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Detection of lighting Consumers by Correlation of Control Signals and Illuminance

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Abstract

This study is to further develop a procedure for detecting the electrical consumer in commercial buildings, such as public buildings and office buildings with a research laboratory for Solar Technology and Energy System (LSE) to identify and quantify energy efficiency measures. The study implements and examines the Room Climate Monitor for measuring the light of artificial light sources, which was developed in the previous study “Optimising for an Indoor Climate Measuring Device”. This study develops a largely automated methodology for assigning lighting groups to the associated KNX group address in order to perceive the electrical consumer for more energy-efficient.

The project consists of measuring the light of an artificial light source with the local measurement device in the spectrum of visible light and infrared, and developing a code to detect the light switching signals and correlating the detected signals with the associated KNX group address at Electrical and information department of Munich University of Applied Sciences (MUAS).

Measuring the light of an artificial light source with RCM can be successful if the light sensor is covered from direct sunlight. Using a cover is an affordable and easy way to implement the measurement. In addition, detecting the associated KNX group address of the light consumer depends on the amount of switching signals “on/off” detected and the time interval of measurement.

Tiivistelmä

Tämän opinnäytetyön tarkoituksena on kehitellä sellaisen metodin, jolla havaita valonkuluttajan liikerakennuksissa, kuten julkiset ja toimisto rakennukset aurinko teknologian ja energia järjestelmän laboratorio tutkimuksella (LSE), jotta tunnistetaan ja kvantifoidaan energiatehokkuutta koskevia toimenpiteitä. Lisäksi tavoitteena on kehitellä automatisoitua menetelmää, jolla luokitella valaisin ryhmiä liittyviin KNX ryhmä osoitteisiin energiatehokkuuden parantamiseksi.

Työ sisältää laajaa keinotekoisten valonlähteiden mittausta näkyvän ja infrapunan spektereillä mittauslaitteella (Sisäilman mittauslaite) ja sen toiminnallisuuden tarkastelua, mikä oli aiemmassa tutkimuksessa kehitelty “Sisäilman mittauslaitteen optimointi”, myös koodin kehittämistä, jolla huomataan valonlähteiden kytkentäsignaalit “1/0”, ja niitä havaituja kytkentäsignaaleja korreloidaan yhdistetyn KNX-ryhmäosoitteen kanssa. Projekti toteutettiin sähkö- ja informatiikan kampuksella, Münchenin Korkeakoulussa.

Keinotekoisten valonlähteiden mittaaminen vaatii sen, että mittari peitetään suoralta auringon valolta mittaamisen aikana. Mittarin peittäminen suoralta auringon valolta on edullinen ja helppoa. Lisäksi, valonkuluttajan KNX ryhmäosoitteen havaitseminen riippuu kytkentäkertojen määrästä ja sen väliajalta jolloin se on suoritettu.

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Abbreviations and Special Terminology

LSE	Laboratory for Solar Technology and Energy System
Spectrum	A range of Colours representing Light
SI	International System of Units
E_v	Illuminance in Lux
nm	Nanometer
FWHM	Full Widt at Half Maximum
KNX	Home and Building Automation Standard
ETS	Engineering Tools Software
EIB	European Installation Bus
EHS	European Home System Protocol
BatiBUS	Home Automation

1 Introduction

A large amount of energy consumption in buildings is accounted for lighting. It is important to provide a sustainable solution to reduce the energy consumption, save and manage energy. As the University of Applied Sciences Munich has recognised the potential of saving energy in the institution. The project concerning saving energy was originally launched in 2016 by developing a room climate monitor for measuring the important parameters such as light quality. The MUAS wanted to develop the procedure based on previous study by using the room climate monitor 2.0” for detecting the light consumer with help of bachelor´s study in the laboratory of solar technology and plant technology in electrical and information technology department. Detecting light consumer took place by correlating the switching signals from measuring the light of an artificial light source with the associated KNX control events in different locations at the institution. The focus in this study was to further develop an automated and intelligent system of lighting switching events to identify and quantify the electrical consumer. The study consisted of research based on measuring the illuminance observation concerning a possibility to separate the natural light (sunlight) from the artificial light.

2 Basics of the Important Factors for Detecting the Light Consumer

In order to undrestand the topic, detection of light consumer, it is importamt to achieve an overview on the background of induvidual factors related to the measuring of light from an artificial light and KNX system. The research is generally focused on investigating the light in different units for measuring, the light color and its wavelnegth emitted by different light source and if there is a possiblity of separating the artificial light from natural light. In addition the basic knowledge of KNX system, specifically the group and physical addresses are handled. The main part of the project is software and measuring the light is focoused on the spectrum of visible light and infrared from artificial light sources, other spectrums of light are not in this study investigated. All measurements are performed with the existing RCM (explained in chapter 4).

2.1 Light

Light is electromagnetic radiation within a certain portion of the electromagnetic spectrum, usually known as visible light. The wavelength of the visible light is between 400-700 nanometers. Radiometric and Photometric are two main light measuring units [1].

This project is focused on measuring the amount of light from artificial light sources in purpose to detect the light switching signals. The measurement will be performed in different locations at Munich University of Applied Sciences. For this reason, it is important to identify, how to measure the light produced by an artificial light source so that the influence of sunlight is minimized or eliminated: which measuring light unit is recommended for this measurement and in which spectrum of light the measurement gives an optimal outcome, or is it possible to distinguish the sunlight from artificial light.

2.1.1 Radiometric

Radiometric is the measurement of light power in all wavelenght (also invisible light). It measures the optical radiation. Optical radiation is electromagnetic radiation within frequency between 3×10^11 and 3×10^16 Hz, which match to wavelength from 0.1 to 1000 micrometers. The common radiometric quantities are defined as radiant energy, radiant flux (radiant power), Radiant flux density, radiance and radiance intensity.

Radiant energy is the absorbtion of light by an object and it is measured in joules. Radiant flux is energy in time or joules in second which means power and it indicates the absorbtion of energy by light during a period of time. Radiant flux density is radiant flux per square meter which is the amount of flux spreading into a surface and is measured as joule in cube meter. Radiant intensity measured in power per solid angle area and other unit is Radiance, which is measured in power per projected area per solid angle area [2].

2.1.2 Photometric

Photometric measurement consist wavelength weighted with human brightness standardisied model. It is used to measure the concentration of natural or artificial light by absorbing the wavelength of light. The common light measurement units of photometric are luminous intensity, luminous flux , luminance and illuminance. Colorimetere, Photometer and Spectrophotmeter are the three types of photometric instrument [2].

2.1.3 Photometric Quantities

Photometric uses different units for measuring the light from a light source depending on the purpose of the measurement. The following table describes different photometric units.

Table 1. SI Photometry Quantities [3].

SI Photometric Quantities and Units				
Quantity	Symbol	Unit	Unit Symbol	Description
Luminous intensity	I_v	candela (lm/sr)	cd	Luminous power per unit solid angle
Luminous flux	Φ_v	lumen (cd·sr)	lm	Luminous energy per unit time - the product of luminous intensity and steradians
Luminous energy	Q_v	lumen second	lm·s	Energy emitted as light - the product of luminous flux and its duration
Luminance	L_v	candela per square meter	cd/m^2	Luminous power per unit solid angle per unit projected source area
Illuminance	E_v	lux (lm/m^2)	lx	Luminous power incident on a surface in lumens per square metre
Luminous exitance	M_v	lux (lm/m^2)	lx	Luminous power emitted from a surface in lumens per square metre
Luminous exposure	H_v	lux second	lx·s	The product of illuminance and its duration
Luminous energy density	ω_v	lumen second per cubic metre	$lm \cdot s \cdot m^{-3}$	Luminous energy per cubic metre
Luminous efficacy	η	lumen per watt	lm/W	Ratio of luminous flux to radiant flux or power consumption, depending on context
Luminous efficiency	V	-	-	Luminous efficacy expressed as a fraction of the maximum possible luminous efficacy - a dimensionless quantity, usually expressed as a percentage

Depending on the type of light sources, each one emits the light differently. Some of them such as an incandescent bulb emits the light in all directions and some light sources like a flashlight, emits the produced light only in one specific direction. This difference of light emittance by light sources makes the measurement more complex [3] [4]. In the following section each unit will be briefly explained.

2.1.4 Luminous Flux

Luminous flux is the amount of light produced from a light source in all direction per unit time. It measures the power of those wavelengths, which are among visible part of electromagnetic spectrum. The unit for measuring luminous flux is lumen and one lumen is the total amount luminous flux produced by a light source that emits one candela of luminous intensity over a solid angle of a steradian. The device for performing luminous flux is typically photometer or spectrometer. [3] [4]

$\Phi_v = I_v \cdot \Omega$ (1)

Where
Φ_v is lumen inside the solid angle
I_v is the luminous intensity in candela
Ω is the angular span in steradian

$\Phi_v = 4\pi\, I_v$ (2)

Where
Φ_v is lumen
4π steradian is for isotropic light
I_v is the amount of candela falling from the light source

The number 1 equation above is used when the light source emits one candela of luminous intensity toward a solid angle of one steradian and the total luminous flux emitted to that angle is one lumen. Equation 2 is used, when the light source emitts one candle of luminous intensity in all direction, which is 4π times to steradian [5].

2.1.5 Luminous Intensity

Luminous intensity is one of the SI-quantity and measures the length-weighted power of light sources in a specific direction per unit solid angle. Luminous intensity measures the wavelength of the visible part of electromagnetic spectrum. The difference between luminous flux and luminous intensity is that luminous flux is the perceived power emitted by light source in all direction, whereas luminous intensity perceived power of the light in a specific direction. The unit for measuring luminous intensity is candela [3] [4].

$$Iv = \frac{\mathbf{lm}}{\mathbf{st}} \qquad (3)$$

Where
I_v is candela
lm is the amount of lumen
st is the solid angle in one steradian

Luminous intensity is measured by emittance of candela from a light source in the range of angular spam.

2.1.6 Luminance

Luminous intensity per square meter emitted or reflected by an object in a specific direction is called luminance. The SI unit for this quantity is defined candela per square meter. Luminance is actually the brightness of an object and when we look at an object, we see the object´s luminance. Luminance represents the variation of brightness with wavelength but doesn't show how the brightness or perceptual variable varies if the energy of a light of certain wavelength is changed [3] [4].

$$L = \frac{1}{\pi}E \qquad (4)$$

$$L = \frac{\mathbf{R}}{\boldsymbol{\pi}}E \qquad (5)$$

Where

L is luminance (candela per surface)

E is illuminance in lux

R is the fraction of incident light

$$L = \frac{1}{\pi}bPcosV \qquad (6)$$

Where

L is luminance (candela per surface)

b is the factor for reflectance of a surface

P is the beam intensity

V is the angle of incidence

The equation number 4 above is for luminance of a perfect diffuse. A perfect diffuse surface reflects the brightness in all direction. The diffuse surface reflecting only a fraction of light is calculated as number 5 and the number 6 describes the calculation of reflectance of a surface, which is not a perfect diffuse [6].

2.1.7 Illuminance

One of the common photometric quantity to be measured from a light source is illuminance. Illuminance is the amount of light spreading over a surface, also known as the total luminous flux incident on a surface. It is defined as the rate of lumens per unit area. Usually the illuminance is measured in lux but also can be measured in footcandles [7].

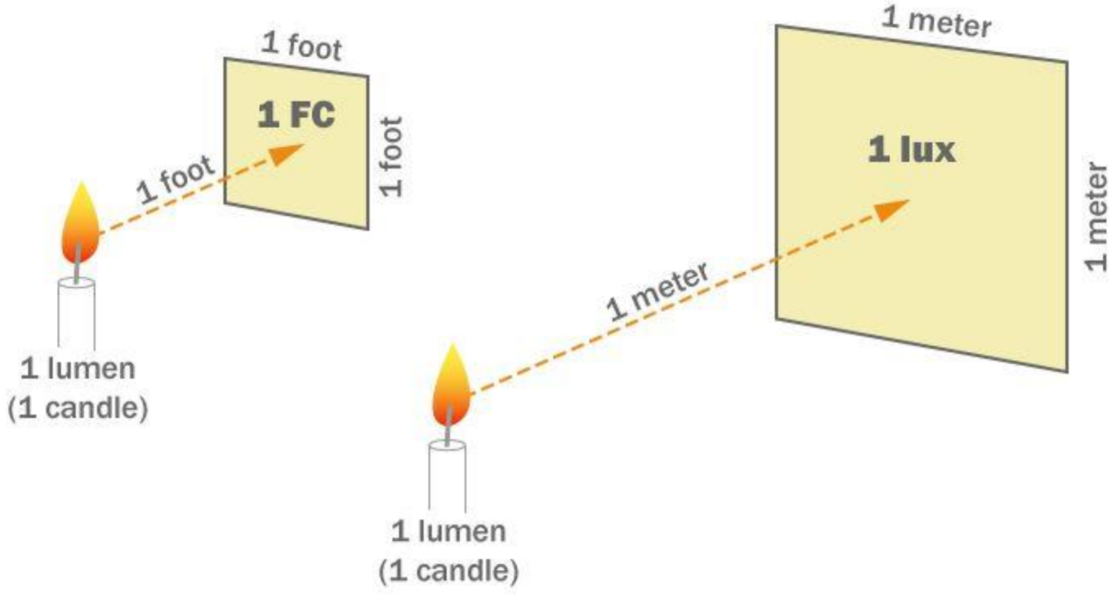


Figure 1. Showing Illuminance in Lux and Footcandle [8].

The above figure 1 shows two different measurement for illuminance. In SI, the illuminance of a surface is measured in lux, square per meter. However, it is also measured as well in footcandle, candela per square foot which is a non-metric unit. The illuminance in footcandles is equal to illuminance in lux times to 0.09290304.

$$Ev = \frac{\Phi v}{A} \quad (7)$$

Where

E_v is illuminance of a surface in lux Where

Φv is the amount of lumens

A is the the surface, which is illuminated by lumens

$$E = \frac{cd}{ft2} \quad (8)$$

Where

E is illuminance of a surface in footcandle

cd is the amount of candle falling from the light source

ft^2 is foot per square meter which is illuminate by cd

The two equations are used for measuring the amount of illuminance spreaded from a light source. Illuminancne measured in lux equation 7 is the common measurement principle and footcandle in equation 8 is usually used for measuring illuminance in English speaking countries and is a non-SI unit of illuminance or light intensity. One candle per suare foot is equal to one lumen per square foot and one footcandle is 10.764 lumens [9].

2.2 Measuring Unit for Detecting the Switching Light Signals

As explained, there are many measurable units for measuring light and every quantity measures a specific area of light. However, the measuring principle for each unit of light is different. Measuring each unit requires different equipment and calibration and the purpose of each unit ranges. Nevertheless, the main aim of measuring the light of a light source in this project is to detect the light switching signals and to provide an affordable procedure for implementing this measurement, which can as well accomplish the same result in different location.

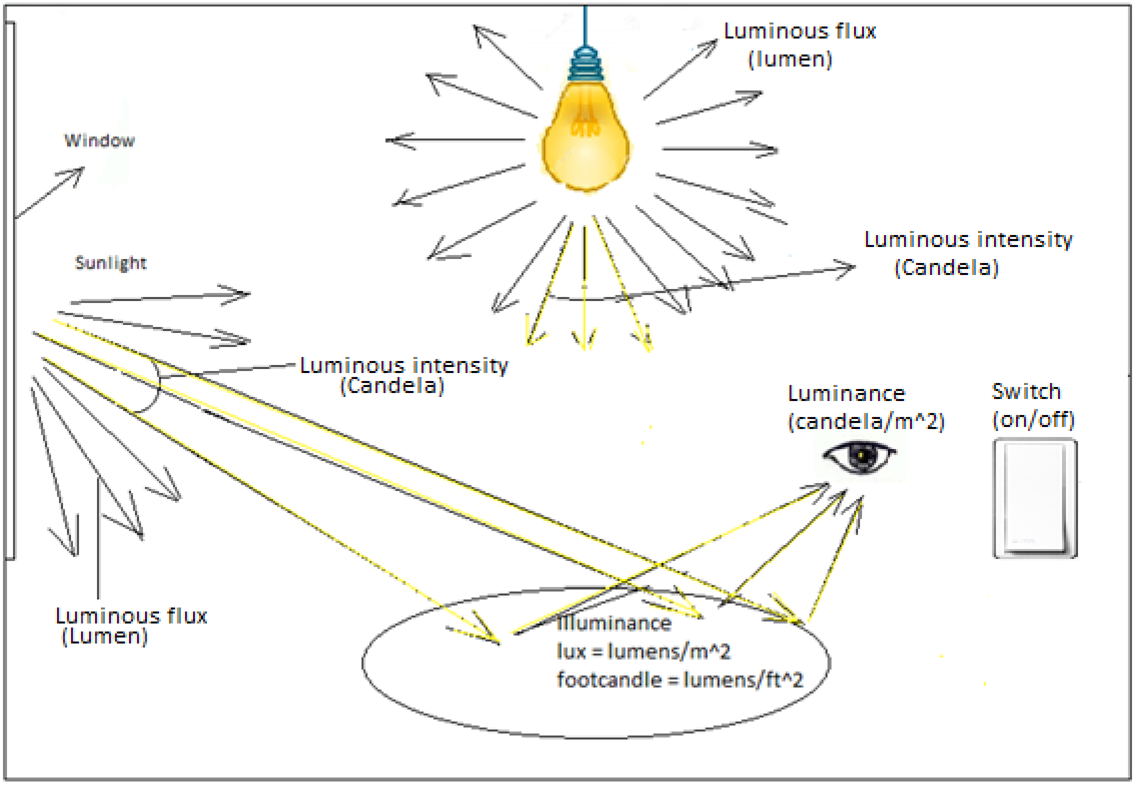


Figure 2 The common units for measuring the light

As the figure 2 shows, the luminous intensity (unit candela) is measured to characterise the brightness of a lamp and how much an area is illuminated. It is also used in purpose of identifying that how much a light source produces the glare. However, measuring this quantity is expensive and requires at least a digital camera. Luminous flux, which measures the total amount of light given off by a light source and is basically used to investigate how much energy is emitted by the light source, is the amount of radiative energy that a human can see. In fact, measuring luminous flux is the most accurate measurement among photometric quantities. However, measuring this light in lumen requires an integrating sphere or at least a large array of sensor to approach its output. It is very complex and the measurement can be determined only in a laboratory. The measurement devices are expensive. Also, it is important to know exactly the spectrum of each light source to be measured. Furthermore, one of the priority in this project is to develop an affordable and simple procedure [10].

