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Profitability analysis of energy efficiency measures in office buildings: A study case in Germany

Jessica Elisa de Sousa

Fortaleza - Munich
2019

JESSICA ELISA DE SOUSA

PROFITABILITY ANALYSIS OF ENERGY EFFICIENCY MEASURES IN OFFICE BUILDINGS:
A STUDY CASE IN GERMANY.

Undergraduate thesis presented to the Department of Electrical Engineering of the Federal University of Ceará, as a requirement to obtain the Degree of Electrical Engineer.

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EXAMINING BOARD

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Prof. Dr. Raphael Amaral da Camara

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Dr.-Ing. Sérgio Daher

____
Dip-Ing. Christoph Schleider

FORTALEZA
2019

To God,

Family and friends,

I dedicate this work.

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I thank my family, for always being by my side and give me support in every moment of my life.

I'm grateful all my work colleagues at BMW, who taught me so much and were always helpful, as well as the colleagues at IBFU, who also helped a lot in many ways and made this paper possible.

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I also want to thank my advisor Raphael Almeida for the support on this paper.

"Freedom of choice is what we want,

freedom from choices is what we need."

Devo

ABSTRACT

With the aim of improving the energy consumption levels and safe resources in an office building, the work presents a study of the implementation of energy efficiency measures as well as a smart building automation project to save energy resources. The work presents the economic analysis of all suggested actions to improve energy savings and the payback of each solution.

Key-words: Energy efficiency. Smart Buildings. Lighting. Heating. Economic analyses.

INDEX OF FIGURES

INDEX OF ABBREVIATIONS

IEEE	Institute of Electric and Electronic Engineer
ROI	Return of Investiment
HDD	Heat Degree Days
H.L.	Heat Loss
kWh	kilo Watt hour
MWh	Mega Watt hour
CUSUM	Cumulative Sum
MT&R	Monitoring Targeting and Reporting
IEA	International Energy Agency

CONTENTS

1. INTRODUCTION

Energy efficiency and energy management was a subject that emerged in the 1970s with the oil crisis, but in that period the concept was only characterized as saving energy, since the 1980s the term energy efficiency and management gained more focus, with the creation of Monitoring & Targeting tools for analyses of Energy consumption, then the Energy Efficiency Market began to increase. (DR STEVEN FAWKES, 2016)

With the coal crisis and various measures to reduce the consumption of fossil fuels developed in the 2000s, energy efficiency has become a very important tool to reach energy goals. Since 2010 there has been an increase in political interests in energy efficiency projects, which has brought economic opportunities and gained funding.

Energy efficiency is key to ensuring a safe, reliable, affordable and sustainable energy system for the future. It is the one energy resource that every country possesses in abundance and is the quickest and least costly way of addressing energy security, environmental and economic challenges. (IEA, 2017)

Strong efficiency gains have had a significant impact on global energy demand, reducing consumers' energy bills, holding back emissions growth and making energy systems more secure.

In the universe of energy efficiency, the automation is the tool that can optimize the efficiency gain, monitor energy levels and help to create data to energy management tools.

Smart buildings use automation to optimize all or some of the processes that occur inside a building: heating and cooling, security, lighting, ventilation, water usage, and more.

A lot of this comes from data collection. By connected sensors, microcontrollers, and automation software to building's control systems, facilities operators and engineers can gain valuable insights into the building's functions and reap all the benefits of smart building technologies.

1.1. Aim of the Paper:

This work aims the implementation of energy efficient actions and smart building technologies to improve the energy consumption levels and safe resources in an office building at BMW Group Plant Munich in Germany.

1.2. Work Structure:

This work is divided in 4 chapters, the first chapter is the introduction, aim of the work and structure.

Chapter 2 presents terms and definitions on lighting and heating, as well as smart building automatization measures that can be implemented in each case. It also shows how to do the economic analysis of proposed solutions using the payback and return of investment method.

Chapter 3 shows the study case in the building defined in the plant, the solutions found for the optimization and reduction of the energy consumption, smart building technology and the economic analysis of the costs for the implementation of the measures.

Conclusions are presented in Chapter 4.

2. TERMS AND DEFINITIONS

2.1. Lighting

Around 14% of the end energy consumption in Germany is for lighting, this 75TWh per year. Lighting is 4% of the total energy consumption in industrial sector, 36% in commercial sector and 8% of householder consumption (BMWi, 2017)

A good lighting is essential for a focused and productive work atmosphere. Lighting needs to ensure that all visual tasks at the workplace can be performed satisfactorily with no adverse impact on health (Licht.wissen 04). For this, there is standards to accomplish in a lighting plan for office buildings. The EN 12464-1 is responsible for those standards.

To assure the quality of the lighting, three concepts are important to understand how to plan a better lighting project: Illuminance, luminous flux and luminous efficiency.

Illuminance is defined as the attached light flux per unit area. The usual unit of measure is lux (Feitosa, M. V. e, 2011). For lighting projects is important to accomplish lux levels defined in the EN 12464-1. For Offices and task areas, the minimum needed luminance is 500lx.

Luminous flux is the total amount of light emitted in all directions. It measures in lumens.

Luminous efficiency is the measure for efficiency with the generation of light, and is specified in lumens per watt (lm/W). (Trilux, 2019).

2.1.1. Main Types of Lamps

- Fluorescent tube lamps

Fluorescent lamps are high luminous efficacy, good color rendering and a live between 7.000 to 15.000 hours. Because of the low price is the most common lamp type in offices.

- Compact lamps

Also known as energy-saving lamps, this is also a fluorescent lamp, but in the compact form, which allows it to substitute the incandescent lamps

- Metal halide lamps

Lamps with high illuminance and good color rendering.

- Halogen lamps

Halogen lamps can be found in low voltage (12V) and high voltage (230V). Both have a good color rendering, but a high energy consumption.

- LED lamps

It is the best type of lamps available in market nowadays, it can work for 50.000 hours, or at least 30.000 hours without any loss in the brightness and color rendering. A high luminous flux per watt that provides a really high efficiency.

- LED modules

The LED solution to technical and design lighting.

The Fig. 1 represents the lamps explained in this section. 1 to 4 represents fluorescent tube lamps, 5 to 7 compact lamps, 8 to 10 metal halide, 11 and 12 halogen lamps. 13 to 16 are LED lamps and 17 to 20 LED modules.

Figure 1: Types of Lamps.

Source: licht.wissen 4

Although LED Lamps bring the best efficiency and useful life to lighting projects, their price still is a disadvantage to use them in retrofits.

