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USING AUTOMATION IN NON-RESIDENTIAL BUILDINGS TO CUT OFF STANDBY DEVICES

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ABSTRACT

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Master's Thesis

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Residential and commercial buildings are one of the major contributors to energy consumption in the EU, accounting for up to 40% of total energy consumed (European commision, 2015). As Indicated by the Energy Performance of Buildings Directive, all new buildings after 2020 have to be nearly zero stock and overall the EU is moving towards zero stock energy use in buildings by 2050. With this in mind there is a need to lower current energy consumption in buildings. While many studies focus on the energy usage of households, few of them discuss energy use in a university and company context (i.e. commercial buildings). Within this area a low hanging fruit that could help decrease energy consumption is stand-by power, the consumption of power when a device is not in use. Stand-by power can consume up to 8% of a devices total energy use over its lifetime. To alleviate this problem this research, first collected data from other literature to understand the composition of an office building and with this data we created scenarios to calculate the time it would take for an automated system using different levels of automated to return a monetary value. The return on investment varies per country and scenario it is 400 days on average for Germany and 700 for Finland.

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Darren Andrew
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Skellefteå, Sweden

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1 INTRODUCTION

When many people stop using a device they never turn it off and let it go into standby mode. Devices that are on standby are for the most part taking energy that is not needed and could be easily saved. This is why some people dub it as vampire energy, phantom load or leaking electricity. By looking to lower and potentially eliminate this type of energy we can lower energy consumption, and therefore save money.

When we look at standby energy we can see that it is used in all environments but if we compare the savings that could be made in households that are running several devices on standby to businesses and universities that could potentially be running a couple of hundred devices then we can see that there is a bigger potential for savings to be made in a corporate environment.

When looking into standby power, as much as we tell people to turn of the lights, their computers and devices we still see it account for a significant portion of a devices total energy use, with research showing between 5% -12% of a total devices energy consumption (Meier, 2005). This has lead the research to look at an automated approach. This is to help cut off devices energy use with the idea that the individuals at the companies comfort will not be affected as they have usually little to no input into the decision to automate the office.

1.1 Background

Climate change is a problem that is getting worse at an unparalleled rate.The solutions are not simple and there is a need for a multitude of changes to help lower greenhouse gas emissions. With the Paris climate agreement, the EU have all pledged to emission targets and while a lot of work is being done to lower emissions and more money is being spent on renewable energy, there is still a lack of urgency that makes the goals which have been set inadequate and easily achievable. Germany for example has modest targets and it has the target of not letting the average temperature rise by 2C but if it tried to meet the 1.5C rise then it will have to act now and fast (Kumar and Madlener, 2018). It can also been seen with Germany's move away from nuclear and increase reliance on fossil fuels that they are struggling to meet their 2020 targets.

Along with climate change there is also the problem of 11% of EU citizens, mostly in southern and central eastern Europe living in energy poverty. The solution to this is for the use of renewable energy and for more efficient energy utilisation (Bouzarovski, 2018). Many people argue that energy is a basic human right and that makes it a tough task to balance the demands with the renewable needs.

One way in which the EU is increasing its efforts is to introduce policies that will help reduce environmental impact and carbon emissions. One area of these policies are for buildings. There are several types of policies for buildings as buildings have different functions and needs. Currently in the european union 40% of all energy consumed is from buildings (European commision, 2015).

There is not one solution for this problem and as mentioned the country, building type and building needs impact this. Mata, Kalagasidis, and Johnsson (2018) research looked at the energy conservation measures for buildings, both residential and nonresidential, and looked at 5 EU countries. We can see from this study that there is some overlap in measures when countries have similar climates but even then there never seems to be universal agreement in what is being measured. For example, Germany and France are using the term deep renovation to mean deep thermal renovation but the UK lists each method of renovation separately.

There is also the general push towards making appliances more efficient or encouraging the purchase of smart meters that can help a consumer be more informed. The introduction of stand by modes in applications have improved the energy efficiency of devices but with people buying more and more devices there has not been any energy savings in buildings. Jensen (2009) Research shows that between 2000 and 2007 TVs and PCs per household doubled and this trend would continue.

It can be argued that smart meters have not been adopted or used well by consumers. We can see that for smart meters, different countries have chosen different roll out procedures, where Finland has a forced adoption policy and they currently have 97% adoption with 3.2million installed smart meters. (Finnish Energy, 2017)

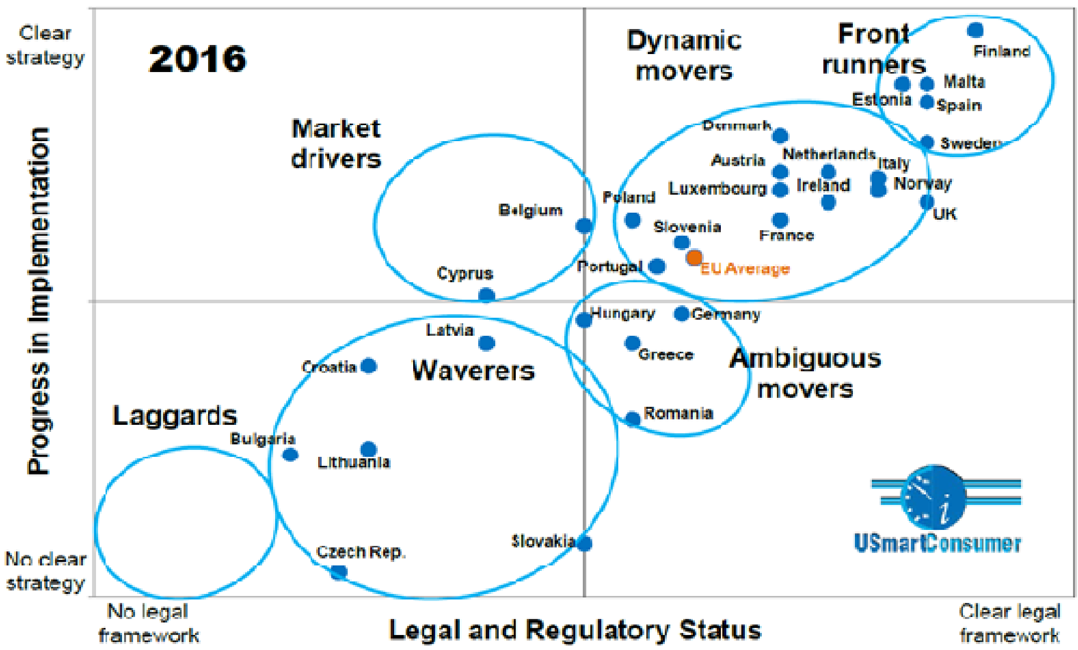

Figure 1.1: EU smart meter strategy and adoption(UsmartConsumer, 2016)

Figure 1.1 shows european countries and their steps towards a smart energy system for the home. We can see that countries are on the right tracks and are moving forward but there are still many countries lagging in terms of roll out. These countries generally being central and eastern european countries.

Figure 1.2 shows that the needs of countries vary. We can see in colder and darker countries such as Finland, there is more electricity used overall due to the difference in lighting and heating needed. Whereas warmer climates will have less focus on the heating and lighting and more energy will be used on the cooling.