To measure the illuminance of a light source, there are some disadvantages such as the illuminance meter can´t tell the pattern of light, and if the area is illuminated or not. The light being in the area can be blended with sunlight, which results in a wrong and inaccurate outcome. As an example, a room where usually there is a window and the sunlight is entering the room during the day depending on the time, weather and the location of window, it is not easy to measure precisely the amount of light emitted from the desired light source and distinguish the sunlight. Nevertheless, there are a few methods to measure the light in the unit of illuminance more accurately, such as avoiding the sunlight and using a blind or measuring in a time of day when the influence of sunlight is reduced and doesn't interrupt the measurement. Furthermore measuring illuminance from a light source is simple and there are many different meter for this measurement available in the market. The price of illuminance meter is reasonable and can be executed in different locations [10] [11].

2.2.1 Illuminance Measurement

It is very critical to measure the actual illuminance from a desired light system. Today illuminance measurement is becoming significantly important due to safety concerns, people´s comfort and saving energy. The measurement of light sensitivity (illuminance) is either a real daylight measurement or a mixed measurement. A real daylight measurement measures the illuminance from the daylight and a mixed measurement measures a mix of daylight and artificial light. Usually the amount of illuminance falling from a light source is measured in lux but it can be measured also in footcandles. Measuring the illuminance is performed with an illuminance meter (lux meter) in a defined surface. Many factors including attributes of the measurement instrumentation such as the setup and achievement of the actual measurements can affect the accuracy of the illuminance measurement. The available range of illuminance measuring equipment is so wide and the equipment can be procured from a recognised company or can be hired.

2.2.2 Illuminance Measurement for Indoor

An accurate measurement for indoor requires such conditions as avoiding the external light as well as sunlight in the place, where the measurement is performed (preferably after sunset), using a meter which meets the accuracy conditions, using the same meter for the whole measurement, avoiding the extreme temperature, checking the power and operating temperature. Regularly calibration of the measurement equipment is recommended for at least once in a year [12]. However, the advice is to calibrate it every six months. The equipment should be calibrated in case the measurement equipment is compelled to intense heat or dropped. It must be ensured, that the sensor head is parallel to horizontal or vertical task plane. To eliminate the small surface differences, it is recommended to place the sensor head on a platform and a correct height for each reading. It must be ensured, that there is no obstruction blocking the direct light form the light source and that no item is so close to the measurement point to reflect the light onto the sensor head [13].

2.2.3 Outdoor Light level

Light level (Illuminance) for outdoor generated by sunlight varies at different time of the day and night depending on the weather. The amount of illuminance can range 120000 lux for direct sunlight at noon.

Table 2. Outdoor Light level over night and day [14]..

Condition	Illumination	
	(ftcd)	(lux)
Brightest Sunlight	11150	120,000
Sunlight	10000	107527
Full Daylight	1000	10752
Overcast Day	100	1075
Very dark Day	10	107
Twilight	1	10.8
Full Moon	0.01	0.108
Overcast Night	0.00001	0.0001

The above table 2 presents the common outdoor light level over day and night. The table shows that in a clear day, the amount of illuminance can exceed up to 10000 lux. However, at noontime and on a grey day, it reduces to 1,000 lux. On a very overcast day, the value of illuminance decrease to 100 lux and at night with a full moon to 0.108 lux [14].

2.2.4 Indoor Light Level

Indoor light level ranges between 100-2000+ lux depending on the activity and purpose of using. Earlier for regular activity, the need of light was between 100 to 300 lux but today it is from 500 to 1000 lux. For indoor light level, the illuminance in the area closest to windows depending on the weather or time of day can be up to 1000 lux, which should be taken into account in designing of the light for indoor. As the table 3 below shows, in some area, the need of illuminance is much more than in other areas, which is derived from the purpose of the activity.

Table 3. Recommended Indoor Light level [14].

Condition	Illumination (lux)
Drawing Office, Chain Stores, Supermarket, Hand tailoring, Precision Assembly and Detailed Drafting	750-2000+
Reading, Writing Room, Working with Computer, Kitchen, Office, Retail shops	500
Libraries, Sport Halls, Teaching Classes	300
Warehouses, Restrooms	200
Changing Rooms, Toilets	150
Night time Walkside, Parking	50

At daytime, the amount of indoor light is varied depending on the type of buildings. The demand of illuminance for working with computer, reading, writing, office and kitchen is 500 lux [14].

2.2.5 Illuminance Meter

There are two types of meters available for illuminance measurement, a multifunctional meter intended for indoor, which can measure room visible light sensitivity (illuminance), temperature, CO_2 and humidity or a meter only for measuring the illuminance. The illuminance is mostly measured in lux in different workspot. Commonly illuminance sensors detect only the spectrum of visible light or one other spectrum such as infrared, but there are also some sensors, that has the ability to measure the full spectrum and infrared diode. The light sensitivity is measured by lux meter with one light sensitivity cell or a spectroradiometer. However, the result of one light sensitivity cell meter doesn't match the human eyes light sensitivity curve but can work with correction factor having one common spectrum. Some lux meter that have optimized and adjusted with optical filters and lenses can follow a result with accuracy condition of L class (maximum accuracy, tolerance < 1,5 %) approximation of human eye's light sensitivity curve. The spectroradio meter measures the total spectrum of the visible light. It catches the light and extracts it with different spectral light components. It measures each 5nm wavelength area by a separate light sensitive sensor. It uses 81 light sensitive sensors for measuring 380-780 nm wavelength area and each sensor is used to measure a narrow band of 5nm of the light [15].

2.3 Light Wavelength

It is so interesting how people can see the colors and how the colors response to our eyes. Wavelength is the electromagnetic wave and each color is emitted in a certain wavelength by a light source. Wavelength ranges from 0.1 to 1000 micrometer and the visible wavelength, which human eyes can perceive ranges between 380 to 780 nm. Wavelength visible to human eyes extends from infrared up to ultraviolet and other than this area is no visible for human. The shortest wavelength is owned by the violet color and the longest by red color.

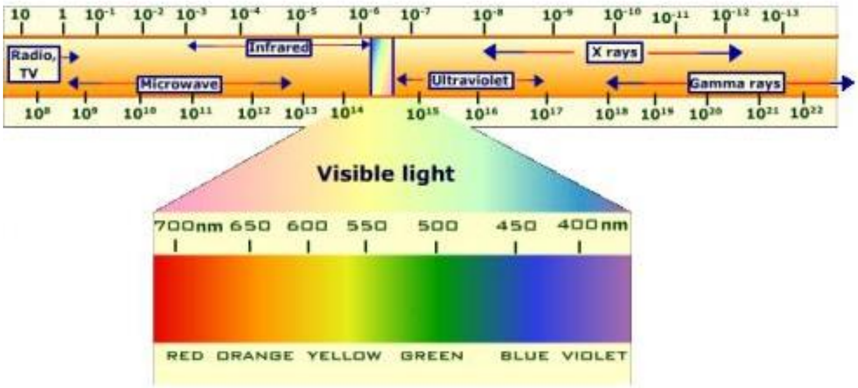


Figure 3. Wavelength in different temperature color [16].

As it is shown in figure above, the visible light ranges between 400-700 nm which is called white light and it consists all colors from red to violet color. Wavelength of red color is about 650 nm, for yellow color around 570 nm, green color has about 510 nm, the blue color also has 475 nm and the violet color 400 nm in the visible spectrum. Ultraviolet, which is not visible to human´s eyes ranges from 10 to 400 nm and in the other side of the line is infrared, which is up 1050 nm [16].

2.4 Color Temperature

Color Temperature is the light appearance provided by a light source. It is known as the temperature of a black body. A light source radiates the same light color temperature that itself has. For example, a yellow color incandescent bulb produces yellow light as output. Color temperature is basically measured in kelvin and ranges between 1000-10000K. Light appearance are commonly defined in three main color temperature areas. As the table 4 represents these areas are called Warm White, Cool White and Daylight

Table 4. Color Temperature for different location [17].

Color temperature	Light Appearance	Source	Match for
2000K-3000K	Warm White	Incandescent/Halogen lamps Fluorescent/LED lights	Living room, kitchen, bedrooms, conference room, restaurant and commercial lighting ambient, outdoor
3100K-4500K	Cool White	Studio lamps/CP lamps Fluorescent/LED lamps	Study/office, bathrooms, basements, garages
4600K-6500K	Daylight	LED/Energy saving, Metal halid lights (HID) Fluorescent daylight	Display areas, garages, task lighting and security lighting

Warm white colour ranges from 2000K to 3000K (red and yellow hue). Warm means a softer colour and is used mostly in home lighting. The colour temperature of incandescent lamps are usually 2700K, also some neutral-white fluorescent and Halogen lamps perform in this scale of colour temperature. The colour of cool white varies 3100-4500K and as can be expected, it produces a cooler colour, which is used mostly in offices, study rooms or basements. Light sources such as cool-white fluorescent produce light in this scale of colour temperature. Daylight in the area of 4600-6500K more blue is best for places such as display areas, garages, jewellery shops. Daylight fluorescent can be used in daylight area [17].

LED is a semiconductor light source and its colour temperature ranges from warm white to over daylight. LEDs are capable of producing light in spectrum of all visible light colour, from ultraviolet to red colour. For producing white light by LED, there are different methods. The common method for producing white light is to mix the three green, blue and red light colours (RGB) or emit these colours by adjusting each of them independently. Another method is coating LEDs of one colour (commonly blue), which uses the phosphor of different colours for producing white light [18].

2.5 Measuring Light from Artificial Light Sources

Light mixes spectrally and there is no method to distinguish artificial light from sunlight unless the spectral and/or temporal behavoiur of one of them is exactly known. Usually light sources are measured in controlled environments which eliminate external lighting. Neverthless there can be a few method for the light separation such as:

- If the artificial light source has a temporal behaviour, like PWM driven LED's, there might be a possiblity to measure the illuminance of daylight only, and measure the illuminance of the artificial light as a function of time. When the artificial light is temporary off will measure the illuminance of daylight and when the artificial light is on again measures the added illuminance of daylight and artificial light. For this a fast sampling light meter is needed. When ordered with a cosine corrector this gives illuminance data over time, sampled at 180.000 samples/sec. Separating halogen from daylight would certainly not be possible with this solution since this light source holds no temporal component [19].

- Spectral separation by using a spectrometer. If the spectral behaviour of the daylight (note that weather and time-of-day changes the spectrum) is known then it might be able to subtract that spectrally from a measurement and the result would be the artificial light. Or vice-versa. For this is recommended a Hera spectrometer with a range of 360-830nm and a FWHM of 2.3nm [19].

- Another difference of artificial light from sunlight is that the energy emitted by sunlight in the blue and red area of light is much more than emitted by an artificial light in the same area [20].

3 KNX Standards

KNX standard is the only open standard in the world for building automation, the successor and combination of EHS, BatiBUS and EIB. The KNX technology is created and owned by KNX Association. KNX is an independent of any hardware platform but networks from 8-bit microcontroller to PC can govern it. KNX Standard is approved by international Standard (ISO/IEC 14543-3) and European Standard [21].

3.1 Structure

The Network is compromised of areas, lines and devices. As the following figures shows, all areas, lines and devices are connected to each other by a bus cable through which the devices can communicate.

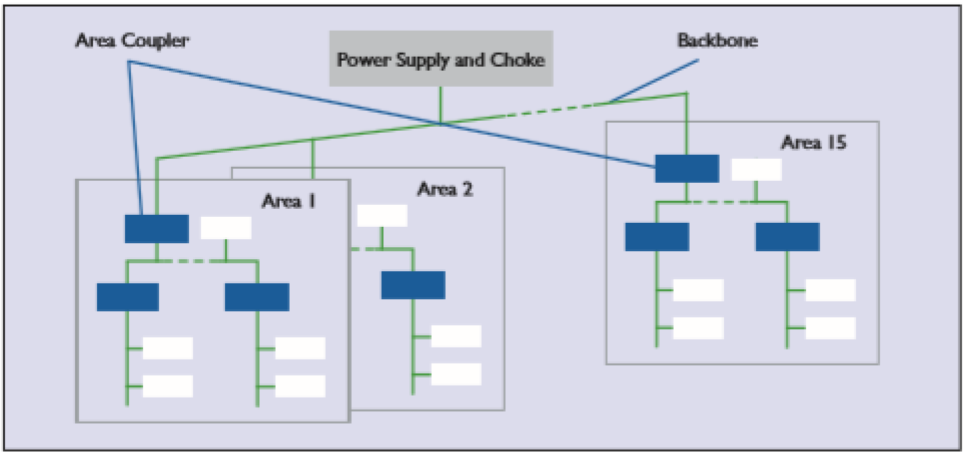


Figure 4. KNX Network Structure [22].

The common used bus topology in KNX System is Tree wiring but KNX also allows Line and Star wiring. The topology can function either individually or mixed but Ring wiring is not allowed. All KNX manufactures use ETS(5) standard software to commission their devices, which makes the product compatible with different manufacture [22].

3.2 KNX Communication Media

KNX Communication Media provides a wide selection, which makes it possible to meet every requirement set in the building automation. The most commonly used KNX communication media installation is Twisted pair data cable (bus cable), where the bus cable connects all the devices with each other. Other KNX Communication Media are such as Power line, Radio (KNX-RF), Infrared and Ethernet [23] [21].

3.3 Components

KNX system has system and end components. System components are as well as power supplies, couplers and programming interfaces and end components are such as Sensors, Actuators. KNX system requires at least a sensor and an actuator to function [23].

3.4 KNX Addresses

In KNX System, every device has a microprocessor and devices in the system function independently and communicate to each other through the bus.

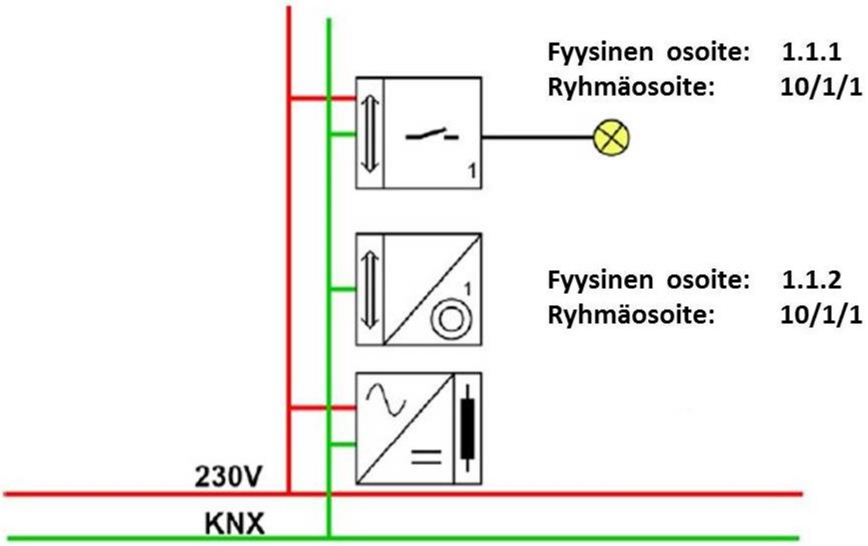


Figure 5. KNX Network Structure.

As the figure 5 above shows, there are two types of addresses in KNX system. Physical address and group address [24].

