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Lighting Control

Possibilities in Cost and Energy-Efficient Lighting Control Techniques

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Lighting control
– possibilities in cost and energy-efficient lighting control techniques

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Abstract

In a modern society there is a constant increase in electrical use but at the same time the environmental awareness among consumers is rising. This master theses aims at investigating the possibilities in cost and energy-efficient lighting control techniques.

This master thesis is written for the Measurement Technology and Industrial Electrical Engineering division, IEA, within the Faculty of Engineering of Lund University in cooperation with AB Regin in Landskrona.

Lighting control systems are studied from an energy saving perspective and the relation to reduction of carbon dioxide emission is addressed. Designing tools, such as LENI and ELI, are introduced and their relation to international standards in electrical and lighting design. To illustrate the cost efficiency of lighting control systems, a case study is conducted at Schenker logistics in Växjö, revealing the payback time of the lighting control installation.

A market study is carried out, where available lighting control systems are investigated. Different protocols are compared based on parameters such as data rate, power consumption and cost. The aim of this study is to select one existing system to be implemented on one of AB Regin's platforms. For this purpose a selection criteria is composed.

Digital Addressable Lighting System, DALI, is chosen for implementation along with the EXOcompact controller from AB Regin. The implementation deals with building an interface between the EXOline, used by AB Regin, and the DALI line, defined by the DALI protocol. A DALI Master Unit is built around an Atmel ATmega186 microprocessor and some testing of sending messages from the EXO system to a DALI enabled lamp is performed.

Based on the case study conducted and other sources, the cost and energy-efficiency of lighting controle systems are proven. The concept of controlling lights from AB Regin's EXOSystem is also proven with implementation and testing.

Preface

This report is a result of my master thesis project carried out at AB Regin, Landskrona with supervision from Industrial Electrical Engineering and Automation (IEA) at Lund University, Faculty of Engineering. The work was carried out from May to December 2009, and during this time I have received help from many persons. The people I want to thank especially are:

Jonas Möller, my supervisor at AB Regin, Landskrona. For his endless enthusiasm for this project, which has been very inspiring and given me the extra power sometimes needed. Without his unselfishness regarding his limited time, this work would never have gone so smoothly. Thanks Jonas.

Lars Mattsson at AB Regin, for his tremendous help with protocols and microcontroller programming.

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Gunnar Lindstedt my supervisor at LTH, for the confidence he showed in me when appointing me for this work and all the help he has provided.

Finally, I would like to thank my family and friends for their support during my university studies.

Lund December 2009

Gudmundur Benediktsson

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Abbreviations

CO_2	Carbon dioxide
ADU	Application Data Unit
ASHRAE	American Society of Heating, Refrigerating and Air-conditioning Engineers
BACnet	Building Automation and Control Networks
BAS	Building Automation Systems
C	A general-purpose computer programming language
CPU	Central Processing Unit
CRI	Color Rendering Index
DALI	Digital Addressable Lighting Interface
DSI	Digital Signal Interface
ECG	Electronic Control Gears
EEPROM	Electrically Erasable Programmable Read-Only Memory
EHS	European Home Systems
EIB	European Installation Bus
ELI	Ergonomic Lighting Indicator
FFD	Full Function Device
HMI	Human Machine Interface
HVAC	Heating, Ventilation, and Air-Conditioning
I/O	Inputs / Outputs
ISO	International Standards Organization

KNX RF	KNX Radio Frequency
LAN	Local Area Network
LED	Light Emitting Diodes
LENI	Light Energy Numeric Indicator
LON	Local Operating Network
MAC	Medium Access Control
MPDU	MAC Protocol Data Unit
MS/TP	Master-Slave/Token-Passing
OSI	Open System Interconnection
PDU	Protocol Data Unit
PHY	PHysical Layer
PICS	Protocol Implementation Conformance Statement
PPDU	Physical Protocol Data Unit
PTP	Point-To-Point
RFD	Reduced Function Device
RTU	Remote Terminal Unit
SRAM	Static Random Access Memory
USART	Universal Synchronous Asynchronous Receiver Transmitter
XML	eXtensible Markup Language

Chapter 1

Introduction

130 years ago, when Thomas Edison demonstrated his invention of the incandescent light bulb, he said: "we will make electricity so cheap that only the rich will burn candles" [51]. Unfortunately the non-rich are still burning candles and the electrical energy cost is still a significant part of the total operational cost of buildings. With increasing use of electricity for lighting some action must be taken in order to reduce the cost.

1.1 Objectives

The objectives of this master thesis is to provide a general understanding of cost and energy efficient lighting control techniques. To make an in depth analyze of some of the most common lighting control protocols and compare them with one another. The final objective of this thesis is then to implement a lighting protocol on one of AB Regin's platforms.

1.2 Background

AB Regin was established in 1947 and the first product, a humidistat, was launched. In the early 70s, Regin's first controller was introduced. It was intended for electrical heating and since then there has been a constant development of controllers and sensors within Regin. From the establishment of the company it has always aimed at providing the customers with good levels of indoor comfort. One of Regin's goal is to be a leading supplier of solutions that contribute to improved energy consumption and sustainable development. It is therefore a natural step towards this goal to expand into other fields of building automation. In the beginning of 2009, AB Regin contacted LTH offering a master thesis work for a student in the field of automation. This thesis and its result is therefore a step for AB Regin towards its goal.

1.3 Methodology

The thesis is divided in three phases, where the result of each preceding phase, forms the base for the next one. Starting with *Empirical study on the potential of lighting energy savings by use of different control systems* provides the necessary knowledge to select candidates for the next phase, the market study. The *market study* then utilizes the knowledge gained from the empirical studies to make an analysis and comparison of the major lighting control protocols on the market today. The comparison of these protocols then provides the motive for the selection of one protocol to be the implemented on one of AB Regin's technical platforms.

1.4 Outline

The report is divided in the following way:

- Chapter two provides a technical background for further reading. The most common light sources and their properties are examined and compared. The basic properties of lighting control systems are defined and the most common procedures of such systems are demonstrated.
- In Chapter three the lighting control systems are studied from an energy saving perspective and questions regarding their efficiency, how they relate to carbon dioxide emission and how they appear in standards and regulations are addressed. Chapter three aims at answering the questions; what types of light sources can be controlled and what the main controlling strategies are.
- In Chapter four the available lighting control solutions on the market are investigated. Different protocols are compared with respect to parameters such as data rate, power consumption, versatility, cost, etc. At the end of Chapter four, the available solutions are evaluated and one selected as the candidate for implementation on one of AB Regins platforms.
- Chapter five describes the implementation of the chosen lighting protocol on AB Regin's platform. Individual steps of the implementation are described with text and schematics and finally a result will be presented based on testing of individual parts and overall performance.

Chapter 2

Technical background

In this chapter some technical background to lighting systems and lighting control systems will be provided. The most common light sources will be introduced and compared with respect to some key factors. The different approaches in lighting control systems will be introduced and evaluated with respect to factors such as simplicity, cost and efficiency. This chapter is intended to provide the reader with sufficient knowledge to be able to easily read the following chapters.

2.1 Lighting systems

One important thing in every building is the lighting system, whether it is a window passing the sunlight into the room or a lamp lighting it up. But having some amount of light is just not enough, the lighting system has to fulfill some characteristics to provide us with the right Illuminance (lux, lm/m^2), colour temperature (Kelvin) and colour rendering index, CRI. The CRI is often denoted as R_a and indicates how accurately the light source renders colours compared to the ideal light source[1][45].

2.1.1 Light sources

When lighting up a building there are numerous light sources available, both natural and artificial. In the subsections below, some of the most common ones will be introduced.

Daylight

The first and most desirable light source is the light from the sun, here referred to as daylight. The sun is in fact a huge nuclear fusion reactor, which radiates energy by its high surface temperature, approximately 6000 °C.

[1] Black bodies such as the sun or tungsten-halogen lamps render colours accurately because they emit a continuous spectrum.

One of the most desirable properties of daylight is how wide spectrum of wavelength it spans, from long wave infrared (about 1500nm) to ultraviolet (350nm). This gives a colour rending index R_a of 100, which is the reference value as mentioned in the previous section. It is therefore desirable that the artificial light sources have the same properties as daylight [2, p.21].

Incandescent lamps

The incandescent light bulb, better known as the conventional light bulb is the type of lamp we can expect to find in most homes but has almost disappeared from office buildings and factories. This lamp is constructed with a very fine wire that is sealed of by a glass bulb and when electricity runs through the wire it heats up and emits light. The disadvantage with this light source is that only around five percent of the electrical energy consumed is converted into light and the rest emitted as heat. This makes this type of lamps the least luminous and energy efficient. Because of this, many countries have decided to eliminate this type of lamps by setting legislation to prohibit their sale and thereby enforce the transition to more energy efficient alternatives. The advantages of the incandescent lamp is its price, its pleasant warm light, the fact that it do not need any extra equipment to operate and how easily it can be dimmed to give different light output [40, 25]. In Table 2.1 [17] we see how the EU has set a regulation that will within the next three years eliminate these old types of incandescent lamps.

Date	Action
01.09.2009	Ban on sale of incandescent lamps 100W and above, and all frosted incandescent lamps.
01.09.2010	Ban on sale of incandescent lamps 75W and above.
01.09.2011	Ban on sale of incandescent lamps 60W and above.
01.09.2012	Ban on sale of incandescent lamps 40W and below.

Table 2.1: The EU phase out of incandescent lamps.

Compact fluorescent lamps

Due to the low energy efficiency of the incandescent lamps and the fact that they will eventually be banned in many countries, producers have come up with some alternatives. One of these alternatives is the compact fluorescent lamp, which can be used to replace almost any incandescent lamp. The main advantages of the compact fluorescent lamp is that it lasts up to 15 times longer than the incandescent light bulb and it consumes around 80% less power for the same amount of light. These lamps are a type of fluorescent lamps with a built-in electronic ballast and starting equipment. The lamps have evolved greatly in the last years and are now available in a broad variety of design, colour temperature, colour rending index and of course price. Older versions used to be equipped with magnetic ballast which made a buzzing sound, startup time was long and they did not look so good, but now many of these things have been fixed and these lights are quite competitive with other types of lamps. Not all types are however dimmable nor suited for rapid on/off switching. The fact that these lamps contain mercury has been one of the things that consumers find hard to accept, since these lamps are mostly used as a replacement for the incandescent lamp in peoples home [33].

Fluorescent lamps

The fluorescent lamp is the type of lamp that accounts for a greater amount of artificial light produced than any other (about 70%). This lamp uses the same principles as the compact one, mentioned previously, except that the ballast is not a part of the actual lamp. Therefore it is possible to make all sorts of combinations with lamps and ballasts. The glass tube is filled with gas and a small quantity of mercury. The tube is coated with a thin phosphorous layer and the ends of the tube are the electrodes. When electricity passes between them a mercury vapor emits UV radiation. When this radiation hits the phosphorous it emits visible light with a colour that varies with different phosphorous mixes. Fluorescent lamps are very energy efficient and only need around 15% energy of an incandescent lamp and have a very long lifetime. A great effort has gone into the development of electronic ballasts for this type of lamps and therefore they are dimmable and the ballasts are in fact a major part of modern lighting control. Because of how popular these lamps are they are available in many variations regarding colour temperature and colour rending index [25].

Halogen lamps

The halogen lamp is known for having a much higher luminous intensity than that of the incandescent lamp. It is this type of lamp, along with the daylight, that sets the reference value for the colour rending index, as they have such a wide colour spectrum. This is the reason for how popular they have been in spot lighting, lighting in exhibitions, in shops, offices, hotels and of course throughout the home. One of their advantages is the lifetime which is as much as five times more than that of an incandescent lamp. Following the elimination of incandescent lamps they have become an alternative with their easy dimming and feel-good light [25].

High intensity discharge (HID) lamps

This group includes sodium vapor, mercury vapor and metal halide lamps. All these lamps are so called discharge lamps and like other gas filled lamps they require a special ballast and fixture depending on type and power rating. Unlike the fluorescent lamp these lamps require a warmup period. HID lamps have mostly been used for outdoor lighting such as street and arena lighting or as factory lighting. They are active for long periods due to the warmup and sometimes cool down time required. Another thing these lamps have in common, beside being discharge lamps, is their great energy efficiency where the sodium vapor lamp is dominating, which is almost twice as efficient as the fluorescent lamp. The disadvantage of sodium lamp is that it has very little colour rendering and shorter lifetime than any other HID lamp. The mercury lamp has better colour rendering but the lowest efficiency of all HID lamps and even lower than Fluorescent lamp. The metal halide lamp has similar colour rending as mercury lamp but much better efficiency, which is about 20% better than that of Fluorescent lamp [40].

LED lamps

Light Emitting Diodes (LED), which are often referred to as the light source of the future, are one of the potential replacement of the incandescent lamp. Based on the semiconductor technology, which has been a hot topic for the last decades, these lamps have evolved at great speed regarding power consumption, colour saturation and compactness. LED lamps are superior to conventional lamps in many ways, such as energy efficiency, wide colour palette and excellent colour saturation but also the fact that they have such compact dimensions that they can be fitted in almost any structure [40]. More and more producers and suppliers are betting on LED as the light source of the future. One of them is the European service company YIT, a leading company in Nordic Countries in the field of Building Systems. According to them it is possible to save up to 15-30% energy by using LED instead of Fluorescent lamps. However it is not only energy efficiency that is gained by the use of LED. The quality of the light is close to daylight and colour rendering is very good and according to YIT, the consumers are pleased with the LED lighting [9]. Figure 2.1 shows the progressions in efficiency of the most common types of lamps [40].

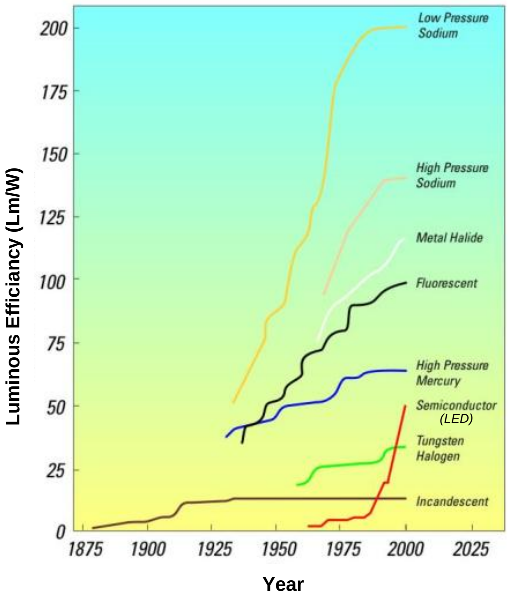

Figure 2.1: Progressions of some common light source's efficiency.

2.2 Lighting control systems

A lighting control system could in it simplest form just be one manual switch for turning the lights on and off. Here we will however refer to more sophisticated system when we discuss Lighting Control System, often known as 'Smart Lighting Control System' or 'Robust Lighting System'. The objectives of such a system are to:

- Provide visual comfort;
- Minimize the energy consumption;
- Preserve the quality of the work environment.

Figure 2.2 shows the structure of a Lighting Control System with one controller, often a microcontroller that has some embedded control algorithm. External devices, such as sensor to detect light level or occupancy and timing device for scheduling are connected to the controller. Human machine interface, HMI , where the user can interact with the system can be a button, display or even a computer program are also connected to the controller. The controller then sends signals to ballasts and actuators that control the lights.

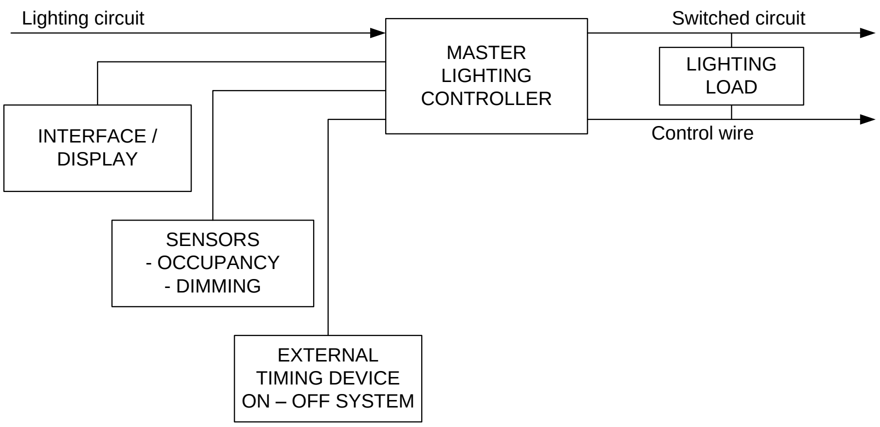

Figure 2.2: Example of robust lighting control system.