2.1.2. Lighting control and management

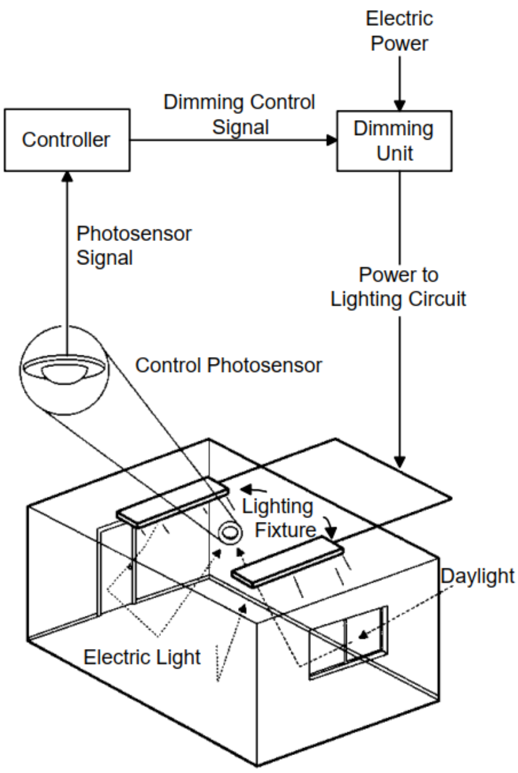
Aligning with a better light source, there are also some others tools that can improve the energy consumption, like dimmers and move sensors, that optimize the time and intensity of the lamp.

- Dimming

Dimming controls reduce the output and energy consumption of light sources. Compared to on-off controls, they can increase energy savings, better align lighting with human needs, and extend lamp life. (PG&E Energy Efficiency Information© "Lighting Dimming Controls")

Dimming minimizes electricity consumption managing the consumption of lumens aligning with the use of natural light, optimizing efficiency and longer lifetime to lighting system, as shown in Fig. 2.

Figure 2: example of dimming system.



Source: Dimming Controls for Lighting.

- Movement Sensors

Sensors are also very used to reach efficiency levels. The expected reduction of monthly electricity energy consumption is between 30% and 40% lower compared to the one without sensors installation.

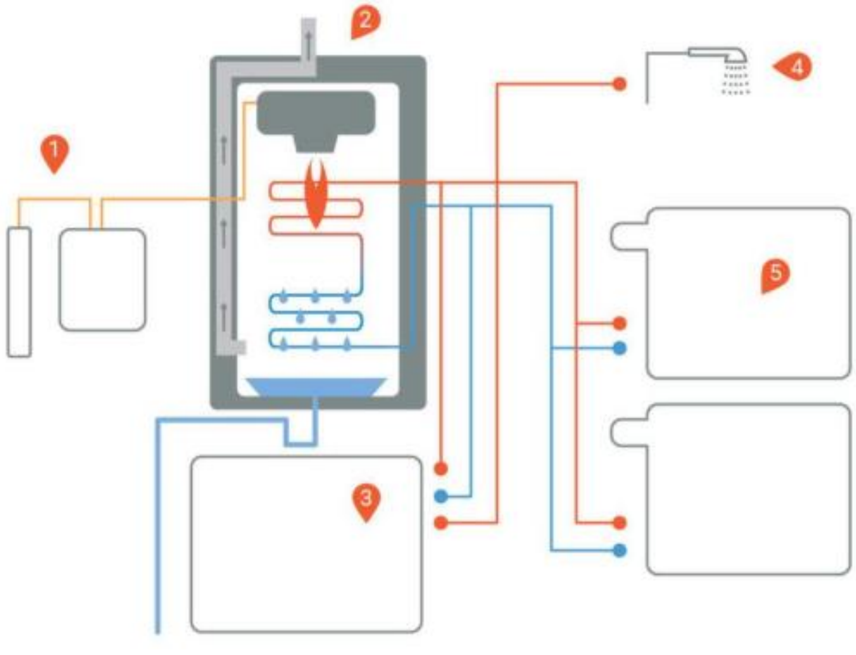
2.2. Heating

In Germany, 29.5% of the final energy consumed is intended for heating buildings. Almost 50% of the heating systems are gas. Heating is responsible for almost 70% of energy costs inside a house in Germany (BMWi, 2017).

2.2.1. Types of Heating systems

All heating systems work basically with the same principles. A source of energy heats a conduct heat material or a boiler, that transfers the heat to water or air, that will run through pipes and ducts to be used to heat the spaces in the building.

Figure 3: Heating system example.



Source: Heizung.de

- Gas

It is the most used system in Germany. Heating consists of a gas condensing boiler generating heat. This heating system has a compact design and an efficiency of 98%.

- Electric

The electrical system can be used to heat spaces and water. It consists of the transformation of the electric energy into heat through the heating of an electric dissipated for the environment or water. This type of system is usually used for individual heating (a room or a shower) and although it is considered to be an efficient and inexpensive system, it is not used on a large scale because electricity in Germany comes from fossil fuels.

- Oil

It is an old technology and is no longer used in new buildings, the oil heating system has a low efficiency. More modern oil condensing boiler systems ensure greater efficiency, but there is still no high utilization.

2.2.2. Heating System Consumption Calculation

The heating consumption in Germany is calculated based on the area of the building. The current average energy consumption is 140 kWh per year per square meter of living space. (TopTarif DE, 2019)

2.2.3. Heat losses

In a heating system, it is important to measure the losses. In this case, losses through doors and windows, which, however closed, losses still exist. The loses happens because of the heat transmission between inside the building and outside.

The losses are calculated according the first thermodynamic law using the following equation (1):

$$\frac{dH}{dA} = \frac{\Delta T}{\sum_{n=1}^{i}\left(\frac{Ln}{Kn}\right)} \quad (1)$$

ΔT = Temperature difference in Kelvin

L = Thickness in meters

K = convective heat transfer coefficient ($W/(m^2.K)$)

The coefficient K depends on type of media, if its gas or liquid, and flow properties such as velocity, viscosity and other flow and temperature dependent properties Engineering (ToolBox, 2003).

The resulting value of this equation is the amount of energy transferred per square meter on a surface, such as windows and walls.

