenheizenkuehlen/
	1	*Testing lamps*	40	-
	2	*Power transformer: 230AC =>24DC*	30	-

5.2.2 Configuration and installation of hardware

The main task for hardware installation was to establish a connection between KL6581 and KL6583. Table 10 and Figure 19reveal the connection details:

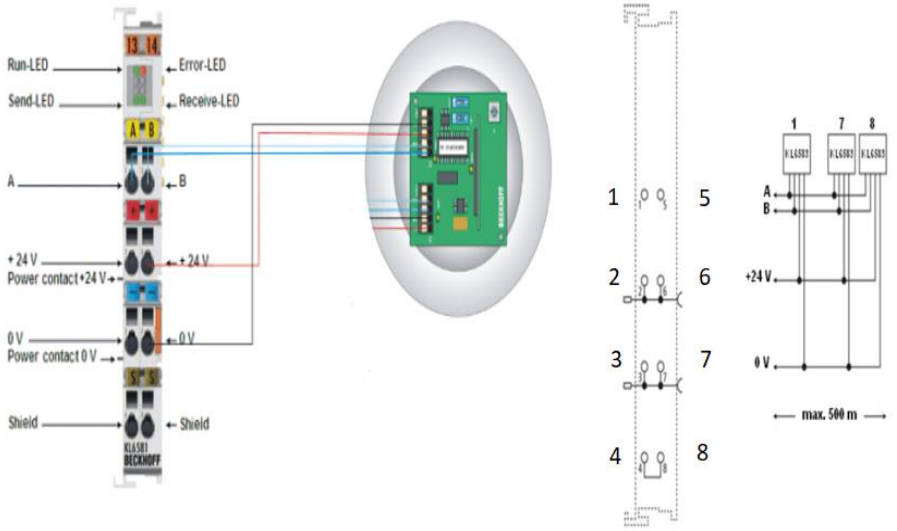


Figure 19. KL6581 and KL6583 connection example (Beckhoff, 2019, p. 21-24)

Table 10. Connection points between KL6581 and KL6583 (Beckhoff, 2019, p. 21)

Terminal point	No.	Connection for
CAN + (A)	1	A (CAN +)
+ 24 V_{DC}	2	24 V power contacts
GND	3	GND power contacts
Shield	4	Shield, internally connected with terminal point 6
CAN - (B)	5	B (CAN -)
+ 24 V_{DC}	6	24 V power contacts
GND	7	GND power contacts
Shield	8	Shield, internally connected with terminal point 4

Node address of KL6583 should be set at S3, as it is done in Figure 20. Generally, there must be just one address in the line out of 8 available. For this project, the node address “1” was selected since only one KL6583 is put into use.

Figure 20. Setting the node address with switch S3 (Beckhoff, 2019, p.22)

Termination resistor needs to be activated in the last module. To achieve that, both of the switches S1 and S2, as shown in Figure 21, must be ON.

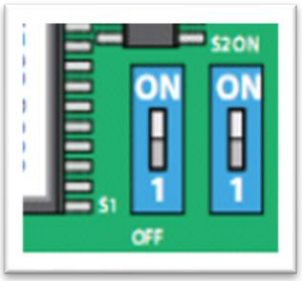


Figure 21. Termination resistor ON (Beckhoff, 2019, p.22)

When it comes to the actual bus connection, the KL6581 master terminal is attached to the BK9050 bus coupler, which receives 24V DC from a 230V AC to 24V DC power transformer and forwards it to KL6581. Since 24VDC connectors are wired between KL6581 and KL6583, the transceiver also receives 24V DC. The figure 22 demonstrates how the bus connections and wirings are executed in practice:

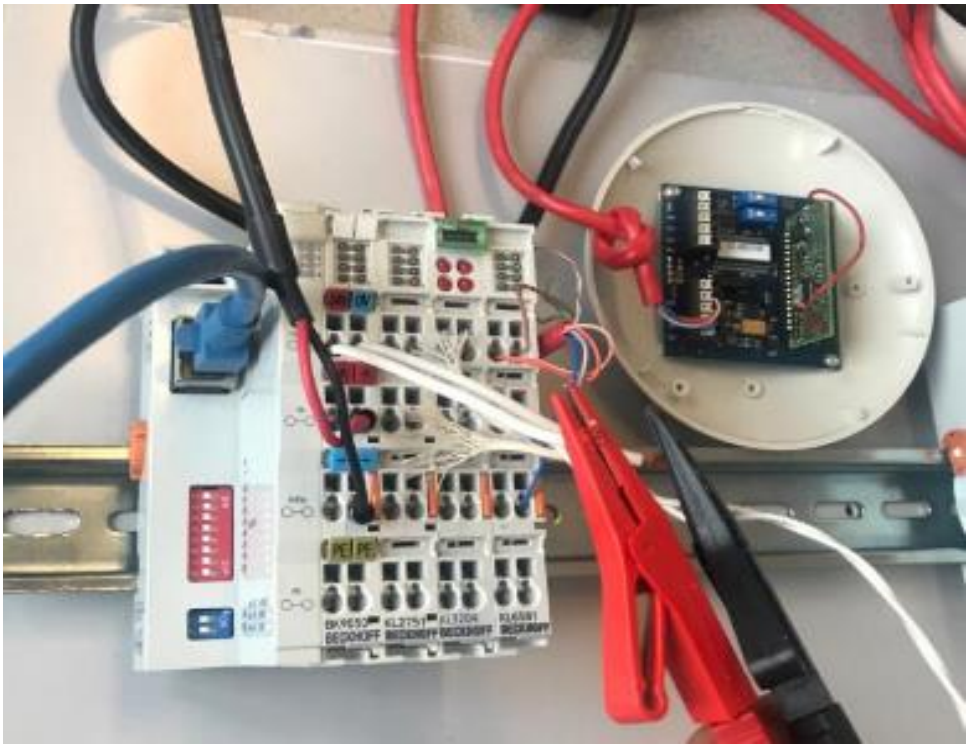


Figure 22. Bus connection

As the project outcomes were tested at Häme University of Applied Sciences, the PLC box with all necessary components, displayed in Figure 23, was utilized. All mentioned configurations and installations were already set and ready to use.

Figure 23. Beckhoff PLC box

5.3 **Software design**

All the programming code is written in the TwinCAT 3 software developed by Beckhoff. A special library PLC Lib: Tc2_EnOcean was put into the use during programming. Figure 24 demonstrates a block diagram of the program:

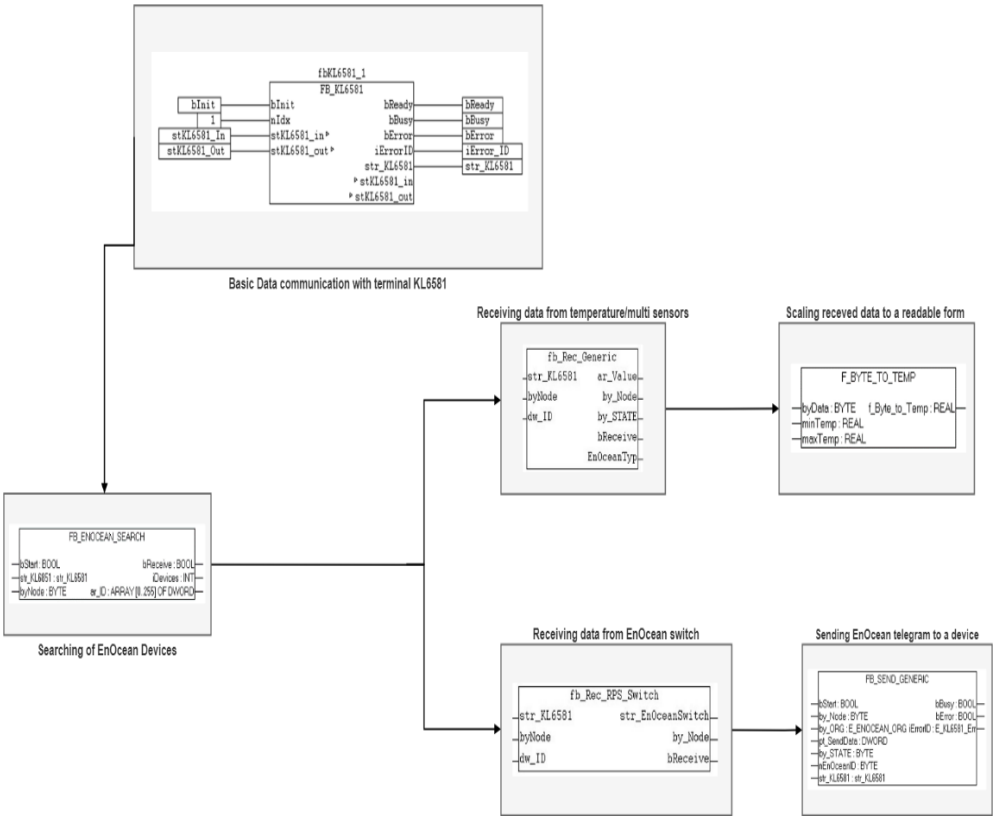


Figure 24. Program block diagram (Beckhoff, 2019)