Physical address (as example 1.1.1) is a unique identification for every device in the KNX network. It has a 16-bit information and the maximum number of devices allowed in a KNX network are 35536. These 16 bits are divided to three parts. The first part with 4 bits represents the areas, the second with 4 bits represents the lines and the last 8 bits are for devices. The area number 0 is reserved for Backbone and the line number 0 for Main line. In a KNX network, there are maximum 15 areas with Backbone line, every area has a maximum of 15 lines with Main line and 256 devices can be connected to a line.

Group addresses (as example 1/1/1) functions differently. Every device can have a different role in KNX network. An ON/OFF pushbutton sensor sends the information about the event which is already happened, a dimming actuator controls the light. A group address is associated at least with two group objects, one for sending the telegram and other for receiving. In addition, a group object can be associated with several group addresses [25].

3.5 Recording Data

The data from KNX system is recorded with an IP-coupler in this project. IP-coupler receives all the data of the telegrams through bus and also can send telegrams to the bus. The data consists of date, time, physical addresses, group adresses and switching signals [26].

4 Room Climate Monitor

This study was to further develop a method for detecting the light consumer by measuring the illuminance of the light sources and correlating it with the associated KNX-data (group addresses). In this project, all measurements were performed by an existing local measurement called Room Climate Monitor with different procedure.

Figure 6. Room Climate Monitor.

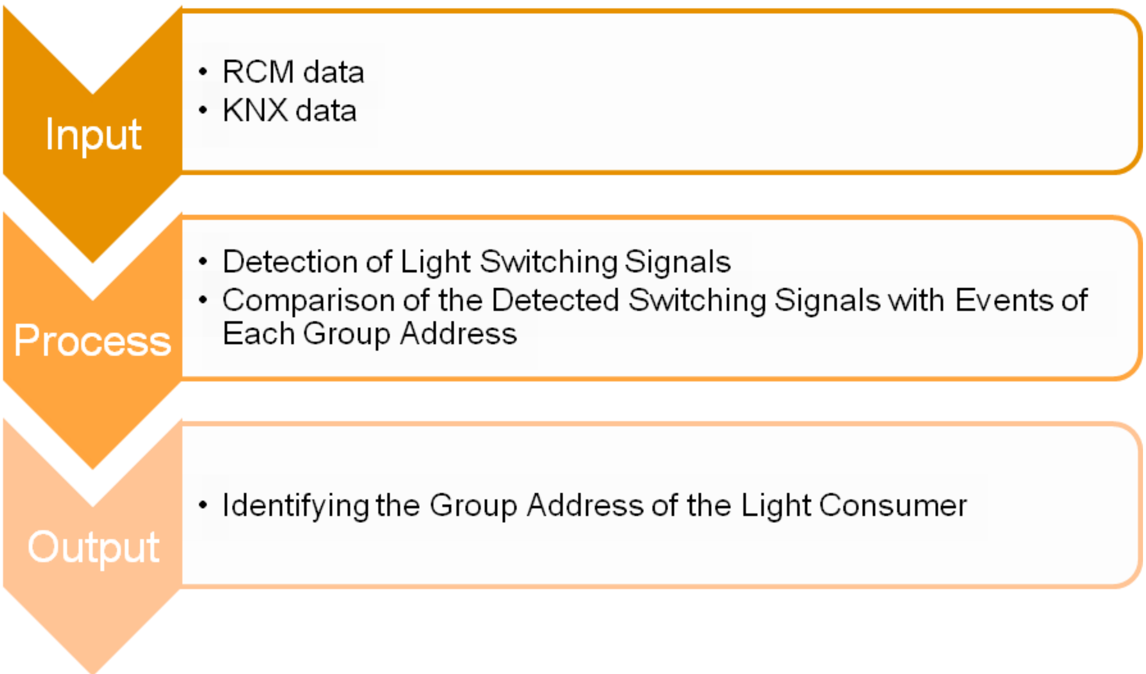
As the name room climate monitor describes, the purpose of the device, is basically used for measuring the room´s humidity, temperature, CO_2 and as well as light level (illuminance). The components such as “Adafruit TSL2561 Luminosity/Lux/ Light Sensor Breakout Board” for measuring lux are located in a hole grid board of Room Climate Monitor and are soldered with one wire.

Figure 7. TSL2561 Lux Sensor.

TSL2561 lux sensor (figure 7) is an advanced digital light sensor that measures the amount of illuminance emitted from a light source. it detects the light ranges from 0.1 to 40000+ lux in the area. While most of the sensors can only detect one of the spectrum TSL2561 has the ability to measure both infrared and full spectrum diode and can be configured for different gain/timing. However, it can only detect the wavelength of electromagnetic spectrum that the human eyes perceive. The sensor is earlier performed in other projects at Munich University of Applied Sciences and the measurements meets the requirements, as well as the compatibility between the Room Climate Monitor and the sensor is acceptable [27].

5 Correlation of Light with KNX

The main task of this project was to formulate and develop a programming code for correlating the light of an artificial light source with the associated KNX events. The project consisted of analysing the data recorded by RCM and KNX, identifying and solving the possible problems with using algorithm and coding.



As the block diagram shows, the project has three main components which are the input, the process and the output. These component is individually explained in details in the following chapter.

- The inputs are the data received from RCM and KNX.
- The process is the main part of the project, it is based on analysing the RCM and KNX data, correlating them and solving the possible problems with software
- The outputs are the result of the correlation of the RMC and KNX data and various method for measuring the light of artificial light sources.

5.1 Software

The main part of the project is accounted by software. For detecting the light switching signals and correlating them with the events of each group address in order to identify the group address of the light consumer, a series of algorithm were needed to be developed that each one performs a specific task.

5.1.1 Programming Language

MATLAB is a high-level language and interactive environment for numerical computation, visualization and programming. It is mainly used for solving mathematical and scientific problems. It allows to explore ideas, gain insight into the data and document and as well share the result [27].

5.2 Input

This chapter gives the information in details on how the measured data from RCM and KNX are received and in which form, how are they structured and what are the interfaces.

The data measured by RCM and KNX are transferred by winSCP (an open source for data transfer from the measurement device to computer) through IP coupler in CSV file formation as tabular data and later to the programming language for analysis or just saving.

5.3 RCM Data

The structure of the tabular data with RMC is shown in the below figure, the data are presented in a two-dimensional table which comprise rows and columns of cells having data. The first row of each column in the tabular data contains the headings of induvidual measured value with the unit value. The data from RMC are stored in the file as double data type.

	1 Date	2 Time	3 CO2_Content	4 Temp	5 Humidity	6 Visible_light	7 Environment_lig	8 Infrared
259	03.04.2018	15:20:43	711	25.9000	24.3000	84	122	38
260	03.04.2018	15:20:48	711	25.9000	24.5000	85	123	38
261	03.04.2018	15:20:53	711	25.9000	24.3000	84	121	37
262	03.04.2018	15:20:58	712	25.9000	24.4000	85	123	38
263	03.04.2018	15:21:03	712	25.9000	24.4000	88	127	39
264	03.04.2018	15:21:08	712	25.9000	24.5000	87	127	40
265	03.04.2018	15:21:14	712	25.8000	24.4000	89	129	40
266	03.04.2018	15:21:19	712	25.9000	24.5000	127	173	46
267	03.04.2018	15:21:24	712	25.9000	24.5000	357	434	77
268	03.04.2018	15:21:29	713	25.9000	24.5000	357	434	77
269	03.04.2018	15:21:34	713	25.9000	24.5000	359	436	77
270	03.04.2018	15:21:39	714	25.9000	24.4000	368	449	81
271	03.04.2018	15:21:44	714	25.9000	24.5000	374	455	81
272	03.04.2018	15:21:49	715	25.9000	24.5000	376	457	81
273	03.04.2018	15:21:54	715	25.9000	24.5000	376	455	79
274	03.04.2018	15:21:59	715	25.9000	24.5000	370	444	74
275	03.04.2018	15:22:04	715	25.9000	24.5000	377	454	77
276	03.04.2018	15:22:09	715	25.9000	24.5000	383	461	78
277	03.04.2018	15:22:14	715	25.9000	24.5000	378	453	75
278	03.04.2018	15:22:19	715	25.9000	24.5000	376	449	73
279	03.04.2018	15:22:24	715	25.9000	24.5000	376	448	72

Figure 8. The data from RMC recorded in CSV.

Figure 8 shows a piece of the recorded data from Room Climate Monitor, the data are from 3 of April and between 15:20-15:22. RCM data is a series of light measured data points that are indexed in time order and it is called a time series. The light values stored in the table are from a fluorescent tube lamp and the measurement was performed in a laboring class (explained in chapter 8.5). the data are stored in a CSV file "yyyymmdd_data" and each data file receives automatically the date when the measurement is executed.

- Date → represents the date when the measurement took place
- Time → the exact time of each value

- CO2-content → the amount of CO2 in the room
- Temperature → the temperature of the room in celcius
- Humidity → how humidity is the air in the room
- Visible light → the amount of light in the spectrum of visible light
- Infrared → the amount of light in the wavelength of infrared red which is not visible to human eyes
- Environment → the combination of the visible light and infrared.

The measured light values are stored in column 6-8 and as the table indicates, the values vary signifacntly. Between 15:20:43 and 15:21:19 the values seem to remain almost the same, however after 15:21:19 it has a prominent rising, this variation is a result of on/off light switching. When the light source is off, the amount of light detected by light sensor is around 120 lux (environment light), after turning the source on, the value rises to almost 460 lux.

Because the RCM is a multi functional device, it measures the other measures as well, however from the measures in above only the measures of light are investigated in this project. As it can be seen in the figure 8, the sensor measures the light every 5 seconds, which is enough fast for recording the values when the input values changes. RMC records the data from each day separeately and store them in a different table as CSV file format. The device has the ability to record the measured data even if it is not connected to the internet, Furtheremore it carries a memory where all measured data are stored. However if the measurements are performed partially and in different days for a short time, all measured values will be recorded in the same file with the date of the first measurement and every time the device is turned off, a new heading will be opened. The measurement time in this situation usually varies from the exact time when the measurement was originaly executed.

5.4 KNX Data

The structure of data recorded from KNX varies from RCM data. Even though the both data are as a tabular data recorded, however the RMC contains the measured data of a single room usually from one light source and it is a time series. KNX data are consisted of the activities of hundreds of group addresses and physical addresses from one day, each group address can have dozens of events during the time of the day.

Every time an event such as on/off light switching signals occurs, the physical address of the KNX device which sends the event and its group address associated with the group object is recorded via KNX bus.

	1 VarName1	2 VarName2	3 VarName3	4 Write	5 from	6 VarName6	7 to	8 VarName8	9 VarName9	10 VarName10
1	2018-04-07	00:00:16	1.5231e+09	Write	from	2.0.1	to	2/0/1:	0	NaN
2	2018-04-07	00:00:16	1.5231e+09	Write	from	2.0.1	to	0/0/99:	1	NaN
3	2018-04-07	00:00:17	1.5231e+09	Write	from	2.0.1	to	0/1/5:	0	NaN
4	2018-04-07	00:00:20	1.5231e+09	Write	from	2.5.130	to	0/4/100:	1	NaN
5	2018-04-07	00:00:46	1.5231e+09	Write	from	2.0.1	to	2/0/1:	0	NaN
6	2018-04-07	00:00:46	1.5231e+09	Write	from	2.0.1	to	0/0/99:	1	NaN
7	2018-04-07	00:00:47	1.5231e+09	Write	from	2.0.1	to	0/1/21:	0	NaN
8	2018-04-07	00:01:16	1.5231e+09	Write	from	2.0.1	to	2/0/1:	0	NaN
9	2018-04-07	00:01:16	1.5231e+09	Write	from	2.0.1	to	0/0/99:	1	NaN
10	2018-04-07	00:01:17	1.5231e+09	Write	from	2.0.1	to	0/1/5:	0	NaN
11	2018-04-07	00:01:46	1.5231e+09	Write	from	2.0.1	to	2/0/1:	0	NaN
12	2018-04-07	00:01:46	1.5231e+09	Write	from	2.0.1	to	0/0/99:	1	NaN
13	2018-04-07	00:01:47	1.5231e+09	Write	from	2.0.1	to	0/1/21:	1	0
14	2018-04-07	00:01:47	1.5231e+09	Write	from	1.3.131	to	0/4/2:	1	NaN
15	2018-04-07	00:02:16	1.5231e+09	Write	from	2.0.1	to	2/0/1:	0	NaN
16	2018-04-07	00:02:16	1.5231e+09	Write	from	2.0.1	to	0/0/99:	1	NaN
17	2018-04-07	00:02:17	1.5231e+09	Write	from	2.0.1	to	0/1/5:	0	NaN
18	2018-04-07	00:02:38	1.5231e+09	Write	from	1.4.11	to	0/4/104:	0	NaN
19	2018-04-07	00:02:46	1.5231e+09	Write	from	2.0.1	to	2/0/1:	0	NaN
20	2018-04-07	00:02:46	1.5231e+09	Write	from	2.0.1	to	0/0/99:	1	NaN
21	2018-04-07	00:02:47	1.5231e+09	Write	from	2.0.1	to	0/1/21:	0	NaN

Figure 9. KNX data from R-building.

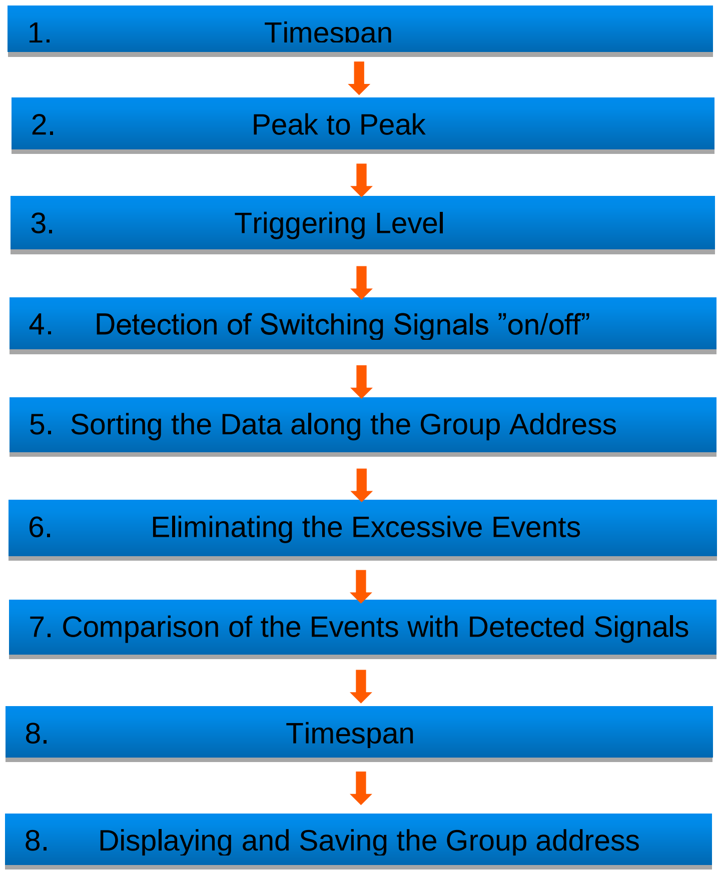
The figure 9 above is a piece of the KNX data in CSV format from R-building (Department of Electrical and Information) at Munich University of Applied Sciences, the data recorded are from 4 of April. The table contains all the active group addresses from R-building for lighting and the addresses are read and stored in the table as a string list. In the table, the name of the variables are missing from the headings and therefore it is explained in below.

- The first two columns represent the date and time of each event.
- The third column contains the time of the events in number.
- Physical addresses are stored in column 6.
- Group addresses are stored in column 8
- The column 9 is the events such as ”on/off”, every time an event is occured the data of the event is recorded to the table including the group and physical address of the event.
- The 10 column shows how many watts are used by the light sources of the group address if there are more light sources controlled with the same group address.

The process starts recording the data at 00:00 and terminates at 23:59. Each day has a new data file which contains the events of all group addresses occurred during the day.

5.5 Process

After coming familiar with the both data of RCM and KNX, this chapter focused on analyzing and processing the measured data step by step, developing a code for detecting the light switching signals, comparing with the events of each group address, solving the possible problems and developing new algorithm for each purpose.



The above block diagram shows how the process is developed, the process consists of two parts, detection of light switching signals and comparing them with the events of each group address in order to identify the group address of the light consumer. Each part consists of steps that perform a specific task. The data from RCM is used for detecting the light switching signals and the detected signals are then compared with the events of each group address in KNX data. To understand better how each task operates, a part of the code is brought up in some part, however the complete code can be found in appendixes 1 and 2.

5.5.1 Timespan

Developing a programming code for detecting the light switching signals was a series of statements and commands that acted as an instruction. The code consisted of several smaller and individual tasks and each task was purposed for determining a specific part of the whole task.