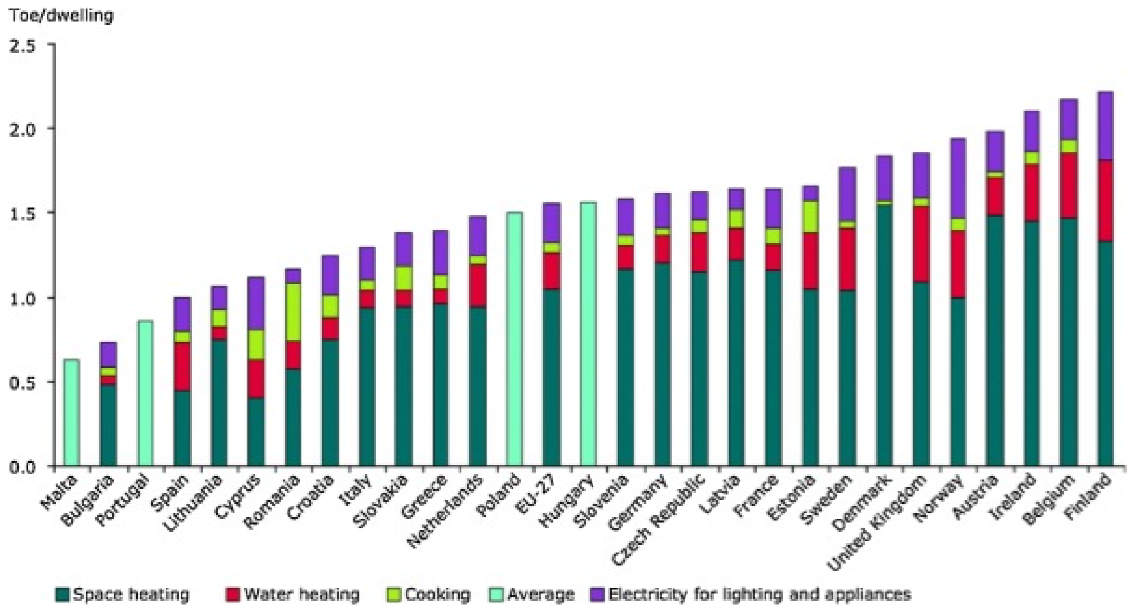

Figure 1.2: Energy consumption in the residential sector per dwelling in EU countries in 2010

There are also the different characteristics of buildings that can be examined and looked at. Houses can come in all shapes and sized. The average house size in the EU is 95.9m2. But there are big differences from the smallest to the biggest even in the same countries, as seen in figure 1.3.

	Total population	Owner		Tenant	
		without mortgage	with mortgage	market price	reduced price or free
EU-28 (1)	95.9	96.8	119.7	74.5	78.7
EA-19 (1)	95.9	105.5	115.8	71.2	77.2
Belgium	124.3	139.0	145.5	85.7	91.0
Bulgaria	73.0	75.0	76.3	53.7	60.9
Czech Republic	78.0	80.7	92.9	59.1	63.1
Denmark	115.6	141.4	146.6	79.6	117.1
Germany	94.3	121.4	127.7	69.2	74.3
Estonia	66.7	68.0	83.4	44.3	53.3
Ireland	80.8	83.0	98.9	63.7	58.4
Greece	88.6	93.4	100.3	70.6	79.1
Spain	99.1	103.3	101.4	81.0	92.8
France	93.7	110.1	108.9	66.7	71.3
Croatia	81.6	82.7	87.6	57.7	72.8
Italy	93.6	99.6	98.6	73.9	82.0
Cyprus	141.4	156.5	177.6	91.9	112.3
Latvia	62.5	64.3	85.1	44.7	48.6
Lithuania	63.2	64.4	70.9	42.5	47.6
Luxembourg	131.1	156.4	147.6	83.2	106.4
Hungary	75.6	77.9	81.2	49.8	56.2
Malta (2)	:	:	:	:	:
Netherlands	106.7	133.1	127.8	78.0	113.2
Austria	99.7	125.3	130.2	66.6	81.0
Poland	75.2	80.4	88.1	45.7	52.5
Portugal	106.4	110.5	123.5	77.6	82.8
Romania	44.6	44.9	44.7	32.4	34.5
Slovenia	80.3	86.0	93.6	47.6	66.1
Slovakia	87.4	89.2	95.4	63.1	76.5
Finland	88.6	99.4	109.8	54.3	55.6
Sweden	103.3	105.1	125.3	69.7	131.4
United Kingdom (2)	:	:	:	:	:
Iceland	130.4	150.8	144.7	88.2	85.9
Norway	123.2	126.7	140.5	67.8	78.9
Switzerland	117.1	140.0	152.9	92.0	96.6

(1) Eurostat estimates.
(2) Unreliable data.

Figure 1.3: Average Dwelling size in europe(Eurosat, 2012)

The age of the building changes how well it is an insulator of heat. Over half of buildings in most countries were build pre thermal regulations are not efficient at retaining heat. The UK has over 50% of its buildings being built before 1960 where other countries are not so bad they have the majority build between 1960-1990. (BPIE, 2011)

There are projects that research the typology of residential and nonresidential buildings. This is on a country basis and while residential buildings are easier to map as a whole as many buildings built in the same time period have the same structure, floor space and rooms. Non-residential buildings are a lot harder to research and log. A lot of buildings are used for multiple functions and this makes it hard to categorise and group them. One attempt is the EPISCOPE project (TABULA project, 2012). From the report produced we can see that for example, offices and Universities account for 23% and 17% of EU non residential buildings, this is a significant number and with more and more computers used in universities and offices they have an increase of devices that are at times turned on and never in use. This creates waste. A study (Marans and Edelstein, 2010) shows that in a university of Michigan 36% of faculty and staff members never turn off their computer.

A way to alleviate this is to use automation. The (U.S. Department of Energy, 2011) say that 70% of the energy consumption of appliances are consumed when the devices are turned off and smart meters are seen to provide a 5% to 15% savings in the EU (Burgess and Nye, 2008).6pt7.2ptThis can be extended to universities and businesses and they have the incentive to do so as it will save the company money and they can use the good PR to promote their green ethics

1.2 Aim and Research Questions

Research questions help to identify the objective of the paper and what will be answered to define the research as complete. The research undertaken seeks to answer the following questions,

- How does individual behaviour affect energy consumption in a non-residential building.

  The objective of this question is to see to what extent an individuals behaviour affects energy consumption and what can be done in this regard to be more sustainable.

- How much energy is wasted by stand-by devices in commercial buildings in Germany and Finland.

  Stand by power and commercial buildings energy use are areas that have little research in them.

- In what way will an automated system affect energy consumption in a non-residentail building.

  Introducing an automated system to turn off devices when they are not used means that energy will be saved but to what extent can energy be saved while keeping user comfort as high as possible.

- When does the financial gains of a system repay the initial cost.

  An automated system itself will cost money and use energy to run. If the savings made do not produce a reasonable ROI then it will be hard to see individuals or companies want to implement such a system.

The main aim of the research is to show the benefits of an automated system has on an office and university room for standby devices in numbers. It is hypothesized that the system would bring benefits in energy reduction by turning off devices but there is no data to show how much the user will save and the return on investment of such a system.

1.3 Delimitation

The data that is used is from other research papers. While it will have certain validity it will have some shortcomings. The data will be a few years old, it was a survey and the questions could of been leading. The country of the survey could also have a different culture or work ethic and this could make the data also not relative.

We are limiting the study to just Germany and Finland. This is due to needing data and both countries being quite different in needs. With Germany falling near the EU average and Finland being the most energy consuming nation. Energy cost is based on when the study was done and with time and market fluctuations the concluding argument on savings will need to be readjust to meet current market rates.

