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SYSTEMS OF AUTOMATION IN SMART BUILDINGS, DESIGN AND IMPLEMENTATION OF A RELAY MODULE

PROSTŘEDKY PRO AUTOMATIZACI INTELIGENTNÍCH BUDOV, NÁVRH A REALIZACE RELÉOVÉHO MODULU

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Prostředky pro automatizaci inteligentních budov, návrh a realizace reléového modulu

POKYNY PRO VYPRACOVÁNÍ:

Práce bude rozdělena do rešeršní a praktické části. Rešeršní část této práce se bude zabývat problematikou automatizace inteligentních budov, tzn. možnostmi a užívanými komponenty. V praktické části pak autor práce navrhne prototyp reléového modulu řízeného ARM mbed LPC1768, který bude dále sloužit jako testovací modul pro další diplomové práce programovacího charakteru.

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ABSTRACT

This bachelor's thesis focuses on smart buildings and their automation. It is divided into two parts – theoretical and practical. The theoretical part of the thesis deals with the division of control and automated systems, thrift and low-voltage systems followed by smart buildings of the future. The practical part of the thesis deals with design of the relay module for the printed circuit board and its testing on breadboard.

KEY WORDS

Smart building, automation, control systems, thrifts, low-voltage systems, relay module, printed circuit board, mbed LPC 1768, breadboard

ABSTRAKT

Tato bakalářská práce je zaměřena na inteligentní budovy a na jejich automatizaci. Je rozdělena na dvě části – rešeršní a praktickou. Teoretická část práce se zabývá rozdělěním řídících a automatizačních systémů, úsporami a slaboproudými systémy následované inteligentními budovami budoucnosti. Praktická část práce se zabývá návrhem reléového modulu pro desku plošného spoje a jeho testováním na nepájivém poli.

KLÍČOVÁ SLOVA

Inteligentní budova, automatizace, řídící systémy, úspory, slaboproudé systémy, reléový modul, deska plošného spoje, mbed LPC 1768, nepájivé pole

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V Brně dne ..... …….....

Petra Bendová

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V Brně dne…….. ……..

Petra Bendová

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Introduction

This work deals with smart buildings and the problems with the automation of these buildings. Nowadays, these smart buildings are more and more expanded. Many people today are trying to save money, especially on energy demands of their homes, offices and factories. Smart buildings can be a solution for the problem of saving, because most technologies are automated and the automation has the advantage of saving the electricity consumption. In the future, buildings that are independent from the electric power from the grid can exist. That may also be good for the environment, because if the electricity requirements are lower, there is no need to produce so much electric power from power plants such as nuclear or combustion.

The whole thesis is divided into five chapters. In the first chapter, the work deals with smart buildings. This chapter is divided into four sub-chapters. The first sub-chapter, called *Smart buildings*, deals with the automation and its types and with the types of control systems. In the second sub-chapter, the work deals with the thrift and the possibility of finding the largest savings in usage of smart buildings. The mostly used components for savings are described in this sub-chapter. The third sub-chapter deals with main basic functions of the building control system. And the fourth one deals with low-voltage systems which are used in smart buildings and with the security help. The thesis deals with the future of smart buildings in the second chapter. This chapter is further divided into two subchapters. The subchapters deal with the division of off-grid systems in buildings. That means how to make the building independent from the electric power from the grid and how the house can produce its own electricity.

The practical part of the bachelor's thesis starts with the third chapter. Components that are used for the design of the relay module, the program in which is the printed circuit board drawn and the microcontroller are described in this chapter. The used components are described how they work and which I choose for my design of a relay module. In the assignment of this bachelor's thesis is to design a relay module for microcontroller mbed LPC 1768, so this part of the thesis deals also with theoretical description of this microcontroller and its peripherals, but before the description of the mbed microcontroller, the thesis deals also with theoretical description of the Arduino microcontroller. It is because the Arduino is the pattern of mbed microcontroller.

In the last part of this bachelor's thesis the design of the relay module on printed circuit board is described. In the fifth subchapter of the third chapter the scheme of the connection of the components is described and it is followed by description of how the individual components work. After this the real testing of the relay module on the breadboard is described and is followed by photographs which were taken during the testing in the laboratory. The bachelor's thesis is closed with conclusion.

1 Smart buildings

Smart buildings are buildings that are automated to save costs and increase the comfort. The requirements of investors and tenants are increasing for smart building control and their energy demands. Owners and operators of buildings require comfort, security, control system, monitoring the energy consumption and the greatest possible flexibility (Automatizace budov - význam a funkce, 2015). However, the setting up of automation systems increases the investment demand of the building. Therefore, the construction of these buildings is accompanied by an extended analysis of future operating costs (Valeš, 2008).

Nowadays people cannot look upon individual professions separately during the designing and the consecutive installing of the technical and energy equipment and during creating the environment of the building. It is necessary to interconnect requirements for energy efficiency, safety technology, equipment and the required level of comfort.

The efficiency is very important. Buildings must be user friendly and comfortable. Any smart house today cannot manage without basic electronics, such as thermostats to control the heating, lightning and security systems. In modern buildings, the automation of blinds and shutters, air conditioning, camera system and sound distribution in some rooms of the buildings can be found.

1.1. The division of control systems

Smart buildings can be divided into offices, homes and factories. According to the type and the usage of the concrete building. In each building, the automation focuses on something different, but the main purpose is the same – to save costs. While in the office buildings, the designers focus mainly on the lights, heating, air conditioning eventually on security systems, in households the comfort of the residents – heating, air conditioning and security systems - is mainly taken into consideration. In factories, it is proper to take into consideration air conditioning, ventilation and heating of the working areas.

These buildings can also, on the basis of their control systems and in terms of their capabilities and abilities, be divided into three basic categories:

a. **Simple systems with fixed communication**

   These systems with fixed configuration allow to implement functions like shielding of buildings, lights, nightfall, heating, air conditioning, ventilation and others with the possibility of a local controlling by the user. These have a dedicated electronic unit with fixed functions. They are particularly suitable for residential buildings, but can also be used for smaller commercial buildings with fewer demands on the control system.

b. **Closed smart buildings**

   It is a sophisticated control system with a lot of options in setting. Their behaviour can thus be adapted to the specific conditions of the installed applications. There is a choice of several operating modes – from preference of control to priority of the user comfort. These are designed mainly for medium and large commercial buildings.

c. **Open and freely programmable systems**

   They can offer the greatest opportunities and the greatest flexibility in implementing user ideas and requirements on the properties and behaviour of for example shielding system. There are no predetermined bonds (they are made up when the system is configured) and it can define the behaviour of each individual element and can also gain the feedback about its current position. Therefore, there is very important timely and accurate definition of the requirements on the properties and behaviour of individual elements.

These systems are the most widely used because of their freedom of usage (Garlík, 2012).