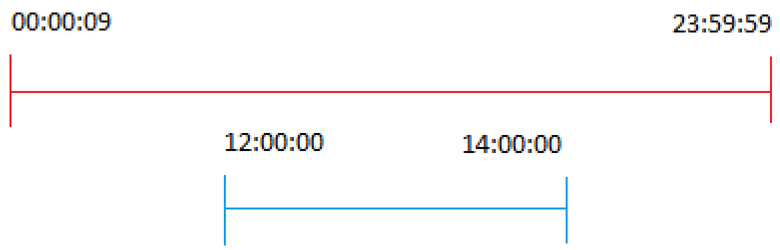


Figure 10. Using timespan

The above figure 10 is an example of using the timespan for RCM data. The measured data from RCM in the table (figure 8) was from the whole day and it contained the values for other variables that in this project were not investigated. Therefore it was essential to develop an algorithm that stores the data of a desired time interval by defining the start and end of the time interval and moreover, stores only the variables which are investigated in this project. The approach stored the data within a timespan and ignored the other data before and after. Using a timespan was a good way to minimize the possible influences that could be derived from sunlight or other external lights before and after the measurement.

```
%******************** Insert the time period *******
% The start
zeitpunkt_start = datestr('07-04-2018','16:22:00');
% The end
zeitpunkt_ende = datestr('07-04-2018','18:15:00');
```

- "zeitpunkt_start" is the start point of timespan, the data are stored from the start point and the data before this point are ignored.
- "zeitpunkt_ende" is the end point of timespan, the data are stored until this point and the rest data are ignored as well.

- “datestr” converts the datetime value in datetime array.

The above code is the input part of the whole code for creating the timespan (The complete code can be found in Appendix 1(1)). The date and time interval are the inputs and the new table “data” is built up from this time interval. The elapsed time by Matlab for performing this code was 8.593614 seconds.

5.5.2 Peak to Peak

By turning the light source ”on/off”, the values of light detected by light sensor ranges and contain only positive values, which start from zero. In this case, detecting the switching signals are very complex. Therefore to recognise automatically when the light has been turned ”on” or ”off”, one of the way was developing a code, that detects the peaks that are derived from ”on/off” signals.

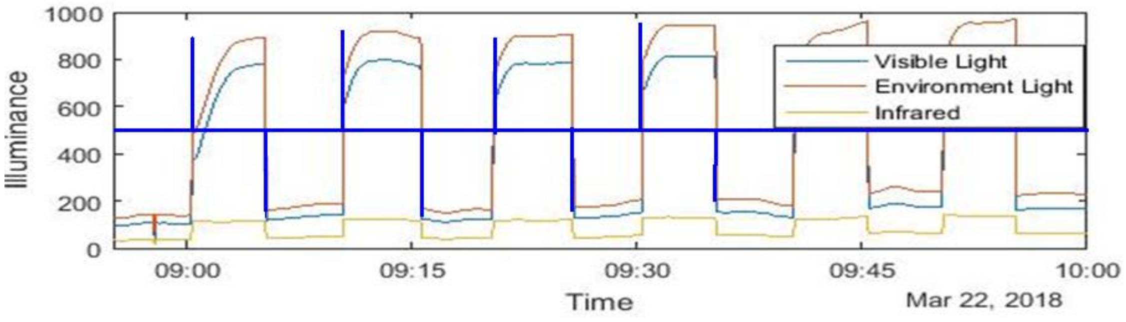


Figure 11. Determining the values of ”on/off” switching signals.

The plot in figure 11 shows the performance of illuminance in respect of time and the defined peaks. The peaks are the points when the light is turned ”on/off”. Each light parameter has its own value and depending on the value of each parameter the peak is built up. The lower peak is a result of light ”off” and is negative, the upper peak is a result of light ”on” and is positive.

- The orange line represents the environment light
- The blue line represents the visible light
- The yellow line represents infrared

The demonstration code can be found in Appendix 1(2). The code is structured in such a way that it subtracts the present value from the previous value repeatedly. If the present value is bigger than the previous one, the result is a positive value and if the resent value is samller than the previous one, the result is a negative value. As an example, the previous value is 50 lux and the present value is 200 lux, or the present value is 55 lux and the previous value 250 lux. Subtracting 50 lux from 200 lux results to 150 lux and subtracting 250 lux from 55 lux results to -195 lux.

$$\text{Newvalue} = \text{present value} - \text{previous value} \rightarrow ne = 200 - 50 = 150 \qquad (9)$$
$$ne = 55 - 250 = -195$$

This approach was good and as the plot shows the switching light singals could be easily found. About 1.133895 seconds were elapsed for performing this task by Matlab.

5.5.3 Triggering Level

After developing a code that finds the peaks of signals by subtracting the values, for detecting the switching light signals from the measured data, first it was necessary to define a triggering level for each parameter (visible light, infrared and environment light) that whenever the value of each parameter exceeds the triggering level, it is equal to a signal. For this part, triggering level for each parameter were defined. A triggering level for signals, when the light is turned “on”, and a triggering level, when the light is turned “off”.

```
%Input 'on'
infrarot_an = 65;   % The value defined for infrared, when the light goes on
sichtbar_an = 120;  % The value defined for visible light, when the light goes on
umgebung_an = 185;  % The value defined for environment light, when the light goes on

%Input 'off'
infrarot_aus = -60;     % The value defined for infrared, when the light goes off
sichtbar_aus = -460;    % The value defined for visible light, when the light goes off
umgebung_aus = -525;    % The value defined for environment light, when the light goes off
```

At the beginning of the project for each data file, new triggering level had to be defined in order to detect the signals and defining the triggering level for each parameter of light was complex and time consuming. The above definition is an example of defining the triggering level manually for each parameter. The definition of each value for each parameter was implemented by plotting the data (figure 10) and writing down the value of each peak of the curves in excel and choosing the smallest value as to detect the signals (negative value for signal “off” and positive value for signal “on”). Since the main task was to develop an automated and efficient procedure for detecting the signals, a new code was developed to automatically set the value for detecting the on/off signals.

```
%************************ The defined values for detecting signals ************************%
% Light on
infr_anl = mean([(0.75*max(data_var(:,3))), 0]); % The average of the maximum value and 0 for infrared
sb_anl = mean([(0.75)*max(data_var(:,1)), 0]);   % The average of the maximum value and 0 for visible light
ug_anl = mean([(0.75)*max(data_var(:,2)), 0]);   % % The average of the maximum value and 0 for environment light

% Light out
infr_ausl = mean([0, (min(data_var(:,3))*0.8)]); % The average of the minimum value and 0 for infrared
sb_ausl = mean([0, min((data_var(:,1))*0.8)]);   % % The average of the minimum value and 0 for visible light
ug_ausl = mean([0, min((data_var(:,2))*0.8)]);   % % The average of the minimum value and 0 for environment light
```

The code in above shows the operation of the triggering levels automatically setted for detecting the light switching signals. The “data_var” is the result of subtracting the present value from the previous value (explained in chapter 7.1.3). The function ‘mean’ the average value of an array finds the average value for each column between the maximum value and 0 value, this was for detecting the signals when the light goes “on”. For detecting the signals when the light goes “off”, the “mean” function finds the average of 0 value and the minimum value. The code defines new triggering values for each data file.

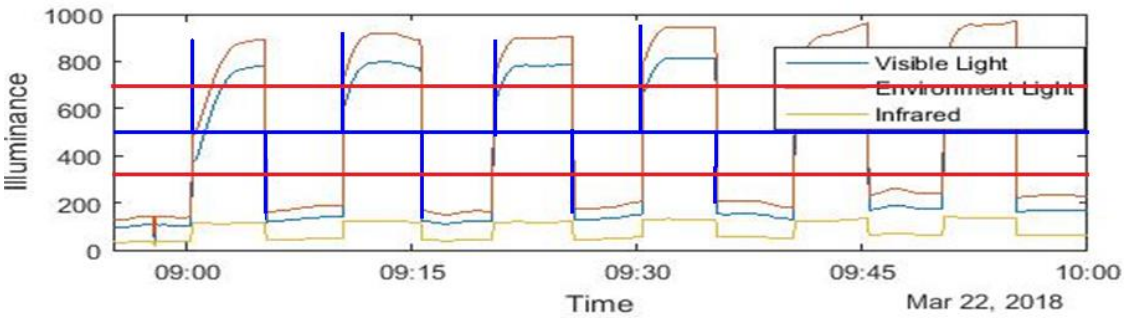


Figure 12. The triggering level for detecting the switching light signals

The plot in figure 12 is the same plot as in figure 11 with two triggering level for detecting the light switching signals. the upper red line is for detecting the signals ”on” and the lower red line is for detecting the signals ”off”. As it can be seen in the plot, the triggering level is performed only for environment light. However, for each light parameter is a triggering level defined. The time elapsed for defining the triggering level was about 0.001471 seconds by Matlab.

5.5.4 Detection of Switching Signals ”On/off”

On the assumption that the main task in this chapter was to detect the signals, after developing a code that defined the constant values for each light parameter , an algorithm was used (see in the Appendix 1) for detecting the switching signals ”on/off”.

```
schalt = NaN*zeros(size(data,1),1);
```

The above algorithm was created for storing the signals. ”schalt” is a one row cell array, has a length of the ”data” (chapter 7.1.2) and is multiployed with zero and NaN, this function returned an array that contained only NaN (not-a-number), usefull for data containing double values. The triggering level was the limit value, each time the value of light parameters exceeded the triggering level, it replaced the NaN with ”1/0” depending on, was the value a negative or a positive. If the value was a negative it replaced NaN with ”0” number and if the peak was a positive, it replaced the NaN with ”1” number. For detecting the ”1/0” signals, the condition was the value of all light parameters are bigger than the constant value.

Event though the signals were successfully detected, however they were stored among NaNs in one row. New algorithm was created to keep the signals, ignores the NaNs, displays as well the signals in the command window and transfer as input in order to compare them with the events of each associated KNX group address. The time elapsed for determining this task was 0.005047 seconds by Matlab.

5.5.5 Sorting the Data Along the Group Address

After detecting the light switching signals from RCM data, it was time to analyse KNX data and investigate how to identify the exact group address of the light consumer with the detected signals. This chapter attempted to provide an approach for identifying the group address based on comparison of the events with the detected signals and solving the possible problem with defining an algorithm. As it was explained in chapter 6.2, the KNX data consisted of handreds of group addresses and the number of them ranged depending on the day and time of the day.

Befor performing any comparison between the detected signals and the events of each group address, it was essential to develop an approach that sort the data based on the group addresses, in other hand to unique the group addresses and arrange the data based on the group address. The sorted data were such as events of each group address including the physical address and date/times of events in order to compare the events of each group address alterantely with the detected signals. For this, a code had to be generated that finds the data of each group address and stores them in cell arrays. Sorting the data was determined to reduce the searching complexity.

	1	2	3	4
1	'Group-Add...	'Phys.-Adre...	'Time'	'Events'
2	"2/0/1:"	2878x1 string	2878x1 string	2878x1 dou...
3	"0/0/99:"	1217x1 string	1217x1 string	1217x1 dou...
4	"0/1/5:"	1439x1 string	1439x1 string	1439x1 dou...
5	"0/4/100:"	344x1 string	344x1 string	344x1 double
6	"0/1/21:"	1439x1 string	1439x1 string	1439x1 dou...
7	"0/4/2:"	686x1 string	686x1 string	686x1 double
8	"0/4/104:"	327x1 string	327x1 string	327x1 double
9	"0/4/102:"	343x1 string	343x1 string	343x1 double

Figure 13. Indexing the data based on the group addresses.

Figure 13 presents the pattern of indexing the data of nine group address as cell arrays. This code was structured with a ”for loop” and ”if statements” (the code in Appendix 2), a new cell array with four rows were created and each cell contained data with different size as it appears in figure 12. This approach was developed in order to find the data of each group address (as example: ”2/0/1”) and store them in cell array. The data were, the events ”1/0”, the physical addresses (as example: ”2.0.1”) and the time of each event (as example 16:30:55), when the event took place. As the figure indicates, indexing the data in a cell array was good for each group address contained various data size. In this project the variables investigated were gorup address, physical address, date/time and the events, the other variables were not neccessary for identifying the group address.

The execution time for sorting the data by Matlab was 2.724840 seconds.

5.5.6 Eliminating the Excessive Events

Detecting the group address of the light consumer by correlation of the detected signals with illuminance and control signals in places such as classrooms, office rooms, or other places where the light switching is controlled manually, was successful. However, in attempting to detect the group address of the light consumer in a corridor where the light switching was controlled by a sensor, there occurred a problem. As the sensor loads the light automatically on the basis of movement, it loads the light source every time it detects a movement even if the light is still on, which means that the switching events from the group address of the same light source recorded to KNX data can have more than one time on switching between two off switching, yet signals detected by measuring the light is alternately (on/off*)*.

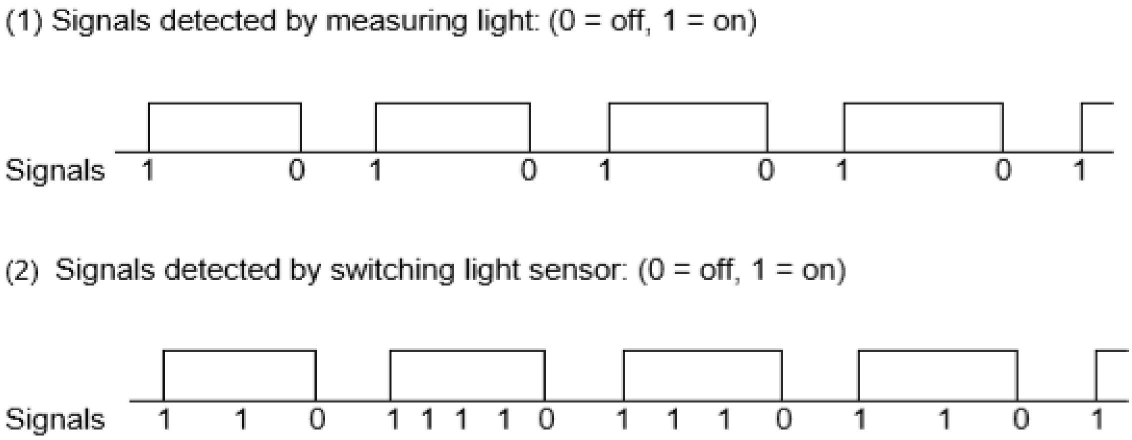


Figure 14. The Function of on/off Signals Detected by Measuring the Light and Switching Light Sensor.

The above figure presents an example of the function of signals collected by measuring the light and the switching events collected from switching light sensor from the same light source by KNX bus. It appears that the switching light signals between on/off from sensors are not always the same, which bring out that the group address of the measured light can´t be identified by program. To solve this problem, there are a few options to do it. The first option is to make sure that during measuring the light there occurs no extra movement between on/off switching. This option is not an efficient solution, it usually requires a lot of time to perform it and during the study time, it is almost impossible because the corridors are mostly used and blocking it from passing people will cause more problems. The other option is to develop the programming part, writing a programming code that eliminates the excessive “on” signals between “on/off” signals. This option was efficient and optimal as a solution for this problem.

The code (see in Appendix 2) was developed to ignore the excessive switching events if between “on/off” switching events occur more than one time “on” switching event (figure 13). This code was executed with two for loop, the first for loop reads the size of cell arrays and the second reads the indexed data of each cell from column 4, where the group events were stored. If the first indexed value was “1” number (event) and the next value was as well “1” number, it replaced the value with NaN as long as the next value was a number. Moreover the time and the physical address of the removed event had to be removed in order to avoid mismatching, therefore, the extra physical addresses and times were replaced as well. After replacing the extra signals with NaN value, they had to be removed from the database in order to enable the comparison of the events of the group addresses with the detected signals.

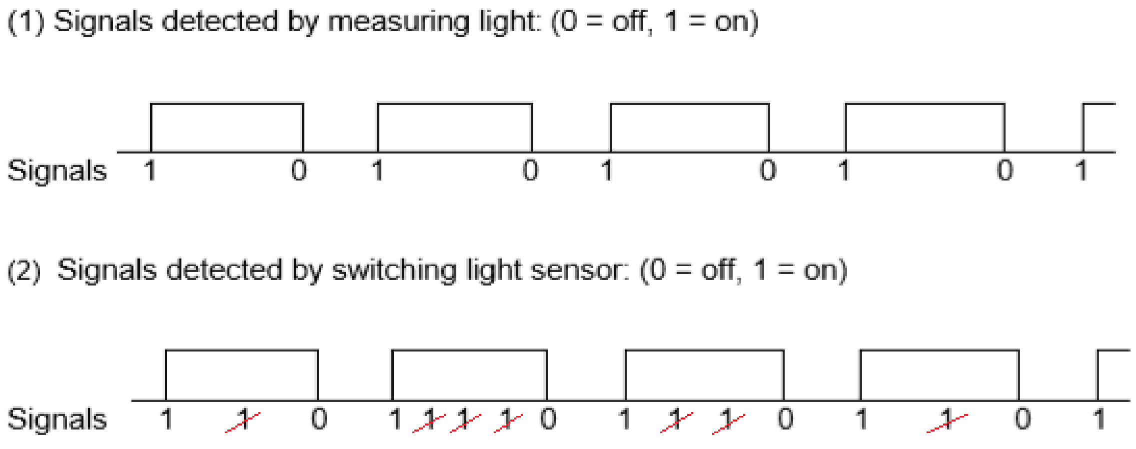


Figure 15. Ignores the excessive Signals Detected by Switching Light Sensor.