To calculate the impact of the losses on the consumption of a building in a year, it is necessary to do this calculation for every day of the year that need heating. This calculation of the consumption of losses is then based on the value of Heating Degree Days (HDD) per year that the building must be heated. This results in equation (2):

$$H.L. = \frac{Area}{Rvalue} * \frac{24H}{Days} * HDD \quad (2)$$

2.3. Smart Buildings

An intelligent building can be defined as one that is capable of offering a productive environment, and with an optimum cost-benefit ratio for optimizing its systems, structure, services, management and maintenance for its lifetime (MARIN, 2019)

From this definition, it becomes possible to evaluate Smart buildings technologies that should be:

- Energy-efficient operations of the technical services adapted to demand/requirements/needs
- Conformity with legal framework conditions (EN 15232)
- Functional office buildings with modern operating options for the users

Currently, efforts to make buildings smarter are focusing on energy efficiency of lighting and HVAC systems. Building automation is critical to these efforts, mainly because it could reduce the annual operating costs of buildings by a whopping 3.6 to 7 cents per square meter (IEEE Spectrum, 2003)

2.4. Profitability Analyses

the profitability analyses are essential to guarantee the measures implemented in this project is viable or not. For this, it will be used two methods: payback and return of investment.

2.4.1. Payback

Payback is used to calculate how is needed to recover the money invested in measures that was implemented in the project.

In projects of energy efficiency and saving, the payback is generated according with the money that is safe after the implementation of the energy efficiency measures.

$$Payback = \frac{Cost\ of\ Investiment}{Money\ safe\ per\ year} = numbers\ of\ years \tag{3}$$

The number of years that is required to pay what was invested is the payback of the investment.

2.4.2. Return Of Investment

Return on investment (ROI) measures the gain or loss generated on an investment relative to the amount of money invested. ROI is usually expressed as a percentage and is typically used for personal financial decisions, to compare a company's profitability or to compare the efficiency of different investments.

$$ROI = \frac{Final\ value\ of\ Investiment - Initial\ value\ of\ Investiment}{Cost\ of\ Investiment} * 100\% \tag{4}$$

3. STUDY CASE

This chapter shows the study case in the building defined in the plant, the solutions found for the optimization and reduction of the energy consumption, smart building technology and the economic analysis of the costs for the implementation of the measures.

3.1. First Considerations

The building chosen for the reform and application of energy efficiency and smart building measures was building 162.0. It is one of the buildings of the BMW plant 1 complex, located in Munich, Germany. The building has a total area of 4112.5m², 5 floors and a basement. In the first floor there is a training workshop area and the other 4 floors are occupied by offices, meetings and training rooms.

BMW pays currently for electricity 0,16€/kWh and 0,06 €/kWh for gas. The company aims to reduce its resource consumption (energy, water, waste, solvents) per vehicle produced by 45% by 2020 in relation to 2008.

In order to study efficiency measures and the automatization tools in the building, a collection of energy consumption data, lighting load and heating units was made. From the obtained data, the appropriate interventions were proposed and the economy of the interventions was calculated.

Figure 4: Building 162.0.

Source: Google Maps.

3.2. Lighting Analyses

A survey was made of the total of light spots in the building and the power of each lamp used. The lighting is composed of double fixtures, represented in Fig 5, with OSRAM FH 28W/840 lamps, lamp in Fig. 6, this is 56W per fixture, more 3W for ballast, which means a consumption of 59Wfixture.

This lamp already has a high efficiency compared to other tubular lamps for being T5 and have a high luminous flux.

Figure 5: Current fixtures.

Source: Author

Figure 6: Current lamp and recommended lamp.

Source: BMW Group

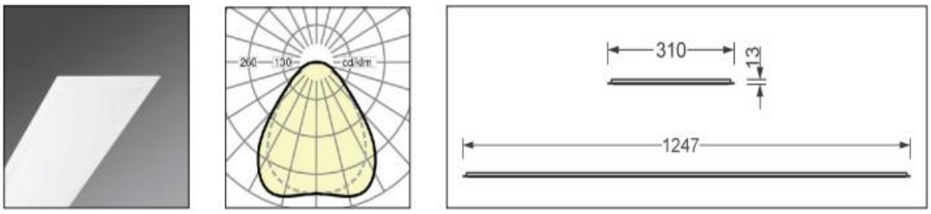
For the retrofit of the lighting, the manufacturer has a model LED substitute of 16W, which means 12W less per lamp and 27W per fixture, since the LED lamps does not use ballast. Out of the reduction of consumption, LED lamps have a useful life of at least 40.000 hours, around 12 years.

Figure 7: Recommended lamp.

Source: BMW Group

The Panella luminaire, from Regiolux, the model used by BMW for replacement of lighting for LED technology, was also used for the calculation of lighting change and is also an acceptable replacement for the current system.

Figure 8: Proposed fixture overview.



Source: BMW Group

With the use of Panella luminaire the reduction is 59W per luminaire for 28W, reduction of 31W per luminaire.

Despite the fact that the Panella luminaire delivers more energy savings, due to its cost, it was decided to make the calculations based on replacing only the bulbs for the substitute lamp from OSRAM.

It was found 520 lamps of 28W in the building, according to the calculations presented, the exchange of this quantity of lamps by the most efficient model causes a saving of about 49% in energy consumption, which is equivalent to approximately an annual saving of more than 16MWh.

Figure 9:Results of Lamp exchange

Lamp type	Total	Total	total
Power (lamp+ballast) (W)	30	16	28
Amount	531	520	260
installed power(kW)	15,93	8,32	7,28
Working hours (h/ano)	2640,00	2640,00	2640,00
FCP	0,67	0,67	0,67
consumed energy (kWh/year)	42055,20	21964,80	19219,20
Anual consumption (€)	6.308,28 €	3.294,72 €	2.882,88 €
Energy saved (MWh/year)	-	20,1	22,84
Economy (€/year)	-	3.013,56 €	3.425,40 €
Energy saved (%)	-	48%	54%

Source: Author

It was also investigated if the actual system attends the correct levels of illuminance according DIN EN 12464-1 that requires the minimum of illuminance established for office buildings, which is 500lx.

The lighting of the rooms was measured with a proper equipment. With the measures was possible to verify that the actual system operates on exactly the right amount of lux predefined for the technical rules, which means that the ideal for the current system is the exchange of lighting through the ideal substitute in LED, suggested by the manufacturer itself.

The only area in which the number of lux was much more than the required was in the workshop. In the workshop was measured 1100lx, the ideal is 750lx, in addition of it, there is no division of lighting circuits in areas that some are more used than others, causing wasting of energy by illuminating areas that are not necessary.