1.1.1 The division of automation systems

Smart buildings can also be divided according to the automation. The automation of building might be technically feasible in several ways. They differ in the principle of the action of the control system at controlled system. From this perspective, it is possible to divide the automatic control into:

a. **Logical**

   Logical control system uses binary variables. Their influence is such that there are always two options, the valve is open or closed, the switch is turned off or turned on etc. Similarly, the information about the state of the object is binary

variables, the level is above or below the minimal value, the temperature is above or below the specified temperature. Binary values are formally expressed as 0 and 1. They are analogous with variables of propositional logic, and therefore the relation between the variables is called logical function. The control circuits which work like that are logical control circuits. Logical control systems are divided into sequential and combinational. The sequential control depends on the previous state while the combinational depends on the current state.

b. Continuous

Continuous control system is a system in which the action incidence is continuously adjusted and the data about the controlled system are measured as continuous variables in time. Continuous control system creates a continuous link between inputs and outputs. All variables of continuous system are continuous in time, none of them are binary or discrete.

c. Discrete

Discrete control system is used extensively today because of the extensive usage of computers as regulators. This control system establishes a relationship between inputs and outputs as a relationship between sequences of pulses scanned in concrete time – so called sampling period. Between the moments of the sampling is not measured the regulated variable and even the action variable is not edited. The sampling period is shorter, the faster the controlled process is.

d. Fuzzy

In the fuzzy control system, there is not the controlled system and its model base, but the attention is focused on a person, who knows how to manage the system but also not know the conception of classical mathematical model of the controlled system. That person then controls the system based on rules such as "if the level drops down, slightly open the water supply" (Garlík, 2012).

e. Higher forms of control

Among these we include neural network, predictive controllers, self-learning systems etc.

1.2 The thrift

As mentioned above, one of the main goals of a smart building is to reduce the energy consumption. It is not only about financial savings, but also about the protection of the

environment. If the buildings use less energy, it is not needed to produce so much energy. The largest part of energy consumption is heating (Valeš, 2008). Almost the most important thing is what is needed for heating and how is the heat extracted. This is particularly influenced by the architectural design of the whole house (e.g. low energy houses or passive houses). Compared to a system that does not regulate heating, the homeowner saves usually about 30% of energy (Valeš, 2008). Many of saving opportunities are based on automation, time schedules, detectors of presence of people and more. In the following sections, there are the options described in detail.

1.2.1 The heating

The most common method of regulation is that there is only one thermostat in the house. And according to this thermostat is regulated the heating in the whole house. But more comfortable and economical way is to regulate heating in each room separately, independently from the rest of the rooms. To this process, it is necessary to ensure the measurement of the temperature in each room by using an electrically controlled valve or head. It is also necessary to design the heating system to allow the regulation of the temperature in the individual rooms. We can then control the heating by an automatic or manual switching between different modes (e.g. comfort, night, damping), by time programs (determine the mode or the temperature according to the time – night, morning, …), by remote control (e.g. switch on the heating before the arrival to house) and by blocking of the heating when the window is opened (to prevent wastage). These modes and time programs can be set for the whole house or only for selected rooms (Valeš, 2008).

1.2.2 The air conditioning

In the air conditioning, all modifications such as air filtration, air heating, cooling, humidification and dehumidification are included. It can also provide ventilation. But for residential building cooling is the greatest function. To achieve the maximum savings, the strategy is almost the same as the saving strategy in heating. The most important are the measurement and regulation of the temperature individually in different rooms using sensors, blocking of the air conditioning when the window is opened, the time selectable programs and the possibility of remote changes if needed. Compared to heating, there is one

essential difference. When heating, we try by the corresponding architectural design to maximize the reduction of heat loss and maximize the heat gain. In the air conditioning, we are, on the contrary, trying to reduce heat gains. These gains may be from solar radiation. To prevent them, it is comfortable to use the passive components – blinds, awnings, plastic films or the use of anti-reflective glass (Valeš, 2008).

1.2.3 The ventilation

The entire volume of air in the room should be replaced within two hours, because of the hygienic requirements. To ensure the optimal exchange of the air and to reduce the energy intensity of ventilation, the mechanical ventilation is used preferably instead of natural. During the mechanical ventilation, it can be used so called recuperation (heat recovery). It means that the air enters the building, it is preheated with hot exhaust air. So, the hot exhausted air is not uselessly taken away as it is with the opened window, but in recuperative heat exchanger transfers most of its heat to the incoming air. Automatic regulation of the amount of air in terms of current consumption can be done through a carbon dioxide sensor, sensor of humidity or sensor of the presence of persons (Valeš, 2008).

1.2.4 The shielding

As mentioned in section *The air conditioning* – in the summer, it is more economical to protect the windows from sunlight and from the heat gain and not rely only on energy consuming air conditioning. It is necessary to shield the windows oriented mainly in southern, southwestern and western side. The most effective are adjustable shading devices that are placed on the outside of the building (e.g. outdoor blinds). The regulation is important to ensure the sufficient illumination of the interior. The automation is facilitated by a motor drive. That, due to continuous movement, does not undue burden the winding mechanism, thus extending its life. If the temperature rises to the set limit, blinds can be started automatically. Closed shutters or blinds reduce heat loss from the building at night. It acts as an additional layer of insulation. In terms of energy savings, it is advantageous for the night, or sleep mode, to automatically close the blinds in the whole house (Valeš, 2008).

1.2.5 The heating of water

The greatest reduction in energy costs for heating the water can be achieved by using the solar collectors. In the annual average, it can cover 50-60% of need, in summer months it can reach 100% of need. In the same way, it is economical and preferable to heat the water in the swimming pool. To lower consumption of water the usage of the thermostatic tap can help. The consumption of the water is also reduced by the automatic temperature control of the outflow of water, which otherwise uselessly flows away during the manual adjustment. So, that water flowed immediately in the required temperature, there should be constantly warm water in the system before the thermostatic tap. This is achieved by circulating of the water by a pump. The circulation increases the heat loss of the piping system, to be more economical it is appropriate to control the circulation by time programming only for anticipated withdrawals. The circulation can be stopped automatically at a time when nobody is in the building and after the house is put into the night mode. This, together with switching off the circulation, suspends the heating of water and there is a more economical mode (Valeš, 2008).

1.2.6 The lightning

In rooms where people reside usually only for a short time (e.g. hallway, basement, storage room, dressing room, etc.), it is economical as well as comfortable switching the lights automatically using the motion sensors or sensors of presence of person. This is possible even outdoors for decorative garden lightning or lightning of access roads. Automatic lightning up is blocked when there is sufficient natural lightning.

In rooms where people reside in longer term, the automatic regulation of light intensity depending on the actual amount of natural light can bring noticeable savings. The system evaluates there the intensity of lightning and artificial light sources only cope the deficit of a daylight.

A manual dimming of lights offers not only agreeable lightning but also savings, because it applies only the light which is needed at the current moment. After turning on the intelligent light dimmers, it can gradually increase the light up to the desired level in a short time. This extends the life of light sources. Not only because of savings but also because of comfort (to prevent glare), it is better during the night to have in automatically switched on

lights at reduced intensity the hallways or in bathroom.

To increase savings, it is economical to evaluate where is the light mostly used and in these rooms, use energy saving bulbs. Nowadays, LED light is also very popular, because it is among the most economical and has many times longer durability than conventional lights (Valeš, 2008).

1.3 The significance and function of smart buildings

Modern equipped building from the perspective of building control is a comprehensive integrated whole in which systems are connected to one communication/visualization platforms. The controlled technology is able to communicate with each other. The heart of the building is clearly a control system called BMS (Building Management System).