2.2.1 Types of systems

The desired functionality of the lighting control system is very dependent on the installation regarding location, operation, complexity, etc. It is therefore convenient to classify these systems according to their main functions. Six of the most common strategies used in advanced lighting control to reduce energy consumption is presented below, as shown in Figure 2.3 [14].

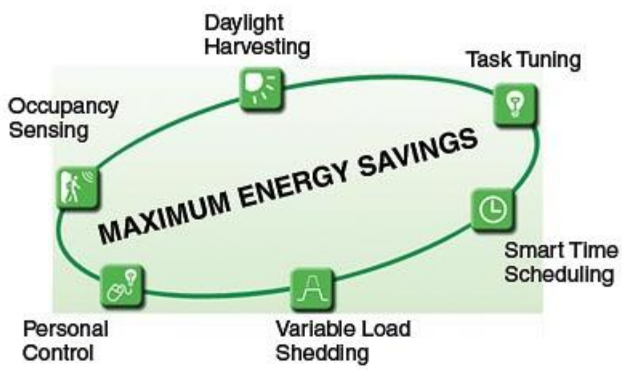

Figure 2.3: Common lighting control strategies for energy saving.

Daylighting

The main concept of Daylighting is reducing or eliminating the use of artificial lighting when there is an adequate contribution of daylight within a space to maintain recommended light levels, i.e. lighting the building using the sky. The traditional way is to use fluorescent lamps with dimmable electronic ballast along with light control sensors (photocell). This method is ideal for offices, classrooms and factory-floors where one or more sides of the room passes the daylight in through windows. To maximize the efficiency of this method, a so called Modular Control can be applied. In modular control, the control system is able to dim small sectors of room independently. Measurements of the light energy savings when using daylight dimming varies a lot and different experiments show savings from around 30% to 70% but there are factors such as location and orientation that will affect the amount of daylight in the room. For new installations, the designer might consider to redirect the sunlight into the building with special mirrors to maximize the daylight and minimize artificial lighting. This type of control system might be one of the most costly due to the number of dimmable ballasts, light sensors and controllers [5].

Occupancy

The concept of the Occupancy control is to limit the use of artificial lighting when there is no occupancy. This method is often used in small rooms or restrooms and then as a standalone system and also in larger areas with some central controller. Almost any lamps can be used with this type of control system, especially in systems where the light is either turned on or off. In larger systems it is possible that dimmable ballasts for fluorescent lamps would be used for dimming the system to a certain value when that area is unoccupied. Tests show up to 20% energy savings using this system and it can also be very inexpensive and simple [5].

Personal control

Many modern lighting control systems offer the user the possibility to manually adjust the amount of dimming they prefer in their offices or work areas within globally set system limits. The user controls the system through individual software clients, web-based interfaces or remote controllers. The actuators may be dimmable ballasts or simple relays. The energy saving of this method depends partly on the user but since he may often choose to use less light-output than is defined by standards the saving might be considerable [14].

Time sheduling

Time scheduling can provide the appropriate light level for different parts of the building during work days, holidays and through different seasons by using advanced scheduling [14].

Task tuning

In modern office buildings it has become more common that the same room is used for different types of work and therefore the lighting requirements vary a lot. Task Tuning allows lighting designers to control lighting according to task and working environments and save energy by designing it in the way that the system only uses the energy needed for each task. This method is often referred to as scenes and is quite popular in conference rooms, bigger offices, etc. [14].

Variable load control

In some cases it can be very efficient to reduce power consumption caused by lighting for a specific time in order to reduce the overall energy consumption. Load shedding is a method to reduce the building electrical consumption during demand peaks or energy price spikes. The system will then, based on either fixed priority or dynamic response, shed the lighting loads selectively and in varying degrees for different areas of a building [14].

Other types

In addition to what was previously mentioned there are some other strategies in lighting control which are not directly related to savings or at least not energy saving. One is the so called Dynamic Lighting, where the idea is to let the artificial interior lighting, both brightness and warmness, follow the rhythm of the light outside. Employees experience the dynamics indirectly and they feel good and active.

Combinations of lighting control system with HVAC systems (Heating, Ventilation and Air-Conditioning) is also possible and could be very interesting. Regarding load control it is powerful to have control over as many power consuming parts of the building as possible. One possible interaction is between passing as much light as possible through a window to reduce artificial lighting but on the other hand we might have to increase ventilation and air-conditioning because of heat passing through the uncovered window. It would then be the lighting controller's job to optimize the position of sun curtains, ventilation and light-output to minimize the cost.

Chapter 3

Empirical studies

In this chapter the Lighting control system will be studied from an energy saving perspective and questions regarding its efficiency, how it relates to carbon dioxide emission and how it appears in standards and regulations will be addressed. Some environmental definitions will be discussed as well as the relation to environmental economics. The chapter aims at answering the questions; what types of light sources can be controlled and what are the main control strategies. This will provide the background knowledge to define a selection criteria for the available lighting control system reviewed in Chapter 4.

3.1 Energy efficiency in modern buildings

As a consequence of global warming and increasing pollution in the world, people and governments have become more aware of how our life habits affect the environment. The relation between global warming, CO_2 emission and the production of electricity has led to new thinking in the way we consume energy and how we can reduce it. One of recent concepts in the environmental field is the "green" concept which is more often used as a prefix for various environmental matters.

3.1.1 Green buildings

Green buildings is a concept we hear more often, but what makes a building a green one? The definitions of green buildings vary between sources but they have one thing in common, being green is being sustainable. One good definition for sustainability is according to Dan Bulley: "Use the resource now (materials, utilities, energy, etc.) so they have zero to minimal impact on future generations' resource." [10, p.12]. Many would like to argue that the green building concept is just a trendy and politically correct thing to state and will only mean more cost for the building owner or tenants. If it costs more, why is this then considered an alternative? In addition to the energy saving, there are at least two reasons why people would choose to do so. One is the possible improvement in human performance. Growing evidence show that things like increased air quality, daylighting, temperature control and reduction of toxic building material may result in better quality of life and therefore less absence of workers and labour turnover. The other reason is the so called "feel-good" factor, which may cause the owner to select sustainable design due to a social value. Within companies this is often related to the "environmental image" that the companies want to present in order to ensure their market position [4].

3.1.2 Environmental economics

Cost

There are many factors that may become more expensive in design and construction of a sustainable building. Environmentally friendly building material, more advanced control equipment for lighting, HVAC systems and more complicated design are to be mentioned. In Section 3.1.1 it was mentioned that companies may expect a better performance and less sickness of employees in "green" buildings, due to a healthier environment. It can also affect the customers as a study showed a considerable sales increase in a US store that was lighted with more daylight per year [8]. In addition to these indirect payback factors, a reduced operational cost may be achieved by reducing energy consumption.

Energy consumption

Energy management is a key for payback of a "green" building and with the focus on commercial and office buildings, the lighting is a good place to start. In a store, for example, the lighting often accounts for over 40% of the energy bill. By making the lighting more energy efficient it is possible to reduce the electricity cost considerably. There are many low-cost tips of how to reduce the electricity cost, such as teaching the employees to adjust the lighting according to actual conditions. These kind of methods are very good, but the most effective one is to combine them with the use of energy efficient light sources and a well designed lighting control system [11].

CO_2 emission

Greenhouse gases include methane, halocarbons, nitrous oxide and carbon dioxide which all have different effects on the climate. The one we are mostly concerned about is the carbon dioxide, CO_2, not because it is more harmful than the others, but because it is the dominating quantity. The main source for the emission of CO_2 is combustion and not only the combustion of gas, oil and coal, but all combustion, including the combustion of biofuel [18]. So why look into more efficient lighting when dealing with CO_2 emission? According to the International Commission on Illumination, lighting accounts for about 19% of the electricity used in the world and therefore the CO_2 emission related to electricity production for lighting is approximately 1,775 billion ton of CO_2 per year, [7].

3.1.3 Standards and regulations

EN 15193 Energy Performance of Buildings, *Energy requirements,* which was published in November 2007 is a part of EU's measure to satisfy the Kyoto Agreement concerning the reduction of greenhouse gases by improving the energy efficiency within EU. With this directive, all properties regarding power consumption must be declared. By this, the focus is set on energy use (power use/ time unit) instead of just the installed power output. The European Performance of Buildings Directive also requires an energy certificate for buildings (EPCs). This certificate gives information about the energy efficiency and environmental impact of the building. In the EN 15193 standard, the methodology for calculating lighting energy consumption per year is defined.

LENI

The Light Energy Numeric Indicator, LENI, has been developed to show how much energy is needed each year to light up each square meter in a building so that illumination and specifications are fulfilled. This index can be used to compare the energy consumption in lighting between different buildings with the same function. These numbers can be used as national recommendations for designers. The following formula is used to calculate the LENI index:

$$LENI_{calculated} = W_{total}/A(kWh/m^2/year) \tag{3.1}$$

where A is the building's total interior area in square meters and W_{total} is:

$$W_{total} = W_{light} + W_{parasitic} \tag{3.2}$$

W_{light} estimates the energy consumption needed for lighting for a certain period and includes all light sources and ballasts. $W_{parasitic}$ contains the standby energy consumption, that is the energy used by the ballast in standby mode, e.g. when charging batteries for emergency lights.

ELI

Even though the LENI index is important for estimating how much energy is needed for each square meter in a building, it does not take things like appearance and emotion into account. Therefore another index, the ELI index, has been designed to work in parallel with LENI [18]. The Ergonomic Lighting Indicator, ELI, takes into account lighting requirements, as stated in standard EN 12464, 'Lighting of workplaces'. To form the ELI index five different parameters are observed and graded from 0 to 5. These parameters are: **Performance** where, among other, the glare control[2] is taken into consideration, **Appearance**, where space and color are inspected, **Comfort**, where shadows and modeling are inspected, **Emotion**, where light distribution and preference are inspected and **Individuality**, where the level of own lighting and personal control for each user are inspected.

By summing up the values for these parameters we get the ELI index for the building as can be seen in Figure 3.1 where the lower one shows two different examples of installations.

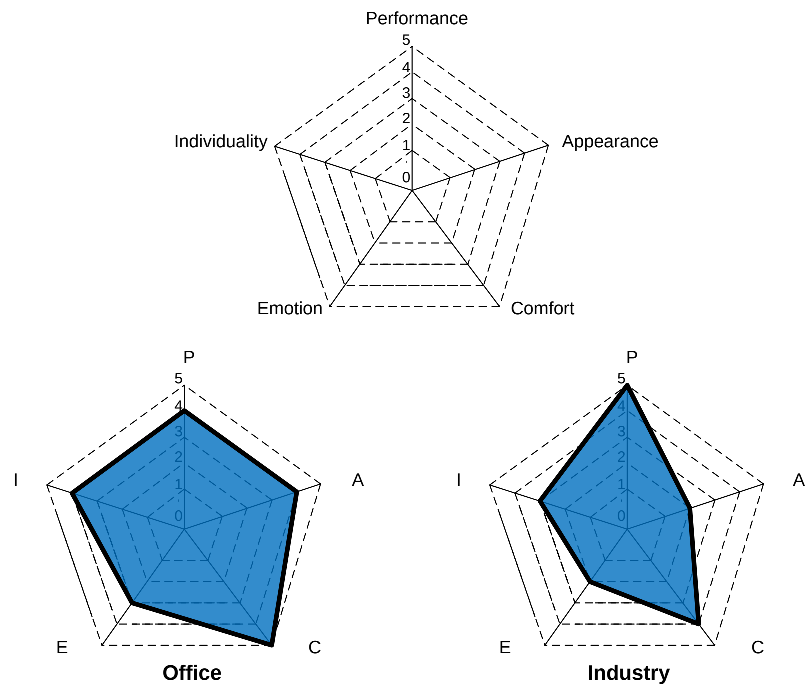

Figure 3.1: Graphical representation of the ELI index and examples of two different installations.

[2]Glare controle aims at reducing the reflection of the light from objects, such as computer screens, by controlling the angle, which the light is able to leave the luminaire.

By applying both these indexes, LENI and ELI, we can calculate the 'Energy-to-ergonomic' ratio of an installation which is simply done by dividing the LENI index with the ELI index. The values of the LENI and ELI indices vary according to installation and operation in the building as the requirements differ. In a normal office building lower 'Energy-to-ergonomic' ratio means better balance between energy efficiency and ergonomic quality [12].

3.2 Case studies

DB Schenker is a leading company in transport and logistics worldwide on land, on sea and in air. In Sweden, Schenker AB has 4000 employees in 30 offices and an annual turnover of 15 billion SEK. One of Schenker's goals is to become the most environmentally sustainable logistics provider in Sweden and therefore they have set a goal to reduce their carbon dioxide emission per ton-km by more than 20% by 2020. This does not only concern the actual transportation because the company has taken a step towards more energy efficient offices as well [32].
For a case study on energy efficient lighting control, the opportunity arose to visit one of Schenkers offices which is located in Växjö and to meet the local director, Thomas Sandström.

3.2.1 Schenker logistics terminal in Växjö

Methodology

The Schenker office in Växjö includes a hub for the transport network where trucks bring in and pick up goods. The facility for this trade is a warehouse that is divided into zones, based on the destination of the goods. The activity within each zone is different during the day because trucks mostly arrive in the morning and then again in the afternoon. The warehouse is lighted with fluorescent lights, mounted on wires hanging from the ceiling which used to be manually controlled with normal light switches. In 2007, the Schenker office in Vaxjö took a step towards its environmental objectives by installing a lighting control system to reduce the electrical energy consumption. The system is an occupancy based control system that utilizes the zone division of the building. Each zone is monitored by a motion detector and if there is no motion detected for a few minutes the light output in that zone is set to 15% of full output by a central lighting controller. When someone enters the zone, the motion detector sends a signal to the controller, which then sets the light output to 95% of full output. The reason for not setting the output to 100% is to increase the life span of the fluorescent lamps. All activity in the system is automatically logged and can be viewed on a computer online or as a collection of data. Figure 3.2 shows different light levels between zones. The inactive zone is marked with dark color for illustration.

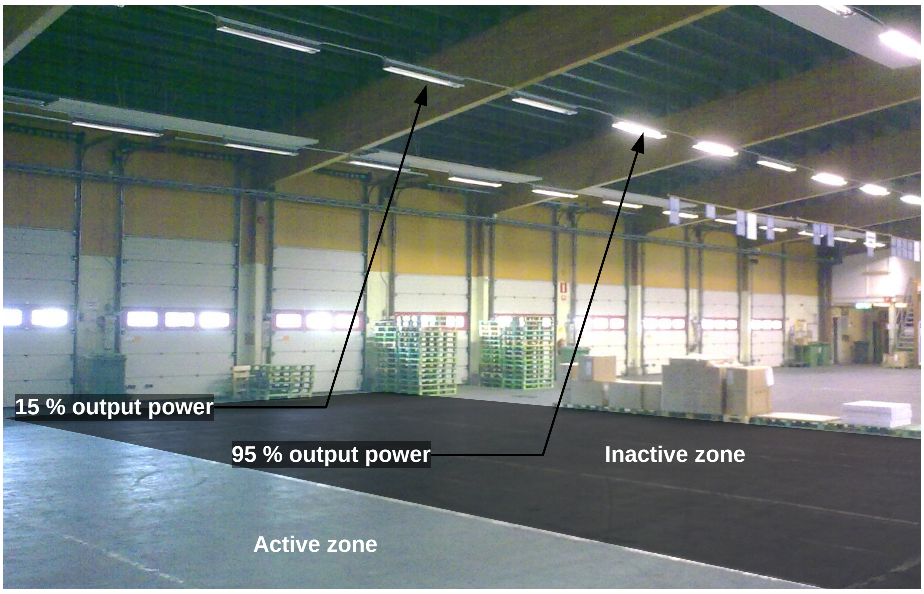

Figure 3.2: The Schenkers warehouse, different light level for different zones.

Figure 3.3 illustrates the lighting control strategy in the warehouse, where workers must use zone 9 to move between zones to prevent activating additional zones[3]. Since the zones are not divided in any physical way the zones are indicated by painted lines on the floor. In other rooms of the warehouse, such as the forklift storage, a standalone occupancy control system with on/off function was installed so that workers do not have to switch lights on and off.

[3]This figure is only for illustrating purpose and does not represent the actual layout of the warehouse.