For the workshop the ideal is:

- New lighting calculation to reduce over-dimensioning of the system
- Divide the circuits into more switches so that complete areas do not waste energy in not used areas.

3.3. Heating Analyses

The heating system of the building has been updated less than 4 years ago, which means the system is still current and there is no need of changes. Annual gas consumption is approximately 491 MWh.

The heating system consists in heating units installed under each window, the responsible of the most part of heat loss of the building. Despite the renovation in the heating system, the windows of the building are still old, about 40 years old and this causes damage to the performance of the heating system, because there is a big heat loss due to the poor insulation that the current windows provide.

Figure 10: details of current windows.

Source: Author

Figure 11: details of current windows.

Source: Author

Block 162.0 will already have its windows replaced regardless of this analysis, due to the adequacy of current German fire and security standards, requiring the exchange of the current ones. But even so will be studied how positive this measure can be in the point of view of energy efficiency.

The current windows are made aluminum with double glass, around of them the damage caused by the time can be seen and in the photos of the thermo camera.

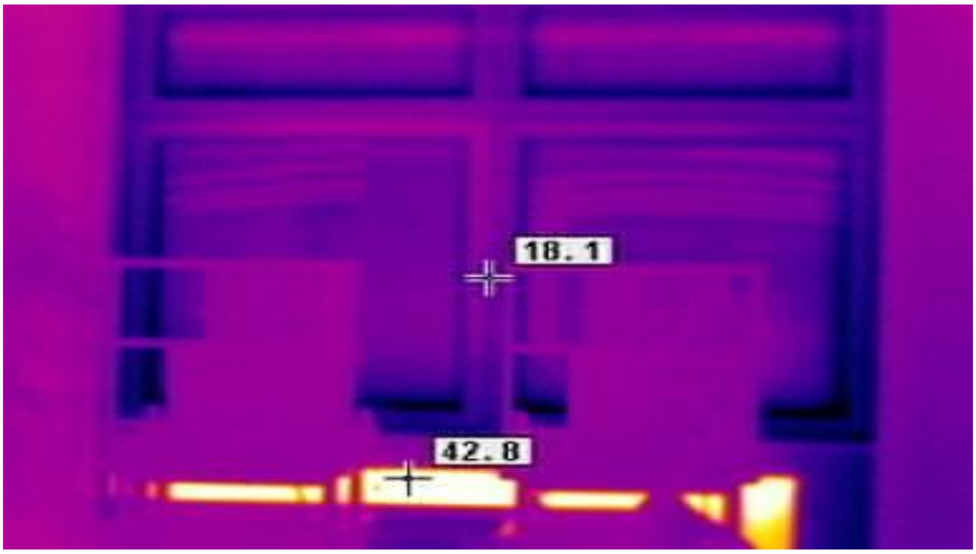
The insulation problems can be detected in the thermic photos through the difference of temperature between the areas with and without windows. In the figures 11 and 12 from the first floor, where the windows are already renovated, there in no big temperature difference between areas with and without windows.

On the other hand, in the other floors with old windows, as shown in the figures 13 and 14, the temperature difference between the walls and the windows area can reach 5°C. Also around them is noted in the second floor a gap between the two parts, this does not happen in the first floor.

Figure 12: Temperature the room in 1st. floor.

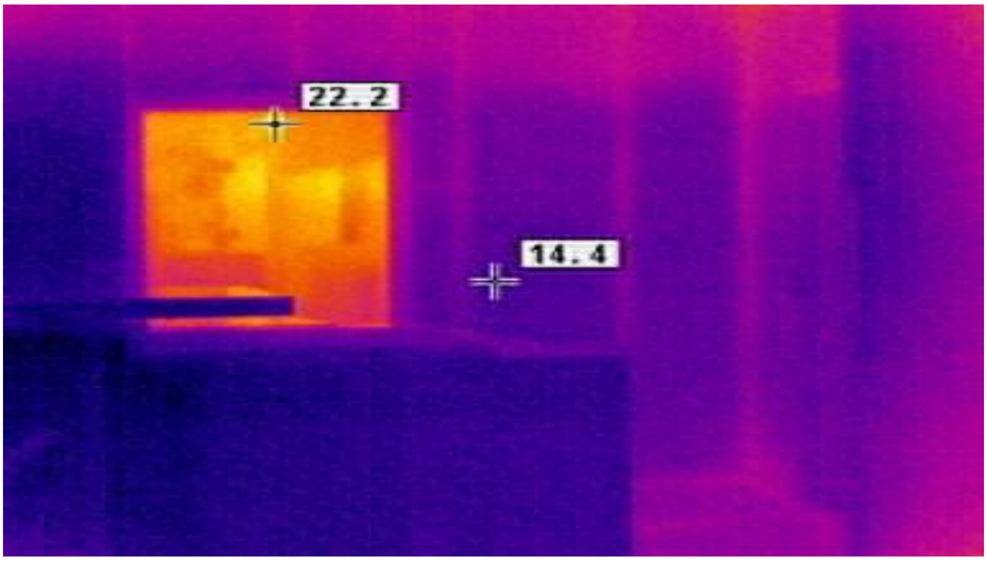
Source: Author

Figure 13 New window in 1st floor with better insulation.



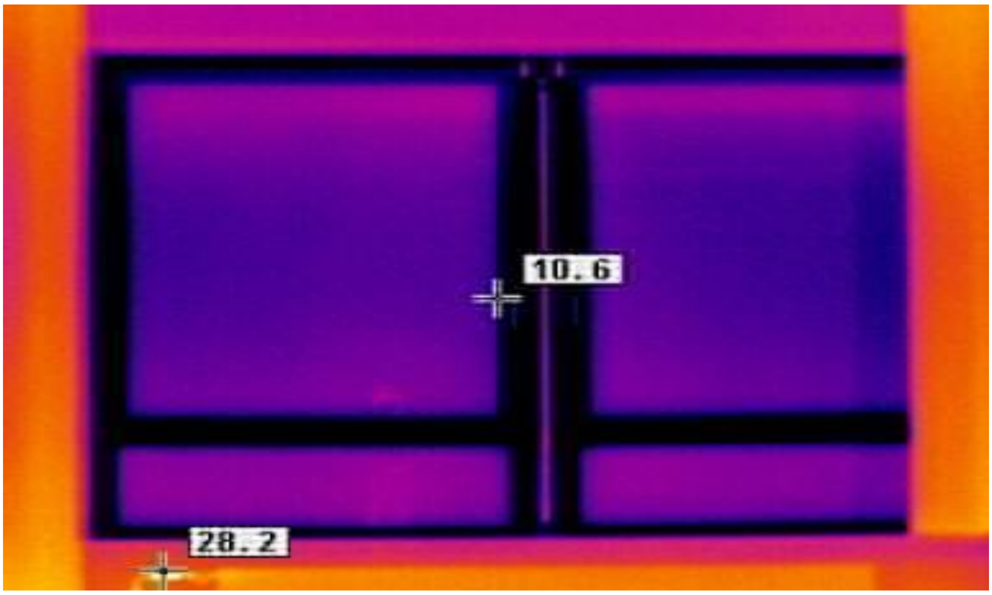
Source: Author

Figure 14: Temperature from the room in 2nd floor.