When looking at building types we have residential and non-residential. The scope of this research is to look at nonresidential and specifically universities and business's or offices. There are two reasons for this. The first being that there are a lot of studies that have already been done on home automated systems and this research would have to focus on a bigger niche to have any good contribution to knowledge. Secondly, with the focus of the research on standby power it is questionable about the positive gains that could be made in a household. Nonresidential buildings on the other hand have much more devices and more potential for them to be left on or on standby mode.

At the end of the research the savings that can be made to carbon emissions will be presented. There is the problem that when looking at the whole system it is hard to have specific data on some areas, along with the fact that you could go deep in relation to the tracing of the raw materials and the supply line. In this case we will draw a line at a stage were we think it is acceptable.

1.4 Contribution

The contribution of this work is in the fields of sustainability and automation. It contributes by providing a scenario and method of improving the energy use of universities and businesses. This method is in terms of a real system that monitors energy use and turns off devices that are not being used under certain circumstances. It also provides the time it would take to see a return on investment if a company or university used such a system with currently there is not much literature on. There is also a discussion on the Co2 that would be saved with a system as money is not the only thing that the system could be used for.

1.5 Thesis Structure

This thesis has six main chapters.

- The first one is the introduction, it provides the necessary information to give people a basic understanding of the subject area, why the research is being done and what the plan is to achieve this.
- The second one is a literature review. This chapter will provide information on the wider context to reinforce the reasoning in chapter one. It also will show what research has already been done in this domain.
- The third chapter is about the methodology. The methodology describes how the research will be conducted and why this specific methodology was chosen.
- The fourth chapter is the scenario setup. This chapter will show the set up of each scenario that will be run in the test, how these scenarios were created and justifying the creation.
- The fifth chapter is the results. The results will be shown and discussed here. They will talk about the related scenario, what was expected, what has recorded and what it means.
- The sixth and last chapter is the discussion and conclusion. This will contextualize the results and say what they mean. We will take this and reference it with the

research aims and hypothesis that were established at the beginning of the thesis and

2 LITERATURE REVIEW

This chapter has three main parts. The first one being the energy use in buildings. We will discuss the research that is being done on buildings in general before having a more detailed section on non-residential buildings, including subsection on universities and companies. The second part will be about user behaviour and automation. With user behaviour looking at why individuals do and do not do energy reducing tasks and automation looking at what has been done in this area and how it can help mitigate the short falls of user behaviour. Lastly there will be a section on standby energy consumption to see where the current literature sits with it.

2.1 Energy use in buildings

The EU knows that 75% of buildings currently are inefficient and are currently implementing a directive to achieve the aim of having zero-emissions from building stock by 2050 (European commission 2012). By looking at residential building energy consumption we can see that with technology becoming more of a part of everyday life that the energy consumption from devices and appliances has increased a lot compared to heating and lighting. The danish energy Authorities (2016) have publish the energy use in Denmark and we can see that between the year 2000 and 2016 that there has been little to no change with total household energy consumption in 2000 being 37,339 TJ and 2016 having 37,151 TJ, a decrease of 0.5% . This can be attributed to the fact that even with energy efficient appliances many people have more in their homes now than before. This can be applied to commercial buildings too. With offices having a computer per person with one or two screens and universities having many computers which for the most of the day are unused. With these facts we can presume that there is a high potential for energy reduction.

One way the EU energy directive are helping improve buildings energy efficiency is by providing a standard and policies in which building owners can follow to improve the energy efficiency of the building. Having a universal standard that companies can follow is one barrier that in the past has hindered green building development (Ma, Cai and Wu, 2018).

When looking at the other barriers for sustainable buildings we have to first look at the two stages in what a building can become green. The initial construction of the building and then any retrofitting done after construction. The latter being more complicated for multiple reasons, such as bad initial design or high costs to refurbish. It can also be hard to get the stakeholders of a building to see the benefits of the retrofit. Olubunmi, Xia and Skitmore (2016) research shows that there are many incentives to be had with greening a building but there can be a lack of knowledge or no clear direction for the stakeholders. It can also be seen that the tenant would be getting more benefit out of any efficiency gains made, lower rent or energy prices (Menassa and Baer, 2014).

2.2 Non residential buildings

When looking at building types for this research we will be looking solely at non-residential buildings. This is due to the fact that standby devices on a home by home basis has a limited potential were there are more potential for a system in an environment with more devices. This leads to a review of literature looking at businesses and universities as they will be the main categories for non-residential buildings that will be looked at.

2.2.1 Energy use in business

There are many factors that play into a businesses view of energy. We have to take a step back and look at the view of the business on sustainability and the social responsibility they have.

Businesses have an interest in lowering energy consumption. It brings instant monetary savings and in a large, global company it can be a significant amount of money. Looking at current knowledge we can see that most of the research is focused on improving the efficiency of HVAC and lighting. This ranges from changing the light bulbs to LEDs or to use automation to have the lights turn on based on motion or a model of the users behaviour.

It has been argued that business have a vested interest in engagement towards social initiatives for a long time. Keith Davis (1973) was an early proponent of this and argued that making gains early will help plan out and have a proactive process will help make gains both better and more measuarable than having a reactive approach. A look at companies in Norway (Brønn and Vidaver-Cohen, 2009) and there motive in pursuing social incentives show that the main motive was to improve their image. There was also a high percentage of companies that said they had no reason not to. The authors do conclude though that the study being Norwegian has the problem that a highly developed country with a high education standard will feel more ethically inclined to do good. This could also be expanded towards the other nordic countries, including Finland.

Although when looking at SMEs that doing a small amount of Corporate social responsibility will only bring on scrutiny and a SME if wanting to take action should do it for non reputation gains (Graafland, 2018).

2.2.2 Energy use in universities

Research into greening universities has been undertaken in depth since the early 2000's. We can see from (Starik, et al 2002) that some universities by 2004 had already begun to do campus projects to be more sustainable, with some of them having green initiatives as far back as the early 1990s. The paper does conclude that it is too early to conclude the success of the green projects and that they should be continually monitored to see and report progress but this should not deter other universities from undertaken similar initiatives.

An obvious way to be more sustainable is to reduce energy consumption. Many universities have policies in place to do this. The Lappeenranta University of Technology (LUT) is unique in that it has a green campus initiative; while the initiative is not unique in of itself, the level at which it is striving to be sustainable is. From this initiative there are targets that have been set with deadlines in 2018 and 2020.(LUT green strategy 2017) Looking at their energy commitments they have policies of 5% reduction in total energy from 2015 to 2018. This is harder said than done, the campus does have many features to help limit energy use such as motion sensor lights but the constant renovations and new buildings being built will only increase the total energy consumption even with new technologies that improve efficiency.

Building renovations are one area that needs major improvement, especially for a country like Finland to improve the energy consumption's of buildings. Niemela (Niemelä, Kosonen, and Jokisalo, 2016) talks about Finnish building regulations and of there introduction in 1976 and therefore there were no standards before for the energy performance of buildings. The study talks about LUT and the age of the different university buildings, with 68% being built before 1980, meaning that there is potential to make a lot of improvements on the older buildings on campus but there has is also further work that could be done on buildings that were constructed in the 80s and 90s but more research is needed to see if it is renovating is cost effective.