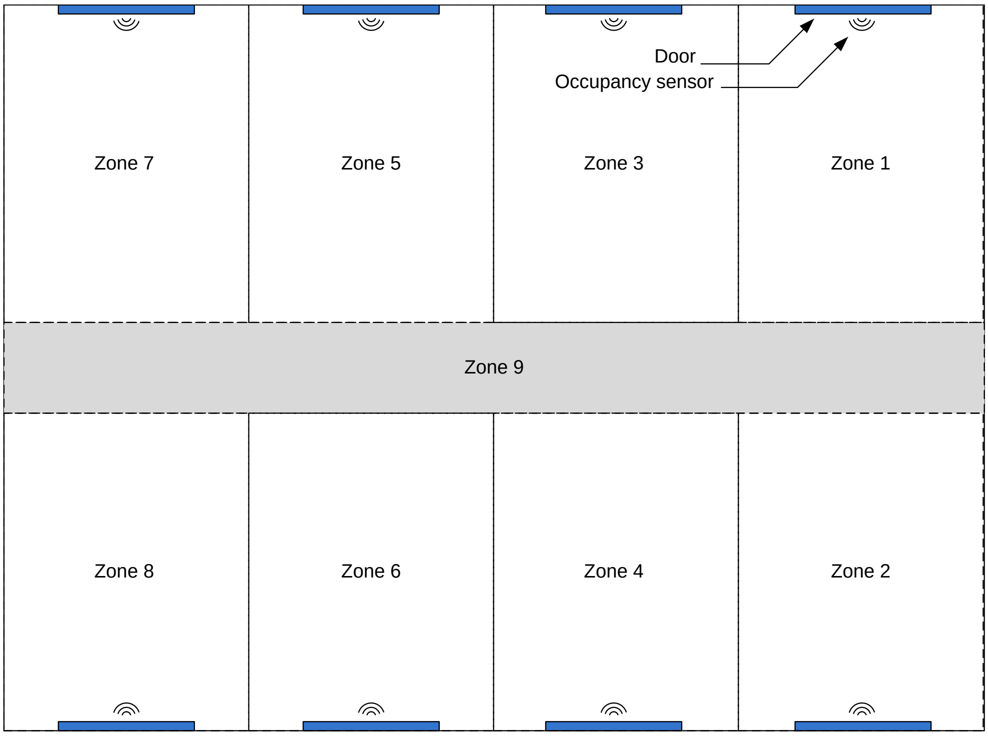

Figure 3.3: Illustration of the lighting control strategy in the warehouse.

Results

One part of Schenker's environmental awareness is to document all their use of resources, such as electricity, hot and cold water. Thomas Sandström was kind enough to provide access to these numbers and the electrical energy consumption was of special interest. Figure 3.4 is based on these numbers and shows how the Schenker office in Vaxjö has reduced its electrical use, during the first two quarters of the year, during the last three years.

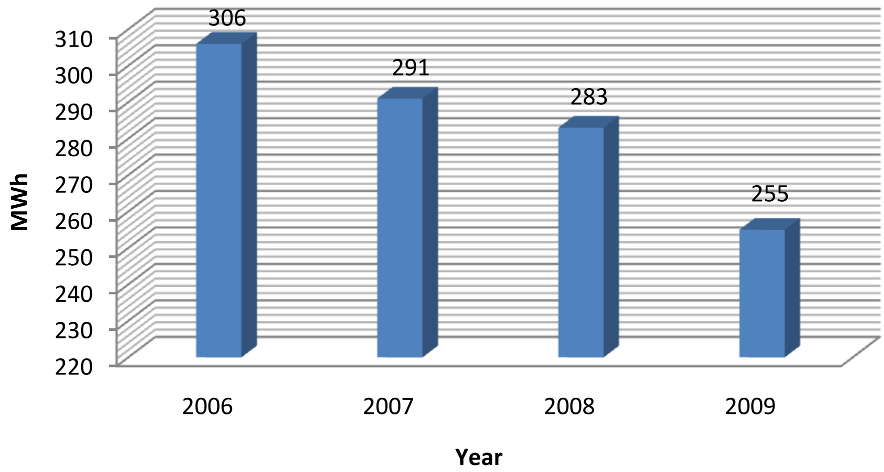

Figure 3.4: Electrical use in MWh for the first two quarters of each year.

It is also interesting to see how much money has been saved during the last years. Table 3.1 shows the savings in SEK of electrical energy for the first two quarters of the years compared to the first two quarters of the year 2006, i.e. before the lighting control system was installed.

Year	Savings (SEK)	Savings in %
2007	15000	4.9
2008	23000	7.5
2009	51000	16.7

Table 3.1: Saving on electrical energy consumption compared to the year 2006.

If we assume that the energy use is similar for the last two quarters of the year the total saving from the installation of the system until the end of this year would be around 178 000 SEK. According to Thomas Sandström, lighting accounts for 80% of the total electrical energy use so by the end of this year Schenker has saved 142 000 SEK by installing the lighting control system. According to Schenker, the cost of installing the lighting control system in the office in Vaxjö was 159 600 SEK. Therefore it can be estimated that around mid 2010 a complete payback has been achieved. The payback time is therefore only three and half years with this simple installation.

Possible improvements

Thomas Sandström says that they are very pleased with the system, it saves energy and money, it does not require much maintenance, is simple and user friendly. The most important thing is, according to him, to teach the users (employees) to use and work with the system. The lighting control system, installed in 2007, only covers the warehouse and not the offices so there might be a possibility to reduce the energy consumption even more. The offices are lighted with fluorescent lights in the ceiling and an individual one above each desk and many of the desks are located near a window as Figure 3.5, taken at the office, shows.

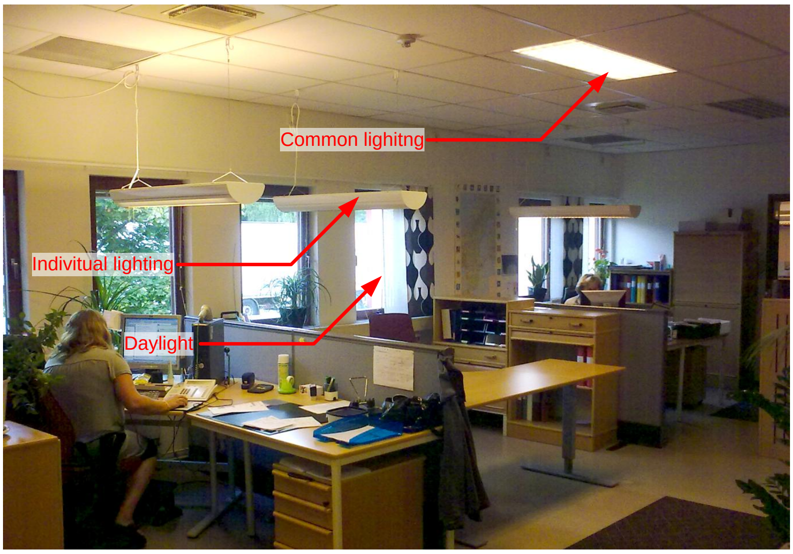

Figure 3.5: Light sources in normal office space at Schenker.

Installing a daylighting or personal lighting control system in this part of Schenker's office in Växjö could reduce the electrical energy consumption even further.

3.3 Conclusion

The world is always changing and so are the habits of people, we produce more, consume more and pollute more than we did before. This has led to increasing environmental awareness among consumers, producers and governments. Sustainability and 'green' buildings is not just the media's darling but a new way of thinking, of preserving the resources and designing buildings. Electrical energy consumption can be related to CO_2 emission and countries are looking in that direction when making standards and directives to fulfill their international environmental commitments. Converting to high-efficiency lamp and combining it with energy efficient lighting control system has proven to be a very efficient way of reducing energy consumption. What properties should then the ideal lighting control system have? The answer to this question will always depend on the installations scope but the system should at least be able to:

- handle the most efficient lamps, such as fluorescent, compact fluorescent and LED;
- turn lights on/off and dim;
- connect to different kind of sensors, such as occupancy and photocell;
- handle time scheduling;
- interact with other systems, such as HVAC and building systems.

Moreover, the system should be:

- user friendly for operation and programming;
- flexible with respect to complexity and price.

Chapter 4

Market study

In this chapter, the available lighting control solutions on the market will be investigated. Different protocols will be compared with respect to parameters such as data rate, power consumption, versatility, cost, etc. To give the reader some background knowledge and a better understanding of the communication part, some basics of such a network will be discussed. At the end of this chapter the available solutions will be evaluated and one selected as the candidate for implementation on one of AB Regin's platforms.

4.1 Communication networks

In smart lighting control systems, as in other automation systems, sensors are not always directly connected to the actuators as often is the case in traditional electrical installation. Instead each sensor and actuator is connected to some media that transfers signals from one device to another or to some common controller. In this way, various devices form a network and the controller then make a virtual connection between devices. To give some insight into these networks it is essential to look at some of their properties.

4.1.1 Network topology

A network topology describes the way nodes are interconnected. In Figure 4.1, the four most common topologies, Bus, Star, Ring and Mesh are shown.

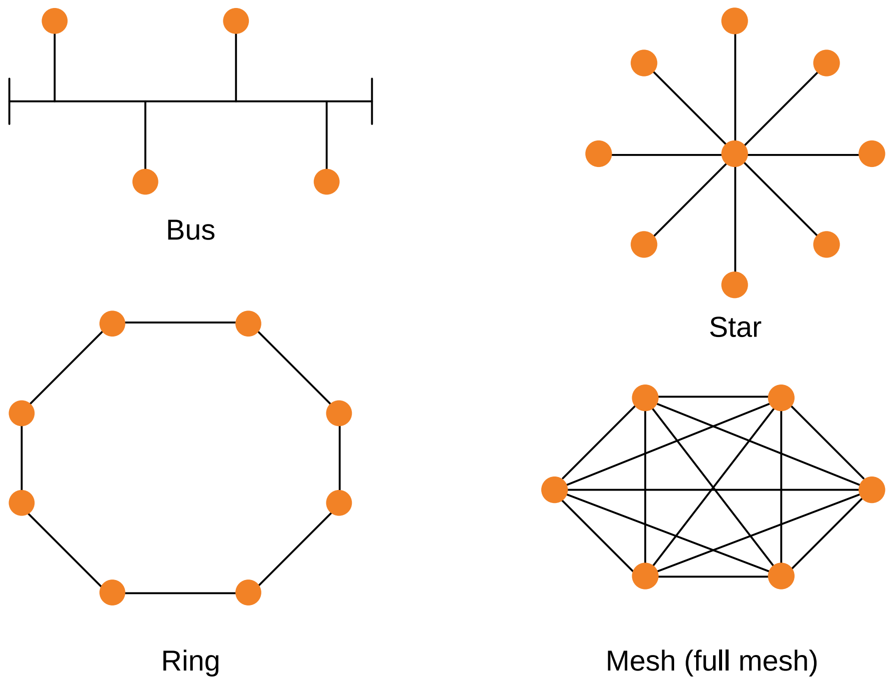

Figure 4.1: The four most common types of network topology.

In addition to these four, there exists a few other topologies, such as Tree-, Linear- and Hybrid topology. A Hybrid topology is when two or more networks with different topologies are connected together. If two or more networks of the same topology are connected, the topology structure remains the same [29].

4.1.2 Nodes

In Figure 4.1 each node is represented by a dot which is connected according to the network topology. In an industrial control network, these nodes represent sensors and actuators. Similarly, these nodes represent occupancy sensors, photocells, switches, lamps, etc. in a lighting control network.

4.1.3 Buses

In an industrial network, buses are used to establish a connection between sensors, actuators and controllers, i.e. nodes. Even though these buses are in fact protocols, since they agree on media, transmission and how data is handled it has become a custom to classify them separately. The term field buses has been used to distinguish the industrialized ones from other network buses but unfortunately it has proven to be hard to standardize them. Therefore there exists quite many field buses on the market, many quite similar.

Profibus is the most commonly used fieldbus in industry and even though it has been developed significantly from its foundation in 1985, the most used version is a simple one using polled master/slave I/O [13].

DeviceNet is based on CAN[4] technology with 24-V on the cable. Its low cost, widespread use and efficient use of bandwidth is a big advantage but its drawback is its small messages size [13].

The Foundation Fieldbus is one of the newest industrial buses, it has become the leading digital protocol for process automation. There are two types of protocols within the Foundation Fieldbus, H1 and HSE. The Foundation Fieldbus H1 uses 4-20mA standard which allows longer distances to devices, which also can be powered by the bus. The High Speed Ethernet, HSE, runs on Ethernet at 100 Mbits/sec and is ideal for backbone control. One great advantage of HSE is that it supports the use of standard Ethernet equipment, which can reduce the installation cost [37].

Ethernet has in recent years become an alternative to the special buses in industrial networks. It runs on fiber, copper or wireless Local Area Networks,LAN with a speed from 10 Mbits/sec up to 10 Gbits/sec depending on the medium. The fact that it is not vendor-centric, its relatively low cost and its widespread use makes it an attractive alternative. Since Ethernet is not a protocol but a physical layer, existing automation protocol, like the ones mentioned before, are ported to Ethernet and thereby some data format agreement is accomplished [13].

[4]CAN was originally designed for use in cars but has then also spread out to other industries

4.1.4 Transmission media

A transmission media can be defined as anything that is able to carry information from sender to receiver. In data communication it is, however, common to divide it in two categories, guided and unguided media as shown in Figure 4.2.

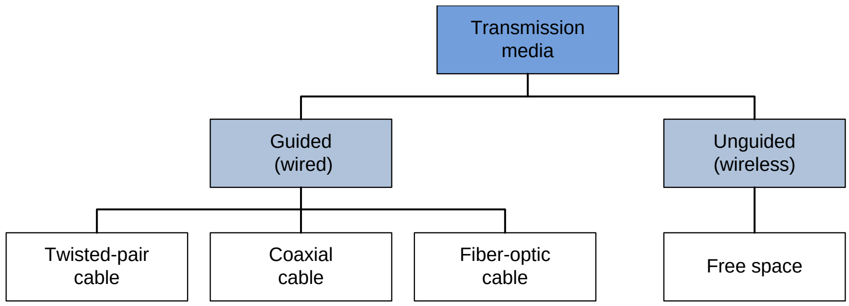

Figure 4.2: Classes of transmission media.

Twisted pair

As the name suggests, the twisted pair cable consists of two wires that are each isolated by plastic material and twisted together. One of these wires is used to carry the signal and the other one provides a ground reference. The reason for twisting the wires is to divide the noise, that the cable may be affected by, more equally on both the signal wire and the reference wire and therefore maintaining better signal quality. Some Twisted Pair Cables also provide extra shielding from environmental disturbances. The twisted pair cables have been classified in seven categories by the Electrical Industries Association. These categories are determined by the quality of the cable where 1 is the lowest in quality and 7 the highest. Each of them is suitable for certain use, where for example the Category 7 cable has the data rate of 600 MHz and is suited for LANs [1].

Coaxial cable

The coaxial cable consists of a central core, a copper wire, which is enclosed in an insulating sheath. This sheath is then also enclosed in a metallic wrapping which serves both as a shield against noise and as a second conductor. Finally there is an insulating sheath that encloses the whole cable. The coaxial cable is able to carry much higher frequency signals than the twisted pair cable. The coaxial cable has mostly been used for transmission of analog signals, for example in Cable TV Networks. In digital communication networks the coaxial cable has been used for Ethernet LANs where it can carry up to

10 Mbits/sec of digital data. The maximum length for coaxial cables is in 10Base-2 Ethernet[5] 185m but in 10Base-5 Ethernet it is 5000m. The latter system requires much thicker coaxial cable. In many applications the coaxial cable has been replaced by the fiber optical cable [1].

Fiber-optic cable

A fiber-optic cable transfers signals as light through a glass or plastic core. The core is surrounded by cladding which guides the light through the cable. The cladded core is surrounded by plastic coating to cushion the fiber. Outside this plastic coating Kevlar[6] strands are located to strengthen the cable. Finally there is a outer jacket made of PVC or Teflon. Figure 4.3 shows how a signal is sent as light through the cable [1].

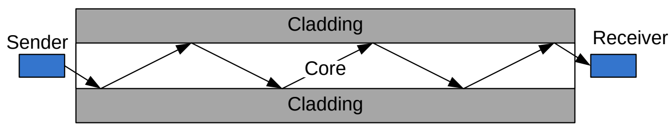

Figure 4.3: Optic fiber cable.