Source: Author

Figure 15: Old window in 2nd floor with poorly insulation.



Source: Author

Considering that the current windows has a heat transfer coefficient 2,8 $W.(°C.m)^{-1}$, the comfortable temperature inside of the building of 22°C and outside in the winter, the temperatures can reach -20°C, the heat loss trough windows can be:

$$\frac{dH}{dA} = \frac{k\Delta T}{L} = \frac{(2{,}8W.(°C.m)^{-1})(42°C)}{2 * 0{,}0035\, m} = 16800W/m^2$$

$$\frac{dH}{dA} = 16.8kW/m^2$$

Now with new windows with triple glass insulation, this coefficient decreases to $0{,}9\ W.(°C.m)^{-1}$ the new heat loss estimative is:

$$\frac{dH}{dA} = \frac{k\Delta T}{L} = \frac{(0{,}9W(°C.m)^{-1})(42°C)}{3 * 0{,}005m} = 2520W/m^2$$

$$\frac{dH}{dA} = 2.52kW/m^2$$

This is a reduction of 14.28kW/m², which consists in a reduction of 86.9% of losses in heat per square meter.

The whole building has 108 windows of 4.2m². To calculate the annual heat loss in MWh, it was used the total windows area of the building, which means 453.6m², and the average of the heat degree days of last three years, from 2016 to 2018, that was 3651,36(Gesellschaft für Energieplanung und Systemanalyse m. b. H., 2019). for old windows this results in:

$$H.L. = \frac{Area}{Rvalue} * \frac{24H}{Days} * HDD = \frac{453{,}6}{1{,}72} * 24 * 3651{,}36 = \ 23{,}11MWh\ per\ year$$

For new windows, the heat loss is:

$$H.L. = \frac{Area}{Rvalue} * \frac{24H}{Days} * HDD = \frac{453{,}6}{3{,}22} * 24 * 3651{,}36 = \ 12{,}34MWh\ per\ year$$

It is expected a reduction of 10,77MWh per year in the heat consumption, this is a reduction of 46% of losses in heat. However, the impact in the total energy consumption of the building is of only 2.2% of the total consumption per year of the building.

3.4. Smart Building Technologies

After the initial measures that will improve the energy performance in the building and does not require new technology, the next step in optimize the system through the implementation of the automation system to turn the construction into a Smart Building.

The system was designed according to the aspects established in EN 15232, which regulates smart buildings projects. In addition to the standard was used the guideline for BMW automation projects with specifications of how the project meets the needs of the company. First, the scope of the project was defined, meeting the following specifications:

- Heat

Single-room control with communication between control units and the generators

Demand-based temperature regulation for the supply and return circuits as well as the generator

Load-dependent speed control of the circulation pump

Switching between day/night operation depending on the demand

Automatic turn off, while windows are open.

- Lighting and shading

Automatic feature for switching lighting on or off or for dimming it, while automatically taking into account any daylight entering the rooms

Shading in coordination with the need for lighting and avoiding heating through sunlight.

- IT-based Systems

Control capabilities while using digital media (smartphone, tablet-based PC, PC) incl. specific permission management for user and group level

Interfaces to further IT-Systems (room booking systems, analytical systems, energy consumption processing) and database systems

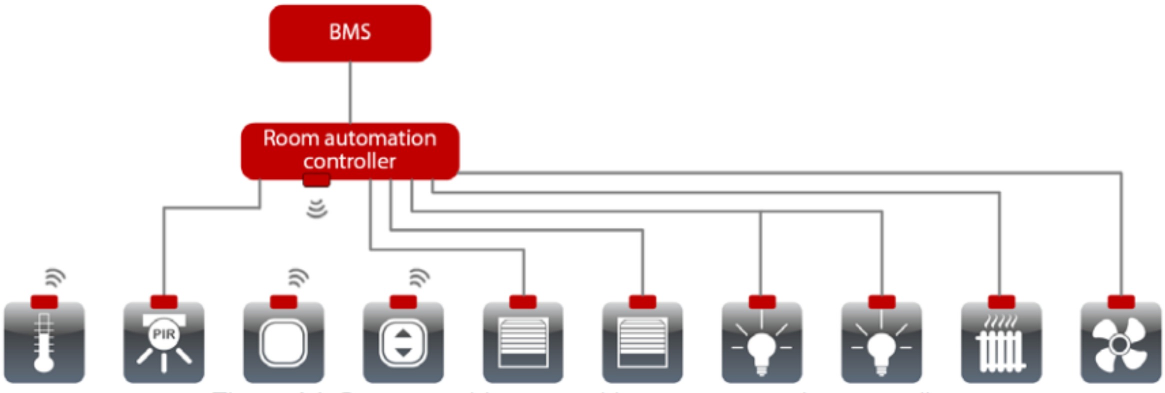
- Technical building management

Automatic detection and reporting of errors and malfunctions.

Automatic detection and processing of energy consumption

After the project scope, the topology and architecture of the project was planned. The variant architecture Single Room Automation was chosen, which consists of a controller to manage the sensors and functions of automation in the environments, in communication with a BMS that is responsible for the control of the building's resources, such as central heating and energy metering. The architecture is shown in Fig. 15.