The figure 15 shows how the excessive switching events are ignored. The algorithm defined with the written code is to search and analyses the value of switching event of each group address and if there occurs consecutively two switching events of the same value (1 = on), then it eliminates one of them and keeps the other one. The process runs until the next value is different than the previous one.

	1	2	3	4
1	'Group-Add...	'Phys.-Adre...	'Time'	'Events'
2	"2/0/1:"	*2878x1 string*	*2878x1 string*	*2878x1 dou...*
3	"0/0/99:"	"2.0.1"	"23:58:37"	1
4	"0/1/5:"	*1439x1 string*	*1439x1 string*	*1439x1 dou...*
5	"0/4/100:"	"2.5.130"	"23:58:59"	1
6	"0/1/21:"	*1346x1 string*	*1346x1 string*	*1346x1 dou...*
7	"0/4/2:"	"1.3.131"	"23:58:18"	1
8	"0/4/104:"	*327x1 string*	*327x1 string*	*327x1 double*
9	"0/4/102:"	*343x1 string*	*343x1 string*	*343x1 double*

Figure 16. After ignoring the excessive switching events.

The table in figure 16 indicates the result of ignoring the execcive switching events. Even though the table above in figure 16 is same as in figure 13. However, it appears that the data size of some group addresses are changed. This is derived from ignoring the other unneccessary switching events. The programming ignores as well the physical address and time of the excessive events, otherwise there occurs an error if the cell arrays have are with different size. The execution time for eliminating the excessive “on” signals by Matlab was 0.486311 seconds.

5.5.7 Comparison of the Events with Detected Signals

Indexing data of each group address was performed and the code worked as it was planned, the next task was to compare the detected singnals from measuring the light source with the events of each group address in order to identify the exact group address of the source. For this, a script was developed as well with a for loop statement that compares the events of each group address with the detected signals and store them in a new table.

```
% Searches string for occurrence of pattern
pos_sig     = strfind(transpose(aktsignal),(signal));
```

As it was mentioned in section 6.2, the data are stored in the table as a string list and therefore the strfind function was usefull. The above strfind function searches the switching light signals from each group address and if it finds a group address that contains the same events, it stores in a new table the data of group addresses which were found through strfind function. The ”aktsignal” is the events of the current group address in the ”for loop” and it is compared with the pattern which is the detected signals. The time for the execution of this task by Matlab was 0.023768 seconds.

5.5.8 Timespan

During the day, the number of group address in KNX data traffic was enormous and plenty of group addresses had the same events , in order to increase the prospect of indentifying the exact group address, a timespan seemed to work for this matter. Setting the time interval when exactly the measurement was performed, ignored the other group addresses that had similar events but in different time interval.

```
zeitpunkt_start = '16:25:00'; % The start time point
zeitpunkt_ende = '18:30:00'; % The end time point
```

The above timespan is an example timespan and it searches the identified group addresses that have within the timespan. This code was consisted of an start time and end time. After setting the timespan, most of the group adderesses were ignored and only a few were remained which were within the time interval. The whole code for executing this task can be found in Appendix 2. The time elapsed for this task by Matlab was 0.777348 seconds.

5.5.9 Displaying and saving the Group Address

The software displays the group address found in the command window within the time interval defined in the previous chapter without printing the data of the group address, the group address was automatically displayed in the screen and if there were more than one group address found, the group addresses were displayed in number, starting from one until the end so that there is a possibility to choose the desired group address or more and it helped to see how many group addresses are found. By choosing the group address the data of the chosen group address could have been imported to a text file for more analaysis.

120	1/5/22:
121	1/4/1:
122	1/4/1:
123	1/4/1:
124	1/2/22:
125	1/2/22:
126	1/2/22:
127	1/2/22:
128	1/3/20:
129	1/3/20:
130	1/3/20:

Figure 17. Displaying the group addresses found with similar events.

The above figure presents how the group addresses found are displayed and numbered in the command window. There were 130 group addresses found between 12:25 and 18:30, the amount of detected signals were 20 signals for finding the group address of the light consumer. The time period was setted so long to find more group addresses with similar events to show how the group addresses are displayed.

Verbraucher	Gruppen_adresse	Physikalische Adressen	Zeit
Corridor	1/6/1:	2.4.30	16:30:04
		2.4.30	16:35:06
		2.4.30	16:38:31
		2.4.30	16:44:02
		2.4.30	16:49:08
		2.4.30	16:52:59
		2.4.30	16:57:19
		2.4.30	17:01:56
		2.4.30	17:09:28
		2.4.30	17:13:07
		2.4.30	17:14:30
		2.4.30	17:19:50
		2.4.30	17:24:57
		2.4.30	17:28:47
		2.4.30	17:33:33
		2.4.30	17:37:44
		2.4.30	17:51:16
		2.4.30	17:55:37
		2.4.30	18:09:51
		2.4.30	18:15:45

Figure 18. The data of the desired group address imported to a text file.

After displaying the number of group addresses found in the screen, there was a possibility to import the data of the desired group address to a text file. The data imported to the text file consisted of the consumer where the light is consumed like a corridor, the group address, the physical address and the time when the events occurred. The text file gets the current date of the day, when the correlation is performed. This part was 3.348824 seconds elapsed by Matlab.

6 Measurement

The measurement in this project was carried out in the region of illuminance from artificial light sources with the existing local measuring device. Measuring the light of an artificial light source in places, where the natural light is mixed with the artificial light is very challenging. Therefore, it was important to identify the factors, which influence the measurement and provide a method that minimises the influence. Furthermore, a method that was not difficult to implement or time-consuming, and is successful regardless of the time of the day or the amount of sunlight striking to the place, where the measurement takes place, was needed.

- The main factor influencing the measurement is sunlight and as well as the reflection of sunlight from walls and ceilings.
- Room parameters, such as the colour of walls, ceiling, size of the room, use of the room and the location of the room.
- The distance between the light sensor and the light source, the type of the source, the size of the source and the amount of illuminance produced by the source.
- The weather, is it sunny or overcast
- Time of the measurement, measuring the light at night or at day, in the morning or afternoon.

Consideration of each factor for obtaining an accurate and meaningful measurement is essential and each factor has an influence on the result, however the influence of each factor varies.

All measurements in this project are carried out at Munich University of Applied Sciences in different places, such as laboring class for solar technology, office room, washroom and corridor at different time of the day. The light sensor measures the visible light, infrared and environment light (the combination of visible light and infrared in the area). The values of these three regions were analysed and examined to ascertain in which region the artificial light source emits more lights and in which region the affection of sunlight is less. Even though, the sunlight covers all regions of light including the visible light but during the day, it ranges.

6.1 Method 1. (Sensor not covered from sunlight)

As one of the main task for measuring the light was to examine the functionality and suitability of the measurement device it was essential to perform the measurement in variable locations at the institution. One of the location for measurement was an office room and it was located in the right side of the building (east facing), the office room was selected because it was used often, had a small size and the light sources were controlled manually. The measurement was performed on the 18 of January between 8:50-16:30. There were two fluorescent tube lamps in the room, each fluorescent tube lamp produced about 600-700 lux.

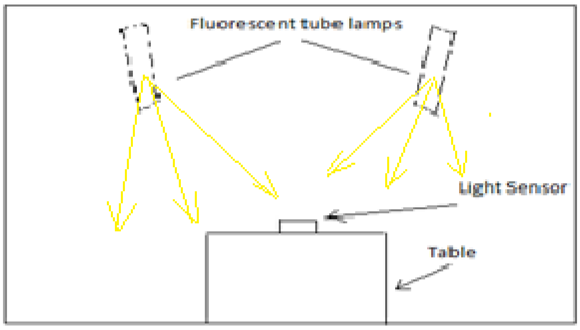


Figure 19. Measuring two fluorescent tube lamps.

The above figure 18 shows the how the two fluorescent tube lamps are measured. The illuminance sensor was located on the table between two lamps, the distance between the lamps horizontally were 2 meters and each lamp had a distance of about 2 and half meters with sensor and it was not covered from direct sunlight. The room was a size of 12 m^2 with a height of 3.5 m, the colors of walls and ceiling are white and as well the table. The measurement took place on a partly sunny day.

The purpose of this measurement was to perceive the influence of direct sunlight striking into the room and how the sensor reacts to the change. Furthermore, how accurately it measures the light falling from the lamps in question. In addition, is it possible to detect the light switching signals through this procedure or do we need to change the procedure.

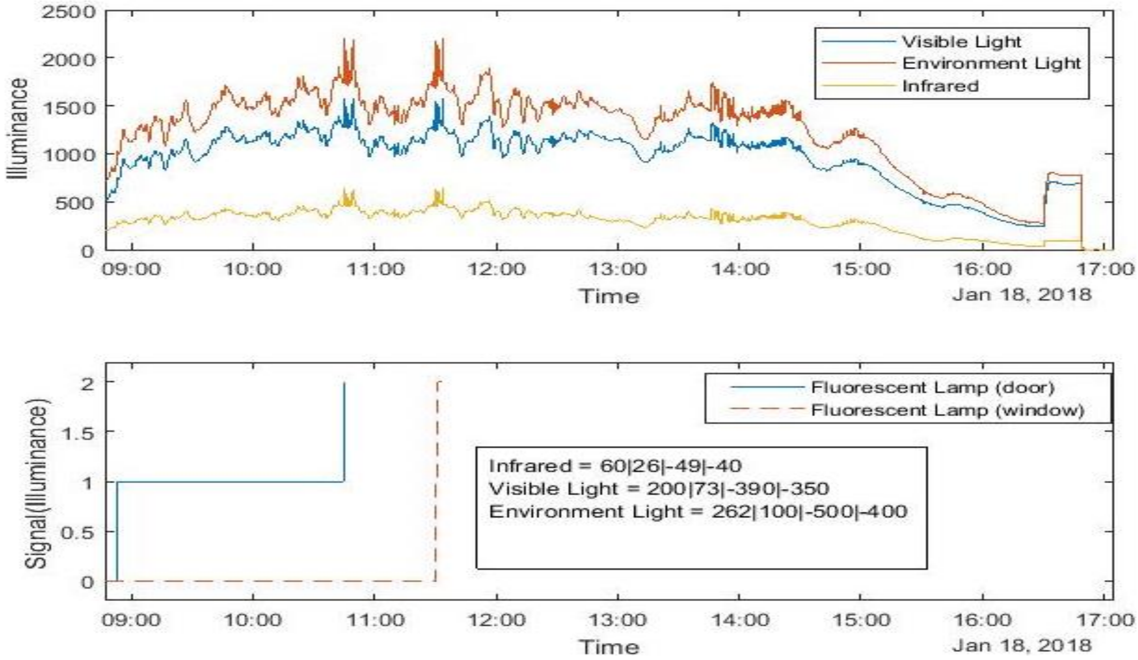


Figure 20. The graph of Illuminance Performance and Detected Signals (the light sensor not covered).

The above graph shows the illuminance performance of two fluorescent lamps in the room during the day. The upper graph shows the activity of illuminance in function of time, which consists of the spectrum of visible light (the central wavelength) and infrared (the longer wavelength) and the environment which is the combination of visible light and infrared in the surrounding area. The red nonlinear line represents the performance of environment light. The lower nonlinear line, which is blue represents the amount of visible light and the lowest yellow nonlinear line represents the amount of infrared. The lower graph shows the signals detected by measuring the illuminance of the light sources. The blue line shows signals for the lamp close to the door and the orange dashed line represents the signals for the lamp close to the window. The lower graph contains as well a constant value for each light parameter, these triggering levels were manually defined and signals are detected according to these triggering levels (explained in chapter 5.5.3). The positive values are detecting the signals “on” and the negative values for detecting the signals “off”.

For testing illuminance sensor, each lamp was switched “on” at different time but both were switched (off) at the same time. The first “on” switching occurred at 8:53 and the second one 17:31, both lamps was switched “off” on 17:50. Each lamp had one “on/off” signal in total. It can be clearly seen in the graph that the amount of light is not constant and has a temporal behavior and detecting the exact switching signals can´t be detected. This measurement clarified that measuring the illuminance in a partly sunny day (not constantly shining) with a light sensor, which was not covered from direct sunlight will not succeed. As it appears, sunlight has a temporal behavior and the amount of sunlight received by the earth depending on the weather and time of the day is not constant. Striking sunlight inconstantly into the room during the measurement induces wrong switching signals and the measurement fails. As it was earlier claimed, there is no such method to distinguish or eliminate sunlight from artificial light, however it is possible to separate the sunlight from artificial light by using a spectrometer, if the spectral behavior of sunlight is known. Nevertheless, this solution is expensive and time consuming. the simplest way for this problem is only to avoid sunlight emitted into the room as possible, determining the measurement at a time of the day when the sunlight is not shining straightly into the room and covering the light sensor from direct sunlight.

6.2 Method 2. (Light Sensor inside a Carton)

In this method, a dark yellow carton was used to cover the light sensor from direct sunlight and measure the illuminance of the same light sources as in the previous method. The carton was a size of 50x40cm and has a height of 30cm. It was located between two light sources on the table to measure the amount of illuminance falling from both lamps and examine how sunlight influence the measurement. The distance between two lamps were 2 meters and the distance from sensor to each lamp was one meter horizontally. The measurement was performed between 10:50 and 11:40. The light sources were separately switched “on/off” for several times, the one close to the door was switched “on/off” and then the other one close to the window was switched on/off and each one for one time between 10:50-11:10 in the morning. The both light sources were switched “on” one after another and as well switched “off” between 11:10-11:30. From 11:30-11:40, both light sources are switched “on/off” in the same times. The both light sources were switched “on/off” 10 times in total.

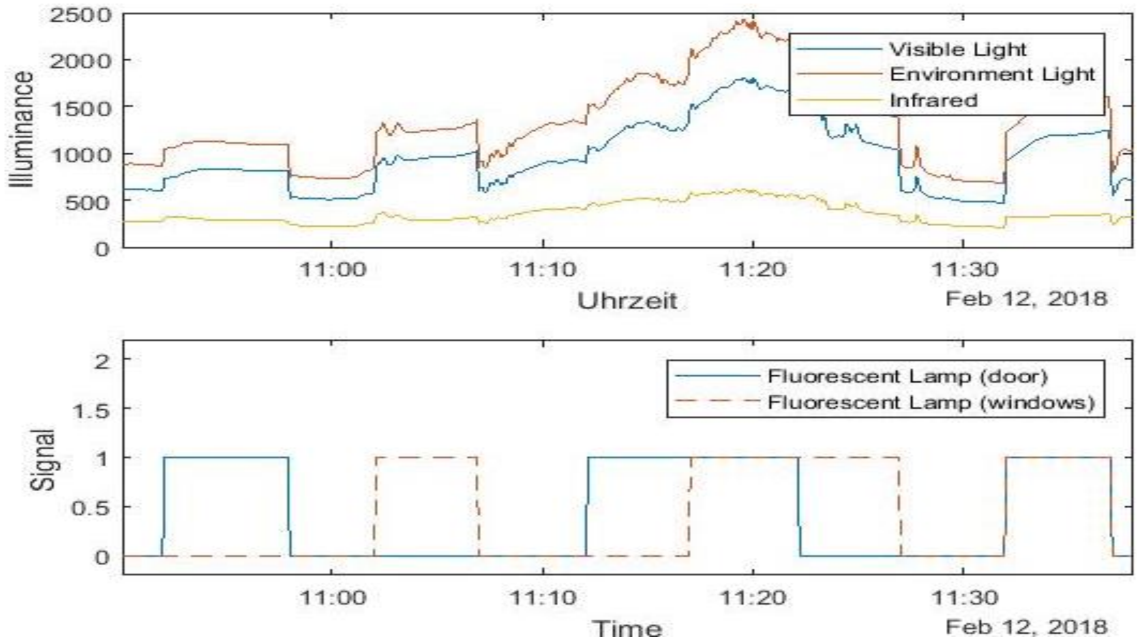


Figure 21. The graph of Illuminance Performance and Signals (Sensor is located in a Carton).