5.3.1 TwinCAT Home Automation source code

The system, in general, consists of following parts:

a. Main program
b. POU: EnOcean integration
c. POU_1: Control unit code
d. IO: All global variables
e. Visualization of the system

In Figure 25, there is Main program code, which calls all other program optimization units:

```
PROGRAM MAIN
VAR

    POU: POU;

    search: POU_1;
END_VAR
```

```
        POU();

        search();
```

Figure 25. Main program

Moving on, Figure 26 shows the list of all variables of the program:

```
VAR_GLOBAL

    stKL6581_in AT%I*: KL6581_Input;
    stKL6581_out AT%Q*: KL6581_Output;
    Com: FB_KL6581;
    bInit: BOOL:=0 ;
    nIdx: USINT ;
    bReady: BOOL;
    bBusy:BOOL;
    bError: BOOL;

    start_search: BOOL;
    str_KL6581: str_KL6581;
    byNode: BYTE;
    search: FB_EnOcean_Search;
    ReadGeneric: FB_Rec_Generic;
    ReadGeneric2: FB_Rec_Generic;
    ValueArray: ARRAY [0..3] OF BYTE;
    ValueArray2: ARRAY [0..3] OF BYTE;

    id2: DWORD:= 84051228;
    id: DWORD := 26067769;
    Temp: REAL;
    Temp2: REAL;
    CO2: REAL;

    Humidity: REAL;
    Humidity2: REAL;

    switchId: DWORD:= 4277824813;
    SwitchOut: str_EnOceanSwitch;


    Lamp1 AT%Q*:  BOOL;

END_VAR
```

Figure 26. Global variable list

The next program to be reviewed is the EnOcean integration code, which is displayed in Figure 27. This function block provides data exchange with

EnOcean network, specifically a communication with the KL6581 EnOcean Bus Terminal.

```
FUNCTION_BLOCK POU
VAR_INPUT
END_VAR
VAR_OUTPUT
END_VAR
VAR
END_VAR
```

```
Com(
    bInit:= bInit,
    nIdx:= nIdx,
    bReady=>bReady ,
    bBusy=>bBusy ,
    bError=> ,
    iErrorID=> ,
    str_KL6581=>str_KL6581 ,
    stKL6581_in:= stKL6581_in,
    stKL6581_out:=stKL6581_out );
```

Figure 27. Function block – EnOcean Integration

The last function block, Figure 29, is quite complex. It has the EnOcean device searching code lines. Then there is the function block, which is put to read the EnOcean device IDs and write them in an array. After the IDs of all devices are discovered, they could be saved as constant variables, which then cannot be changed by the program. To print the temperature value in Celsius and CO_2 value in PPT instead of byte raw value, **F_Byte_To_Temp** converter command was used. As for the humidity, by going through datasheet, it was explored that the third byte in half would give a correct reading. Additional way of scaling temperature and humidity values accordingly is to apply a formula shown in Table 11 and Figure 28:

Table 11. EnOcean Temperature and Humidity Sensor data (EnOcean Alliance Inc., 2019, p. 7)

Offset	Size	Bitrange	Data	ShortCut	Description	Valid Range	Scale	Unit
0	8	DB3.7...DB3.0	Not Used (= 0)					
8	8	DB2.7...DB2.0	Humidity	HUM	Rel. Humidity (linear)	0...250	0...100	%
16	8	DB1.7...DB1.0	Temperature	TMP	Temperature (linear)	0...250	0...40	°C
24	4	DB0.7...DB0.4	Not Used (= 0)					
28	1	DB0.3	LRN Bit	LRNB	LRN Bit	Enum: 0: Teach-in telegram 1: Data telegram	ScaleMax ScaleMin	
29	1	DB0.2	Not Used (= 0)				RangeMax	
30	1	DB0.1	T-Sensor	TSN	Availability of the Temperature Sensor	Enum: 0: not available 1: available	RangeMin	
31	1	DB0.0	Not Used (= 0)					

Conversion: Valid Range ---> Scale

$$\text{Multiplier} = \frac{\text{Scale}_{MAX} - \text{Scale}_{MIN}}{\text{Range}_{MAX} - \text{Range}_{MIN}}$$

$$\text{Device value} = \text{Multiplier} * (\text{rawValue} - \text{Range}_{MIN}) + \text{Scale}_{MIN}$$