Harz university of applied sciences also has sustainable policies but they are not as big a priority as LUT, but LUT puts a major emphasis and focus on their green campus. Harz has implemented many projects to engage the campus and produce a more sustainable campus. There are also targets that were set in 2014 and were to be met for 2018. These have been met before this deadline, some goals were met in 2015 and 2016 but the goals have not been further improve with the 2017 summary. This could be seen as a missed opportunity to advance the sustainability further. The total energy consumption has met the 5% reduction but 2016 say an increase on the 2015 levels but this can be attributed to the ventilation improvements of house 9. There is also the added energy from students having a more active participant on campus and therefore more devices are used on campus.(Heilmann and Drögehorn ,2017)

We can see from these two examples that universities take different approaches based on their needs but with the difference in reporting, tracking and full implementation of solutions we can think there is a need for a consensus. Abdul-Azeez and Ho (2015) also mention that the trends point towards a lack of universal direction. This can be due to a sustainability project having many areas and the need for a policy on each one is imperative but it is daunting when you have to start from nothing.

Harz uses the EU's Eco-Management and Audit Scheme (EMAS) standard. This is a framework for improving the environmental performance of an organization. It uses the ISO 14001 as a template and expands upon it. There are many studies on the planning and implementation of EMAS but there is a lack of research and information on the results of EMAS standard and how well it actually improves an organization's environmental performance (Tourais and Videira, 2016).

When looking at the creation of policies we first form a strategy and then we implement it. These two steps are very different and are both needed to create a good policy that can be measured. Individually they both have problems. Mason, et al (2003), talks about that written commitments do help with funding and principle but they do not provide the necessary motivation for action. Kemp, Parto and Gibson (2005) talk about the difficulties of sustainable development. Surprises are inevitable and the end of the plan is open as there are always further improvements. These are two things that are discussed in Kemp's research and these contribute to a planless strategies being more likely to fail.

2.3 User behaviour and Automation

When looking at businesses and their use of devices, we can see that no matter how good the company culture is in relation to sustainability, the responsibility often falls to the employees themselves and this can create a different work environment between businesses. Slack, Corlett and Morris (2015) talks of the outcomes of ethical corporate behaviour comes from an employees willingness to collaborate and cooperate, with some employees seeing it outwith their main obligations as an employee. Talking about obligations, Arminen, et al, (2018) study shows that offices of the same company in different countries will have different attitudes and behaviours. This can often be attributed to the fact that the culture of the country can be seen as the norm.

With user behaviour being autonomos, it reflects the individual's own self interests, values and expectations (Cooper, 1982). We can see that the person might have good intentions, Greaves, Zibarras, and Stride (2013) research shows that 61% of employees at a company planned to turn of there computers if they left for longer than an hour, but are not always committed fully to a sustainable strategy if it impacts these self interests. For instance a financial interest is something an employee rarely have any care for unless they are management or above. For employees that do care and conserve energy it can be hard to stay motivated as there is often a lack of transparency with how much energy is being saved (Carrico and Riemer, 2011). Carrico and Riemer talk about feedback providing a change in energy consumption. A total of 5-15% could be saved but it is unclear how frequent the feedback needs to be before it loses its effects. There are also areas where individual feedback might not be feasible, such as an office but group feedback could be provided and this can add peer encouragement as a motivator.

Carrico and Riemer's study results show that only 2 out of the 15 peer educators carried out the study properly but there was many individuals who asked for additional sustainable initiatives to take, but that was outside the scope of their study. Hence it shows that certain individuals in organizations might be able to reduce energy consumption greatly with the proper support systems in place.

A study by O'Brien and Gunay (2014) talks extensively of user comfort and the habits that people can fall into. They say that users often, are reactive and not proactive with them only taking action when an event occurs. They will over compensate for minor annoyances and take the easiest, quickest option rather than the best or most appropriate. They also make the observation that the user is more likely to take positive actions if they have the controls to do so and they are within reach, allowing them to alter and adjust the heating or lighting in a moments notice without needing to move away from thier desk.

But there are some studies that show that feedback does not prompt individuals to be more energy efficient, even when there is a financial incentive. Buchanan, Russo and Anderson (2015) research, although looking to challenge the notion that smart meters will reduce energy consumption found that in the short term only a 2% saving is made and it is hard to tell if this will be sustained over time.

Due to human error and lack of action, we can look towards using an automated system to help enforce change without replying on individuals. This is not full proof though, and there needs to be some things that need to be considered when creating and implementing such a system. When looking at the automation for energy use, we should look at the general opinion of automation for people and universities. Ahmadi-Karvigh, (2017) researched the level of automation that a person would accept for reducing energy use. There were a few users that were still not convinced and would prefer manual control, but this was the smallest section of users. When looking at the users that chose full automation to the other types (Adaptive and Inquisitive) there is a correlation between the education level of the person and the level of control they want. This could extend to a university setting with staff and students thinking that they are following policies better than they are.

Zhang, Siebers and Aickelin (2011) research looked into the modeling a floor of a university's school of computer sciences building and running energy tests. In this they test automated scenarios and those scenarios where compared to human behaviour. One test compared the automated light system to a staff controlled one and it showed that the automated system has lower peaks and a lower base electricity use, especially on the weekend. The staff controlled system did have lower consumption when people left there office and there was a sharper decline in light use. But a second test was carried out where was a staff wide initiative about going green. In this test we can see that over the standard automated system the staff controlled system was better.

2.4 Devices in standby power mode

To have little to no impact on user comfort, the research will mainly focus on devices that are in standby power. Standby power can have a different definition depending on the device that is being measured. Firth, et al (2008) research talks of the different energy modes for appliances. with there being continuous applications, that need a constant power. cold applications, such as fridges that cycle between power states, active applications that are either on or off and then stand by devices that have the power state of, on, off or standby. Standby power consumption accounts for different values based on different countries. In residential buildings it can be seen to be anywhere from 5-12% of total energy consumption (Meier, 2005). The research by Meier notes that there has been a lot of savings been made by introducing standby power options on devices but with more devices having this option has offset these savings and it can be said that since this study was completed in 2005 that more devices have been brought into the home environment thus increasing or at least keeping the percentage of standby power constant over the years.

When looking at commercial buildings the studies are far less numerous and where undertaken in the late 1990s, early 2000s. To get an idea from this time we can see (Rath et al, 1997) suggests that for every two Watt of standby energy in residential buildings there is one watt in commercial buildings. But Nakagami (2001) study in japan showed that the total energy consumption of stand by energy consumed 10% of total energy, but this was only researched in one building. If this is true for all commercial buildings we could say that both the stand by power in both residential and commercial buildings are similar as a percentage.

Commercial buildings have set working hours and with that comes the bulk of the energy use. This will mainly be with office equipment, the HVAC system and lighting. While it is true that there is a surprising amount of energy when the office is not in use, Masoso and Grobler (2010) research shows that on average 23% of a buildings energy was used on unoccupied parts of the weekend. It also seen that one cause was for people to leave their computers on after working hours. Gul and Patidar (2015) research backs this up with surveys at a university building with 20% of respondents saying that they rarely or never turn off their PC. But (Cox, et al, 2012) this behaviour only lasts as long as the project and there needs to be a high degree of persistence for the behaviour change to become commonplace.

3 METHODOLOGY

In this chapter we will discuss the methodology that we will use for the thesis. The methodology is an important part of the thesis as it helps define the philosophy of the research and sets out what steps will be taken to achieve the end goal. There will also be discussion of the data gathering process and the development of the artifact.