In lower graph in figure 21, the blue straight line represents the light source close to the door and the dashed orange line the light source close to the window. As the performance of illuminance in the graph can be seen, the amount of light measured by light sensor from the source close to the door is less compared to the other light source close to the window. This difference is caused by the sunlight that has more influence on the source close to the window therefore for detecting the switching signals of each light source, a separate constant value was defined manually and each value had a different size. By looking at the performance of illuminance and detected signals for the both light sources, it is clear that this procedure has successfully detected the signals for both light sources. However, using a carton to reduce the sunlight is not so promising and efficient, as the graph shows; between 11:10 to 11:30 the amount of illuminance measured is mixed by sunlight and the shape of the graph is not so clear, this can lead to detecting wrong signals.

6.3 Method 3. (Light Sensor in a black wastebasket)

The visible light waves consists of many frequencies and wavelength, each of the frequency or wavelength corresponds to a specific color. When a light wave with a single frequency strikes an object, it can be reflected, absorbed or transmitted by the object. When the visible light with many waves or all waves strikes an object then the object has a selectivity, which wave to reflect, transmit or absorb. If an object has a color of green, it reflects the wave of green color and absorbs the waves of other visible colors. A blue color reflects the wave of blue color and absorbs the color of all other waves but an object of black color, which doesn't contain any wave of visible light, absorbs almost all of the color waves and human eye sees it as a black object.

The wavelength, angle and behavior of sunlight ranges during the day and as well depending on the weather and season. The laboratory for solar technology where the measurement was performed is located in the left side of the building (west facing). Usually at morning time the sunlight is not shining into room directly but during afternoon between 1-4 pm it strikes at its strongest. The room is usually used for executing researches, performing presentations and for lectures as well. There are 12 fluorescent tube lamps in the room and each one produce about 600-700 lux, the walls and ceiling are white.

Figure 22. Sensor located in a Black Wastebasket.

As figure 21 shows, a black wastebasket was utilized to minimize the external light from outdoor. However, it doesn't absorb the light perfectly and still sunlight shines from the right side of the wastebasket and reaches inside the wastebasket. The waste-basket was on the table, which is about 70 cm high from the floor and the light sensor was set vertically to the lamp to read the amount of light spreading from the lamp in a distance of 2 and half meters. The light sensor was in the wastebasket and measurement was performed for about one hour. It was an overcast day and the amount of lux striking into room was about 300 lx. About 20-30 % of sunlight reach into the waste-basket. The light source was for 12 times switched “on/off” during one hour.

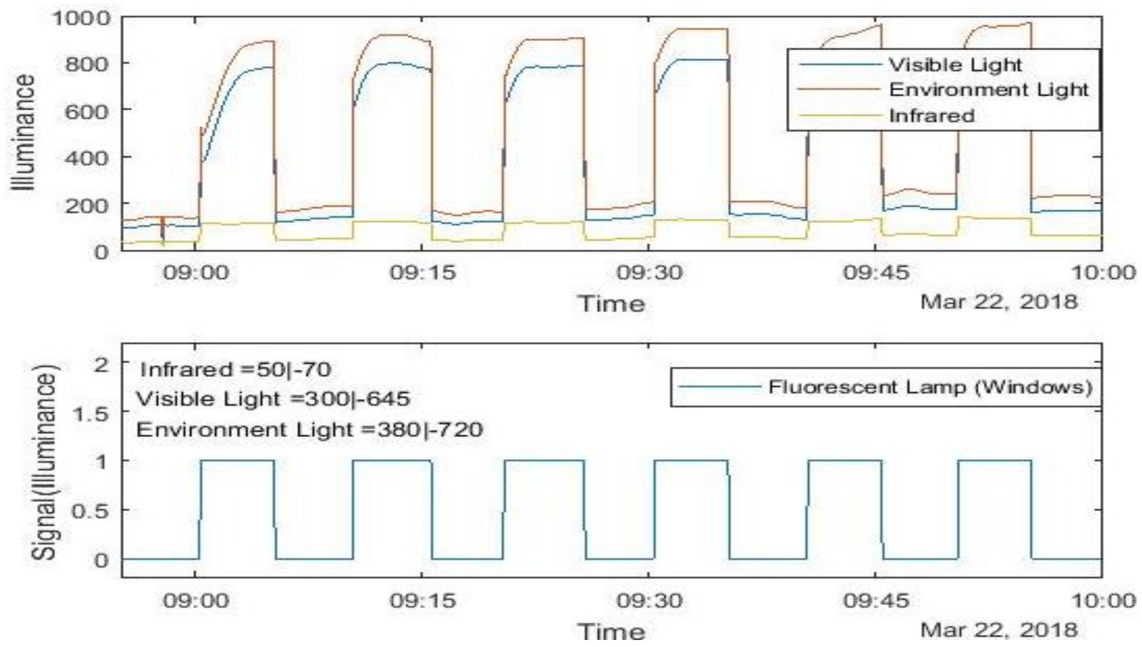


Figure 23. The Graph of Illuminance Performance and Detected Signals (Black Wastebasket).

Measuring the illuminance from a fluorescent lamp is shown in figure above, was performed between 9:00-10:00 am. As earlier mentioned, it was a cloudy day, which resulting the above graph. According to the graph, between switching light “on/off”, the fluorescent lamp produces and emits the light more in wavelength region visible light, which is the function of visible light and the amount of visible light detected by the sensor ranges from almost 100 to over 800 lux. Infrared is feebly shown in the graph and it ranges between 20-110 lux because the lamp emits more light in the central wavelength than in longer wavelength. When the switch is turned “on”, the amount of lux falling into sensor increases and when the switch turned off, no more light is emitted by light but still the sensor detects light, which is emitted by sun through windows. Detecting the switching signals in this and the following methods are executed by automatically defined constant values. As the outcome indicates, this method measuring the illuminance on a cloudy day and putting the light sensor in a black wastebasket can resulting an accurate outcome and this method can work perfectly.

6.4 Method 4. (Light Sensor in a green Wastebasket)

The green color on the visible spectrum is a combination of blue and yellow, which has a dominant prevalent wavelength of approximately 495-575 nm. The green color object absorbs long wavelength (red) and short wavelength (blue) much more efficiently than other colors in the visible light. This method was executed with a green wastebasket in which the light sensor was located vertically to the fluorescent lamp (from the same fluorescent tube lamp), at the same day as the previous measurement. The light source was 10 times switched "on/off". The weather was still cloudy and the amount of light entering the room remained almost same. Using a green wastebasket for covering sunlight was not better than black wastebasket and the amount of light entering into the basket was more compared to a black wastebasket.

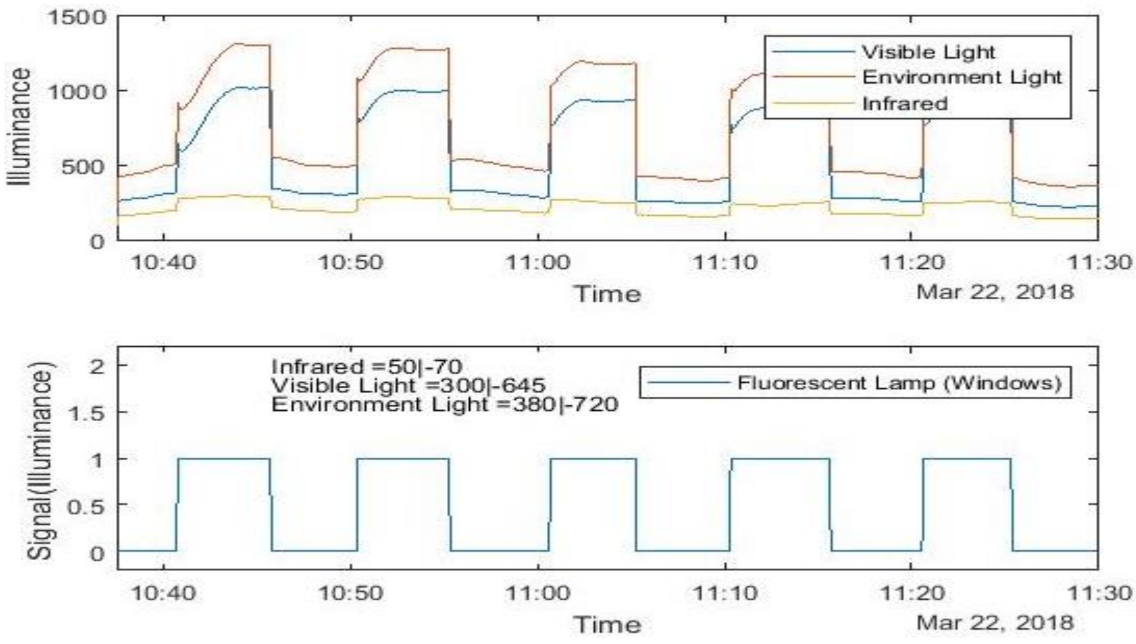


Figure 24. The Graph of Illuminance Performance and Detected Signals (green Wastebasket).

By looking at the figure 23, it can be seen that the amount of lux is significantly increased even though the weather is still cloudy (not as cloudy as over the previous test). The graph indicates that when the light is off, the amount of sunlight perceived by light sensor is about 250 lux in the region of visible light and in the region of infrared almost 150 lux, which is much more compared to the previous measurement. However, constant values defined for detecting the switching signals “on/off” of the same light source by two methods appear to be exactly same, which is the result of a constant sunlight entering the room. These two tests with different color wastebasket indicates as well as that the measurement is more accurate and stable when it is performed at a time of the day, when the sunlight is constantly entering the room and doesn’t change significantly during the measurement.

The two measurements above were performed on a cloudy day and the sunlight striking the room was constant. This method could work only in cases, where the weather is constantly cloudy or sunny, however, measurement in a day when the amount of sunlight changes temporally is not recommended. The reason is that when the amount of sunlight received by light sensor changes temporally during the measurement, the values of constant values for detecting the signals can change or remain the same and detect a wrong signals which is caused by sunlight.

6.5 Method 5. (Light Sensor in a Cylinder)

Even though using a wastebasket to measure the artificial light brought a good result however, measuring the light when the sunlight has a temporal behavior, doesn’t put out a proper result. In this section, another method is examined in purpose to obtain a more proper result, which could be executed in different locations and despite of the sunlight, it identifies the switching light signals. In this method, a circular cylinder was made out of two black and thick papers to cover the light sensor from direct sunlight, the cylinder has two same

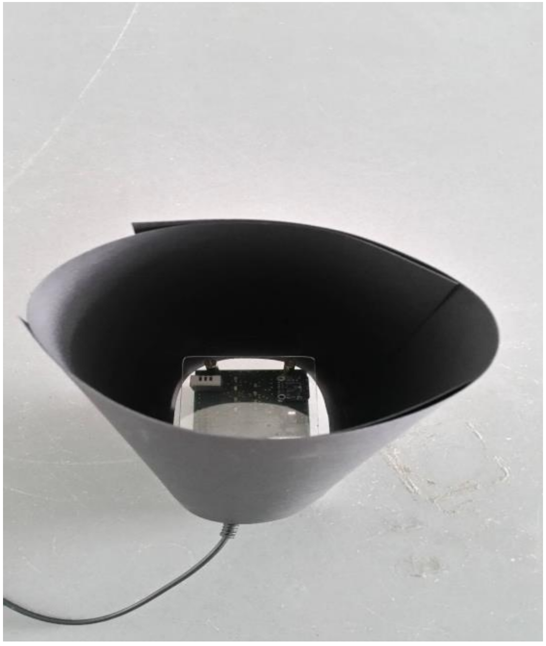


Figure 25. The Light Sensor in a Black Cylinder.

circular bases and the diameter of its surface area was about 10 cm, which is much smaller compared to a wastebasket and it allows less light into the light sensor.

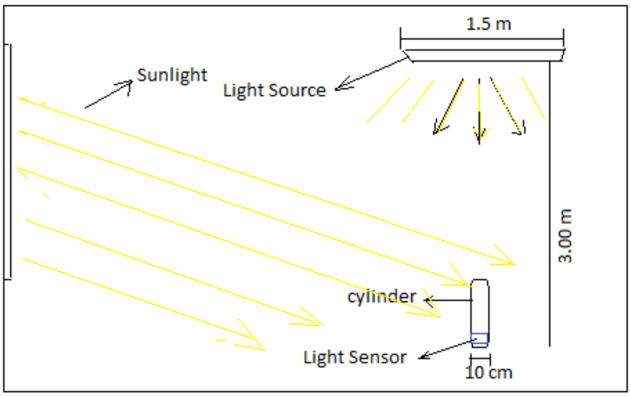


Figure 26. The cylinder on the floor.

As figure 25 shows, the cylinder is located vertically to the light source. The distance between the light source and light sensor (located on the floor) was 3 meters. The light source had a size 1.5 meters and it produced 600-700 lux. The small size of the cylinder reduces the amount of light reaching into the cylinder, in addition the black color of the cylinder absorbs more light than other colors and this will as well reduce the amount of direct sunlight or as diffuse reflection from walls, ceiling or floor reached to the cylinder (depending on observation of them).

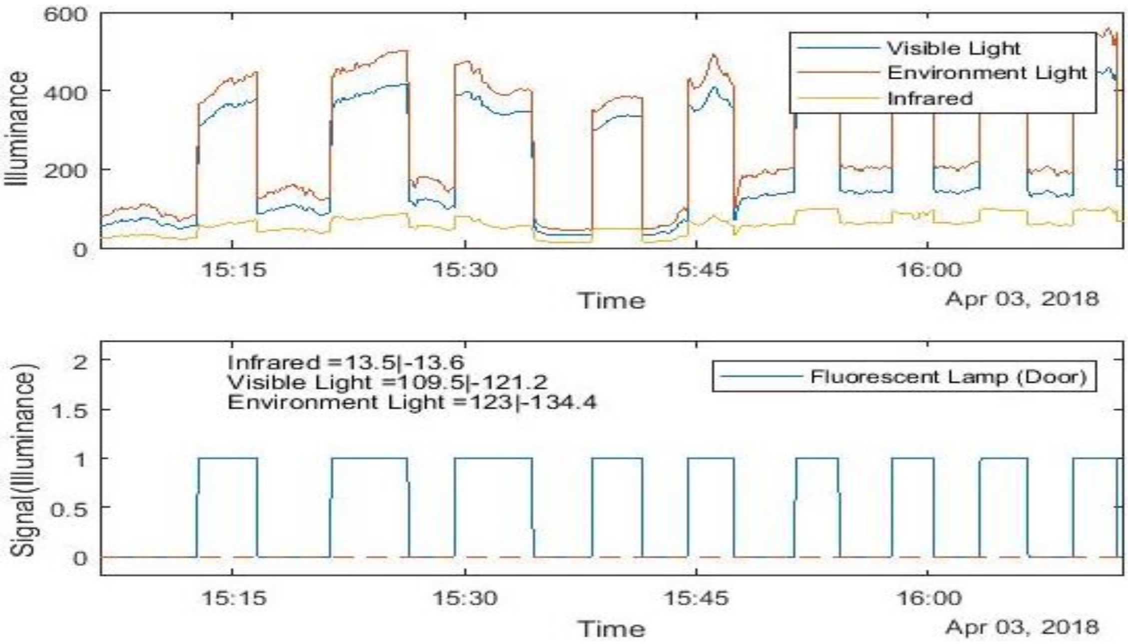


Figure 27. The Graph of Illuminance Performance and Detected Signals (Black Cylinder).

The measurement took place in the same olaboratory but this time the measuring light source was the one close to the door (the darker side of the room). The weather was partly sunny and the amount of light entering the room ranged. It can be seen in graph in figure 26, the amount of illuminance is significantly decreased compared to the previous graphs, which is derived from two reasons. The main reason is the size of the cylinder, which is much smaller than the wastebasket and let less sunlight in, the other reason is the distance of the light falling from the light source into the light sensor. The measurement was performed between 15:00-16:20 with 18 times switching “on/off” and as it is shown in the graph, the light switching is not regularly executed. The amount of external light ranges between 100 up to 200 lux when the lamp is “off”. This change appears because of sunlight, which is entering the room unsteadily. however, the illuminance values from the lamp in question remain nearly same.

After completing the measurement in the laboratory, the next location was a washroom. Measuring the light in a room such as laboratory, or office room, where the light switching are performed manually was fast. However, in a washroom, where the light is loaded on/off automatically by an infrared switch sensor was fractionally dense, which activates and deactivates automatically on the basis of movement. The duration of each switching “on” took 10 minutes and the measurement endured approximately two and half hours for switching the lamp for 20 times.

Washroom is a place in the building, where usually there is no window and it is lit with an artificial light source such as LED. This means that there is no natural light in the washroom and the light sensor doesn’t require a cover. However, the purpose was to measure the light with the same method in different location. In this method to improve the outcome, the light sensor was located in a bigger cylinder, which was about 40 cm high and had a larger top to detect the light from a larger area, in the same time avoiding more external light. The longer the height of cylinder is, the less sunlight reaches inside it and more light is absorbed in the way to where the light sensor is located. The distance between the point, where the sunlight strikes and where the light sensor is located defines how much sunlight can be absorbed by the black color of the cylinder.