Figure 16: Single Room Automation Architecture



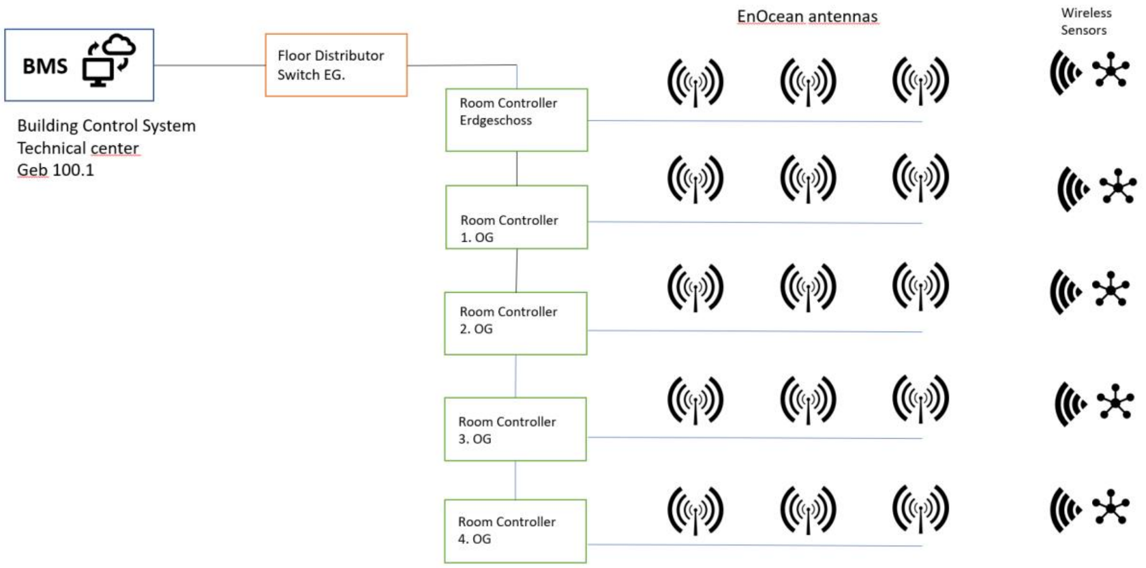
Source: BMW Group

This architecture is the easiest to implement, because the controllers used in this architecture are easy to program and low complexity, following what regulates in the IEC 61131-3. For the building the WAGO 750-852 PLC controller was chosen.

The selection of sensors was made to use the smallest number of sensors, for which combined sensors were used. It was used a sensor for movement and lighting, and a sensor for temperature and air quality (humidity). In addition to the sensors is also defined the actuator used in the heaters and wireless switches. For this project only wireless components were used, as shown in Fig. 16.

Since these gadgets do not need any intervention for implementation and have low maintenance costs. All sensors used in the project are EnOcean technology, for the communication between the controller and the sensors, EnOcean antennas and signal reception modules WAGO 750-462 were used. It was also used connected to the PLC modules of digital and analog input and output. To control the lighting, a DALI module was also included in the PLC.

Figure 17: Configuration of the Automation Sistem



Source: Author

The lighting will work in combination with the movement and lighting sensors. Since the movement in the room is on, the temperature sensors command the heaters to reach a comfortable temperature. The combination of lighting and temperature can turn on or off the sun protection. In addition to sensors, the users can by themselves turn the lights and sun protection on and off using the wireless switches. The position sensors in windows are responsible to send a signal when some window is open to turn the heaters either off or decrease the work temperature of them. Other functionalities are also programmed, as the automatic turn off of lighting or decrease the temperature in the heaters at night and weekends.

Through the smart building system, it is possible to calculate a decrease at least 40% in the consumption of electric energy and 20% in the consumption of gas.

3.5. Economic Analyses

3.5.1. Lighting

The current lighting power installed in the building is 15.93kW, the proposed solution has a total power of 8.32kW, the current annual consumption is approximately 42MWh per year, it is estimated that this consumption will reduce to 21,8MWh per year, a reduction of 49% in lighting consumption.

The price of kWh is 0,16€, only the exchange of lighting brings the saving of € 3,013.56 per year, the initial investment is € 17.280,00. This corresponds to a payback of 6 years to replace the tubes to LED lamps. For the replacement from old fixture to the new, the investment is € 38.940,00 and a payback of 11 years.

3.5.2. Heating

The annual heating consumption of the building currently stands at approximately 491MWh. The energy saved by window replacement is in the amount of 10.77 MWh per year, a reduction of approximately 2.2%.

BMW pays 0.05€ per kWh. Only the exchange of windows corresponds to a saving of € 397.50 per year, but the calculation of the financial return was not made, since the exchange of windows is linked to the fire measures.

3.5.3. Automation System

After the installation of the building automation system, there is a 40% reduction in lighting consumption in the building. Combined with the new lighting, the consumption can reduce to 13.13 MWh per year. This means, the implementation of all interventions can bring a reduction of up to 69% in the initial lighting consumption of the building, this corresponds a total economy of € 4,338.78 per year.

After the replacement of windows, the annual gas consumption is 480.23 MWh, with the smart building system, it is expected a consumption reduction of approximately 20%.

The expected consumption after the implementation of the automation system is of 384.2 MWh per year, that means a total reduction of 106.8 MWh. The estimated reduction in heating costs is € 5,340.00 per year.

The initial investment in the automation system is € 65,349.20. With the economy in the heating and lighting system, there is an annual saving of up to 6,665.22 €. In the calculation of simple payback, it has been that the investment will be paid in 10 years.

However, by calculating all measures implemented, there is a saving of € 9,678.78 per year. The total investment of the measures proposed is € 82,629.20. The payback of this investment is 9 years.

3.6. Further Optimizations.

Further the functionalities already defined in the scope, that meets the Standards and Guideline provided, there is a lot of new possibilities since the system has been applied and has no extra investment. This topic aims to show some of them.

3.6.1.1. Survey customer satisfaction

The improvements proposed by an automation system are defined not only in efficiency of resource use and energy savings, but also in the satisfaction and comfort that the system provides. To evaluate this, it is necessary that the user can be heard and evaluate their experience of the automated spaces.

The intelligent buildings of BMW have labels that inform that the user is in an intelligent environment, as heaters that adjust automatically and system of solar protection automatic. These tags have QR Codes so the user can learn how this technology works.

Figure 18: Information label next heater automated system. Reference: Author

Source: Author

However, there is no method used at the current time, that the user can evaluate the performance of the system, send suggestions and possible complaints. for this, it was thought in the implementation of a system of QR-Code that can take the user to a survey of satisfaction, in order to be documented what the impressions of the user in relation to the smart building system.

Figure 19: QR Code label for a Client satisfaction survey redirection.