3.1 Research process

For this thesis we will be using Design Science Research (DSR). DSR is a research methodology where we state the problem, define the requirements and then create an artifact to address the problem. We then evaluate the artifact that was created and see if it fulfills the requirements that we predefined. If these requirements are not met we iterate over the requirement definition and artifact development stage until we are happy with the outcome (Peffers et al, 2007.).

As mention above the DSR has a set process with five stages. These can be better represented in the image below.

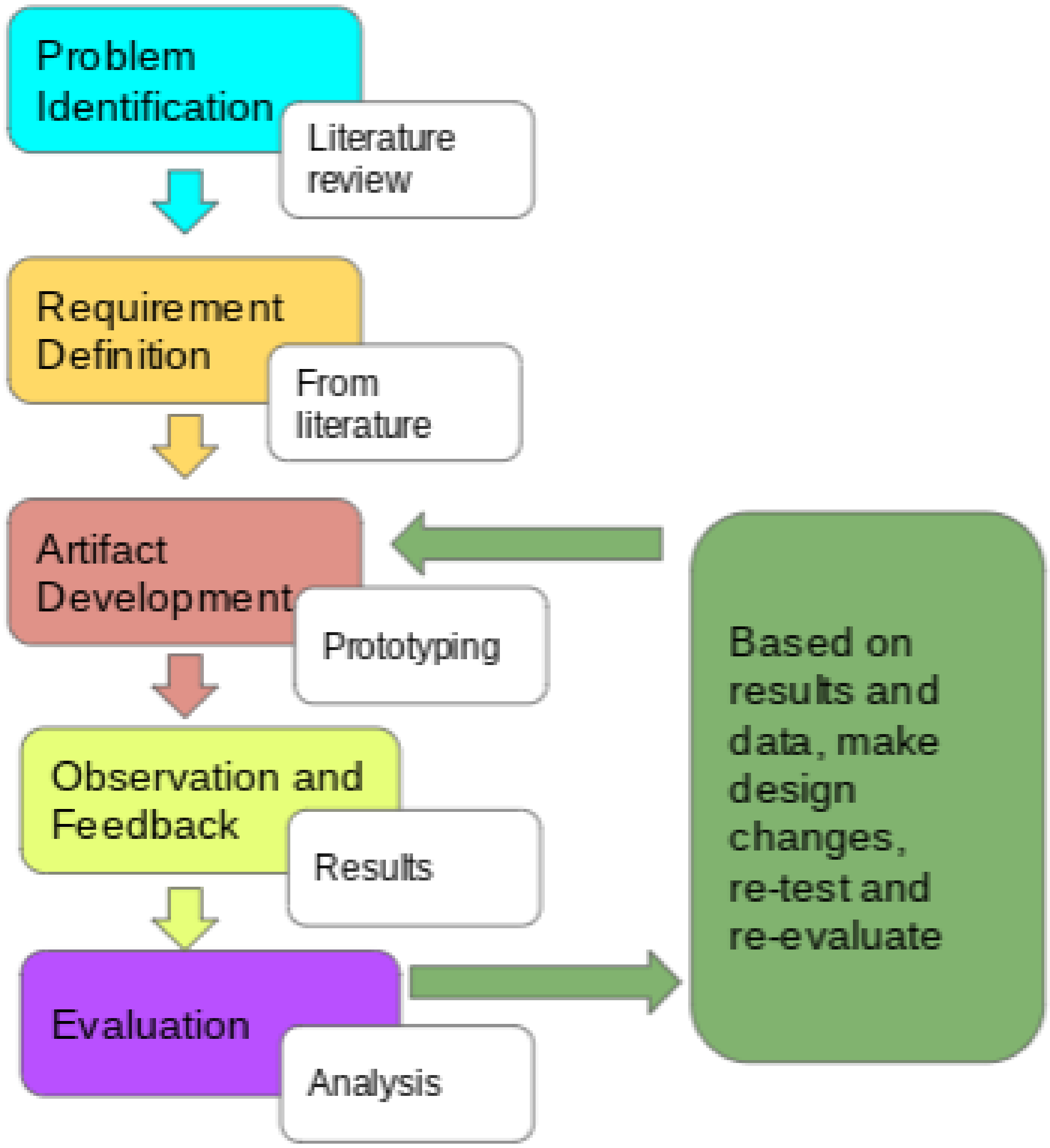

Figure 3.1: Five Stage research Flow

As seen in figure 3.1 the first stage of DSR is problem definition. This stages focus is discussing the problem that is trying to be solved and justifying why it is a worthy problem to be solved. Next is the requirement definition. This stage is the process undertaken to layout the requirements and tasks that need to be completed to solve the problem identified in stage one. This stage is iterative and we can go back to it after we develop the artifact and evaluate it. The artifact development stage is where we create an artifact that we will use to meet the requirements set out at the stage before. This will then be evaluated and feedback will be collected to see if the origin problem has been solved, if not we can go back and either redefine the requirements and then create a better artifact. Once we are happy with the results achieved we will evaluate the results and see where the research that was done was a success or if anything unexpected happened.

Table 3.1: Research stages mapped to research questions.

Stage	Done by	RQ	Description
Problem identification	Literature review	1,2	This will include the literature review to look at the trends in current research and see what problems are in the domain and current ways where they have tried to be solved.
Requirement definition	Scenario creation	-	When we create scenarios we are looking at the ways in which we can take the data acquired, map it to the real world and use it in the artifact creation.
Observation and feedback	Analysis results	3	We will see after the artifact is created and after it provides data if it is what we expected and if it is true.
Evaluation	Analysis of results and discussion	4	This looks at the results got from the scenarios and will allow us to draw conclusions.

Looking at table 3.1 we can see which part of DSR is represented by the stage of the researching being undertaken. We can also see what research question is answered at this stage and how it helps when we move on further with the research.

3.2 Data gathering

Data gathering is an important part of this research. Without data it is hard to compare or evaluate what the results mean or even set up and quantify the research in the first place. There are several ways in which we can get data. Firstly we can look at past research. This will allow us to see other researchers data which they have used in studies and got results from. This method will help us in using real data and it also means we can compare our results to other results too. The data being used in a journal also means that it carries validity.

another way in which we can get data is from the real world. This can be done in two ways. Firstly we can look at publicly available data. This can come in the form of press releases or open data. We can alternatively ask for the data both from a company or by doing the research ourselves. This can be done with a survey to the businesses or universities. Doing the research ourselves would be the best method as we get to control the results and get the data that suits the research scenarios that we would do after but it can be time consuming and can be seen to be a waste of time if there is already data that is similar that can be used.

For this thesis we will be taken data from past research and with these numbers we will find averages and make some assumptions to help suit the research and scenarios. When making scenarios there are many different compositions to a modern office or university class that the data got can be used as a guideline. Thus, we can take that data and create scenarios with small tweaks.

There are two main sources of data that we are going to look at when helping to develop the artifact. The first study (Gunay, et al, 2016) helps to get information on certain parameters. This study has a survey of 203 academics in offices. It looked at the energy consumption and it got the workstation composition of each individual, with how many laptops, desktop computers and monitors they use. This will allow us to set up the scenarios with the number of devices. The survey also asked about the computer habits and if they get put to sleep at all throughout the day and at night. This can be used also to give a value to the devices that would be in a standby energy mode or otherwise.