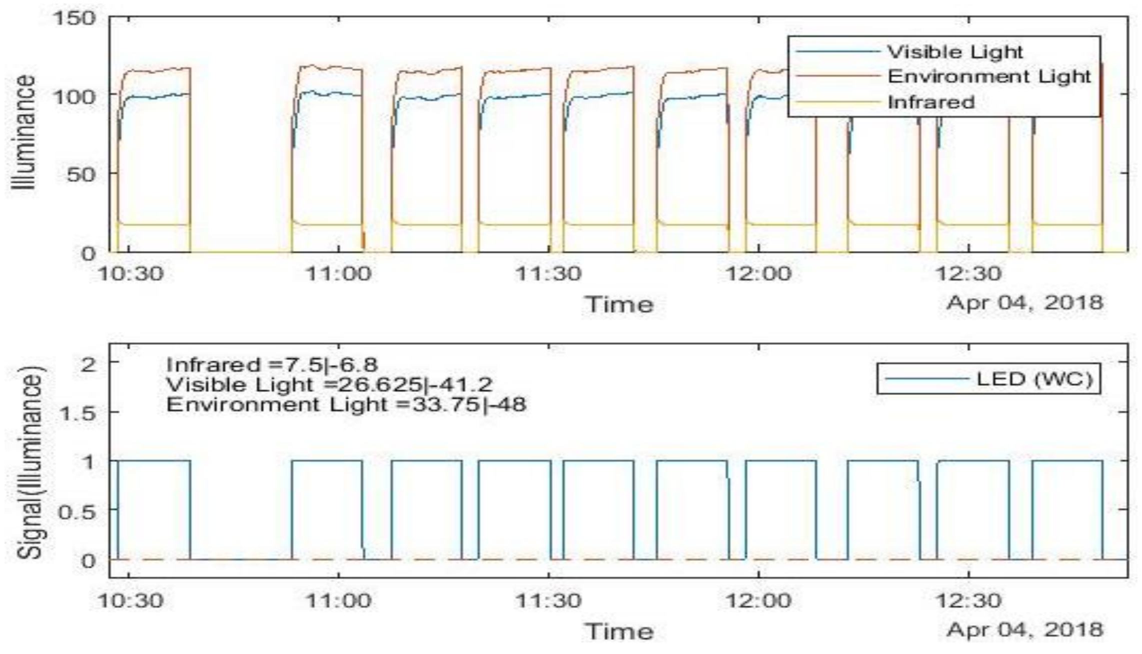


Figure 28. The Graph of Illuminance Performance and Detected Signals (LED Lamps).

The graph in figure 28 shows the illuminance performance of LED lamp. During the time, when the light is “off”, there is no lux detected and the amount of lux between “on/off” switching ranges from zero up to 120 (the environment light). Compared to the previous measurement, which was determined in a laboratory, the amount of lux detected by the light sensor in the washroom is significantly decreased. The amount of lux produced by the LED lamp is 300 lux (according to a measurement separately), therefore about 30 % of the light falling into the surface is detected by sensor. However, this method in the washroom works perfectly and no great difference between the light switching events occur. Moreover, switching light signals are clearly perceived.

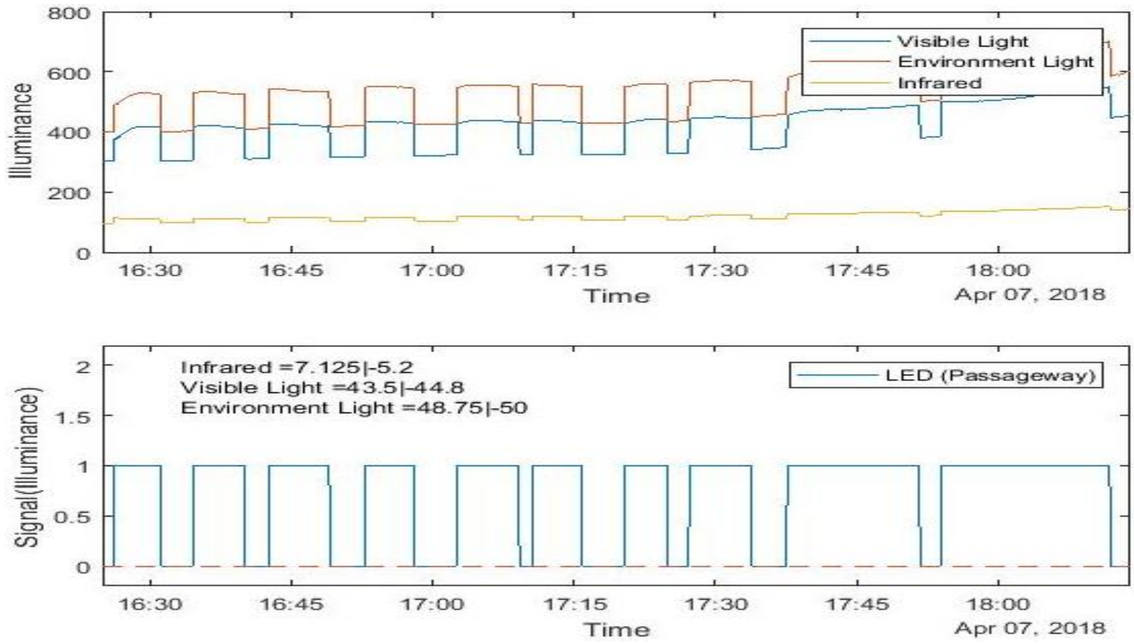


Figure 29. The Graph of Illuminance Performance and Detected Signals from LED (Corridor).

The last light measurement took place in a corridor between 16:30-18:15. The light sensor inside the cylinder was located close to window and sunlight was directly striking to cylinder. Figure 29 shows the graph of illuminance performance during the measurement, the major difference between the graph above and the graph from figure 27, which was performed in a washroom, appears to be that sunlight in the spectrum of visible light is not constant and its value detected by the light sensor ranges from 300 to up 450 lux. Regardless of sunlight, the visible light falling from LED lamp measured by the light sensor is constantly about 120 lux. By looking at the two graphs and comparing the amount of light produced by the LED lamps, it becomes clear that the same LED lamp is used in both Places. Considering that, the sunlight has a temporal behaviour (not significantly) during the measurement and its value ranges notably. However, it looks that the exact switching signals are detected.

6.6 The Evaluation of Measurement

The light measurement was performed with five different methods to examine the operability of each method and to come across with a method, which meets the requirements and is adjustable in variable locations. The light measurements were determined in lux and, as it was earlier mentioned, with a local device.

Table 5. The Operability of Methods for measuring the artificial light in different Weather.

Method	Operability (For Detecting Switching Light Signals)			
	Sunny	Overcast	Partly Sunny	Dark Places
Light Sensor not Covered	poor	good	poor	good
Light Sensor in a Carton	poor	good	poor	good
Light Sensor in a black Wastebasket	good	good	poor	good
Light Sensor in a green Wastebasket	good	good	poor	good
Light Sensor in Cylinder	good	good	good	good

After determining and examining the measurement with different methods, it clears that the main factor influencing the measurement of light of an artificial light source is the sunlight specifically in a partly sunny. The other factors, which should be taken into account are size of the light source and that how much it produces light, the more light it emits the better result brings out. The distance of light source and measuring device and the color of walls and ceilings have as well an influence. The reflection of sunlight from walls and ceiling or other factor don't have a prominent influence.

Places, where there is no external light such as a cellar or WC, there is no need for covering the light sensor and the outcome is always the artificial light. In an overcast sky, the amount light reaching the Earth is significantly reduced and does not require a separate cover for the light sensor. However, on a sunny day, it is recommended to use a cover for avoiding direct sunlight. Sunlight occurs mostly in places like an office room or a classroom where there are wide windows, using a blind or other thing for avoiding direct sunlight into the room has an important influence in measuring the light of an artificial light.

7 Result

This chapter analyses the result of detected signals and correlation of detected signals with the events of each group address in order to identify the group address of the light consumer. For identifying the group address of the light consumer, there are five important factors that need to be taken into account.

- The first factor is a successful light measurement in order to detect the switching signals, this required avoiding the sunlight from the measuring place by using a cover for light sensor or implementing the measurement at a time of the day when the sunlight's influence is not so great.
- The number of switching light signals in order to identify the exact group address of the light consumer. During the day, there are hundreds of group addresses activated and many of them having the same events, it is essential to investigate that how many switching signals are required for identifying the exact group address. This is explained more in chapter 8.2.
- One of the important factor is the time interval for measuring the light and number of switching signals. In order to have an efficient outcome, it is essential to implement more switching signals in a shorter time as possible.
- The distance between the light source and the measuring device, the shorter the distance is, the more light is detected by the light sensor.
- The amount of light emitted by the light source. The amount of light emitted by a light source had a significant impact in result.

Those factors mentioned above are necessary for an efficient and accurate result. The other factors such as the reflection of sunlight, room parameters, location of the room or any other factor than can influence the measurement are mostly dependent of those main factors explained in above. However, covering the light sensor or measuring at a time the day when sun is not shining directly to the room, are basic ways for measuring the light of an artificial light.

7.1 Correlation of Detected Signals with the Events of its Group Address

In this chapter, two graphs were investigated as the result of correlation. The first graph was from the laboratory of solar technology, where the light switching signals were implemented manually and the second one was from the corridor, where the light switching signals were implemented by a sensor.

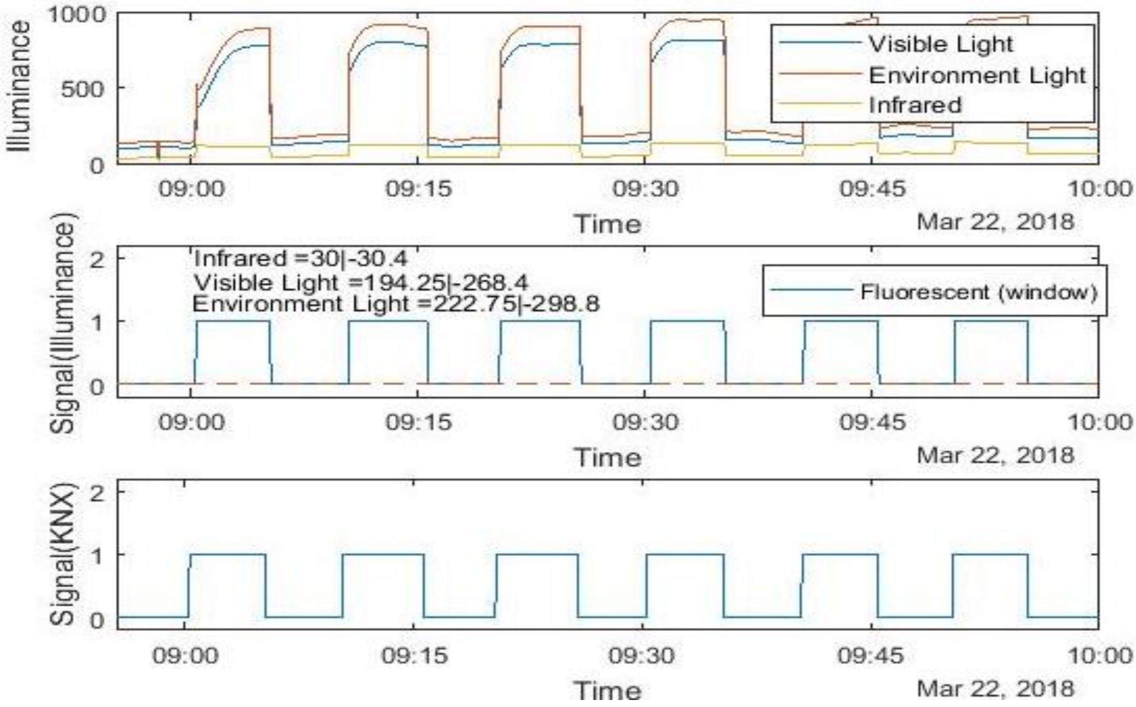


Figure 30. Correlation of signals detected by measuring the light with KNX signals (Labor).

The above figure shows an example of the correlation of signals detected by measuring the light of an artificial light source with KNX signals. The measurement is from 22 of March and it was performed with a black wastebasket in the laboratory for solar technology. In the figure there are two discrete graphs describing the function of signals, the second graph portrays the function of signals collected by measuring the light of an artificial light source in the time domain and the lowest graph portrays the function of events found from the group address of the light consumer in question. As it can be seen in the graph, the detected signals and the events of the group address of the light consumer have the same functionality in the same time domain.

KNX database contains a huge amount of group addresses from all part of the building. These group addresses are used for light switching, dimming or controlling other automatic components. During the study time at the university, consuming light is significantly increased, which means that there are more group addresses in use. The more the group addresses are in use, the more switching signals are needed to identify the exact group address.

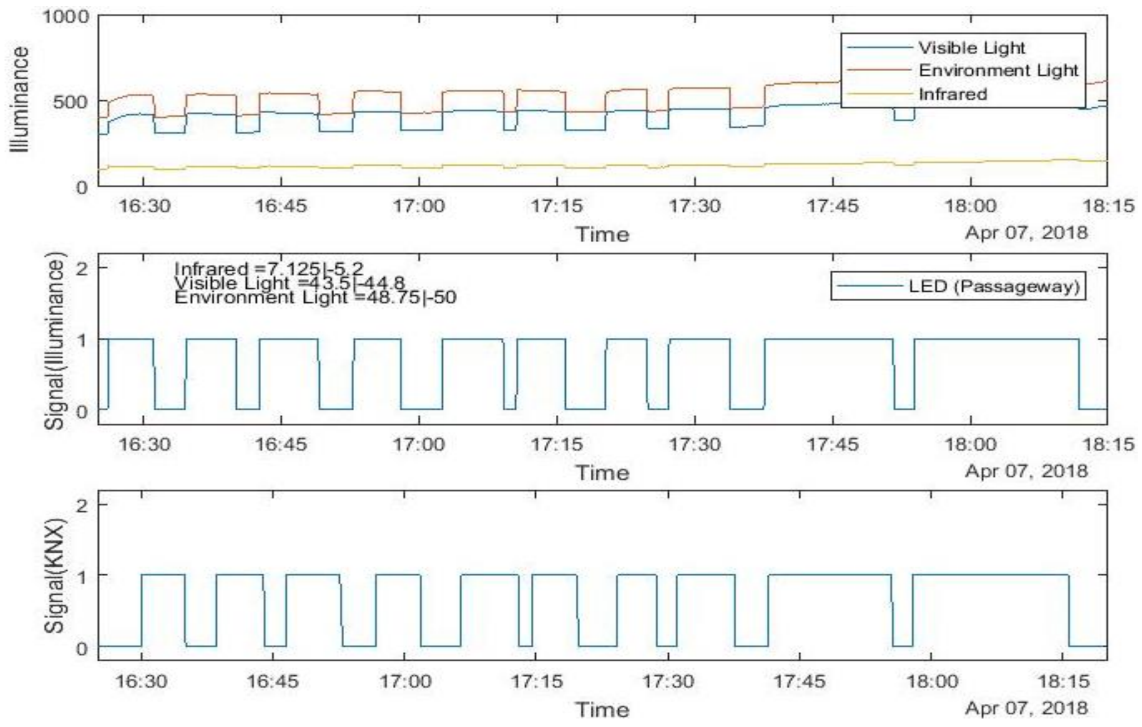


Figure 31. Correlation of Signals Detected by Measuring the Light with KNX Signals (Corridor).

As the figure above shows the function of the switching light signals and the events of its group address. Even though the time duration between each “on/off” switching light is same however as the second graph represents the function of the switching light signals detected by measuring the light, the light goes “on” at around 16:26 and according to the graph representing the function of the events of its group address, it goes “on” at 16:30, which is the exact time that the light is been loaded. The possible answer for the deflection is that the RCM records the data imports them with an inaccurate time. However, this can be solved with calibrating the device.

7.2 The probability of detection

Detecting the exact group address of the light consumer requires also a certain amount of switching light signals with the intention that other light sources have possibly the same signals and furthermore, the time interval for switching light source “on/off” is important as well.

(1) $$Probability\ of\ detection = \frac{\textbf{The exact group address}}{\textbf{The number of group address found}} x\mathbf{100\%}$$

$$P = \frac{\mathbf{1}}{\mathbf{N}}\ x\ \mathbf{100\%}$$

P is the probability of detecting the group address of the light consumer in %

1 is the group address of the light consumer

N is the number of group address found

The probability equation is the measure of how likely an event is to occur out of the number of possible outcomes. This calculation is used to define, what is the likelihood to detect the group address of the measured light source, and how many signals are need to define it. In this project the group address in question is divided in number of group addresses found by a certain number of switching signals and multiplied with 100%. As an example, the measurement is determined on a weekly day in two hours and the number of detected signals "on/off" are 10 and 18 group address have been found, Therefore we want to know what is the probability to detect the exact group address of the measured light source → $P = \frac{\mathbf{1}}{12}\ x\ 100\mathbf{\%} = 5.6\mathbf{\%}$. By 10 signals, the probability of detecting the group address of light consumer is 5.5 percent, which means that more signals are required to detect the group address.