Figure 28. Conversion equation for temperature and humidity reading (EnOcean Alliance Inc., 2019, p. 7)

Therefore, having a temperature multiplier value of 0.16 and humidity multiplier value of 0.4 would give the same readings for device value as using the converter command.

```
FUNCTION_BLOCK POU_1
VAR_INPUT
END_VAR
VAR_OUTPUT
END_VAR
VAR
    Switch: FB_Rec_RPS_Switch;
    b_switch: bool:=0;
END_VAR
```

```
search(
    bStart:= start_search,
    str_KL6581:=str_KL6581 ,
    byNode:=byNode ,
    bReceive=> ,
    iDevices=> ,
    ar_ID=> );

ReadGeneric(
    str_KL6581:= str_KL6581,
    byNode:= 0,
    dw_ID:= id,
    ar_Value=> ValueArray,
    by_Node=> ,
    by_STATE=> ,
    bReceive=> ,
    EnOceanTyp=> );

Temp:=F_Byte_To_Temp(byData:= ValueArray[1] , minTemp:= 0, maxTemp:= 51);
CO2:=F_Byte_To_Temp(byData:= ValueArray[2] , minTemp:= 0, maxTemp:= 2550);
Humidity:= ValueArray[3]/2;

ReadGeneric2(
    str_KL6581:= str_KL6581,
    byNode:= 0,
    dw_ID:= id2,
    ar_Value=> ValueArray2,
    by_Node=> ,
    by_STATE=> ,
    bReceive=> ,
    EnOceanTyp=> );

    Humidity2:=ValueArray2[2]*0.4;
    Temp2:=ValueArray2[1]*0.16;
```

```
Switch(
    str_KL6581:=str_KL6581 ,
    byNode:=0 ,
    dw_ID:=switchId ,
    str_EnOceanSwitch=> SwitchOut,
    by_Node=> ,
    bReceive=> );

    lamp1:=SwitchOut.bT1_ON;
    IF(SwitchOut.bT2_ON) THEN
        b_switch:=TRUE;
        IF(b_switch) THEN
            lamp1:= NOT lamp1;
            b_switch:=FALSE;
        END_IF
    END_IF
```

Figure 29. Function block – Receive and Send

5.3.2 Visualization

The visualization design, which is portrayed in Figure 30, was also made in TwinCAT. It has two panels: lighting and HVAC control. The latter was not developed until the end since It was only possible to read the data from sensors but sending data to HVAC units would have required more programming. However, just to give a better overview of things, there is an illustration example for HVAC as well. The program for the lighting control works in a following way: when the program is on, it starts searching for EnOcean devices at the range of its accessibility. If user clicks the light switch, the program identifies the device, receives signal from it and turns the light on.