The other source is (Zhang, T., Siebers, P.O. and Aickelin, U., 2011). In this study asks people if they turn off their devices at the end of day. We can see that 60% never do, with 31% barely. We also have to factor in that people have a tendency to think that they do more than they actually do, especially when asked about it for research. This is generally to sound good, but it can often be general ignorance to their own actions. But with this study we can see that 90% of individuals in the study didn't turn their computer off.

3.3 Artifact Development

As there will be an iterative cycle on the development of the artifact, we will have to examine the approach made for each cycle with using literature for data to see if it still holds true to the research we are undertaking. The nature with literature is that there could be more relevant papers discovered over time and these can have contradictory opinions on the research was done. While the papers chosen have a high number of citations and have been published in respectable journals with good impact scores they provide just one value and more data would always be welcomed to help improve and verify the assumptions being made. The system should therefore be created in a flexible way to allow for adjustments on the methods used to calculate the energy consumption.

The main artifact that will be created is the automated system that will run on set rules set out in section four. It will comprise of a system of physical devices and the software that will be run on it to mo niter and analysis the energy use of the system. There will also be a visualization part to the research which will be in the form of a website to allow the data to be presented to users so that they are more informed. With the creating of anything visual we will look into creating an early prototype and being iterative with improvements until we get the desired artifact that meets all the criteria we set out to achieve.

4 SYSTEM DESIGN

Before we develop the system we need to get the initial design and parameters and set up what will be done. This will help in the replication of the thesis work. Scenarios are a set of events and variables that are setup to map an environment based on the factors input. For the goal that we set out to achieve with this thesis we will have scenarios that mimic an office environment, the user behaviour and the devices used in that environment. This should help to provide a guide on the energy used and the energy saving potential of the scenarios. This chapter of the thesis will talk about how the scenarios where created, justifying the assumptions made or backing the decisions with research. There will also be a small section talking about the technology set up and software used for the implementation.

4.1 Scenario reasoning

Before we create and set up scenarios we need gather data. The data for these scenarios are based on papers and normal knowledge and they help ground the research.These scenarios and the outcomes they provide can be used and analyzed for companies and businesses to look at their own energy consumption or as they might not be aware of the energy that they are using in there day to day activities and the energy use outside of office hours they could see it as a tool of energy awareness.

Looking at the variables that we can use for our scenarios, there will be three main areas that will differ. Gunay et al (2016) talks about these factors in office buildings and how they vary and make it hard to be exact when creating research that should be broad. They also talk about power management system settings as another variable but we can presume that if a company wants to implement a system that reduces computer energy use they will have a policy for it, but in our system the automation will overwrite it. Firstly it will be the office equipment. Offices do not have the same composition, with many IT companies moving away from desktop computers to laptops or even thin clients. While laptop themselves can have low power consumption, desktops can vary depending on the specifications of the machine. A high end desktop with the latest graphics card and CPU can consume double the energy of a low-medium desktop.

The second variables that changes is the user behavior. Traditionally companies work from 9-5 or have a 40 hour work week. But this is not set in stone and many companies have their own work policies. In japan for example employees often stay late in the office and do extra work. Companies can have flexi-time and allow users to arrive an hour late or early but only as long as employees work the 40 hours. A lot of companies also have shorter days on Friday. And there is a movement where people are trying to get the work week to be 4 days or 32 hours a week (6 hours a day). This is also not factoring in Academia where there is no strict times and the energy consumption can be seen to start before 6am and lower at 4pm but still not reach the default energy use until 8-9pm.

The third variable is the level of automation. Standby power is the power state of devices that with the correct power settings such down after a period of inactivity and this is generally happens after working hours when people forget to turn them off and they go into these power saving state. There is also the behaviour of why people do not turn off their devices. This can be attributed to a few things but one of them is that they do not want to turn the device on in the morning for time saving and also to keep the current state they of their work open. Due to this we need to look at different levels of automation to keep individuals comfort at a level where the automation doesn't encroach on their day to day work life.

As for the country part of the scenarios, we will look at some key factors that separate them. The scenarios will not change much as behavior is pretty similar across EU countries. Looking at the difference between Germany and Finland there might be the increase in coffee breaks and also a different start and end time for the working day and for us that might mean that devices can be turned off more throughout the day. A second factor that changes for different countries is the cost of energy. This can also change a lot in a country itself as throughout the day energy prices will fluctuate depending on supply and demand and energy can be priced based on region with access to power determining the price. Therefore the cost and savings that can be made on each scenario will alter depending on the country that the scenario is based in.

With all of these factors we can see that the number of potential scenarios could be extremely high, therefore to help with consistency we will keep several factors the same. For instance the work day will be from 9-6 and with this we can consider that the energy consumption will be arced, or a spike up, relatively flat and then spike down. The arc at the start can be associated with the computers being turned on individually and gradually as people turn up and begin to work. The end of the day will be people turning off devices at different times, or even not turning off devices and the power saving modes begin to active after several minutes of inactivity. It can be assumed that the energy for the non working hours will be similar with the same individuals not turning off devices fully.

It is hard to find about how many devices are used in an office or university. It is assumed that mostly all employees will have a workstation but there is also the increasingly more common practice of shared workstations or open offices. We therefore will have a few scenarios with the number of devices differing. These scenarios will have adjusted numbers and therefore it is not too hard to simulate them.

4.2 Scenario creation

Below are examples of scenarios that will be used to show the energy saving potential of turning off standby devices. We have three different sizes for the scenarios, small, medium and large businesses. It is important to point out that these scenarios are taken from the definition of business sizes and are not based on real offices or data, but the data used to make up the scenario competition is taken from the literature. While there are other domains of interest such as a micro sized company we believe that the savings for a business of that size, i.e. below 10 employees would be insignificant and that the businesses could potentially group offices with others of the same size to form a group of the size of a small business.

But when looking at a building and an office scenario we can assume that a medium and large business could be split up into multiple offices. With the buildings themselves hosting several companies. Unless these buildings are incubators they will have different sustainability policies between the businesses.

We also have the problem that with globalization that many companies can be spread pretty thin around the world. There are many start-ups that will have their development office in one city and have the marketing and sales team based elsewhere. Due to this there will be a few different scenarios for a small business while there will be less for the medium and large ones. Also to hypothesis the results the growth of a business should allow for an automated system allow for an exponential growth in savings.

4.2.1 Small business

A small business can be defined by a business that has less than 50 employees. This of course can vary on the industry. For IT or general start-ups it might be hard to scale to 50 employees fast and it would take many years, therefore 50 would be the upper limit and for this example we will look at 50 employees as this is more realistic to mimic for a real world small business. There is also the idea that many offices will have a set amount of employees split over multiple sites and 50 employees in one office will be near the upper end of an office.

Table 4.1: Small business device list

Small business	Quantity	Energy use	Low power energy use	Stand by power
Computers				
High end desktops	10	300	100	10
Low end desktops	20	120	50	5
Laptops	20	40	4	4
Screens				
21”	25	26	2	1
24”	20	40	2	1
Other equipment				
Printer	0			
Photocopier	1	220	40	40
Total in kWh		7.78	2.21	0.365

4.2.2 Medium business

As for a medium sized business we will take the same structure as a small business but of course there are more employees and thus more devices that will be in use. By the same standard as above we can say that a medium sized company can be between 50-250 employees. Therefore in this example we will look at 150 employees. This is because it can be thought that the small scenario can be scaled up whereas at 150 employees the company might start to operate differently.