There are two types of fiber-optic cables, single- and multimode. In multimode cables, many beams of light go through the core along different paths. The advantage of fiber-optics is its wide bandwidth and therefore these cables are often found in backbone networks. By using wavelength-division multiplexing it is possible to transfer data at 1600 Gbits/sec. Other advantages of using fiber-optic cables are; less signal attenuation, immunity to electromagnet interference and light weight. Disadvantages are, for example, the cost which is relatively the highest of all guided media and the requirement for specialized expertise of the installer [1].

Power lines

Power Line Carrier transmission is a method that uses the existing power lines to transmit data together with the electrical power. This method is popular in home control systems. Data is transmitted by super-positioning the low energy data signal on the power wave [46]. Since the powerlines are designed to transmit electrical power with a frequency of 50-60 Hz, and at

[5]The 10BASE is an Ethernet variant where 10 stands for the maximum speed 10 Mbits/sec, Base stands for Baseband signaling and the following number represents the maximum length, in this case 200m (although it was later changed to 185m).

[6]Kevlar is very strong material and is for example used in bulletproof vests

most 400Hz, there are some physical drawbacks in its use as a data transmission media. The data that is to be transmitted is in constant danger of electrical disturbance caused by the power line and the equipment connected to it [23].

Wireless

In unguided media transport, the signal is transmitted without using any physical conductor. The wireless transmission methods are further divided into three categories; Radio waves, Microwaves and Infrared. This classification is based on division of the frequency band, where radio waves spread from 3 kHz to 1 GHz. Microwaves span the frequency band between 1 and 300 GHz and above that and up to 400 THz are the infrared waves. Another thing that distinguishes these categories is the usage, where radio waves are used for multicasting and sometimes addressed multicasting. Microwaves are used for unicast communications, as in wireless LANs, cellular telephones and satellite networks. Infrared transmission is used for short distance communication and requires a line-of-sight [1].

4.1.5 OSI model

In digital communication processes, a large number of steps may be involved before data reaches its destination. This calls for some standardization and in the late 1970s the International Standards Organization, ISO, introduced the Open System Interconnection (OSI) model [1].

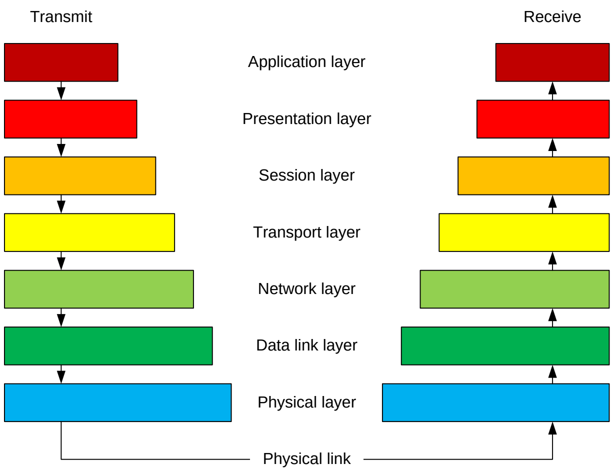

Figure 4.4: The 7-layer OSI model.

The model is composed of seven different layers where each layer defines what should be done at each level of the communication process. When data is sent down the layers from the sender, information is added in each layer involved and removed at analogues layers at the receiver side. Even though the layers are seven, some may be combined into one or even omitted, like in the case of communication in industrial automation. It should be made clear that the OSI model is not a communication standard but a framework for communication standards [1].

4.2 Protocols

There are numerous lighting control systems on the market today. Dedicated lighting control system exist, which are often produced by the illuminator producers. In addition to them, many Building Automation Systems, BAS, support lighting control among other operations. Since the aim of this thesis is to implement a lighting control protocol on AB Regin's BAS, these systems are of special interest. To investigate the different parts of BAS, a hierarchical model is introduced which structures the automation field in three layers. Figure 4.5 shows the mapping of the systems, covered in this report, onto the architectural levels of BAS.

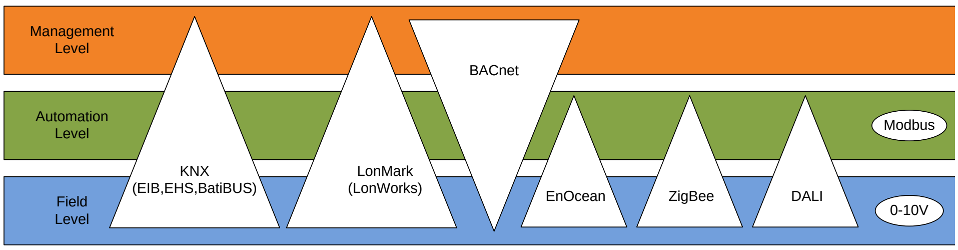

Figure 4.5: Standards in building automation.

At the Field level, a data collection is performed (metering, counting, measuring) and the process is controlled (setting values and switching). Here the data quantity is in bits and response time and frequency in ms. The Automation level handles the aspects of automatic control, e.g. executes the control loops. On this level the data quantity is measured in bytes and response time and frequency in ms to seconds. The highest level of the hierarchical structure is the Management level, where global configuration and management tasks are handled. Here the data quantity is measured in Mbytes and response time and frequency in days [3]. As shown in Figure 4.5 there is a difference between protocols, which level they span and in what way. The KNX protocol is built up from the field level to the management level but

BACnet has its focus on the management level and is not as defined in the field level. Because of the different emphases of systems, regarding levels in the model, it is not always easy to compare them. In this thesis the focus is set mostly on their lighting control approach as well as implementation or connection to BAS.

4.2.1 KNX

The history of KNX goes back to 2002, when the standard was defined as a combination of EIB, EHS and BCS[7]. In 2004 it became a European standard and also an international standard in 2006. Now the KNX is a standardized (EN 50090,ISO/IEC 14543) open system administered by the Konnex Association [39].

Functionality

In the KNX system each device, sensors and actuators, has a built in microcontroller and is able to exchange information with other devices on the network without any interference of a central controller. The connection of devices supports both wired and wireless media and topologies such as bus, star or combinations of these two. When an installation of the KNX system is planned, the first thing to do is to select a configuration mode. Currently there are three possible configuration modes to choose from. One is the System-mode, which is suitable for big installations and requires a database for each device. Second is the Easy-mode which does not require a PC tool. The mechanism is defined on the basis of so-called functional blocks, channels and connection codes that describes the functionality of the device. Easy-Mode devices are pre-programmed and loaded with a default set of parameters. With a simple configurator, each device can be partly reconfigured. This mode has, however, less functionality than the System-mode. The third mode is the Automatic-mode, which is a plug and play mode [22].

[7]The three standards combined in KNX are European Installation Bus, EIB, European Home Systems, EHS and BCS (BatiBUS).

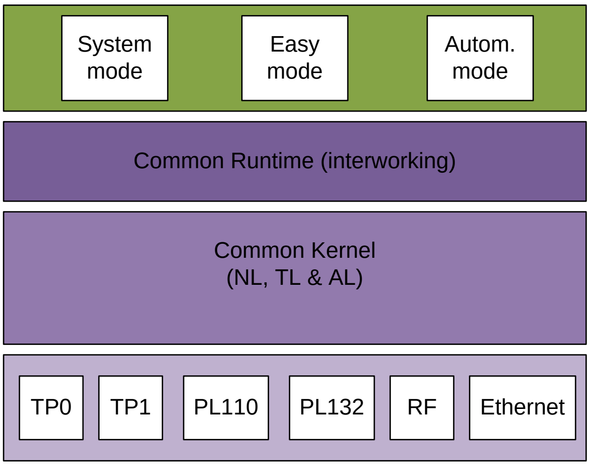

Figure 4.6: The KNX stack.

In Figure 4.6 a normal KNX stack is demonstrated. At the lowest level, different types of media, used by KNX, are presented. The most common type is the KNX TP1, around 90% of KNX buses are of this type. It was introduced by EIB and uses twisted-pair cables and free topology with a maximum bandwidth of 9.6 Kbit/sec [22].

Structure

The KNX system's topology is media independent and built up using three different transmission paths, backbone line, main lines and lines. In every system there can only be one backbone line. Up to 15 main lines are then hierarchically subordinate to the backbone line. Each main line is then able to connect 15 lines at the most. Up to 256 KNX end devices can be connected to each line. This hierarchical structure of the KNX system is shown in Figure 4.7 [19].

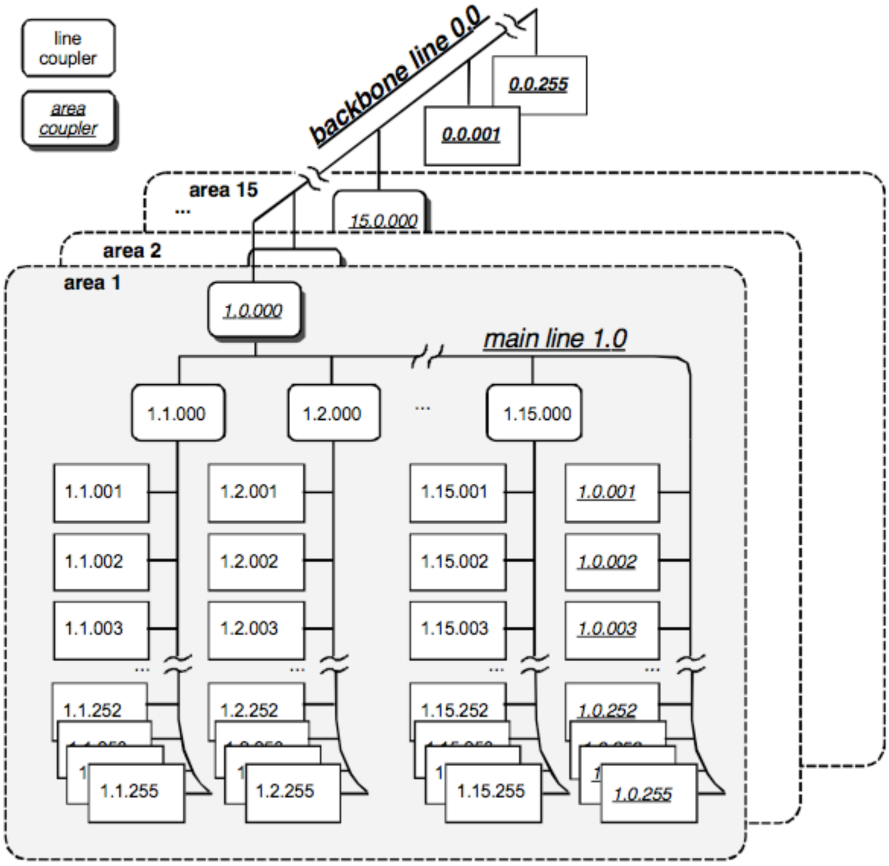

Figure 4.7: Logical topology of the KNX system.

Couplers join together lines or segments, both within certain media or different media together [19].

Each device must have its own address to distinguish it in the system, as shown in Figure 4.7. This individiual number system is constructed from 16 bits that are divided in three numbers representing the hierarchical structure [22].

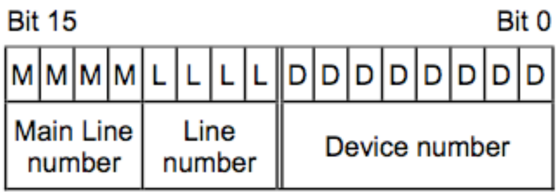

Figure 4.8: KNX's individual numbering system.

The individual number is written as M.L.D, where M is the number of the main line that the device is hierarchically connected to, L stands for the line that the device is physically connected to and D is a unique number of that device within the 255 devices on that line. The device number "0" is reserved for backbone- and line couplers, which are the connecting devices between the different types of lines. In addition to this an area, domain and subnetwork may be defined. An area consists of one main line, the subordinated Lines and all devices connected to them. Domain is a part of the network, connected together with one type of media. A subnetwork is defined as having the same main line- and line number and therefore a maximum numbers of devices in such a network is 255. The smallest domain is a subnet but may span over more than one subnet. KNX supports the use of twisted-pair cables, power-lines and a wireless method called KNX Radio Frequency, KNX RF [22].

Protocol

The data packet, shown in Figure 4.9, includes among others the actual data and the source and destination address of the data. The two latter fields then include a zone, line and device number. The source address field always contains the physical address. The physical address is only used as destination address for initialization, programming and diagnostic operations. Functions of devices that belong to the same group can be controlled by sending just one message, a group message, from the source device. In this case the destination address contains the group address. A sensor can therefore only transmit on one group address but an actuator can receive on many [19].

8	16	16	8	Up to 16x8	8
Control field	Source Address	Destination Address	Length	LSDU -data-	Check byte

Figure 4.9: KNX/TP1 data packet.

When two devices want to exchange information it is achieved by transmission of data packets. Each data packet must be acknowledged and therefore it is encapsulated into the telegram, which adds delay and acknowledge data to the packet. The telegram is sent to the TP-UART memory of the physical layer. When the whole telegram is received into the memory and the bus is free, the Telegram is sent out to the bus. This is only required for the transmission and when a telegram is received it is sent straight to the microcontroller [19].

Cost

The KNX system is built up by technically complex system parts which can be quite expensive. Since there are different installation modes, where one is a plug and play mode, the installation cost can be reduced by reducing the need for specific knowledge. In most cases a special software is required, which increases the installation cost. Due to the wide spread use of KNX and especially the EIB protocol in Europe the knowledge of installing and maintaining the system is available from many installers.

4.2.2 LonMark

In 1994 LonMark was established as an international, unincorporated organization and since then LonMark and its member companies have created 80 functional profiles and over 750 products have been certified. Its platform, LonWorks or Local Operating Network, LON, provides a fully open system of components for multiple sources. The main focus is set on creating a well structured system where all proprietary hooks are forbidden and the end user is provided with wide variety of options [41].

Functionality

One of the major advantages of LON is that any device can communicate with any other device on the net. There are no masters or slaves in the system and interfaces are treated as any system controller. This is similar to the functionality of the Internet, and in many ways LON operates and follows the same rules as the Internet. The main difference lies in the real-time demand design of LON [41].

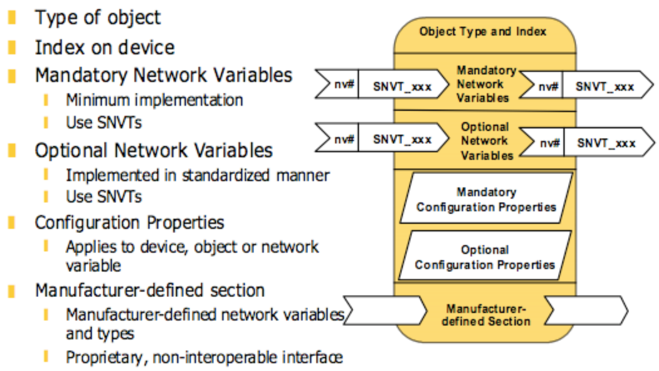

Figure 4.10: Functional profile of LON object.

By publishing so called Functional Profiles, which are similar to objects in object orientated language, a set of basic generic functions are provided. These functions can then be used to implement a broad set of applications. Figure 4.10 shows how these profiles describe in detail the application layer interface [47].

Each device on the LON, is a fully functioning network object. Figure 4.11 shows how a normal LON-device is constructed. The microcontroller can almost be of any type as long as it meets the requirements set by LonMark, but in most cases a Neuron Chip microcontroller is used. The Neuron Chip has the OSI layers 2-6 embedded and an application layer in on-chip application CPU [48].

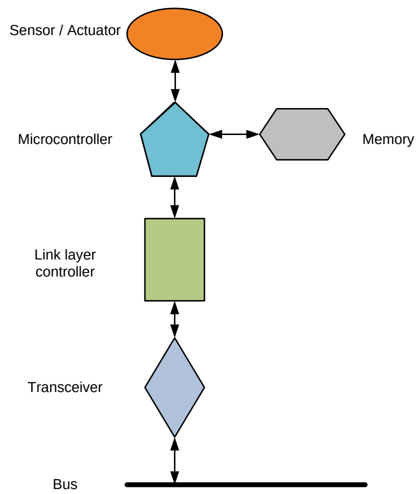

Figure 4.11: Block diagram of a normal LON device.

The Neuron chip uses a unique identifier, the Neuron ID, to be addressed within a network. Having all the 7 layers included in the protocol, allows the developer to write in high-level application programming interface. All the layers may be configured at installation time via a network management protocol [48].