Selection of main basic functions of the building control system:

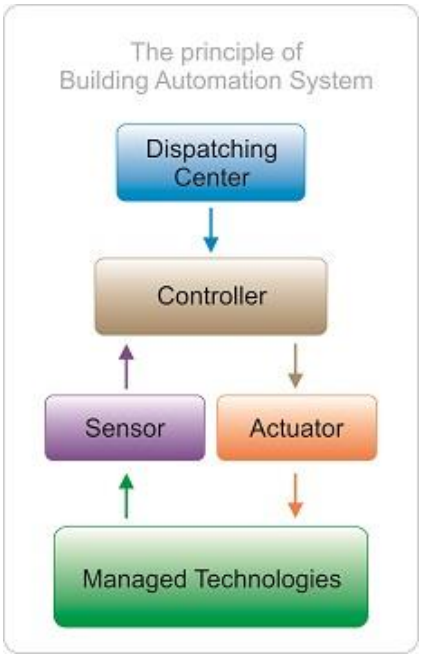

Figure 1 - The principle of building automation system (Automatizace budov - význam a funkce, 2015)

- The control of actuators (e.g. closing of valves, dampers, etc.)
- The data collection from connected systems (e.g. monitoring of valve positions, energy metering data etc.)
- Scanning physical values from sensors (e.g. temperature, pressure, etc.)
- Surveying variations from measured values and control outputs (e.g. comparing the current and the desired room temperature)
- Enter and set commands for controlled technologies (e.g. response to unexpected or critical operating modes)
- Data collection and monitoring of varied values (e.g. for subsequent data analysis and control management decisions)
- Real time control management of technologies (the time value for all technologies is the same)

- Data transfer to other systems (e.g. integration of lightning control management, control of blinds, elevators, access control systems etc.)
- Data archiving and data visualization for operators and maintenance staff (that is a particular feature of control dispatching centre) taken from (Automatizace budov - význam a funkce, 2015).

The main functions of the control centre are collection and archiving of readings or otherwise acquired data (such as automated calculation) and visualization of values and process state (i.e. MMI – Man Machine Interface).

The BMS system often provides links and exchange data with other systems or building technology such as alarm system, access control system, lightning control system, shutters and blinds, power backup system of essential technologies, elevator control, regulation of motors frequency inverters, renewable energy, heat recovery units and powerlines throughout the building.

1.4 Low-voltage systems

Low-voltage systems are widely used in smart buildings. The types of these systems like CCTV, ACS, EPS and more are inscribed in this chapter. These systems are important for the security, access to the building, detection of a fire.

1.4.1 The structured cabling

The basis for the structured cabling is the division of the entire cabling to parts and separate the solution of different parts. This solution is prescribed for individual cable systems by the appropriate description. The most commonly used structure is the tree cabling structure. This structure is derived from the principle of creating telephone networks. In addition to phones, however, other network devices (terminals, computers, etc.) may be connected to the ends of the tree structure (Slaboproudé systémy, n.d.).

The patch panels and an active network components like switches, multiplexers and repeaters are placed in the nodes of the tree structure. Each branch of cabling leads from the connecting field, which is in the node of the network, to a socket in your office or to the subordinated node. The type of equipment that is plugged in this socket is determined by

interconnection of the end of the cable from the socket and the active element on the connecting field. It means that if the active element of computer network and the output of the telephone central are in the node, the socket may be connected either to a computer or to a telephone network. The determination of the socket can be easily modified and it is not necessary to install new cables (Slaboproudé systémy, n.d.).

1.4.2 Electronic security systems

An electronic security signalization is a system of security sensors (detectors) which are scattered throughout the building. Their main goal is to guard the entrances to the building – doors, windows, etc. The electronic security system announces the alert by the transmission of information to the centralized protection. In case of intrusion of the building or the fire, the system announces the alert by a loud siren. It can keep an eye on itself. It means that it can announce the alert in case of attempt to disconnection of the system. The electronic security system is able to run from its own backup power source up to 16 hours in the case of power failure. The motion detectors, the glass break detectors, the smoke detectors and the water detectors are connected to the input of the security system. These detectors are positioned according to the object where they are used (Elektrická zabezpečovací signalizace, n.d.).

Currently, the necessity of protection of physical assets and important data increases. Therefore, the electronic security systems are a common standard of basic structure of the building. The prices of basic components of the electronic security systems are very favourable. The initial costs of installing these systems become a profitable investment with a quick return (Slaboproudé systémy, n.d.).

There are many types of alert. The central (switchboard – alone or sensors or detectors) react with selected alar. to the disturbance of the security system area. The safety system can also use the programmable outputs. It can virtually choose anything. Reactions of the system can by divided into following categories:

- Light alarm (lights in the area, the beacon)
- Sound alarm
- Warnings via computer (doorman or manager present the area, internet)
- Notification via GSM (ringing, SMS)

- Connection to the centralized security
- Police warning (only for government facilities)
- Other types of actions – closing doors, etc.

For each form, individually alert can be then chosen its behaviour – the time lag or immediately run, etc.

1.4.3 CCTV Camera systems

CCTV means Closed Circuit Television. A camera system becomes a part of an alarm system thanks to very rapid development of digital scanning method and image recording. The image is already commonly transmitted in data infrastructure and in a very high quality at a great distance. There is also a digital evaluation of events (such as motion in the camera view) and digital storage and retrieval of records (Slaboproudé systémy, n.d.).

The public television broadcasts are available to anyone, CCTV image is accessible only to those who are involved in a particular CCTV circuit. This system is an important part of protecting the objects (buildings) and can also provide monitoring of the movement of persons, vehicles or various technological processes. The camera system is used for monitoring outdoor areas and locations inside the building. The system may consist of many kinds of cameras from static to revolving ones. It can operate in automatic mode or can be controlled by security guards or another person (Kamerové systémy CCTV, n.d.).

The camera system may be known by the name industrial cameras, which largely reflects the original use of CCTV cameras for industrial applications. Over time, this system begins to be used in education, health care, traffic monitoring and many other fields. They started to be used in the security of various objects and that is why there is many names such as security cameras or industrial cameras (Kamerové systémy CCTV, n.d.).

1.4.4 Time and attendance systems

The entire system consists of one or more hardware elements – attendance terminals. The employees perform the records of arrivals and departures on these terminals. These records are written to the database of evaluation software, which is set according to the requirements of the employer. It records and calculates the hours when employees worked in accordance to the Labour Code. Thus, the detailed processing of attendance of employees

is used for easier calculation of their salary. The access control systems can be integrated with attendance system. Their contribution is to increase the safety of the building and control of movement of persons in the workplace (Docházkové systémy, 2014).

Properly designed and implemented security system can automate the operation of buildings and facilities in terms of continuity of attendance system for electronic security systems and CCTV camera systems.

1.4.5 Electronic fire alarms

The electronic fire alarm is a device that allows early warning and reduction of the amount of damage caused by fire. A frequent cause of fire are non-compliance processes and inconsistent monitoring of safety regulations. The buildings are defended against fires by responsible approach to fire prevention and by using the latest technologies. The early detection of incipient fire is very important. It largely affects disposal of the fire and thus the amount of incurred damages (Slaboproudé systémy, n.d.).