Table 4.2: Medium business device list

Medium business	Quantity	Energy use	Low power energy use	Stand by power
Computers				
High end desktops	20	300	100	10
Low end desktops	40	120	50	5
Laptops	90	40	4	4
Screens				
21”	100	26	2	1
24”	90	40	2	1
Other equipment				
Printer	0			
Photocopier	1	220	40	40
Total in kWh		20.82	4.78	0.99

4.2.3 Large business

A large business is one that is defined as having over 250+ employees. This number can scale massively, looking at some of the biggest Technology companies we can see that they have 1000+ people on site at a time. For our scenario we will have 300 number of employees.

Table 4.3: Large business device list

Small business	Quantity	Energy use	Low power energy use	Stand by power
Computers				
High end desktops	50	300	100	10
Low end desktops	100	120	50	5
Laptops	150	40	4	4
Screens				
21”	225	26	2	1
24”	150	40	2	1
Other equipment				
Printer	0			
Photocopier	1	220	40	40
Total in kWh		45.07	11.39	2.015

It is worth noting that screen use can vary drastically due to personal preference. Firstly we have to think that all desktop computers will use one screen and there is a high potential that two will be used. As for laptops we can say that the user will often use an additional screen as laptop screens are usually of poor quality. But it is hard to say how often the screen is in use or if the person is just using the laptop device itself.

4.2.4 Scenario for university

The scenarios mentioned above are suited to offices, this includes offices in universities where professors or PHD students are working but this cannot be extended to other rooms in a university as they have different compositions and many have a different use case. A lot of the literature and research that is on standby power in universities look at the university office and a computer lab use cases. Universities also have libraries and computers in open spaces, where there can be many computers that are free to use for student. With a lot of universities having 24 hours open access it might be hard to implement a scenario that improves upon the standard built in computer policies.

The other type of room is a computer lab that will be generally have 20-30 computers.

This is a use case that can be automated as when students are finished with the class they generally don't turn off the computer and tend to log out. To automate this we can use a door lock system that when the door is locked we turn down off all the devices. This is a lot cheaper than the office scenario as user comfort is not a big deal compared to the office scenarios.

Table 4.4: University room device list

University Lab	Quantity	Energy use	Low power energy use	Stand by power
Computers				
Desktops	30	120	50	5
21"	30	26	2	1
Total in kWh		4.38	1.56	0.18

If we take this information we can see the total energy used by an IT room is low and thus the potential saving are small but when comparing it to the office use case the time that a lab is in use can vary drastically. It might be in use for only an hour a day and not in use at all throughout the summer making the hours of savings to be at least the 16 hours that the office scenarios give.

4.3 Power consumption justification

Looking at the scenarios above we can see that there are values given to the power consumption of each device. This data can vary wildly depending on the device used due to its components, energy efficiency features and the age of a device.

4.3.1 Power consumption reasoning

The data that we used had to be gotten from online sources as many literature that has been done on getting power consumption from devices are dated and we can see that the energy consumed by a desktop computer in the year 2004 (Kawamoto, Shimoda and Mizuno, 2004) would be drastically different to today's and this is why when on the desktops have a high power draw while on standby it can lower as a percentage as past devices. Monitors are similar in that energy use for different devices are similar as long as the devices have the same screen size and of a similar age.

Laptops vary but due to the battery life being a major selling point they have many energy saving features that are automatically enabled, Shutting the screen for a quick way to go into standby mode and save energy is one thing that many people will do throughout the day that doesn't translate over to desktop. Most laptops have a lot power consumption of 40Kwh's when compared to desktops we can see that this is a big decrease and this

There are also other office equipment that can consume energy. Printers and copiers can add a lot to an office energy bill and they will likely always be on due them needing to be able to accept requests at random times throughout the working day.

We settled on the energy consumption for desktops by looking for averages. The low spec desktop consumes 120 Kwh, while the high end Desktop consumes 300 Kwh. We see the low end machine to be more inline with a clerical machine or a general purpose machine that is not fancy in the components it has but it gets the job done. The high end machine will be for more data processing and could have a GPU, 300 Kwh is used but it could be a lot higher if it has a new GPU, with top of the line desktops consuming 800+ Kwh. Research shows that these Desktops can save two thirds of their energy when not in use with the energy efficiency features turned on and when in standby mode consume between 2-10% of the devices total energy.

4.3.2 Energy cost for scenarios

Looking at the scenarios above we can have a total energy cost for the business scenarios above. Taking this information we can now map it to the energy costs in different cities and countries to get the true energy cost.

The average cost of energy in Germany in 2017 was 30.5 Cent per KWH. This is the joint highest with Denmark in Europe. Finland on the other hand has a cost of 15.8 cent per KWH. The EU average is 20.4 but this is brought up significantly by the two highest costs. (European commission, 2019)

While these were the two scopes of the thesis we can also look at other countries if we use such a model. Along with other countries it would be also possible to look into other cities and times of the day or year. In the UK energy has a different price based on where it came from and demand, this means that area's that are near the coast will have cheaper energy due to the wind farms in the north sea. Whereas more densely populated cities like London will have a higher cost due to the big demand of such a massive city.

With the supply and demand being a factor in energy cost we can also look at the cost of energy throughout the day and night. When people are less active and rely on less energy is during the night, this could potentially be used to charge devices and this lowers cost throughout the day when demand is higher. This can also be a factor when it comes to seasons. The longer the day is the more need there is for lighting. Again this will increase energy demand and the cost of energy, on the other side in the summer there will be more demand for air conditioning.

4.4 Scenarios with automation added

Taking these the scenarios above we can see a snippet of the energy use that they use throughout the day and at night when the devices are in low power mode. This is only one part of the bigger picture as we now need to look at these scenarios while adding automation and calculate how much energy could be saved.

These calculations will be done in three steps. Firstly we will calculate how much energy can be saved from the current system's devices. We will then factor in the devices in the automated system that would need to be implemented for the overall system to work. For instance each device needs either a energy sensor or we can use a power strip to group devices. These devices both consume energy and cost money to buy.

With each automated scenario the next one will have more potential for energy saving. These results will thus provide companies with values in which they can see whether or not the implementation is worth it on a cost saving scale.

For the automation scenario we will have four different levels of automation that aim to reduce the energy consumption these levels are, no automation, simple automation, simple+ and max.

Table 4.5: Office automation scenarios

Automation type	Justification for scenario
0 - no automation	This is the base level and the highest energy demand, where the users are in full control. Can be used as a control and see what the current energy use is.
1 - Devices off on weekends	This will turn off the devices on the weekends helping to decrease the load for non working days. This is a scenario type due to it having no impact on the users comfort. From Friday afternoon to monday morning is equal to the out of office hours throughout the week.
2 - Devices off after hours	This is a next stage of automation. This is the main culprit of standby energy use. This will turn off device that are inactive after work hours.
3 - Devices off after hours+	This is an improvement on scenario two, by using the energy levels of devices we can turn off the devices before the end of the work day that have went into standby mode, increasing energy savings by a little.
4 - Away from computer	This is the final level of automation. This will turn off devices that are deemed inactive for too long. While lunch might be too little time, the main use case is to help alleviate people that leave work early, go home sick or don’t use their devices for a large part of the day.

For the university lab scenario there will only be two scenarios. One without automation which allows us to get the base level to compare the other scenario too and the second is with the automated system activated.