Structure

LON systems are media independent and support the use of twisted pair, coaxial, fiber-optics, RF, infrared, power lines and LonTalk over IP. The topology depends on which media is used. A free topology allows devices to be connected with one another, in bus, daisy chain, star, ring, or loop topologies, or combinations of these. It only requires one termination anywhere in the network [48].

Name	Media	Bit Rate	Definition	Standard
FO-20L	Fiber Optic	1.25Mbps	ANSI/EIA/CEA-709.4	Yes
FO-20S	Fiber Optic	1.25Mbps	ANSI/EIA/CEA-709.4	Yes
IP-852	EIA/CEA-852 IP Tunneling	N/A	ANSI/EIA/CEA-852	Yes
PL-20A	CENELEC A-band Power Line	2613bps	ANSI/EIA/CEA-709.2	Yes
PL-20C	CENELEC C-band Power Line w/access protocol	3987bps	ANSI/EIA/CEA-709.2	Yes
PL-20N	CENELEC C-band Power Line w/o access protocol	3987bps	ANSI/EIA/CEA-709.2	Yes
TP/FT-10	Free Topology Twisted Pair	78.13kbps	ANSI/EIA/CEA-709.3	Yes
TP/RS485-39	RS-485 Twisted Pair	39.06kbps	EIA/TIA-232-E	Yes
TP/XF-1250	Transformer-Isolated Twisted Pair	1.25Mbps	LONMARK Interoperability Guidelines	Yes

Figure 4.12: LON media types.

Figure 4.12 shows different properties of some of the media most frequently used in LON systems. The LON system structure is hierarchically subordinate and can be classified in networks, domains, subnets, groups, channels and devices. In Table 4.1 the size limitations of the system is listed [49].

Protocol

All LON devices communicate with each other using the LonTalk protocol, which is also known as ANSI/EIA/CEA-709.1. The protocol is a layered, packet-based, peer-to-peer protocol and as Ethernet and Internet protocols it is a published standard that utilizes the OSI reference model. LonTalk

Devices in a subnet	127
Subnet in a domain	255
Devices in a domain	32385
Domains in a network	2^{48}
Groups in a domain	255
Channels in a network	No limit

Table 4.1: LON structure limits.

implements all the seven layers of the OSI model but since it is media independent it has several physical layers, dependent on the communication medium. In Figure 4.13 a typical EIA-709.1 packet is presented.

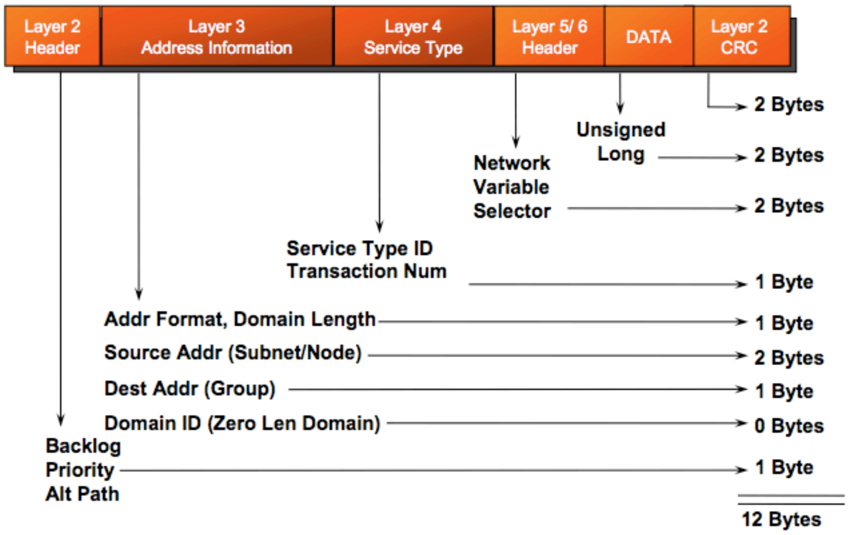

Figure 4.13: A typical EIA-709.1 packet.

The packet is built up as it passes the layers and information is added. Layer 3 holds the address information and the protocol supports several types of addresses such as Physical address, Device address, Group Address and Broadcast address.
One of LON's methods in the direction of interoperability are the network variables. A network variable is any data item that a particular program of a network device expects to get from some other device, e.g. switching lights on or off. With this method, sensors publish information but actuators subscribe to the information of their interest. Devices are then logically connected by the application program, stored in the microprocessor. In addition to the network variables, LON also supports the use of eXtensible

Markup Language, XML. XML is a meta-markup language that provides a format for describing structured data and LON uses it to retrieve data from the network and populate it to databases [49].

Cost

The flexible structure of LonMark makes it quite scalable and therefore the installation cost depends partly on the requirement and the extent of the system. Since each device is a fully functioning network device, they are quite complex and expensive. Each device is equipped with a microcontroller, which in most cases is the Neuron Chip or some other microcontroller that is supported by LonMark. This ties the producer down and can possibly mean increased cost. Installing and maintaining a system of such advanced type as LonMark requires a special knowledge by the installer and thereby increased cost. LonMark has a fairly good market position in Europe with many products from numerous vendors available.

4.2.3 BACnet

A Data Communication Protocol for Building Automation and Control Networks, BACnet, is an American national standard, a European standard and an ISO global standard. Founded by the American Society of Heating, Refrigerating and Air-conditioning Engineers, ASHRAE. It has been under constant development since 1987 and is defined for all three levels of building automation, i.e. Field, Automation and Management. One of the things that distinguish BACnet from many other protocols is the fact that from the very beginning it was intended to be a standard. Another speciality of BACnet, compared to other protocols in this report, is that it is mostly used on the management level as shown in Figure 4.5. Its Ethernet transport medium allows a straightforward integration of the BAS management with an office network [30].

Functionality

The main goal with the establishment of BACnet protocol was to create interoperability between devices from different vendors. This goal is achieved by an interface with a standardized set of data types that are independent of industry and applications. This is an abstract, object-orientated representation of the equipment in the BAS. Every input and output that is connected to the system, such as switches, sensors, actuators, dimmers, are represented by a BACnet object. Concerning the lighting control most inputs and outputs can easily be represented by these objects but when it comes to creating groups of lighting units that should be controlled as a unit it is not as trivial. This is also the case with preset scenes where BACnet objects does not include this functionality. According to the structure of BACnet, it would be in the hands of lighting producers to create a robust lighting control object [6].

Structure

BACnet has a four-layer collapsed architecture with physical, data link, network and application layers, as shown in Figure 4.14, where the BACnet layer model is compared with the OSI layer model.

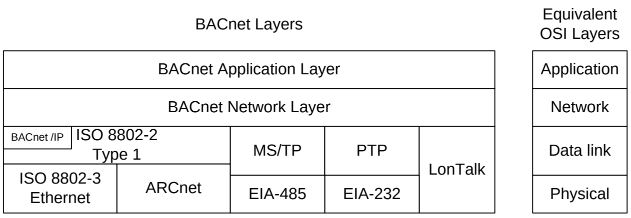

Figure 4.14: The four layer BACnet model and equivalent OSI layers.

BACnet provides six wired data link layer options which are Ethernet, ARCnet, MS/TP(Master-Slave/Token-Passing), PTP(Point-To-Point), LonTalk and BACnet/IP. Unfortunately it has no option for wireless communication, except through some gateways. Even though LonTalk is defined at the Datalink/Physical level in BACnet layers, it does not mean that BACnet is able to communicate with any devices using LonTalk. BACnet uses LonTalk to convey BACnet messages in an identical manner to the way BACnet messages are transported by Ethernet, ARCNET and MS/TP. So even though both BACnet and LonMark uses LonTalk, they are using different languages and can not interoperate. Figure 4.15 shows the BACnet-based building automation system architecture and how it is divided in different levels of the BAS model.

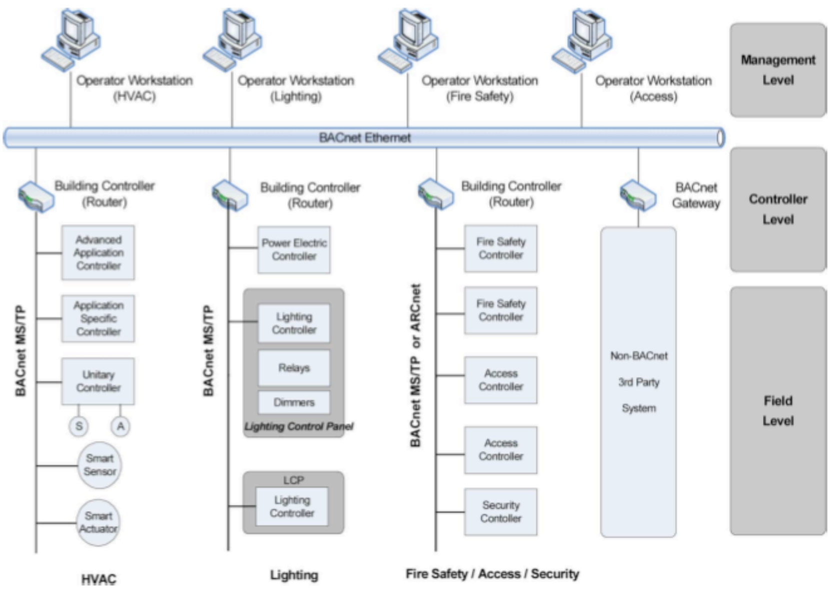

Figure 4.15: BACnet-based building automation system architecture.

The figure shows how a BACnet system can be constructed. Where, for example the MS/TP data link layer, with a data rate of 9.6-78.4 kbps, is used to communicate with the HVAC and lighting equipment. MS/TP or ARCnet is used for fire safety, access and security and any 3rd party system is linked through BACnet gateways. For a backbone communication, the BACnet Ethernet is used, which is the strength of BACnet, providing a robust connection at the management level [15].

Protocol

All information within the BACnet network is encapsulated in BACnet objects, a data structure that is spread out on the network. These objects represent environmental parameters, trend analysis, calculation result, etc. By using a mechanism called service request, all nodes in the network can access this informations. BACnet currently defines 35 message types, divided into 5 classes like alarm and event service. In order to guarantee that BACnet devices from different vendors will function and interoperate on the network, BACnet requires a so called protocol implementation conformance statement, PICS, from the vendor. It is basically a BACnet specification sheet containing a list of a device's BACnet capabilities [30].

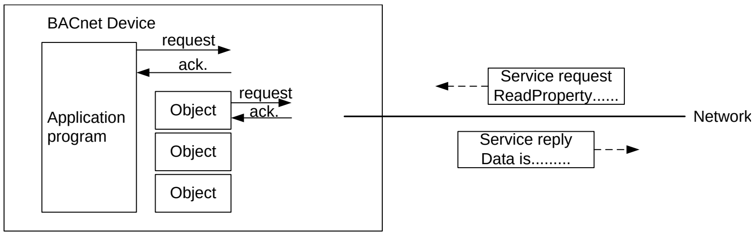

Figure 4.16: BACnet service requests and replies.

In Figure 4.16 the application program running on the BACnet device sends service requests and receives replays to process. Within each device the application program is the actual software that performs the operations [30].

Cost

Event though BACnet originates in America, it is widespread in Europe and as a European standard it is supported by many vendors. The fact that BACnet provides six wired data link layer options makes it very scalable and therefore the installation cost can vary due to the extension of the installation. The system is, however, very technically advanced and the need for specific knowledge by the installer as well as specialized software is needed.

4.2.4 EnOcean

EnOcean technology is a maintenance-free wireless sensor solution for use in building automation and industrial installations, produced by the German company EnOcean. The company was established in 2001 as a spin-off from Siemens AG. The product range of EnOcean has grown enormously in the last years and today wireless modules from EnOcean are used worldwide by more than 100 vendors to enable their system ideas for BAS [35].

Functionality

The basic idea behind EnOcean technology is the fact that when a sensor measures a value, the energy state constantly changes. When a switch is pressed, the temperature changes or the luminance level variations generate enough energy to transmit wireless signals. So instead of using batteries, linear motion converters, solar cells and thermal converters are used to produce enough energy to transmit the signal. Figure 4.17 demonstrates this method [36].

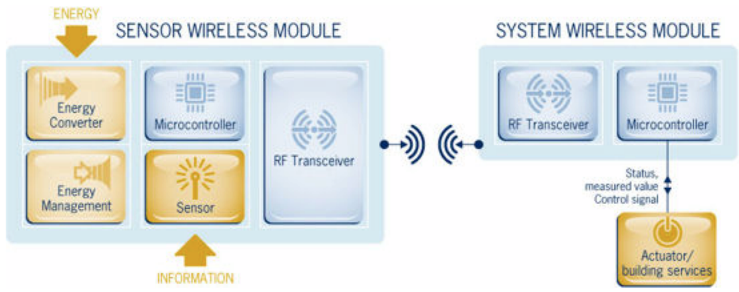

Figure 4.17: Self-powered wireless sensor technology from EnOcean.

When a button is pressed, for example, the linear motion can be transformed into enough energy to transmit the information about the action. These solutions from EnOcean are used in Lighting, HVAC and as a subsystem in BAS, such as KNX and LON [36].

Structure

In a wireless sensor network, based on EnOcean technology there are three types of system components: sensor, repeater and end node, as shown in Figure 4.18 [21].

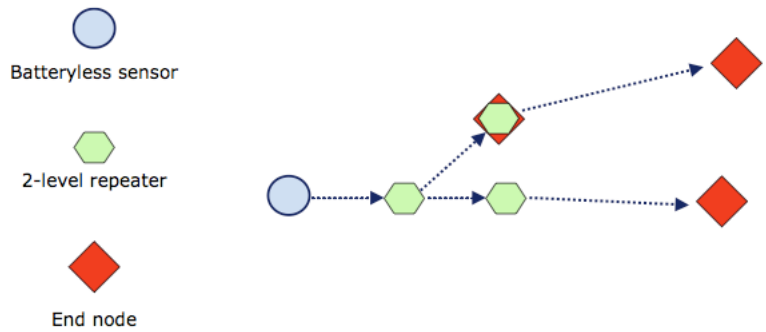

Figure 4.18: EnOcean smart repeating concept.

The Smart Routing or Smart Repeating, shown in Figure 4.18, is often sufficient in small systems such as residential homes. The Smart Repeating is a plug and play setup so no complex system configuration is needed. For larger system, the 2-level repeating is, however, not sufficient and therefore a mesh routing is required [21].

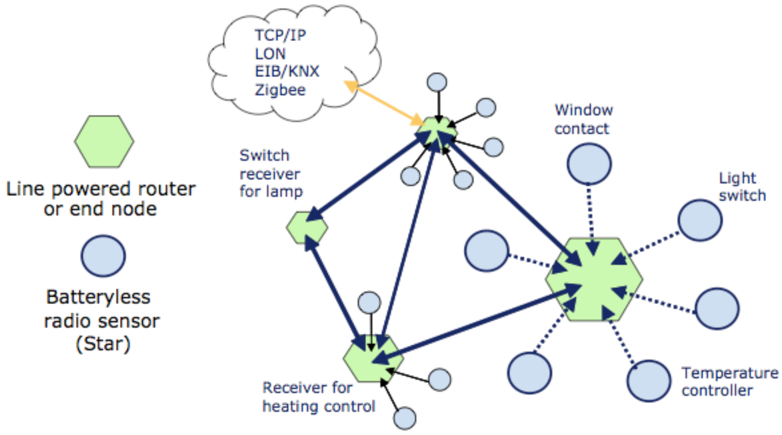

Figure 4.19: Mesh routing concept.

In a normal (line powered) system, the routing concept is based on bidirectional transmission between all devices. In the EnOcean system this is not possible, due to energy aspects. This calls for a Mesh Routing concept as shown in Figure 4.19. Here the line powered end node also acts as a router and/or gateway. Even in this case the routing does not call for any special configuration and the network is self-organizing [21].

Protocol

The energy minimization aspect of EnOcean's system is the main factor behind the construction of the protocol. The basic energy equation shown below illustrates the concept.

$$Energy = Power \times Time \tag{4.1}$$

EnOcean uses the 868.3 MHz transmission frequency which guaranties a 30m indoor distance between communication nodes and up to 300m in open area. In order to be able to transmit a signal over this distance, sufficient power is required, so reducing the power is not an option for energy reduction. Reducing the time it takes to send the signal is however an option. This is the reason for EnOcean's short data packet, which is only 112 bits and can be transmitted in only 1ms. In Figure 4.20, a normal 14 byte EnOcean data packet is illustrated [20].