Source: Author

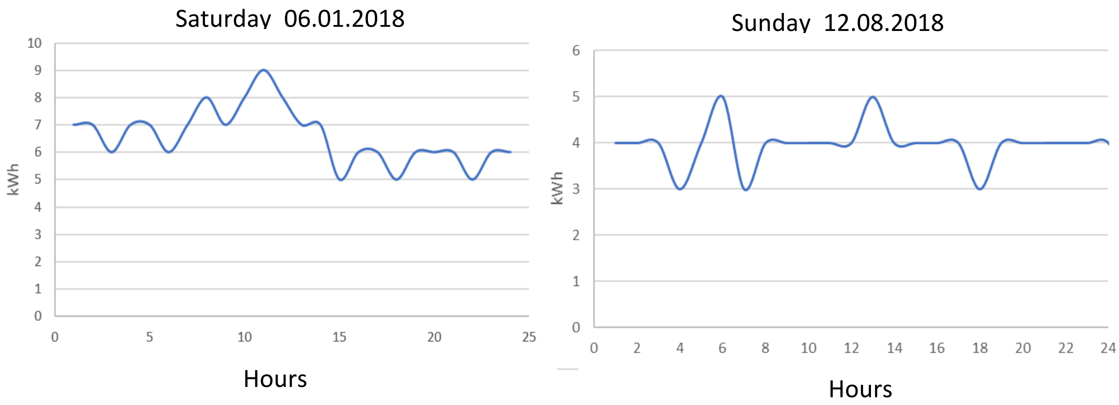
From this, it is possible to generate a database where the performance of the automation system can be monitored in a way that directly pleases the user, for example by studying if the standard temperature set for the rooms is satisfactory as planned.

3.6.1.2. Monitoring Consumption

The smart building system can also be programed to meter the consumption energy to make a further energy management and analyses. Currently, the data of energy consumption measured per hour is not totally reliable, since the data from last year show some gaps with no apparently reason.

But even with some disorders it is still possible to draw a curve of consumption profile and work on it. As it showed at picture 1, at the weekends, the energy consumption is very low and the similar the consumption at Monday to Friday nights.

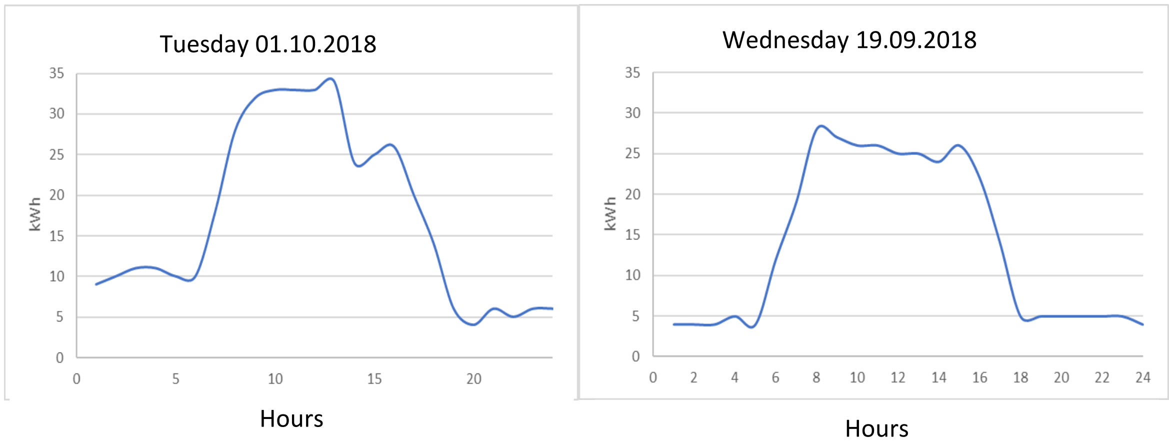
Figure 20: Example curve of consumption at weekends.



Source: Author

During the week, the energy consumption rises around 6 am. and goes down around 6pm., concluding that the building has a working load of around 12 hours.

Figure 21 curve of consumption under the week.



Source: Author

In both examples, though the curves have similarities, it can be seen that the consumption has a high range difference. The consumption in the weekends can fluctuate in the end of the day of up to 60 kWh. During the week this difference can reach more than over than 100 kWh per day.

To decline those deviations and decrease the consumption, it is suggested the study of this curve and the cycles of energy consumption per day, week and month. With the use of the consumption analysis it is possible to:

- Define forecast consumption and demand, which can be used to improve buying and selling energy actions.

- Make more accurate maintenance plans.

- detect faults and leaks in system, waste and consumption out of the usual.

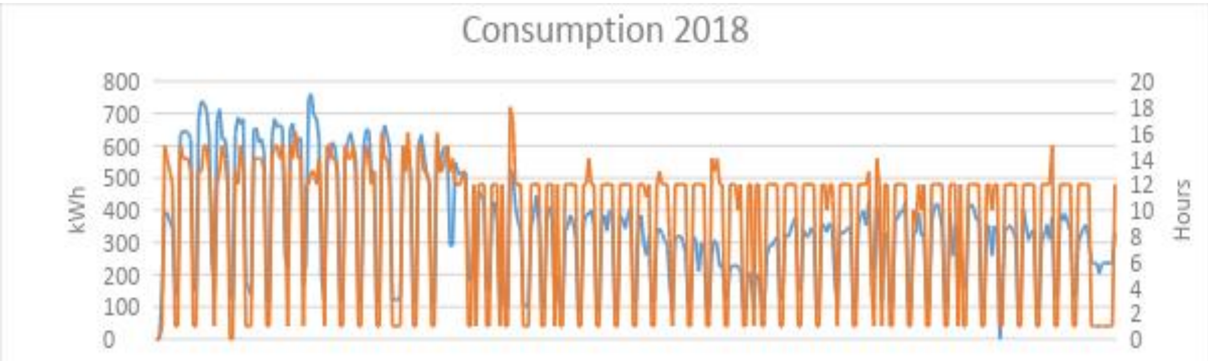
- define new action plans to reduce energy consumption.

All of these measures can be planned only by looking at consumption charts.

This consumption graph model can also and should be evaluated for gas consumption and check for possible leaks, generator defects, or leaks or failure of window insulation. Detecting abnormalities is an important step in improving predictions and better planning for action plans.

However, to analyze this kind of variation, it is recommended to use other tools that can give an easier graphic visualization of deviations in the curve line. To analyze big periods, this type of graphic does not show precise information to make a simplified analysis.