The fire system can consist of a set of equipment that can evaluate the fire situation in the building. It is used for early detection of fire danger and thus consequently to protect persons and property from fire. The early detection of incipient fire often prevents multi-million dollar losses and save many lives. The basic unit of each electronic fire alarm system is central. It is able to operate different amounts of terminal equipment like alarms and detectors (Elektronická požární signalizace - EPS, n.d.).

The electronic fire systems can be divided into three subsets in terms of their architecture:

a. **Conventional systems**

   They are particularly suitable for less demanding applications with a smaller number of end devices. They are usually 1-24 loop. On one loop, there can be connected up to 30 end devices. The main advantage of these systems is their price (Elektronická požární signalizace - EPS, n.d.).

b. **Addressable systems**

   Addressable systems are able to control hundreds of end devices with specific addresses in one continuous (usually circular) loop. Individual groups of alarms or individual alarms can be individually controlled, the threshold of sensitivity can be set and, if necessary can be switched on or off (Elektronická požární signalizace - EPS, n.d.).

c. Wireless systems

Their use is particularly in applications where it is not possible for any reason to install cables, or there is a requirement for portability of the system. Typical installations are mainly historically protected buildings like churches castles and so on. The need for complicated building cable routes and distribution is eliminated in these systems. The installation excels by its speed (Elektronická požární signalizace - EPS, n.d.).

1.4.6 Door phones and video phones

The systems of home phones and videophones increase the safety in controlling who entry the house, apartment building, office, operational and administrative buildings. The basic user system components are internal stations (telephones and videophones) and push-button panels on the building entrance on interior doors. The inbound person performs the selection of the internal station by using a key or by entering a code number. After the identification of incoming person, the resident can click on the device and release the electric lock in the front door. Other features are an intercom or a discreet conversation. The intercom function allows the communication between two or more internal stations. The function of discreet conversation ensures that the conversation the push-button panel and the called station is not allowed to listen in other internal station (Slaboproudé systémy, 2012).

1.4.7 Telephone systems and centrals

The condition for the smooth functioning of any society is not only the high quality of data network but also telephone network or data phone network. Under this term covers not only the outdoor wiring (wiring in the ground or hanging cables), but also the internal telephone wiring or telephone exchanges and active elements in the buildings themselves. The functionality and reliability of classic telephone centrals are combined with the possibilities and applications of modern technologies. The result is an office communication system that provides advanced solutions for phone calls, messaging, video conferencing and effective mobile wireless communications. The building of connections and telephone lines are long-term investment (Slaboproudé systémy, 2012).

1.4.8 The system of uniform time

A system of uniform time should be used where it depends on the time synchronization within the larger complex of rooms or buildings. The typical application of the system of uniform time are educational facilities (schools), medical facilities or large factories or offices. At the headquarters of the uniform time can be connected downstream devices that react to events caused by the headquarters. The typical example is a ringing in school or notification of the end of working hours in the factory. The right time can take care of the subsystem of radio time management.

The system of uniform time consists of signalling autonomous hour (central), manifolds, which can be implemented by a specialized standardized cabling or using structured cabling, by subordinated clock that can be of different types (analogy, digital or with electromagnetic bails) and by an interface for connecting systems (acoustic signalling equipment, attendance system, etc.) (Systém jednotného času, n.d.).

2. Smart buildings of the future

Smart buildings have their place in the future of mankind. The electricity consumption is growing, so people will have to find new way how to save with electric energy. In the future "Off-grid" house will be more and more popular. That means the house is self-sufficient in production of the electricity and is not connected to the grid. There are many ways how to make the building self-sufficient by different types of used technology. Two of the technologies are described in the following subchapters.

2.1. Off-grid systems

The off-grid system is different from normal on-grid system. It is different in the way it is not connected to the grid and the system has accumulators included automatically. Nowadays these systems are built in areas where is not possible to connect to the grid or in the areas where the building of the electrical connector is very expensive. But this kind of system has its own future. Smart buildings may include photovoltaic power plant and be self-sufficient and all the automation of the building may be powered by the electric energy by the photovoltaics or wind power plant.

2.1.2 Photovoltaic off-grid system

The basic components of photovoltaic off-grid systems are photovoltaic panels, charging regulator, overvoltage protection (circuit breaker), accumulators and inverter and of course the appliances. The photovoltaic panels are plugged into the charging regulator and the regulator is connected to the accumulator or to the system of accumulators. The regulator controls the charging voltage and current from the solar panels to match to the recommended values and it also includes monitoring of the capacity of the accumulators – disconnect the solar panel if the accumulator is overcharging and in case of deep discharge, it disconnects all appliances and the loads. The inverter allows us to use normal household appliances that run on 230V (Jak funguje ostrovní fotovoltaický systém?, 2015).

2.1.2 Wind power plant off-grid system

The wind power plant has the same basic components as the photovoltaic one, except the photovoltaic panels. The wind power plants have wind turbines – vertical or horizontal. Horizontal wind turbines (classic blades) are dependent on the wind direction, because the rotor must be rotated according to the wind direction. This kind of turbines often produce lot of noise. Vertical wind turbines need a relatively small and permanent place and they are very quiet during the operation. They are a little less powerful than horizontal, but they are not dependent on the wind direction. They can also use the variable wind and flow around buildings or roads, including gusts from passing vehicles (Vintr, 2015).

3. The design of the printed circuit board

This chapter deals with the description of the Eagle program that is used for creating a scheme and a printed circuit board with power traces. Also, individual components which are used in the design are described in following subchapter as well as the scheme and the testing of the relay module on the breadboard.

3.1. The Eagle program

This part deals with the features of Eagle. The name of this program is an acronym of Easily Applicable Graphical Layout Editor.

The Eagle is one of the most popular international design systems for electronics. The program comes in three versions: Light, Standard and Professional. All versions are identical, but Light and Standard versions have limited the maximal dimension of the printed circuit board. The Eagle program consists of three separate modules – Editor of schemes, Layout editor and Autorouter. (Kraus, n.d.)

3.2. Used components

Components used in the design of the relay module are described in this chapter. One of the component is a microcontroller mbed. This chapter also deals with this microcontroller and its pattern Arduino. Used components are mbed microcontroller, transistor, resistor, relay, LED diode, and Schottky diode. The transistor and relay are described with their working cycle.

3.2.1 The transistor

A bipolar transistor is an electronic component that is made up of three semiconductor regions with different types of conductivity in NPN or PNP configuration that then form a pair of PN junctions. The transistor has three electrodes, namely base (used to control the transistor), collector and emitter. The base is much thinner compared to other electrodes. The emitter is more powered than the collector with the same type of conductivity. The transistor is used as a signal amplifier or as a switch. It is also part of many other devices

such as logic circuits. The use of unipolar transistor is predominant in complex integrated circuits (Vzdálená internetová laboratoř, n.d.).