Bit 7	Bit 0
SYNC_BYTE1 (A5 Hex)	
SYNC_BYTE0 (5A Hex)	
H_SEQ	LENGTH
ORG	
DATA_BYTE3	
DATA_BYTE2	
DATA_BYTE1	
DATA_BYTE0	
ID_BYTE3	
ID_BYTE2	
ID_BYTE1	
ID_BYTE0	
STATUS	
CHECKSUM	

Figure 4.20: An EnOcean data packet.

The packet starts with some synchronization bytes and information about its type, if it is a send-packet or receive-packet[8], and then follows information about the packet's length. This is followed by 8 bits, noted as ORG, which describes the packet type. The different types are listed in Figure 4.21. After the type description there are four bytes containing the actual data to be transmitted. The data bytes are then followed by the identification of the sender, a status information and a checksum [20].

ORG	Description	RRT / TRT Acronym
0x05	Telegram from a PTM switch module received (original or repeated message)	RPS
0x06	1 byte data telegram from a STM sensor module received (original or repeated message)	1BS
0x07	4 byte data telegram from a STM sensor module received (original or repeated message)	4BS
0x08	Telegram from a CTM module received (original or repeated message)	HRC
0x0A	6byte Modem Telegram (original or repeated)	6DT
0x0B	Modem Acknowledge Telegram	MDA

Figure 4.21: EnOcean protocol functions.

[8]The send and receive telegrams have the same structure. The only difference is that a send telegram is identified by "3" in H_SEQ instead of "0" for the receive one.

Cost

As EnOcean systems are both wireless and basically self powered, the installation cost is mainly the cost of the system units and the startup of the system. The operation cost is minimized by the self powering units, where no batteries are needed nor the work of replacing them. With the emergence of EnOcean Alliance wireless standard more producers are producing EnOcean equipment, which will lead to lower price [34].

4.2.5 ZigBee

ZigBee is a wireless network standard, based on IEEE 802.15.4 Physical Layer, PHY, and Medium Access Control sub-layer, MAC. The ZigBee protocol is defined by ZigBee Alliance, which is a group of global companies, sharing the interest in creating wireless solutions for residential, commercial and industrial applications [50].

Functionality

The main focus of ZigBee is to create a low power consumption, low cost wireless control/sensor network that has high density of nodes. By introducing an active (send/receive) and sleep mode, ZigBee manages to keep power consumption at the minimum, which is crucial for battery operated devices. The simplicity of ZigBee's protocol and its small data packets, makes it suitable for control/sensor network and in the same time it reduces cost and power consumption.
In order to make it possible for vendors to supply the lowest possible cost devices, IEEE standard defines two types of physical devices, full function devices, FFD, and reduced function devices, RFD. The full functioning one works on any topology, can be the network coordinator and is able to talk to any other device. The reduced function device can not become the network coordinator, is limited to star topology and can only talk to the network coordinator [27].

Structure

The ZigBee topology is determined by the devices included. As previously mentioned there are two types of nodes, FFD and RFD, and the composition of these types determines the structure as can bee seen in Figure 4.22.

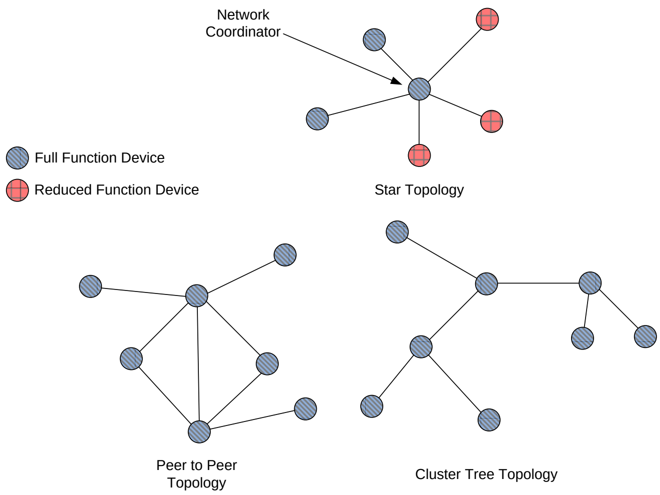

Figure 4.22: ZigBee topology.

In Figure 4.22 it is shown how FFD can act as coordinator and router for the network but a RFD can only work as end devices, with no routing possibilities, and therefore limited to star topology. The coordinator is responsible for starting and maintaining the devices on the network [27].

Protocol

The ZigBee network technology is based on the seven layer OSI model. The lower layers are defined by the IEEE 802.15.4 standard but the network layer and framework for the application layer are provided by ZigBee Alliance. The application layer, and profiles, at the top are left for the user or vendor to implement. Figure 4.23 shows the structure of the ZigBee stack architecture [26].

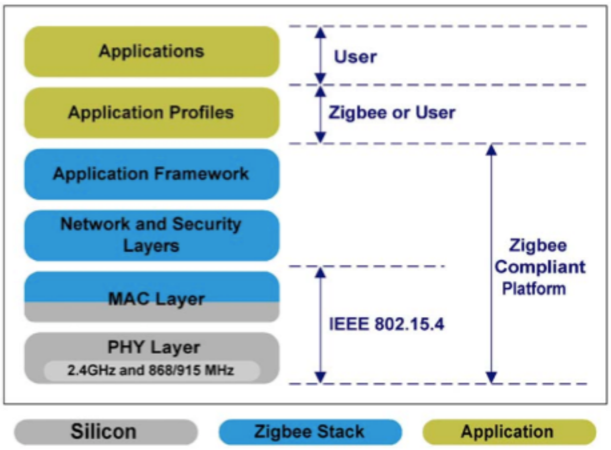

Figure 4.23: ZigBee model, stack architecture.

The frame structure of the ZigBee system is designed to provide minimum complexity and maximum robustness for transmission on noisy channels. In Figure 4.24 the Physical Protocol Data Unit, PPDU, is illustrated. The PPDU includes the information that is to be transmitted through the air [27].

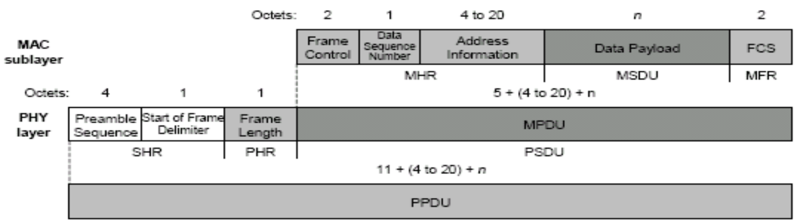

Figure 4.24: ZigBee PPDU.

As can be seen in Figure 4.24, the PPDU adds some physical layer packets to the MAC Protocol Data Unit, MPDU. The MPDU contains the actual data as well as the destination address and some other overhead bits. In summary the total overhead for a single packet is around 120 bits, but that depends on the addressing scheme used (short or 64 bits addresses) [27].

Cost

With Zigbee the installation cost mainly rests with the price of products and to start the system. Since it is wireless the installation cost is reduced due to less or non cabling requirements. If a Zigbee product is to be produced it is required to become a part of the Zigbee Alliance and to do so, an admission fee must be paid [50].

4.2.6 Modbus

The Modbus Protocol is a messaging structure, established in 1979 by Modicon and is therefore celebrating its 30th anniversary this year. Modbus is a de facto standard, i.e. it is widely used and recognized by the industry as being a standard. Modbus is an open protocol and has been implemented by hundreds of vendors on thousands of different devices. The protocol can be translated to almost any other protocol through gateways and most industrial devices are available with a Modbus option. There are many variations of Modbus, but the focus of this report is on the Modbus Remote Terminal Unit, RTU, which is based on serial (twisted pair) communication like RS485 and RS232 [43].

Functionality

Modbus is a protocol that provides client/server communication between devices connected on different types of buses or networks. It supports one master node and up to 246 slave nodes but the distance of the bus varies according to the baud rate. The baud rate in a RTU system is then based on the limitation of RS232 and RS485 [43].

Structure

Modbus is usually structured according to the bus-topology, as can be seen in Figure 4.25

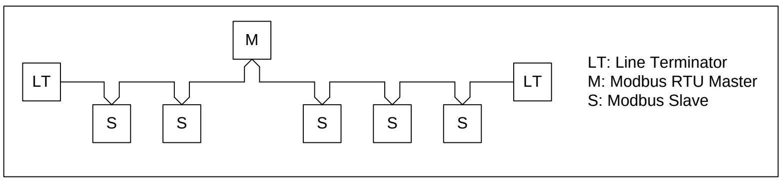

Figure 4.25: Modbus with master and slave units on bus topology.

The master communicates with a specific slave by placing the 8-bit slave address in the address field of the message. The address field contains 8 binary bits. Valid addresses are from 1-247. When the slave responds, it places its own address in this field to let the master know which device is responding [43].

Protocol

The Modbus protocol is an application protocol, positioned at level 7 in the OSI model. The protocol defines a simple protocol data unit, PDU, which is independent of the communication layers used. The mapping of the protocol on a specific communication network can add some fields on the application data unit, ADU, as shown in Figure 4.26. In the RTU protocol, each word size is 8 bits, which consists of two 4-bit hexadecimal characters and the messages is transmitted in a continues stream [43].

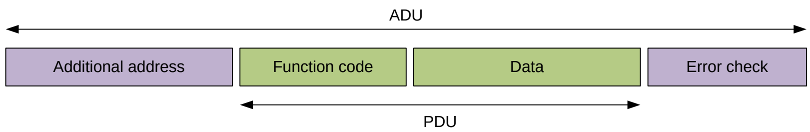

Figure 4.26: General Modbus frame.

The Modbus protocol is a request/reply protocol and its service is specified by so called function codes. The function code field of the data unit is coded in one byte and when a message is sent from a client to a server the function code field tells the server what kind of action is to be performed. Figure 4.27 shows how these transactions are performed [43].

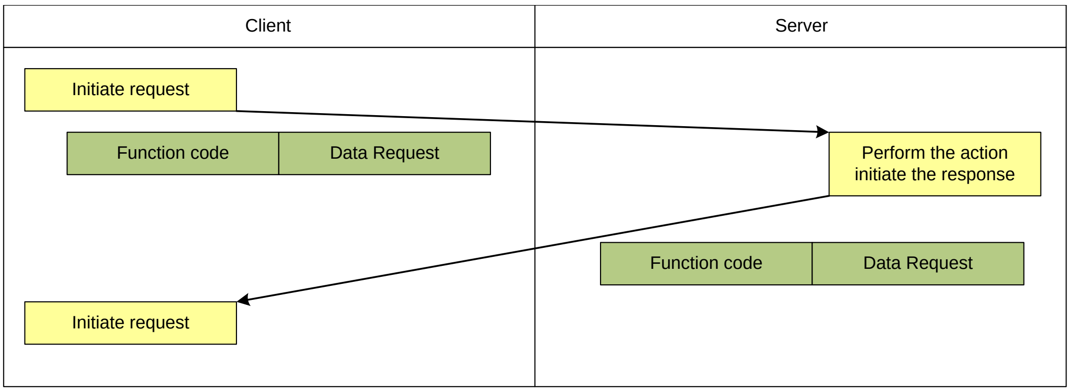

Figure 4.27: Modbus transaction, error free.

In addition to the function codes there are sub-function codes that are added to define multiple actions. When a server sends a response to a client, it uses the function code field to indicate the nature of the response. It can be either a normal response or an exception response, when some kind of error has occurred. In the case of a normal response, the server just echoes to the client the original function code [43].

Cost

The installation cost of a Modbus system can be moderate because of how widespread the protocol is among producers. The simplicity also reduces the overhead and a tailored control system can be accomplished without to much cost. The maintenance cost depends mostly on the products used as nodes in the Modbus system, but as with the installation cost, the simplicity and widespread use, reduces the need for highly trained professional skills, i.e. less cost.

4.2.7 DALI

The Digital Addressable Lighting Interface, DALI, is an international standard that guarantees the exchangeability of dimmable ballasts from different manufacturers. The difference with this system, compared to the others in this report, is that it was designed as a protocol purely for lighting control. The DALI-interface has been described in IEC 60929, the fluorescent lamp ballast standard, under Annex E [31].

Functionality

Today the 0-10V control interface is still the most common standard for dimming ballast for fluorescent lamps. It is the goal of DALI's design to replace it. DALI offers a simple wiring of control lines that are connected to devices such as DALI ballasts, switches and sensors. Control of individual units or groups is possible and even simultaneous control of all units through broadcast addressing. When selecting a scene, automatic and simultaneous dimming of all units as well as logarithmic dimming behavior[9] is possible. The dimming speed or fading can also be adjusted. In a DALI system there are two types of devices, the Master controller and Electronic Control Gears, ECG. An increasing number of lighting producers, produce lighting equipment for DALI, such as HELVAR, TRIDONIC, PHILIPS, OSRAM and many other [31].

[9] Logarithmic dimming behavior aims at matching the eye's sensitivity.

Structure

Due to the simplicity of DALI, which is in fact its intention, it is not suitable for building automation or similar complex operations. Its main focus is on lighting control and to work as such. The three structure variations that are most common are standalone, standalone subsystem and subsystem [31].

Standalone

In Figure 4.28, DALI is shown in its simplest form, as a standalone system. In this case, all functions, including startup, is done locally.

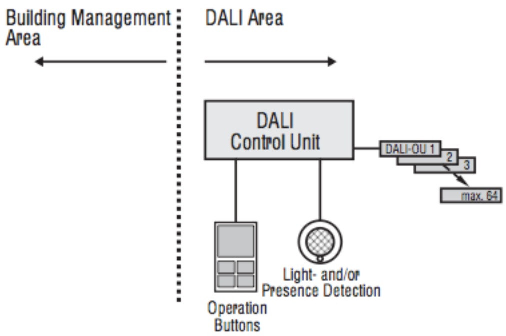

Figure 4.28: The DALI as a standalone system.

All actuators, sensors and switches, wired or wireless, are connected to the control unit, either in analog or digital form. This setup shows how simple this system can be [31].

Standalone-subsystem

An example of DALI as a standalone subsystem, within a BAS, is shown in Figure 4.29.

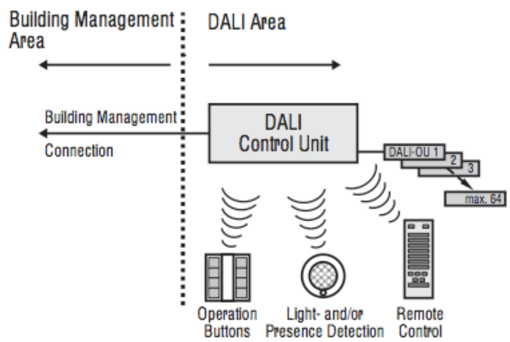

Figure 4.29: The DALI as a standalone sub-system, with wired or wireless external units connected to the DALI controller.

In this configuration, only the most important information, fault status, central switch functions, etc. will be communicated with the BAS. This communication can be of a very simple form, such as simply yes or no to some fault conditions. External devices such as sensors, control elements, programming units and remote controllers can be connected as usual, wired or wireless [31].

Subsystem

In Figure 4.30, the system is configured as a subsystem with the BAS. When this is done, a gateway must be included for the communications between these systems.

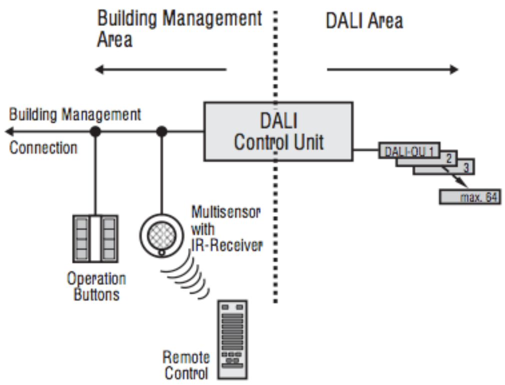

Figure 4.30: The DALI as a subsystem.

The gateway then translates from BAS to DALI and reverse to establish the communication between these two systems. This is often applied, e.g. in

EIB/KNX systems where the system uses its own sensors and switches but the DALI system controls the lamps [31].

DALI defines the system's maximum size as 64 single units (individual addresses), 16 groups (group addresses) and the topology of the system can be bus, star or a combination of these two, but a ring topology is to be avoided. DALI communicates in serial mode and the medium supported by the system is a two wire control lead where control and supply leads can be wired together, the minimum lead diameter according to Table 4.2 must be fulfilled.

Lead length	Minimum lead diameter
up to 100 meters	$0,5\ mm^2$
100 -150 meters	$0,75\ mm^2$
above 150 meters	$1,5\ mm^2$

Table 4.2: Wiring table for DALI media.