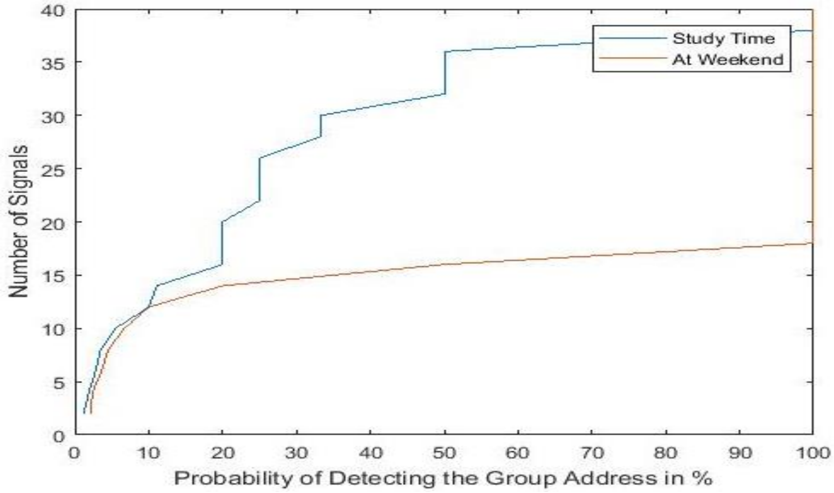


Figure 32. The Probability of Detecting the exact Group Address.

The above figure 32 shows the probability for detecting the exact group address in percentage. The y-axis represents the amount of signals and the x-axis shows the probability for detecting the group address. There are two lines in the graph, the orange line shows the probability for detecting the group address at the weekend and the blue one at the study time. The given signals starts from 2 signals until 40 signals are examined in two hours through the programming to investigate how many signals are required for detecting the exact group address at each day. The plot shows that during the study time, the amount signals needed for perceiving the group address are 38 signals and at the weekend only 14 signals. The figure above doesn't guarantee that the group address can be always found according to this outcome, it can ranges depending on the time of the day and how many lights are in use.

7.3 Conclusion

According to the research in this study on separation of natural light from artificial light, distinguishing them is not possible unless the behavior of one of them is known. Light switching signals can be usually detected by measuring the light of an artificial light source through the procedure developed in this study. However, it depends on the time of the day, the weather and the place, where the measurement takes place. For further development, measuring the artificial light by two light sensors. One measuring only sunlight and the other one measuring the light of artificial source, which is mixed with sunlight. By subtracting the measured data of sunlight from the mixed light data, the result would possibly be artificial light.

Identifying the exact group address of the light consumer by comparing the detected signals with the events of each group address is depended on the number of switching signals and duration of the execution. In addition, the day when measurement took place. For further development, changing the parameters of RCM for recording the measured data in such a way that it records the data in a new data file, each time a measurement takes place. This can simply the signal detection and there is no need for a timespan for RCM data. Also, developing a code, that correlates the detected switching signals with the events of each group address by the time interval between two signals. It identifies the group address that the time interval between two signals of the group address is same as the time interval of two detected signals.

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Light Switching Signal Detection

Timespan

```
%******************* Insert the time period *******
% The start
zeitpunkt_start = datestr('07-04-2018','16:22:00');
% The end
zeitpunkt_ende = datestr('07-04-2018','18:15:00');

% Timespan, collects the data from a desired time interval.

% Converts the start time (datestr) to datetime.
zeitpunkt_start = datetime(zeitpunkt_start,'format','dd-MM-yyyy HH:mm:ss');
% Converts the end time (datestr) to datetime.
zeitpunkt_ende = datetime(zeitpunkt_ende,'format','dd-MM-yyyy HH:mm:ss');
% Converts the start time into number
zeit_start = datenum(zeitpunkt_start);
% Converts the start time into numbe
zeit_ende = datenum(zeitpunkt_ende);

% Keeps the data from timespan and ignore the other data befor and after
% the time span.
for i = 1:size(data1,1)-1
    zeit = [data1{i,2};data1{i+1,2}];
    zeitstart = datenum(zeit);
    if zeitstart(1) < zeit_start && zeitstart(2) >= zeit_start
        start = i+1;
    end
    if zeitstart(1) < zeit_ende && zeitstart(2) >= zeit_ende
        ende = i+1;
    end

end

% Save the data in new table.
data = [data1(start:ende,1:2),data1(start:ende,6:8)];
data.Properties.VariableNames{1} = 'Datum';
data.Properties.VariableNames{2} = 'Zeit';
data.Properties.VariableNames{3} = 'Sichtbar';
data.Properties.VariableNames{4} = 'Umgebung';
data.Properties.VariableNames{5} = 'Infrarot';
```

Peak to Peak

```
%************* Subtract the previous value from present value ************%

% New data table with the same site as "data"
data_var = zeros(size(data,1),3);
for i = 2:size(data,1)
    % The values of visible light in column 1
    data_var(i,1) = data{i,3}-data{i-1,3};
    % The values of environment light in column 2
    data_var(i,2) = data{i,4}-data{i-1,4};
    % The values of infrared in column 3
    data_var(i,3) = data{i,5}-data{i-1,5};
end
```

Triggering Level

```
%************************ The defined constant values for detecting signals ************************%
% Light on
infr_anl = mean([max(data_var(:,3)), 0]); % The average of the maximum value and 0 for infrared
sb_anl = mean([max(data_var(:,1)), 0]);   % The average of the maximum value and 0 for visible light
ug_anl = mean([max(data_var(:,2)), 0]);   % % The average of the maximum value and 0 for environment light

% Light out
infr_ausl = mean([0, min(data_var(:,3))]); % The average of the minimum value and 0 for infrared
sb_ausl = mean([0, min(data_var(:,1))]);   % % The average of the minimum value and 0 for visible light
ug_ausl = mean([0, min(data_var(:,2))]);   % % The average of the minimum value and 0 for environment light
```

Detection of the light switching signals

```
%%%%% Detect the switching light signals and mark them in "schalt" %%%%%

schalt = NaN*zeros(size(data,1),1);
for i = 1:size(data_var,1)

    %     For detecting the signal "on"
    if (data_var(i,3)*infr >= infr_anl*infr) && (data_var(i,1)*sb > sb_anl*sb) && (data_var(i,2)*ug >= ug_anl*ug)
        schalt(i,1) = 1;
    end

    %     For detecting the signal "off"
    if (data_var(i,3)*infr <= infr_ausl*infr) && (data_var(i,1)*sb < sb_ausl*sb) && (data_var(i,2)*ug <= ug_ausl*ug)
        schalt(i,1) = 0;
    end
end
```

Detection of KNX Group Address

Sorts the events along the group address

```
%**** Sort the events along the group address ***%
Logdatei = cell(1,3);
Logdatei{1,1} = 'Grupp-Adress';
Logdatei{1,2} = "Phys-Address";
Logdatei{1,3} = "Time";
Logdatei{1,4} = 'Signal';

    % The group address from KNXdata
gr_adr = string(KNX_log.VarName8);
    % Physical addresses from KNX data
ph_adr = string(KNX_log.VarName6);
    % Time of the events from KNX data
time = string(KNX_log.VarName2);
    % The events from KNX data
sig = double(KNX_log.VarName9);

    % Searches the data, stores the group addresses and indexes the events and
    % other data along the group address
for i = 1:size(gr_adr,1)
    akt_adr = string(gr_adr(i));
    akt_log = string(Logdatei(:,1));
    if contains(akt_adr,akt_log) == 0
        Logdatei{size(Logdatei,1)+1,1} = gr_adr(i);
        pos = strfind(gr_adr,gr_adr(i));
        temp_phys = [];
        temp_zeit = [];
        temp_sig = [];
        for j = 1:size(pos)
            if isempty(pos{j,1}) == 0
                temp_zeit = [temp_zeit;time(j)];
                temp_phys = [temp_phys;ph_adr(j)];
                temp_sig = [temp_sig;sig(j)];
            end
        end

        % New table for saving the data sorted
        Logdatei{size(Logdatei,1),2} = temp_phys;
        Logdatei{size(Logdatei,1),3} = temp_zeit;
        Logdatei{size(Logdatei,1),4} = temp_sig;
    end

end
```

Ignores the consecutive events

```
%  Ignores the exessive events if occurs two the same signal consecutively

logdatei = cell(0,4);
for i = 1:size(Logdatei,1)
    % Group address
    logdatei(i,1) = Logdatei(i,1);
    % Physical address
    logdatei(i,2) = Logdatei(i,2);
    % Time of the events
    logdatei(i,3) = Logdatei(i,3);
    % Events
    logdatei(i,4) = Logdatei(i,4);
    for k = 1:size(Logdatei{i,4},1)-1
        if Logdatei{i,4}(k) == 1
            if Logdatei{i,4}(k+1) == 1
                % If there occurs two same events consecutively, it
                % replaces the event with NaN
                logdatei{i,2}(k) = '';
                logdatei{i,3}(k) = '';
                logdatei{i,4}(k) = NaN;
            end
        end
    end
end

% ignore the NaN values and other empty cells from physical address, time data
for j = 1:size(logdatei,1)
    for a = 1:size(logdatei{j},1)
        ph = logdatei{j,2}(:);
        ze = logdatei{j,3}(:);
        x = logdatei{j,4}(:);
        ph(strcmp('',ph)) = [];
        ze(strcmp('',ze)) = [];
        x(isnan(x)) = [];
        phy{j}(a,:) = ph;
        Zeit{j}(a,:) = ze;
        signa{j}(a,:) = x;
    end
end

% Stores in a new table.
phy = cellfun(@transpose,phy','UniformOutput',false);
Zeit = cellfun(@transpose,Zeit','UniformOutput',false);
signa = cellfun(@transpose,signa','UniformOutput',false);
Logdatei_neu = cell(0,4);
Logdatei_neu = [logdatei(:,1),phy,Zeit, signa];
```

Finds the group address of the detected signals

```
% "auswertung": Alle Gruppenadressen und Zeite, in denen "signal" vorkommt
% Searches the events by detected switching light signals
auswertung = cell(1,3);
auswertung{1,1} = 'Gruppenadresse';
auswertung{1,2} = 'Zeit';
auswertung{1,3} = 'Physikalische Adressen';

for i = 2:size(Logdatei_neu,1)
    aktadresse = Logdatei_neu{i,1};
    phy_adr    = Logdatei_neu{i,2};
    aktsignal  = Logdatei_neu{i,4};
    aktzeit    = Logdatei_neu{i,3};
    pos_sig    = strfind(transpose(aktsignal),signal);
    if pos_sig >= 1
        for j = 1:size(pos_sig,2)
            phys_adr = phy_adr(pos_sig(j):pos_sig(j)+size(signal,2)-1);
            zeit_sig = aktzeit(pos_sig(j):pos_sig(j)+size(signal,2)-1);
            auswertung{size(auswertung,1)+1,1} = aktadresse;
            auswertung{size(auswertung,1),2} = zeit_sig;
            auswertung{size(auswertung,1),3} = phys_adr;
        end
    end
end
```

Timespan

```
%*********** "ergebnis": Datenbank mit gefundenen Verbrauchern ***********%
% stores the group addresses found in timelimit to ergebnis data table
ergebnis = cell(1,4);
ergebnis{1,1} = 'Verbraucher';
ergebnis{1,2} = 'Gruppen_adresse';
ergebnis{1,3} = 'Physikalische Adressen';
ergebnis{1,4} = 'Zeit';

%************************** Time limit *************************%
% Converts the datetime values in datetime array to serial date number
zeitpunkt_start = datenum(zeitpunkt_start, 'HH:MM:SS');
zeitpunkt_ende = datenum(zeitpunkt_ende, 'HH:MM:SS');

%******* Findet die Signale von der gleichen Adressen in einer Zeit*******%
for b = 2:size(auswertung,1)
    zeit = auswertung{b,2};
    zeit_start = datenum(char(zeit(1))); % Zeitpunkt erstes Signal
    zeit_ende = datenum(char(zeit(size(signal,2)))); % Zeitpunkt letztes Signal
    Adresse = auswertung{b,1};
    if zeit_start > zeitpunkt_start
        if zeit_ende < zeitpunkt_ende
            phys_adr = auswertung{b,3};
            Zeit = auswertung{b,2};
            ergebnis{size(ergebnis,1)+1,1} = Verbraucher;
            ergebnis{size(ergebnis,1),2} = Adresse;
            ergebnis{size(ergebnis,1),3} = phys_adr;
            ergebnis{size(ergebnis,1),4} = zeit;
        end
    end
end
```

Displays the group addresses found in the commend window

```
%Zeigt die gefundene Adresse/n an und davon kann eine/mehrere Adresse/n wählen
% Displays the group address in the commend window and if more address
% found then there is possibility to select one or more addresses
Ausgabe = cell(1,4);
Ausgabe{1,1} = 'Verbraucher';
Ausgabe{1,2} = 'Gruppenadresse';
Ausgabe{1,3} = 'Physikalische Adressen';
Ausgabe{1,4} = 'Zeit';

if size(ergebnis,1)-1 >= 1
    disp('Folgende Adressen gefunden:')
    n = 1;
    for k = 1:size(ergebnis,1)-1...

    a = input('Gewünschte Adresse(n) eingeben (Mehrere durch Komma trennen): ', 's');
    b = [];
    if contains(a,',') == 1
        komma = strfind(a,',');
        b = str2double(string(a(1:komma(1)-1)));
        if size(komma,2) > 1
            for z = 2:size(komma,2)...
            b = [b;str2double(string(a(komma(end):end)))];
        elseif size(komma,2) == 1
            b = [b;str2double(string(a(komma(end):end)))];
        end

    else
        b = str2double(string(a));
    end
    if b(end) > size(ergebnis,1)-1
        disp('"Es ist viel, bitte versuchen Sie  kleinere Nummer"')
    else
        for y = 1:size(b,1)         ...
    end
else
    disp('Keine Gruppenadresse gefunden')
end
```

Displays and saves the data of the group address found

```
%**** Druckt die Verbraucher, Physikalische Adresse/n und die Zeit aus ***%
% Print the light consumer, group addresses, physical addresses and the
% time of the events
if size(auswertung,1) > 1

    ausgabe = ["Verbraucher", "Gruppen_adresse", "Physikalische Adressen", "Zeit"];
    test = ["Verbraucher", "Gruppen_adresse", "Physikalische Adressen", "Zeit"];

    for k = 2:size(Ausgabe,1)
        if size(Ausgabe{k,3},1) > 1
            ausgabe = [ausgabe; Ausgabe{k,1}, Ausgabe{k,2}, Ausgabe{k,3}(1), Ausgabe{k,4}(1)];
            for y = 2:size(Ausgabe{k,3},1)
                ausgabe = [ausgabe; '','',Ausgabe{k,3}(y),Ausgabe{k,4}(y)];
            end
        elseif size(Ausgabe{k,3},1) == 1
            ausgabe = [ausgabe; Ausgabe{k,1}, Ausgabe{k,2}, Ausgabe{k,3}, Ausgabe{k,4}];
            test = [ausgabe; Ausgabe{k,1}, Ausgabe{k,2}, Ausgabe{k,3}, Ausgabe{k,4}];
        end
    end

    path = ['auswertung_',datestr(now,'dd.mm.yyyy'),'.txt'];
    pfad = fopen(path,"wt");
    fprintf(pfad,"%-15s\t  %-15s\t  %-25s\t   %s\n",        ausgabe');
    fclose(pfad);
else
    disp('Signal nicht gefunden.')
end
toc
%************** Die Zeit von den Signalen einer Adresse***************%
zeit = cell(0,1);
for i = 1:size(ausgabe,1)
    zeit{i,1}= ausgabe{i,4};
end
zeit = datetime(zeit(2:end),'format',' HH:mm:ss');
```

Signal Number for detecting the Group Address

The number of signals and the amount of detected group address (KNX) at a period time of 2h

(Study time)

Signals	Addresses found	The probability for finding the exact group address (%)
2	84	1.2
4	53	1.9
6	36	2.8
8	29	3.5
10	18	5.5
12	10	10
14	9	11.1
16	5	20
18	5	20
20	5	20
22	4	25
24	4	25
26	4	25
28	3	33.3
30	3	33.3
32	2	50
34	2	50
36	2	50
38	1	100
40	1	100

(Weakend)

Signals	Addresses found	The probability for finding the exact group address (%)
2	47	2.1
4	41	2.4
6	28	3.6
8	22	4.5
10	15	6.7
12	10	10
14	5	20
16	2	50
18	1	100
20	1	100
22	1	100
24	1	100
26	1	100
28	1	100
30	1	100
32	1	100
34	1	100
36	1	100
38	1	100
40	1	100