Digital transistors are transistors suitable for use in digital technologies. It means that they are typically in operation primarily in two stages: open (conductive and closed to saturation) or closed (completely non-conductive). Functionally, the digital transistors have similar requirements as switching transistors – low current and power, sharp characteristics, small capacities, and fast transition from open to closed state and vice versa. In fact, it is nothing but small switching transistors, only one thing is different. (Černý, 2015)

In most cases, when using transistors in digital technology, it is necessary to connect resistors in series to the base, because it is necessary to convert the control voltage to a current reasonable size. And because the transistor needs to be reliably closed, another resistance is necessary to connect between the base and the emitter. It is unnecessary to put this combination of three components over and over again on a printed circuit board when the two resistors can be added to the transistor structure in the production. This created a "digital transistor". It is nothing more than a transistor supplemented by the resistors and enclosed in a standard three-way housing as we can see in Figure 2. (Černý, 2015)

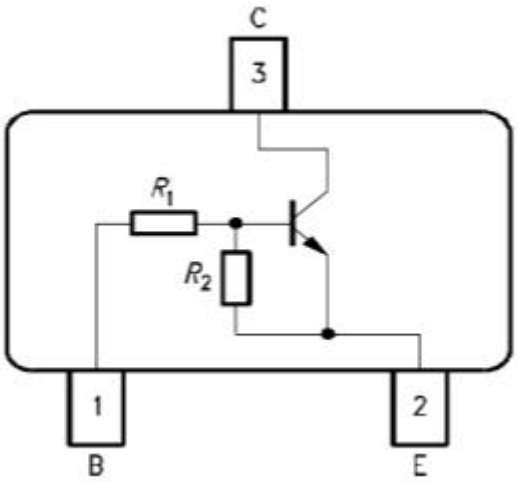

Figure 2 - Digital transistor in SOT23 case (Černý, 2015)

In my design of a printed circuit, I used digital transistor BCR523E6327. This transistor has conductivity type NPN. The transistor had to be soldered to a small board, because it has not got pins that are important if the component is tested on the breadboard.

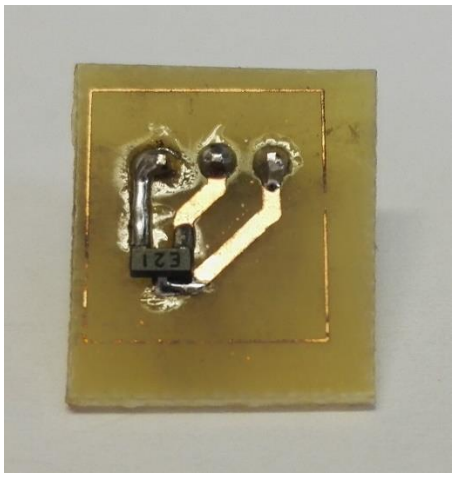

Figure 3 - Digital transistor BCR523E6327

3.2.2 The electromagnetic relay

The electromagnetic relay operates on the same principle as a contactor. The relay is a device for switching or disconnecting electrical connections. The electromagnetic relay is, as the contactor, designed for switching the power. The principle of electromagnetic relay – when the voltage is applied to the switching relay, a magnetic field arises and an anchor with movable contacts is attracted. The flexible contacts connect to the fixed contacts or interrupt existing connections, or they interrupt existing connections and connect to other fixed contacts. I use JQX-14FC1 CS10 DC5V 0.53 3.5 which is relay with DC coil.

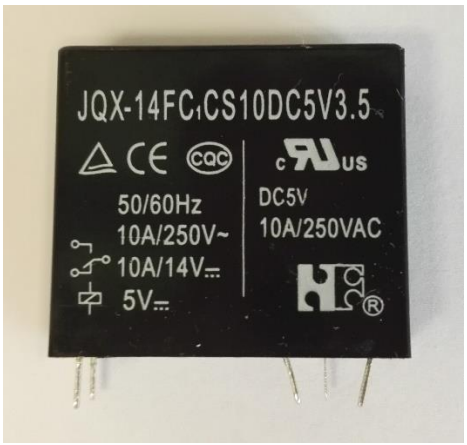

Figure 4 - The JQX-14FC1 CS10 DC5V 0.53 3.5 relay

3.2.3 The LED diode

LED (Light emitting diode) is an electronic semiconductor component that contains a P-N junction. If the electric current passes in the permeable direction, the junction emits an incoherent light with a narrow spectrum. It can also emit other types of radiation. This phenomenon is due to electroluminescence (Co je to LED dioda?, n.d). I used normal blue LED diode, but for the printed circuit board is ideal LED 1206 BLUE 100/120° OSBL1206C1A_N.

3.2.4 The resistor

The resistor is an electronic component that resists electric current flow. Properties of this component results from Ohm's law. The voltage on the resistor is generated by the passing of the electric current and the voltage drop is proportional to the resistance value. The higher the value of resistor is, the smaller the current and the higher voltage is on the resistor. (Rada, 2015)

3.2.5 The Schottky diode

The Schottky diode is a component that uses the rectifying property of the MN junction (metal-semiconductor). A great advantage of this junction is that there is no injection of minor charge carriers. The current flow is realized only by the majority of carriers, which brings a number of advantages. Schottky junctions have lower voltage drops in the straight line than the PN junctions. From the semiconductor N, the so-called hot electrons from the top of the energy barrier pass into metal and in the metal these electons lose excess energy. This predetermines the Schottky diode to process high-frequency signals (Druhy diod, n.d.). I use the Schottky diode to discharge the coil at relay when the relay is not closed.

3.3 The Arduino

The Arduino is the most widespread platform in the word. It offers different types of boards from less powerful and smaller models to complete systems featuring USB, HDMI, Ethernet, or audio ports.

The development of the first Arduino began in 2005 when people from the Italian Interaction Design Institute in Ivrea decided to create a simple and inexpensive development set for students who did not want to purchase the BASIC Stamp, which is widespread but expensive. Arduino catch up among the students and the creators decided to give it to the whole word. Not only by selling their own boards, but also by sharing all the schematics and tutorials (Open Source project). The program part of Arduino is based on Processing, a programming language with its own editor, designed to teach programming. Several hundred thousand Arduino boards have been already sold. The evidence that this platform is not dead shows the recently announced development of new and powerful Arduino Galileo. This is being developed in cooperation with Intel (shown in Figure 5).

Figure 5 - Arduino Intel Galileo (Voda, 2014)

A number of different types of Arduino was created during eight years of development. Because it is an opensource project, a number of unofficial types of so called clones were created along with the main line of Arduino project. (Voda, 2014)

Perhaps the most well-known and most widespread project that uses Arduino compatible pin boards to a large extent is the mbed project which is led by ARM company. The mbed project is very similar to the Arduino project. The programmer does not have to deal with application specific implementation details for specific hardware, but he uses higher level libraries. The mbed project is aimed at processors from the ARM Cortex family. For mbed boards, an online editor and compiler are available. The compiled code downloads

to the computer and then uploads to the development board, which behaves as another disk after connecting to your computer.

Boards that are pin-compatible with Arduino and support mbed are already available very much. These boards are often cheaper than the original Arduino and offer more options. (Bechynský, 2015)

3.4 The ARM architecture

I design the printed circuit board to be controlled by the mbed microcontroller. The mbed microcontroller belongs to the ARM architecture, so this chapter deals with this kind of architecture. The ARM is a family of 32-bit microprocessors designed according to the RISC concept. Their boom began in the 1990s and now it belongs among the most widespread in the number of pieces produced in the world. They are used in many consumer electronics applications, from calculators, mobile phones to powerful game consoles, tablets or PCs. Due to their features, they are also widely used in embedded systems. The ARM processor approach is to integrate as few transistors as possible compared to the competitors and thereby to achieve low power consumption. For this reason, these processors are often deployed on battery-powered systems.