The maximum lead length between two connected systems must not exceed 300 meters [31].

Protocol

The DALI system installation is based on the master-slave principle where the user operates the system through the controller (master). The controller sends messages to all the individual devices containing an address and a command. Then the address determines whether the device should listen or not [31].

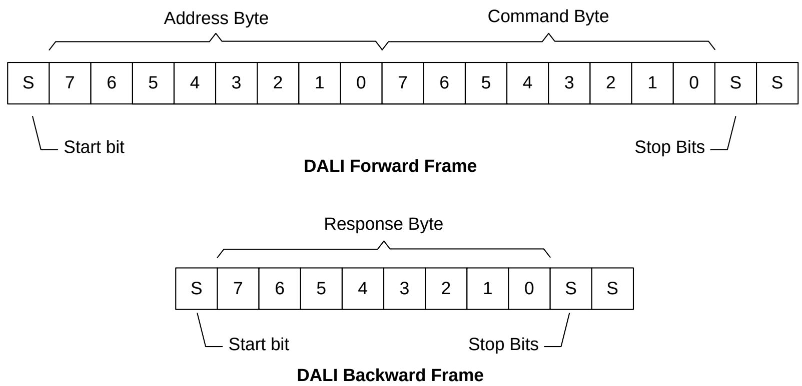

Figure 4.31: The DALI forward and backward frame.

All communications are controlled by the master. Slaves are silent until the master sends a request to them. In Figure 4.31 the forward frame shows a messages structure sent by the master. These always begin with a start bit which is then followed by an 8 bit address part and then another 8 bits of command part. The messages ends with two stop bits. The slave answers with a backward frame which starts and ends in the same way as the Forward Frame but with an 8 bit response in the middle [31].

Cost

Because of simplicity, widespread market positions and scalability of the system its installation cost can be moderate. The cost is also low compared to 0-10V systems that operate in the same level of building automation and DALI has much more functionality then those systems.

4.2.8 0-10V Analog

The 0-10 V analog protocol is one of the simplest ones and has been used for many years in lighting control. The original 0-10V protocol comes from theater lighting but with some changes a new protocol was created for dimming fluorescent ballasts and now even for controlling LED lighting drivers [42].

Functionality

The basic functionality of 0-10V lighting control is that the controller outputs a control voltage from 0 to 10V to the dimmable ballast of the fluorescent lamp or LED driver to produce a varying light output. The controller can therefore be of any type as long as it is able to output an 0-10V analog signal [42].

Structure

The controller of some type needs to be connected by one separate wire to the ballast and by one common wire to all the ballasts. According to IEC standard, the ballast should not draw more current than 2.0 mA. For a controller with 50 mA output capacity, this would mean a maximum of 25 ballasts per output. Figure 4.32 shows the connection of a controller and a few ballasts [42].

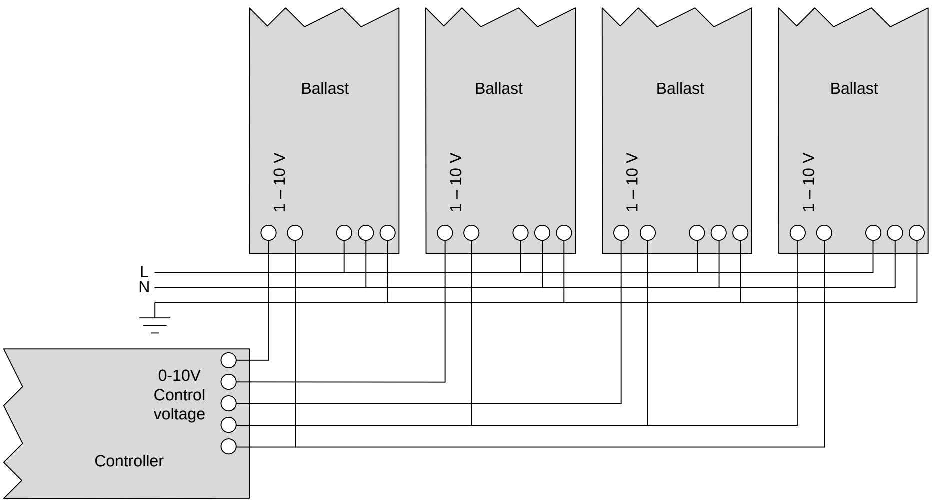

Figure 4.32: Controller and ballasts using the 0 - 10V protocol.

Protocol

The protocol has two current control variations, one is the so called current source which is used within the theatrical dimming. The other one, used with dimmable ballasts, is called current sink and means that the controller is not required to provide the voltage source. The protocol requires the ballast to produce full power at the control voltage of 10V. With reduced control voltage the light intensity is reduced until the minimum is reached at the control voltage of 1V. It varies between drivers (ballasts) whether this minimum is the lowest light output or off and therefore it is sometimes necessary to have a separate relay to switch the driver off [42].

Cost

Because of the simplicity of this protocol it can be combined with many controllers and lighting solutions. Therefore the overhead cost can be reduced and tailor-made solutions obtained. The fact that each ballast must have its own control wire from the controller (or at least each lighting group) increases the installation cost. This also makes any modifications more complex, for example to move one ballast from one group to another would require rewiring [42].

4.3 Other systems

Beside the systems covered so far in this report, there exists quite a lot of specialized lighting system from some of the illuminant producers. To give an overview of these systems, some of the most common ones will be introduced here, but this is far from being an exhaustive list.

DIGIDIM

DIGIDIM is a lighting control system from the Finnish company Helvar which is one of Europe's leading company in the production of dimmable ballasts. The DIGIDIM system includes dimmers, output units, contactors and input units. The system is controlled via pushbutton, sliders or rotating knobs and also supports a DIGIDIM router that uses standard Ethernet communication to combine multiple DALI networks [38].

LUXMATE

LUXMATE is a product from the Austrian illuminant producer Zumtobel. Zumtobel offers three version of LUXMAT: BASIC, EMOTIN and PROFESSIONAL.
LUXMATE BASIC offers two lighting groups and three lighting scenes. It is available for DALI and DSI[10] versions and with the DALI version it supports up to 64 lamps. The system is programmed and controlled via the DALI CSx control panel.
LUXMATE EMOTIN supports up to 128 DALI electronic ballasts, using two DALI lines. It can handle up to 32 groups, addresses for 16 rooms and 16 scenes. The system can handle daylight based, occupancy and scheduled light control and even 12-hour daylight simulation. It supports incandescent/halogen lamps, fluorescent and LED. LUXMATE EMOTIN can be controlled via wireless IR remote controller or the DALI EMOTIN Touch Panel as well as normal switches.
LUXMATE PROFESSIONAL adds a management level to the other systems, including both automation servers and PC operating software. The system has standardized blinds control, and can be configured to control heating and ventilation [28].

Xcomfort

Xcomfort is a wireless control system from the German Automation producer Moeller. The system supports control of lighting, temperature, ventilation

[10] Digital Signal Interface, DSI, is a lighting protocol from the Austrian company Tridonic ATCO.

and blinds. An addition also provides fire and burglary alarm and combines the systems with preprogrammed light routines for comfort and safety. The system is controlled by radio frequency and focuses on the simplicity of installation. Xcomfort also offers a Home Manager and Room Manager for total control or even the possibility of full control through a personal computer or TV-set [44].

4.4 Evaluation

Having looked at a few of the most common control systems within building automation and especially lighting control it is quite obvious that none of them is much better than the other. Systems usually have some specialties, some focus on covering the whole BAS model while others are more specialized and focus on things like energy efficiency and transport methods. Sometimes the system also blend into one another because of their different specialities. It is therefore essential to recall the findings from the previous chapter and use it along with some new factors to create some selection criteria.

4.4.1 Selection criteria

The findings from the empirical studies stated that the lighting control system should be able to handle all of the most efficient types of lamps. It should also be able to interact with different kinds of sensors and input devices and perform the most common lighting control strategies. The system should be user friendly regarding installation and operation and have the possibility to be connected to a second system such as BAS. These requirements were used as guidelines for selecting the discussed systems in this chapter. As stated in the introduction, the result from this chapter should provide a selection of a lighting control system to be implemented on one of AB Regin's platform. It is therefore obvious that in addition to the previously mentioned requirements, the properties of AB Regin's system must be taken into consideration. The fact that AB Regin has its own BAS implemented in the EXO system motivates the selection of a system at the lower levels in the BAS model in Figure 4.5, i.e. the field and automation level. It is also important to know what communication protocols are supported by the EXO system. This information is summarized as Integration with EXO systems and used as a selection criteria in the following selection matrix, along with the criteria discussed in the beginning of the chapter.

4.4.2 Selection matrix

To sum up some of the common key factors of the systems covered, a selection matrix has been constructed. Figure 4.33 shows each system in the upper row and the compared properties in the column to the left. In the cases where no actual numbers are usable, a grading system is used. The grades range from Sufficient up to Best, as shown in the legend on the right.

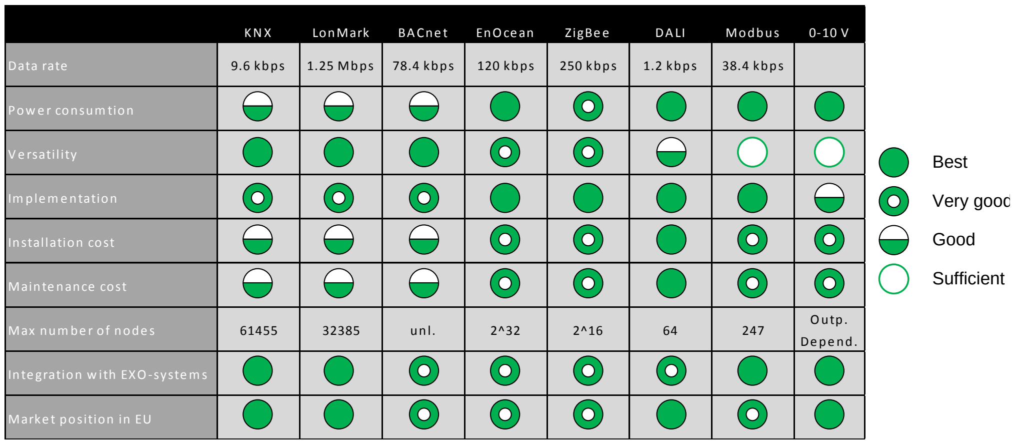

Figure 4.33: Selection matrix for protocols.

4.4.3 Chosen solution

When observing the selection matrix, one might see that the systems listed can be divided into three groups. The first group contains the three systems to the left, a full functioning BAS where lighting control is included as one of many possible options. The next group includes EnOcean and ZigBee, wireless systems that mainly focus on energy consumption of system parts and ease of implementation. The last group contains the systems covering the lowest two levels of the BAS model. DALI, Modbus and 0-10V protocols are field level protocols and require in many cases additional systems to work as fully functioning lighting control system. As AB Regin has its own BAS and is only looking for a lighting control addition to that system with no special attention on wireless systems, the focus is set on the last group. After evaluation of the systems in question, the DALI system has the highest potential, with a good market position within EU and an increasing number of producers supporting the protocol, both for drivers and sensors. Part of the system is integrated in the lamps supported, where as well, part of the software is stored. The power consumption of the system is moderate as the slave devices are asleep until the master wakes them up with a request. The protocol is quite simple and there already exists gateways to DALI from many other protocols. It should therefore not be to much of a problem to implement it on AB Regin's system.

Chapter 5

Practical implementation

In this chapter the process of implementing the DALI protocol on AB Regin's platform will be illustrated. Individual steps of the implementation will be described with text and schematics. The chapter ends by showing results from the implementation, testing of individual parts and overall performance.

5.1 Proof of concept

The purpose of this implementation is to proof the concept of energy efficient lighting control on one of AB Regin's system. The concept is that a light is to be controlled, switched and dimmed, and monitored from AB Regin's EXOcompact controller. All inputs will be handled by the EXOcompact controller which will then send commands to the DALI Master Unit.

5.2 Method

The implementation of the EXO/DALI system is performed in a few steps as listed below:

- Establish a connection between the microcontroller and a USB connected programmer, Atmel AVR Dragon.
- Design, construct and connect an interface between the microcontroller and EXOline.
- Design, construct and connect an interface between the microcontroller and the DALI line.
- Write a program for the microcontroller that interprets from EXOline to DALI line and vice versa.
- Carry out some testing of the system.

5.3 Implementation

The implementation of aa EXO/DALI system follows the basic idea as shown in Figure 5.1.

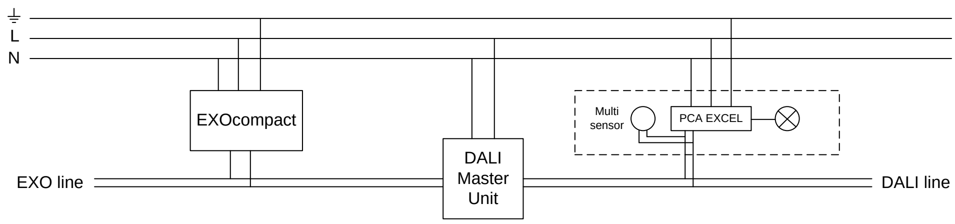

Figure 5.1: Diagram of the implementation, including mains line, EXOline and DALI line.

The DALI Master Unit serves as an interface between the two protocols, EXOline and DALI line. This is the main part of the implantation. In addition to the Master Controller there is an EXOcompact controller from AB Regin and a DALI supported sensor and lamp (ballast). Each of these parts will be explained in more details in the following sections.

5.3.1 DALI lamp

The Lamp used for this implementation is a 2x28W fluorescent lamp from THORN. It has a built in DALI enabled ballast from TRIDONIC.ATCO, as well as a DALI multi-sensor. The DALI multi-sensor combines a photocell and an occupancy sensor in one. The ballast and the sensor are connected in parallel to the DALI line.

5.3.2 EXOcompact

The controller from AB Regin used in the implementation is the EXOcompact.

Figure 5.2: EXOcompact, a controller from AB Regin.

The EXOcompact is a freely programmable controller, and the one used in the implemetation has 28 I/O, 2 EXOline communication ports and an integrated display.

5.3.3 DALI master unit

The DALI Master Unit is built around the ATmega 168 microcontroller from Atmel. The reason for choosing this microprocessor is that it has been used by AB Regin in other projects and its properties are well known within the company. Connected to the central processing unit, CPU, are:

- DALI line interface;
- EXOline interface.

The architecture of the DALI Master Unit is shown in Figure 5.3.

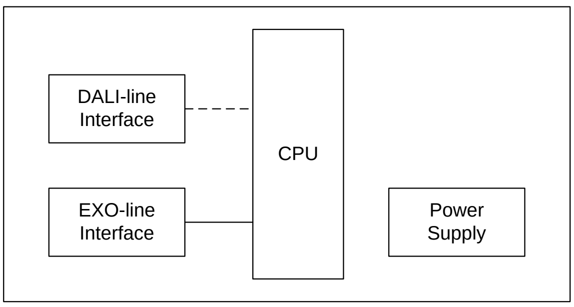

Figure 5.3: Block diagram of the DALI master unit.

Controller

The ATmega 168 is an 8 bit low power microcontroller. The ATmega 168 has 512 bytes EEPROM, 1 Kbyte Internal SRAM and 16 Kbytes of In-System Self-Programmable Flash progam memory. Connection to the two interfaces is obtained by using a Programmable Serial USART, I/O pins and an interrupt input.

EXOline interface

The EXOline interface is a circuit built around the Differential Bus Transceiver integrated circuit, SN75176A. The details are shown in Figure 5.4.

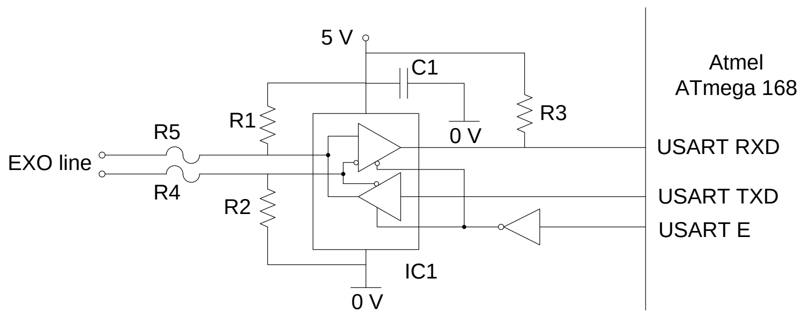

Figure 5.4: EXOline interface.