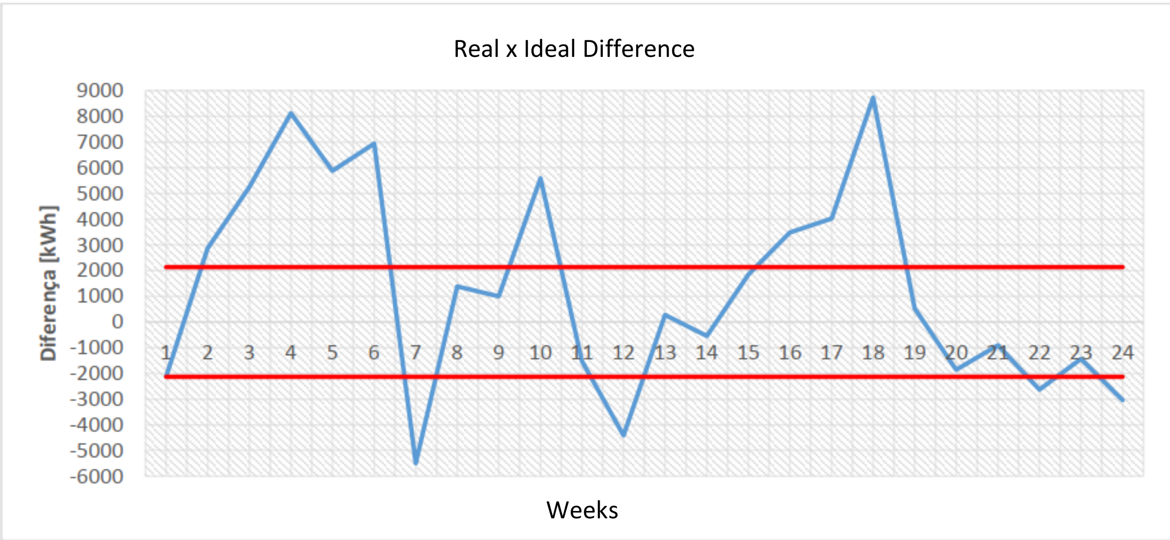
Figure 22: graphic annual consumption 2018 in the building.



Source: Author

For those cases, it can be developed a monitoring tool to target the limits of deviation accepted, so it is possible to visualize more precise when the nonconformities happen, and how to treat then. An example of data treatment is a control graphic of cumulative sum of difference, as known as CUSUM.

Figure 23: Example of control graphic of cumulative sum of difference.



Source: Metodologia Mt&R Aplicada À Uma Planta Industrial De Lácteos Frescos Localizada Na Região Metropolitana De Fortaleza.

4. CONCLUSIONS

This work aimed the implementation of energy efficient actions and smart building technologies to improve the energy consumption levels and safe resources in office buildings.

Through the analysis in this work, it was reached a reduction of up to 69% of lighting costs and up to 16% of heating costs. The responsible for the most part of this reduction was the Automation Building System developed for the construction.

Even though the tolerable percent of energy saving reached in this work, since the price of the kWh is very low, the measures do not bring a great economic impact due to the long payback and small return of investment.

However, after the operation of a smart building system, the energy efficiency of the building was not the only benefit of this project anymore, then also the comfort provided in the building after the modifications. The implanted systems promote better well-being to employees and improvements in ergonomics, that brings also an improvement in productivity and quality of work. For this, it is important the monitoring of the user satisfaction as was proposed in item 3.5.1.

Some proposals informed in this paper can also be implemented without the aid of an automation system. Switching from manual to automatic heater controls induces a reduction of about 7% in gas consumption. Areas of nonfrequent use that do not yet have sensors, such as some corridors and bathrooms, can have significant improvements in energy use with the installation of motion sensors.

The energy price at BMW showed that energy efficiency measures and retrofits are not extremely necessary in office buildings because of the low energy consumption and the number of hours worked in relation to production do not allow BMW to have a faster return of the investment. But the measures pointed out here should be studied with more attention in the future renovation projects and in the future replacement of equipment, since there was no previously studied about the impacts of new technologies in the office buildings before.

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APPENDIX

Survey Lighting and Heatin

Unit		Lighting										moviment sensor	Number of heaters
		FLUORESCENT		LED						Ballast			
				CPT			Tub			magnetic	Eletronic		
		1x28	2x28	10	14	28	16	18	40				
	Flur	5									x	X	0
G0001	automatenraum	8									x	X	1
	Treppenhaus		2								x	?	1
	schulungsraum										x		
	Stützpunktbüro										x		
	Elt-Raum										x		
G0000	Schmlermitterllager										x		
	Elt-raum 2										x		
	Treppenhaus		3								x		2
	Werkstatt 2										x		
	Treppe										x		1
	Lager										x		
	socialsphere								4		x		2
	hubblehub								1		x		1
	conceptionzone								6		x		2
	colaborationloft								3		x		1
	WC-D part 1										x		0
	WC-D part 2	2									x		1
	E-raum										x		
	flur								11		x	x	0
G0010	teekuche		1								x	x	0
	dropbox					1					x		0
	visionaryshot								12		x		3
	visionary...2								18		x		3
	Besprechungsraum 4										x		
	Besprechungsraum 5										x		
	Besprechungsraum 6										x		
	???										x		
	Büro								53		x		11
	Büro links		60								x		13
	teekuche		2								x		0
	vorWC-H	1									x	x	0
	WC-H	2									x	x	1
G0020	WC-D	1									x	x	
	betriebsraum										x		
	Treppenhaus		2								x		0
	flur		4								x		0
	Büro Rechts		42								x		10
	wc-h										x		
	Büro 1								17		x		6
	araquari								8		x		2
	debrecen								2		x		0
	rayong								3		x		1
	spartanburg		6								x		1
	teekuche		2								x		0
	farnborough		3								x		1
G0030	dadong		6								x		2
	WC-D	1									x		
	hams hall		6								x		2
	Treppenhaus		2								x		
	flur	5	4								x		
	san luis potosi		9								x		2
	swindon		12								x		3
	oxford nord		12								x		5
	oxford sud		12								x		
	Büro links		41								x		11
	Kopieraum		2								x	x	0
	Kuche		1								x	x	0
											x		
	vorWC-H	1									x	x	
	WC-H	2									x	x	1
	WC-D	1									x		
	betriebsraum										x		
G0040	Treppenhaus		2								x		0
	flur		5								x		0
	Besprechung 1		2								x		1
	Besprechung 2		8								x		2
	besprechungsraum/erstazteillager										x		
	technikraum										x		
	schulungsraum L7										x		
	schulungsraum 35 up										x		
	TOTAL	29	251	0	0	1	0	0	138	0	0		Fixtures