The basic characteristics of ARM processors can be summarized in several points that follow:

- 32-bit architecture and 32-bit data bus
- Load/store architecture – To perform an arithmetic-logical operation, the operands must first be loaded into the registers. After performing the operation, the result can be recorded back to the memory. Most instructions work only with registers.
- A set of sixteen 32-bit registers for all ARMs
- Two address modes – The usage of the instruction counter or base addresses in the registry
- Two levels of interruption priorities
- Powerful and efficient instruction set for compilers of higher programming languages.

3.4.1 The basic description of the development board

This development board is designed for connection to a breadboard with 40 pins that are corresponding to the DIP housing pin assignment. It features a built-in USB programming interface that behaves like a classic flash drive when it is connected to a computer. To upload a new program, it is necessary to copy the compiled program in the .bin format and then reset the device. This copies the program to the internal memory and start it. With this solution, we can work with the development board on Windows, MAC OS or Linux operating systems without installing special drivers. A free integrated online compiler is available on the manufacturer's website for developing programs directly. However, it is more advantageous to use development environments such as Keil uVersion or Code Red for more effective software development.

The board is based on the ARM Cortex-M3 core running at 96 MHz. It further contains 512 KB Flash, 32 KB RAM, and a large number of expanding peripherals, such as Ethernet, USB, UART and other. These peripherals are output to the board output. Pins from P5 to P30 can be used as digital input or output. Figure 6 represents the basic description of the development board (Libicher, 2013).

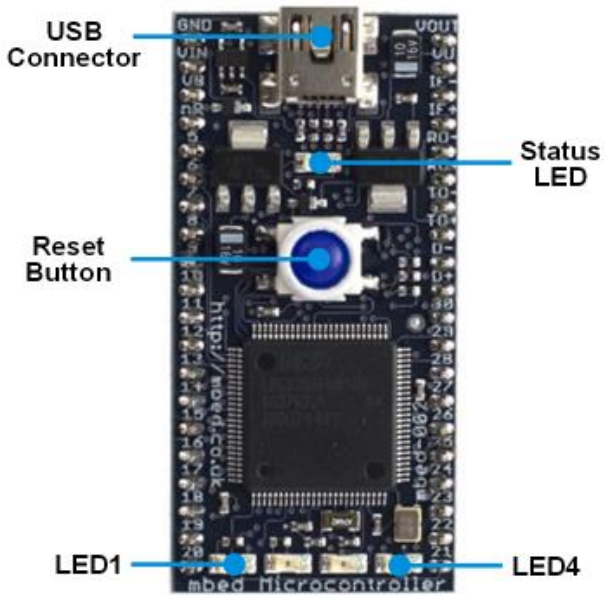

Figure 6 - The basic description of the development board (mBed NXP LPC1768 Downloading, n.d.)

3.4.2 The periphery of the board

As mentioned above, the board provides a large number of peripheral circuits. These circuits can be divided into several categories. Mbed has a large amount of serial peripheral interfaces, which I mention as first. These serial peripheral interfaces include SPI, I2C and UART. Through these interfaces, it is very efficient to communicate with other integrated circuits, such as EEPROM memory, external A/D or D/A converters, displays and many other circuits. The use of these interfaces can very effectively simplify the design of the device instead of using parallel communication. Another group includes circuits for analogy circuitry. For these purposes, A/D or D/A converters are used. The AD converter on the board operates on the principle of sequential approximation with a resolution of 12 bits and a maximum sampling period of 200 kHz. To control analog devices, a 12-bit D/A converter is integrated on the board, on which it is possible to set the output voltage in the range 0 to 3.3 V. As can be seen in Figure 7, the converter has only one channel output to pin P18. In this group is also included a pulse width modulation (PWM) circuit that can replace the D/A converter in many applications, especially for example when needed to ensure the drive control. The last category includes the interface mostly used for communication with the superior system, such as USB and Ethernet. It is also important to note that the board producer offers downloadable libraries for easy operation of all the above-mentioned C++ peripherals, which greatly simplifies their operation.

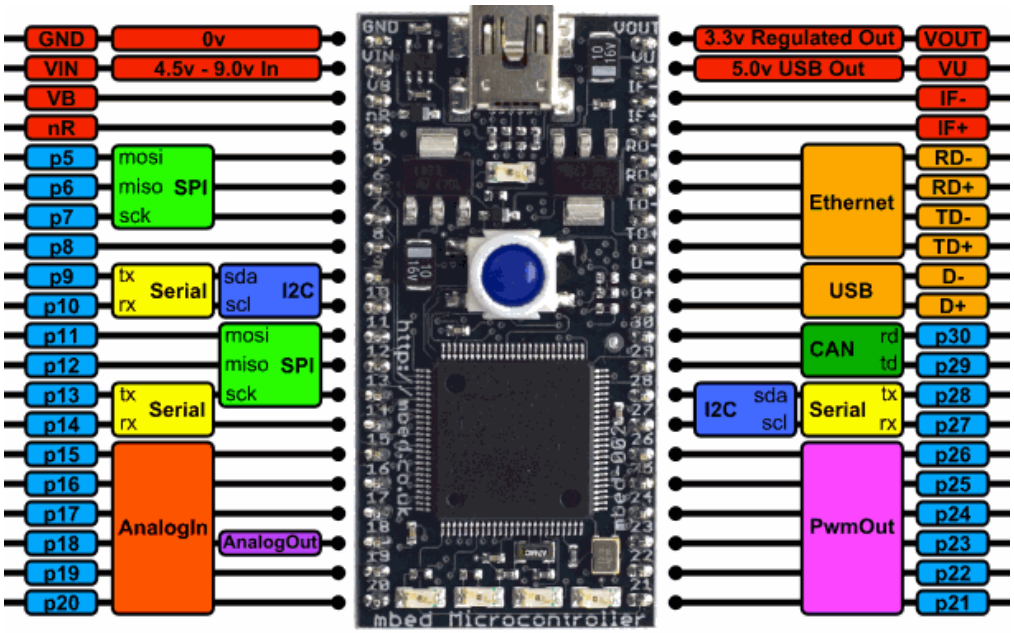

Figure 7 - The peripherals of the mbed (mBed NXP LPC1768 Downloading, n.d.)

3.5 The scheme

The circuit is permanently powered by voltage of 5V (shown in the top of Figure 8). The voltage from mbed microcontroller serves as a control signal for switching the relay. In the idle state, the relay switch is in position 0, the voltage from the microcontroller is also 0. Since the voltage is from mbed 0, the transistor is closed and hence the LED diode is off. When mbed changes the voltage level to 3.3V (the output pin at the control microprocessor is set to 1), the transistor opens. The transistor here works as a switch. After switching, the transistor is in saturation. The current begins to pass through the relay coil. The coil creates an electromagnetic field and pulls the contact in position K. The LED diode lights up, it indicates that the relay is closed. The resistor act as a protective resistance for the diode. The Schottky diode is parallel to the relay coil due to the voltage peak. The voltage peak is generated when the transistor is switched on and off. The voltage peak has the opposite polarity in comparison to the supply voltage and it could destroy the switching transistor. That is why I used the Schottky diode – as a protection. This circuit is galvanically isolated, therefore this circuit can also switch the electrical main voltage. It is important to pay attention to the parameters of the relay (maximum current and maximum voltage).