The EXO line interface is connected to the USART pins of the microcontroller.

DALI interface

The DALI line interface is constructed with two separate circuits, a transmitting circuit and a receiving circuit. These two circuits are connected in parallel at the DALI line end. The transmitting circuit, shown in Figure 5.5, consists mainly of a power transistor, T1, to switch the power on and off. The other two transistors, T2 and T3, are used to regulate T1. A low signal from the microcontroller opens T3 and switches of T1 [24].

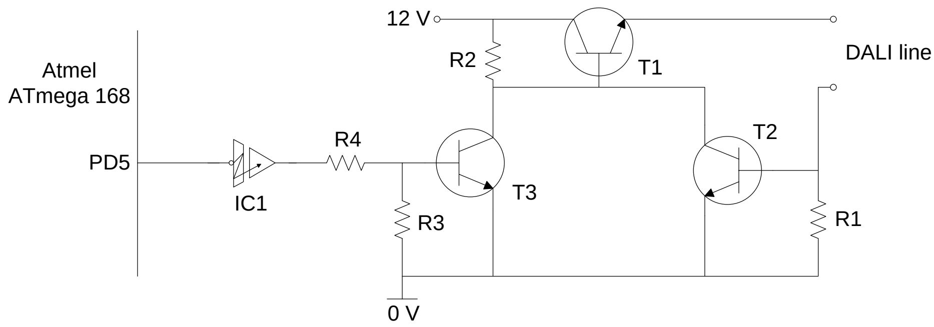

Figure 5.5: DALI transmit circuit.

The values of the resistors are chosen such that when the current exceeds 250mA the voltage level across the resistor will cause T2 to open. This will then in turn cause T1 to close and therefore the current is limited to 250mA, which is according to the DALI protocol.
The receiving circuit, shown in Figure 5.6, uses a comparator, IC2, to handle the reception of a signal from the DALI line and to send it to the microcontroller. The inverter converts the signal to the correct logical level but to achieve a more accurate voltage level the resistors needs to be calibrated [24].

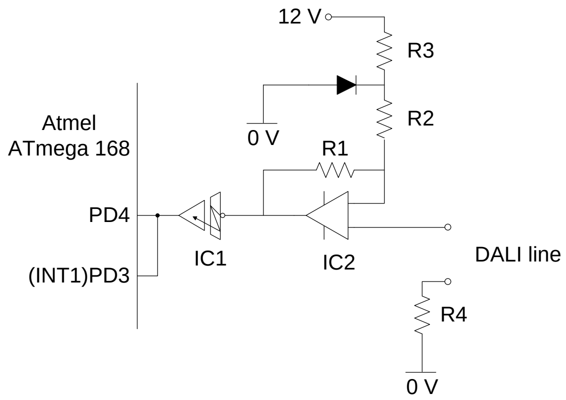

Figure 5.6: DALI receive circuit.

The DALI interface is electronically isolated from the Master Controller by using an inverting optocoupler. The total construction of the circuitry is shown in Appendix A.

Master Unit program

The program for the Atmel ATmega168 processor is written in C-language and compiled and debugged with Atmel debugging tool. The program uses interrupts for communications on both lines. For EXOline communication the USART functionality is used[11]. For the DALI line two types of interrupts are used. A timer interrupt is used to provide the 1200 baud transmission speed, and in order to establish the Manchester encoding[12] each data bit is constructed by eight interrupts. For this reason the timer gives 9600 interrupts every second, which is used for encoding and decoding of messages on the DALI line. The other interrupt used by the DALI line is an external interrupt, triggered by the interrupt pin on the microcontroller (PD3 in Figure 5.6). When messages arrive from a DALI slave, the interrupt pin triggers an interrupt routine in the program. This routine then enables the receiving part in the time based interrupt routine which then encodes the

[11]This has previously been used by Regin in other projects and the methods are well defined by them.

[12]Manchester encoding is a line encoding method where each data bit has a transition that occupies the same time. Clock signal is therefore unnecessary as the transitions can be used for synchronization.

receiving messages and stores the value in a memory. The workflow of the main function is illustrated in a flowchart in Appendix B.

5.4 Testing

To test the functionality of the implementation, a simple operation is carried out. The setup of the testing is shown in Figure 5.7, where a computer running EXO software is connected to the EXOcompact controller using a RS232/RS485 converter. By using a test program from Regin on the PC, called EXOtest, it is then possible to pipeline commands from EXOtest, to the DALI Master Controller through the EXOcompact and back again.

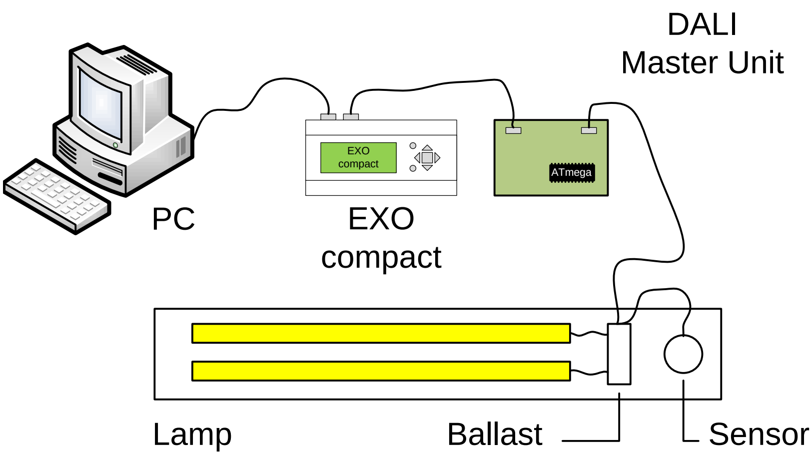

Figure 5.7: Setup of testing equipment.

The following operations are to be tested:

- Send address and command from EXOtest to DALI slave;
- Receive messages from the DALI slave and read them with EXOtest.

5.5 Result

The design and construction of the needed circuits on a protoboard was quite straightforward as well as establishing the connection between the microcontroller and the Atmel programmer. After writing the program for the microcontroller it was possible to test communications over the EXOline and DALI line. Communications over the EXOline worked quite well and initially the testing was carried out by sending a value from EXOtest to the microcontroller that would activate an output and write some value to a memmory location on the microcontroller, which was then read by the EXOtest. The initial tests performed on the DALI line were to define a fixed address and command in the microcontroller's program that would be executed when started. When these communications seemed to work it was time to test the whole communication chain. DALI defines two types of addresses, ordinary and direct. The ordinary is always followed by a command from 0 to 254, which indicates the light intensity to be set(0..100%). The direct address is followed by a command that is called a direct command and is predefined by DALI. The possible direct commands are both instructions like: step up, step down, off, recall max, recall min and queries such as: query status, query ballast, query lamp failure, query power failure, etc. These query commands will then be responded by the DALI slave. For testing, both types of broadcast addresses were used, ordinary and direct. By entering the ordinary broadcast and a command on the interval 0 to 254 in EXOtest, and execute the command the light output of the lamp varied. The direct broadcast address was also used with different types of direct commands, except queries, with success. The query commands are aimed at a specific slave and therefore it is not possible to get any answer from a broadcast address. The slave unit come with a preprogrammed 24 bit address (long) and needs to be programmed with the 8 bit address (short) used in DALI protocol. In order to program the slave with a short address a special programming interface is required or possibly some more advanced program in the DALI Master Unit. Due to lack of time, neither of these options were used and the success so far was considered enough to prove the concept.

Chapter 6

Conclusions and future work

6.1 Conclusions

This master thesis has tried to shed some light on the possibilities to make lighting systems more cost- and energy efficient by applying lighting control. The empirical studies showed the increasing demand on reducing energy consumption and thereby the possibility to reduce carbon dioxide emission. A case study at Schenker office in Växjö showed how a simple occupancy based lighting control system can save electrical energy and has a short payback period. After examining different control strategies within the lighting control, it is obvious that even more savings can be accomplished without increasing the payback time significantly.
The marketing study revealed the characteristics of some of the most common lighting control systems available today. It also became obvious that the systems in question can easily be divided into groups, based on their specialities and coverage of the building automation model. From a selection criteria, partly based on the intention to implement the selected one on AB Regin's BAS, DALI was chosen.
The implementation of the DALI protocol on AB Regin's system EXOcompact was carried out by building a DALI Master Unit around Atmel ATmega186 microcontroller. The reason for choosing this microcontroller was mainly that it was already used in some of AB Regin's product and well known by the development team. Demonstrating the concept, that a DALI slave could be controlled by sending commands from the EXO system was proven before the actual deadline of the project but further implementations were left for the development team at AB Regin.
For a company such as AB Regin, which is a leading provider of HVAC systems, the addition of a lighting protocol to its system will strengthen its market position as a full scale BAS provider.

6.2 Future work

With increased demand, from governments and consumers, to reduce the energy consumption for lighting much work needs to be done. The field of cost- and energy efficient control is very active and the possibilities for an automation company that can supply a solution, which meets these demands are great. Some future work for companies such as AB Regin could be to:

- Include the lighting protocol to their BAS and use the controller to optimize the energy consumption for example by controlling the position of sun curtains, heating, ventilation and light-output.
- Expand the management tools available in the BAS to conduct a deeper cost analysis for the building based on the use of energy consuming equipment such as lights.
- Include a DALI line output in each room controller to have complete control of the energy consumed in that room. By this each room controller would be a Dali Master Unit with the capability of addressing 64 devices, 16 groups and 16 scenes. This would then solve DALI's problem of limited number of devices.

Event though the basic concept of the implementation has been proved and a prototype exists, there is still much work to be done. The following list illustrates some thoughts concerning the next steps towards a final product.

- Get another DALI slave (ballast/lamp) for testing.
- Get a programming interface to program the lamps with short addresses and perhaps for some other operations.
- Test the decoding of messages from slaves when they have been programmed with short addresses and it is possible to send a query to them.
- Fully implement the state machine in the program, to guarantee the correct data flow in the program.
- Implement a GUI in the EXO system, that is able to execute some sequence to search for available lamps and give each of them a short address. Then the GUI could be used to assign the lamps to groups, give the light levels, etc.

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Appendix

Appendix A

Circuit drawings

Figure A.1 shows the wiring of the DALI master unit on a project board. In the figure, some of the major parts are marked.

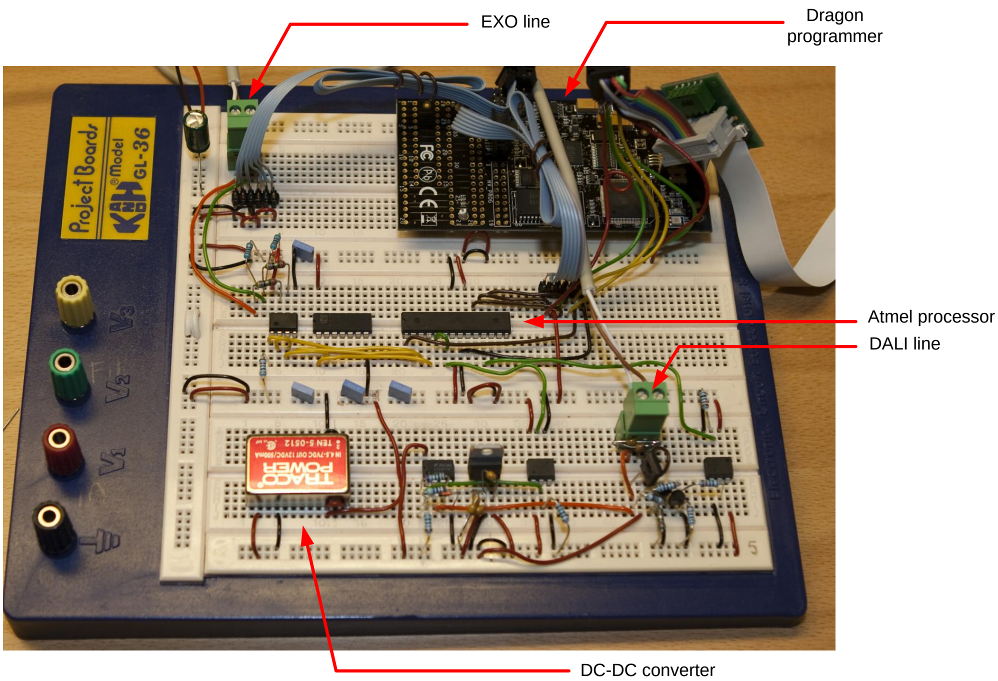

Figure A.1: DALI master unit on a project board.

On next page the schematic of the DALI master unit can be found. In that drawing, no connection to the Atmel debugger is shown.

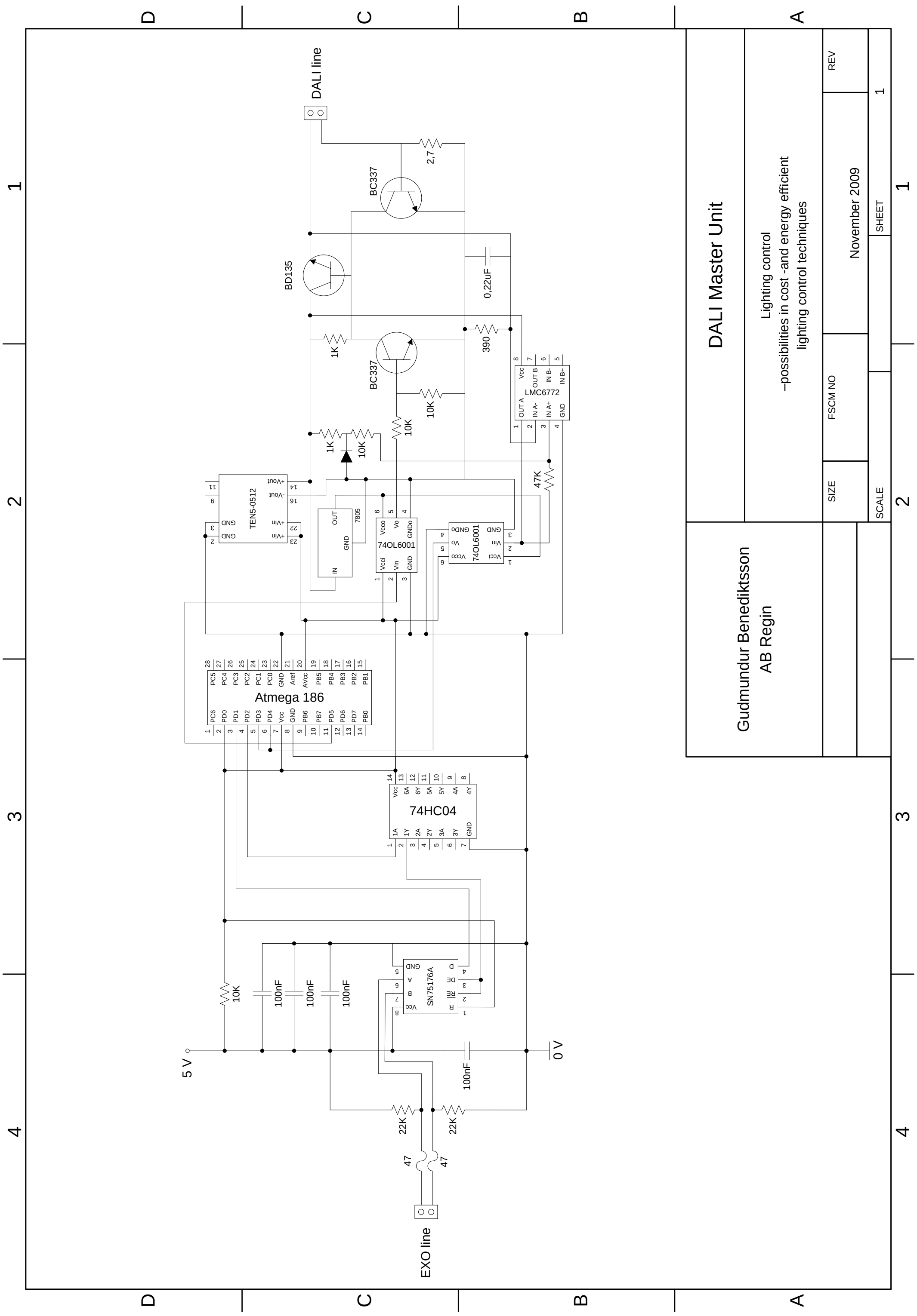

Figure A.2: DALI master unit schematic.

Appendix B

DALI master unit program

The flowchart below illustrates the functionality of the main() loop in the microprocessor program.