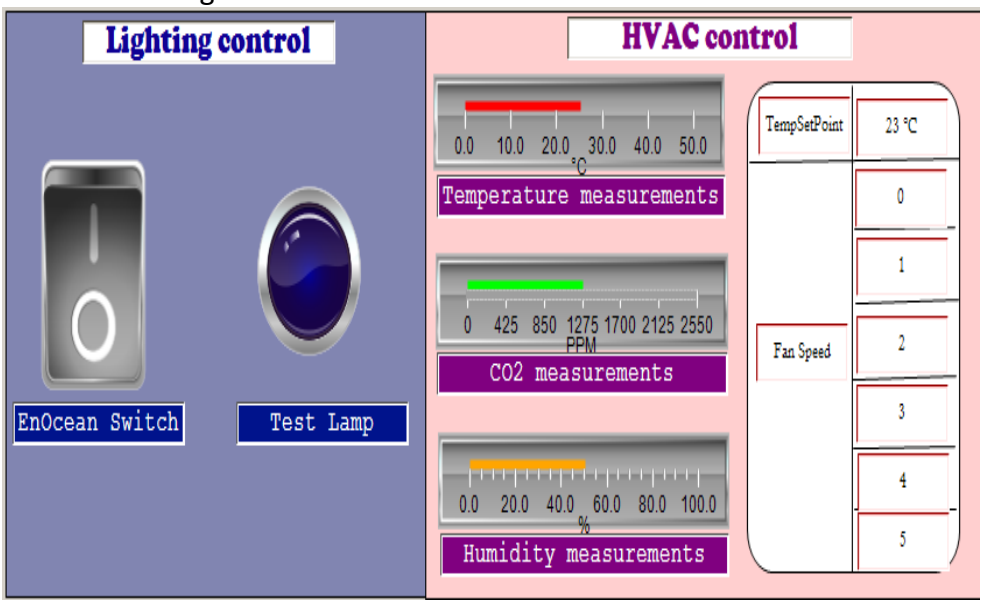


Figure 30. Program Visualization model

6 PROJECT RESULTS

Appraising the project outcomes, the main purpose of this paper, which was to study wireless smart home concept in depth and design a small prototype, was accomplished. The selected systems EnOcean and Beckhoff bolstered issues such as interoperability, flexibility, low installation costs, low maintenance costs, simple configuration, and easy expandability to be addressed in an adequate way. The central point of the system was supposed to be lighting and HVAC control; nevertheless, the HVAC control was not executed at its fullest because of the convoluted attributes there. Although reading data from sensors was achievable, sending data back to HVAC units, and thereby executing control system was not carried out mainly because of the paucity in hardware and necessity to examine this problem more profoundly. Having a look at the research questions, it is important to inquire if the selected research methodology was suitable and sufficient for obtaining all the required answers:

i. The highlights of a home automation system for a plus-energy concept house in Finland is HVAC control. According to the findings from analysis of energy situation of the house, heating and air quality control would make the biggest impact on energy efficiency. Also, since energy is expensive in Finland, it was important to make sure that the energy was used only when needed. Another must-have feature found is lighting control, which contributes both on energy saving and comfort.

ii. Maintaining the extent of the work without any excessive constructions most likely would have been possible with wired system. Wired installation requires to run cables throughout the property, so some sort of rebuilding is imminent. Therefore, as a solution for this question, wireless system was suggested despite its drawbacks which will be discussed further in this chapter.

iii. The estimated cost analysis was a complex agenda, which would obligate more advanced and specific knowledge; however, EnOcean assured low installation and maintenance costs; In general, many researches state that most of the times wired installation is more expensive than a wireless one due to installation charges and cabling cost by a certain labour force.

iv. EnOcean is all about expandability, so there is no problem with adding more to the operating system. The integration of other existing home automation technologies into the system is also possible. There are various kinds of communication frameworks to establish a connection between Beckhoff and other technologies.

Now examining the inevitable drawbacks of the system, it is essential to mention security matter, which is not impeccable. It is almost impossible to neglect the hazard of potential cyber-attacks when discussing wireless connection. On the other hand, wired connections are known to be more reliable, functional, and difficult for hackers to get through than wireless networks because in the latter passwords can be easily undertaken externally without user's knowledge. However, if a proper encryption design is established, wireless connections can be quite secure as well. Unlike Zigbee, which supports a stronger encryption of wireless communications, EnOcean still lacks in this area. Moreover, Zigbee seemed more appropriate and accessible for developers, while EnOcean was directed more towards customer-oriented designs.

Another thing to point out is setting up a wireless system is considered inexpensive compared to wired connections mainly because less equipment is involved and installing does not require a professional help. Nonetheless, some wireless equipment as room controllers, adapters, actuators can be at the pricey side as well, so it may not be easy to judge.

7 CONCLUSION

This chapter is a summarizing unit of the paper. A thorough self-assessment session along with obstacles faced while writing the thesis and ideas for further research are deliberated here.

First and foremost, it is important to mention that this project work was carried out exceptionally for learning purposes, since there was no commissioning company to outline the entire outlook of the project. Therefore, there might be slight shortcomings in the content and overall subject matter. From the personal perspective of the author, the fundamental goal of learning something new and digging deeper into smart home technology was attained.

The major obstacle for the project results to be more concise was changing of working environment. Due to some circumstances, the author was not able to complete the project in Vienna, and thus the testing was executed with different set of hardware. Additionally, the reporting part was also affected by this change. The common thesis structure and standards for reporting at Wien Technikum was quite different from HAMK's thesis procedure and protocols, so consequently it doubled the workload.

When it comes to the project drawbacks, the vital part of the project purpose, which is to build a customized prototype was not successful. The prototype could have been more detailed, complex, and related to the case study house, its energy situation and building features. However, because of a lack of experience in TwinCAT software, time limitations and above-mentioned location change reasons, the prototype turned out to be rather simple than expected.

As there is always room for improvements, the system could be advanced by simply implementing the cases of use mentioned in this paper. This would be possible in the near future after training and gaining prowess in programming.

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