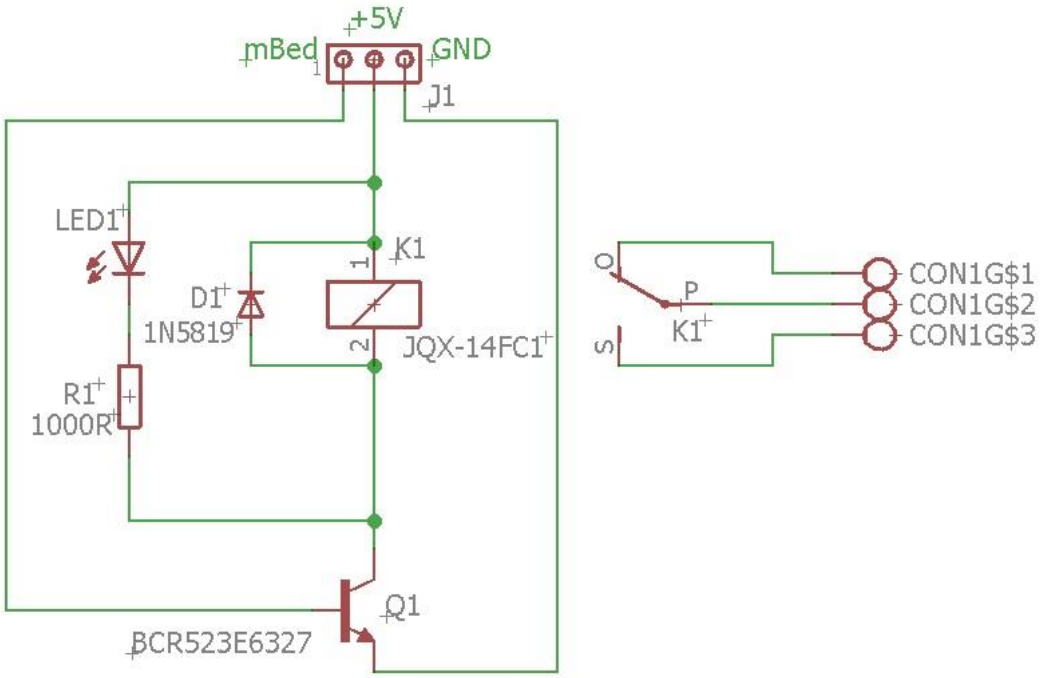

Figure 8 - The scheme

Figure 9 shows a mounting plate. It shows how the components are placed on the board.

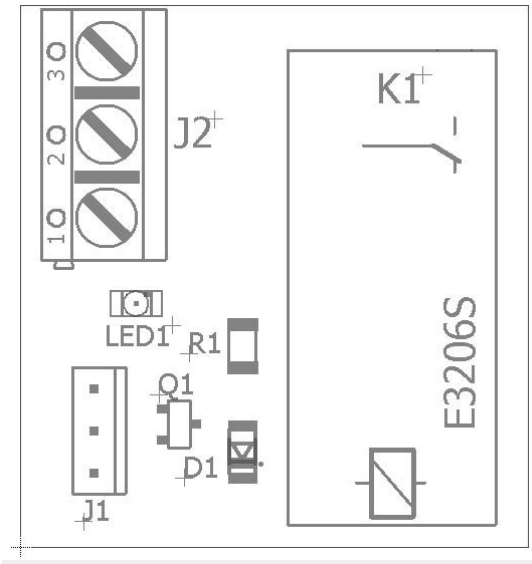

Figure 9 – The mounting plate

The power traces on the printed circuit board are shown in Figure 10. The power traces which are connected to the armature of electromagnetic relay are thicker because it is more efficient when the relay can switch 5V.

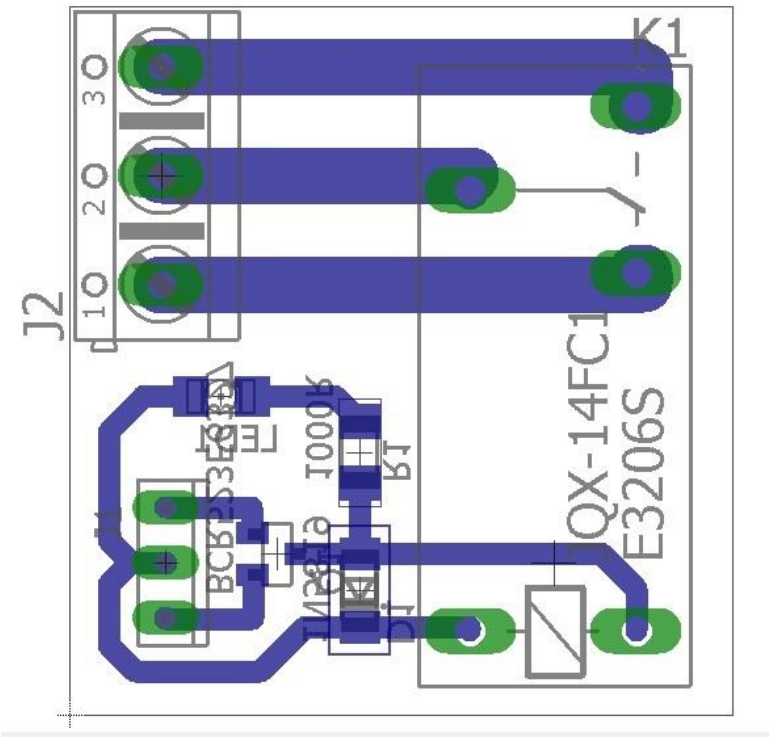

Figure 10 - Board with power traces

3.6 Testing the design on the breadboard

My task first of the practical part is to design a printed circuit board for a relay module and second to test it on the breadboard. But before I started to connect the components according to the design, I had to calculate some parameters. At first, I had to calculate base current I_B:

$$I_B = \frac{V_E - V_{BE}}{R_B}$$

Where:

V_E ……. is the voltage that enters the transistor and is equal to 3.3V,

V_{BE} ……. is the voltage drop between base and emitter and is equal to 0.65V,

R_B …….. is the base resistance and is equal to 1000Ω.

The parameter V_E is a value that goes from the mbed microcontroller. The parameters V_{BE} and R_B can be found in the datasheet of the transistor.

$$I_B = \frac{3.3 - 0.65}{1000} = 0.00265A$$

When we know the base current, we can calculate the collector current I_C:

$$I_C = h_{FE} * I_B$$

Where

h_{FE} ……. is an amplification factor of transistor and is equal to 70.

This value can also be found in the datasheet. Now all values are known and it is possible to calculate the collector current:

$$I_C = 70 * 0.00265 = 0{,}1855A = 185.5mA$$

Now I know that this current will flow to the relay and it can switch the relay on. So, I can connect the components on the breadboard as it is shown in Figure 11.

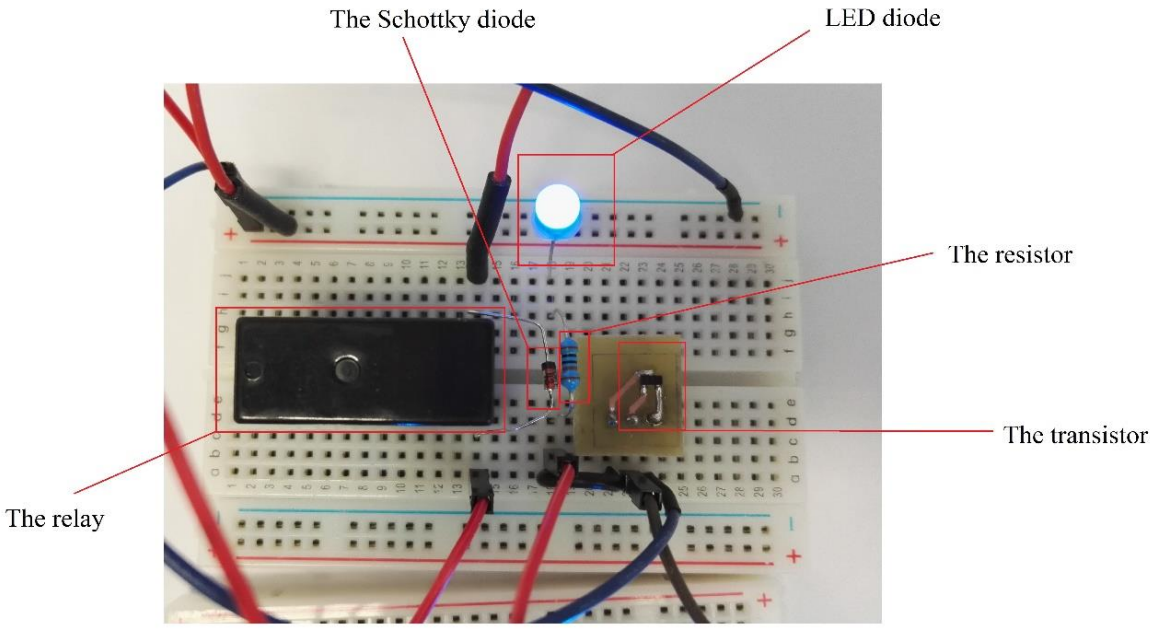

Figure 11 - Connected components on the breadboard

In Figure 12 is shown that after the connection, the LED diode lights up. That means the circuit is closed without problems. After connection, a click was heard – the relay closes the circuit and then the LED diode lights up.

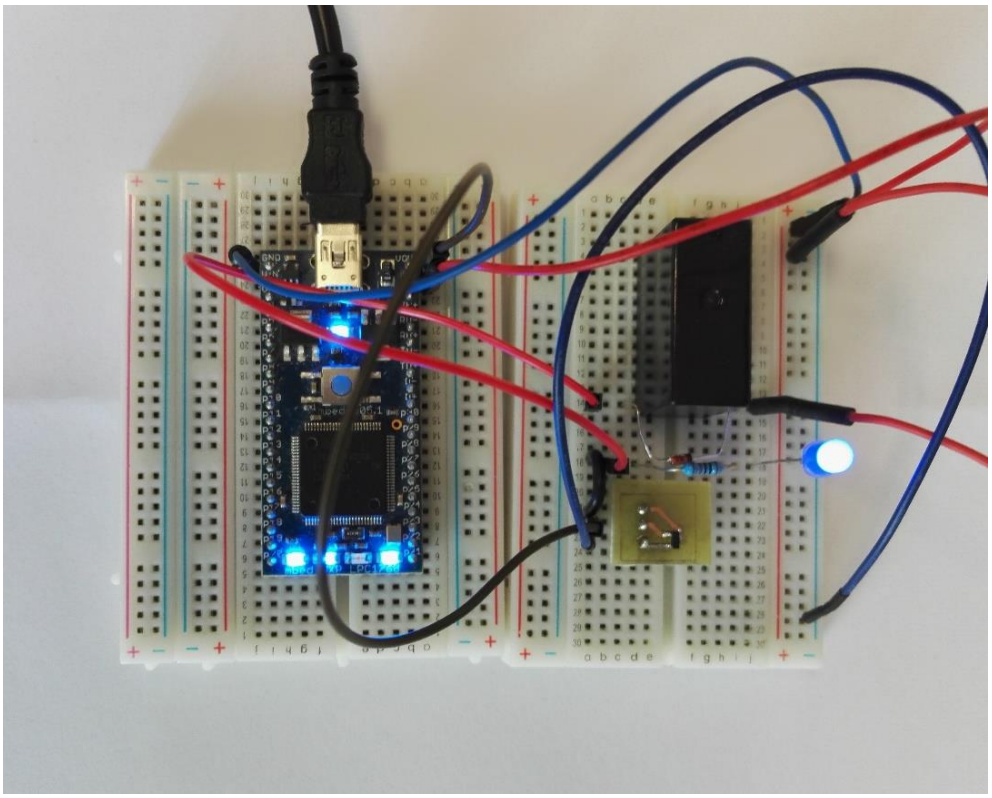

Figure 12 - Testing on the breadboard

Pictures, that are in Figures 3, 4, 11 and 12 were taken by myself during the testing of the relay module in the laboratory.

4 Conclusion

The aim of this work is to design a relay module for printed circuit board and test in on the breadboard. It contained the design of appropriate placement of the components, because it is better to have the printed circuit only on one side of the board (top or bottom) for better clarity.

This work deals with smart buildings and the problem of automation. The first chapter deals with thrifts. Many ways how to save electric power are described in the first chapter. Not only savings are there, but also the division of control systems are described there. In my opinion, it is important as one of the first things to choose the control system. Then it is possible to design whole building for the requirements of tenants. Low-voltage systems that are also described in the first chapter, are important for the security of the building. Nowadays is a big advantage to have the house protected from thieves by cameras and security systems such as alarms. Smart buildings of the future are described in the second chapter. In my opinion, it will not take long time to become it a reality. Nowadays many people want to save their money and when they decide to build a house, many of them think about smart building, because it is saving not only of their money, but also of their time.

In the second part of this work, the design and testing of the relay module is described. When I started to design, there were many problems to solve. I had to solve which components are the best and work together without any problem. I added a Schottky diode to my original design, because when is the relay switched off, the diode discharges the coil in the relay. After I designed the schema in the Eagle program, I tested it on the breadboard. It works without any problems; LED diode lights up and a sound of click was heard and it means that the relay switched on and everything works.

The relay module can be used in smart buildings to control everything that can be programmed to mbed such as lights, shielding, heating etc. This bachelor's thesis can serve as a test module for further diploma thesis of programming character.

5 Appendix

Appendix contains List of Figures and Bill of material. On the enclosed CD is this bachelor's thesis in PDF file and scheme including a board design in Eagle program in WinRAR file.

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5.2 Bill of material

Manufacturer's identification	Pcs	Value	Package	Abbreviations	Description
BCR523E6327	1		SOT23	Q1	Digital transistor, NPN, bipolar
JQX-14FC1 CS10 DC5V 0.53 3.5	1	5V/10A	E3206S	K1	Electromagnetic relay
OSBL1206C1A_N	1	3V/30mA	1206	LED1	LED diode
RC1206FR-07120RL	1	120R	R1206	R1	Resistor
BAR43C	1	30V/0.2A	SOD80	D1	Schottky diode

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