Table 4.6: Automation scenarios for University lab

Automation type	Justification for scenario
0 - no automation	This is done to get the current energy use of the room, and will be used for improved visualization and improved monitoring.
1 - Door lock automation	This will look at turning on power to a room when the door is unlocked and turning off the power when the door is then locked.

4.5 Implementation setup

With each scenario being an improvement and iteration on the previous level we will develop them one at a time of top of each other. For the system setup we used two work stations. One desktop and one laptop, both with two monitors each and ran the scenarios on them. The first scenario is one where the time of day is used to switch off the devices. For this we will get the local time of the individual and wait until the parameters have been met for a change in the system. When this time has met. The system will notify the switch sensor and it will stop all energy consumption.

For the second level of automation we will take the first scenario and add the extra rule of turning off devices when they go into standby or low power modes before the end of the day that they can be turned off. This scenario also used the time of the day but instead of waiting until 6pm the system at 5pm begins to listen to see the current energy consumption of the work station. It then waits and see's if the work station goes into standby mode by seeing if it begins to consume less energy. If it notices this, it will start a countdown timer and then turn off the device. As we are working on one of the workstations through out the day and the other is idle, the second workstation will meet the criteria of this scenario and the device will turn off earlier.

The last level of automation was to turn off devices that were detecting if the user was away from the computer for a period of time. This scenario is a look at the additional part of scenario three and it can be seen to be an invasive level of automation. The parameters are set to firstly detect low power modes of the devices and then to wait for a small period of time, After which point it will turn of the device. This will be mainly useful for a lunch break but it can be set to be more aggressive and thus will turn off devices at small breaks. For the workstations this scenario was observed to turn off both work stations throughout the day, with the main one turning off at lunch time and also the secondary workstation being turned off often and needing to be turned back on.

As for the university scenario, we only had access to the same workstations and thus we set up the scenario to limit electricity when the door was in a locked state, this was by a door sensor optics letting in light. This acted as a simple on and of switch.

4.6 Technology setup and architecture

An energy management system needs to be implemented to do what we want to do. With the EMS we need to define the system, making decisions on the devices that will be used as there are many different devices that could be used along with the software that will be used with said devices, with a need for interoperability.

4.6.1 Our implementation

To judge the systems standby power we need to be able to judge the different power states of the system. Each mains socket needs to have a sensor that can monitor and then eliminate power to it if the thresholds are met. This system will therefore have several sensors, with the exact number depending on how many devices are in use. There are some sensors that will always be there. Firstly we need a hub. This is for the other sensors to connect too and communicate with.

We will also set up a server that will run the code and check that will have the triggers set to change the behaviour of the EMS. The sensors that will be used in the test are from the Homematic brand. The hub will be Homematic wireless configuration adapter LAN. For the mains plug, the Homematic wireless switch actuator 1-channel, will be used. this device will monitor the current energy used by the devices plugged into it and the server will save this in a log file. In an ideal world we would use These sensors on every device and have it disconnect the power when standby mode is detected but these devices themselves take up energy and also cost money (€42 each). They have a two year battery life and therefore the amount used should be maximized to use as few as possible. To do this the devices will be plugged into power strips. Power strips have anywhere from four to ten outlets for devices. This means that devices can be shared for two or three workstations if they are not far apart. Each individual will have a desktop/laptop and a monitor or two and therefore a max of three outlets to use.

4.6.2 Other possible ways

The technology and sensors used are just one way in which we can implement the system. There are eco power strips on the market and newer ones have wifi and allow for control of each individual outlet. This will allow for more control and potential of more energy saving as we can turn off each device separately. But with the power strip connecting to the WIFI it will constantly use energy and therefore throughout the day it would add to the overall total energy consumption.

There is also the possibility that we could use smart fuse boxes. This would be extremely cost effective compared to the current set up of the system. It would allow for one device to be set up to cut power to any number of devices. This could be used effectively to turn off all devices in a room at once. We could make it smart by pairing it with another device such as a smart lock, so that when the door of the office is locked it would shut off power to the devices and when people come back in the morning it will allow power to resume. This method has been rejected as it is not 100% controllable. This means that we cannot turn off individual devices separately. Meaning that all devices will be left on until the last person leaves the office. It is hard to say how much energy this would save. If there is anyone staying late for a report, to do a conference call with a country on a different time zone or if someone is off ill, their work station will still be consuming energy.

4.7 Architecture overview

The system's architecture is simple due the low complexity. First we need to have a server running 24 hours a day, this will be the done on a raspberry pi. This will run the FHEM software and also log he values retrieved from the plug sensor. For the server to connect to devices we need to have an USB Antenna connected to the server and this will allow for communication between it and the Homematic sensor hub . Next the Sensor hub will connect to the plug sensor and will record the energy consumption that goes through it. The plug switch itself will be connected to a power strip and multiple devices on the other end. Below is an image of the system with one device connect. In the real example there would be multiple devices connected to each plug switch.

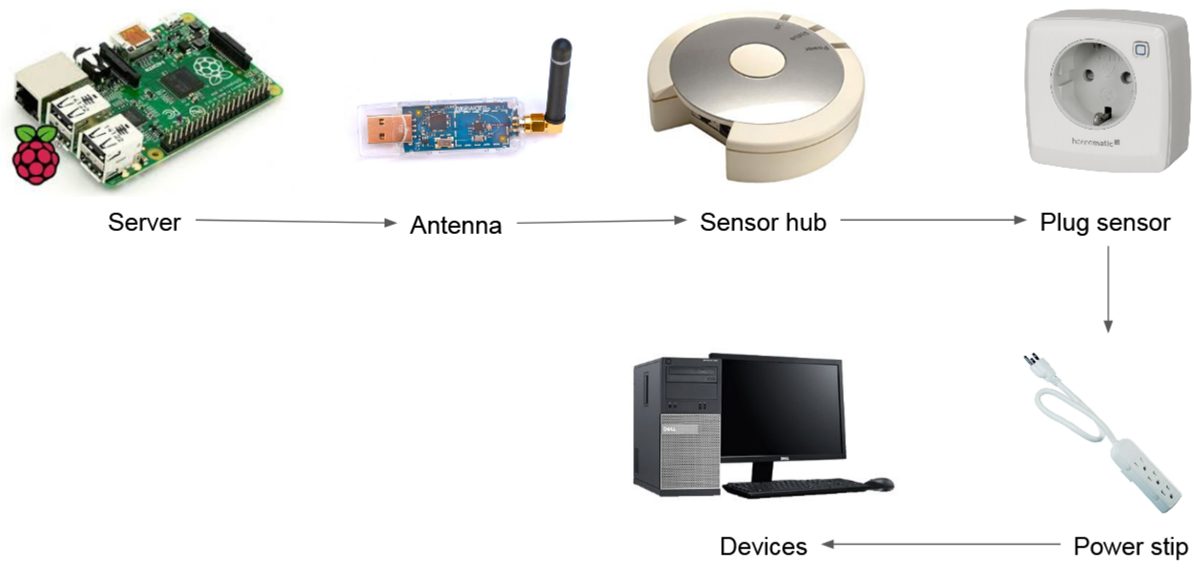

Figure 4.1: Office System architecture

For the university scenario the set up is a little different. The main components are still the same, with the pi as the server , and the homematic USB and hub devices. But we then have the connection between them and the computers being different. The main part of this scenario is to see the connection from the door sensor to either turn on or off the power. In the real setting this would be more of a door lock as if the current sensor was implemented the door would need to be permanently open. The devices are then connected to one central fuse box that will give the room its power.

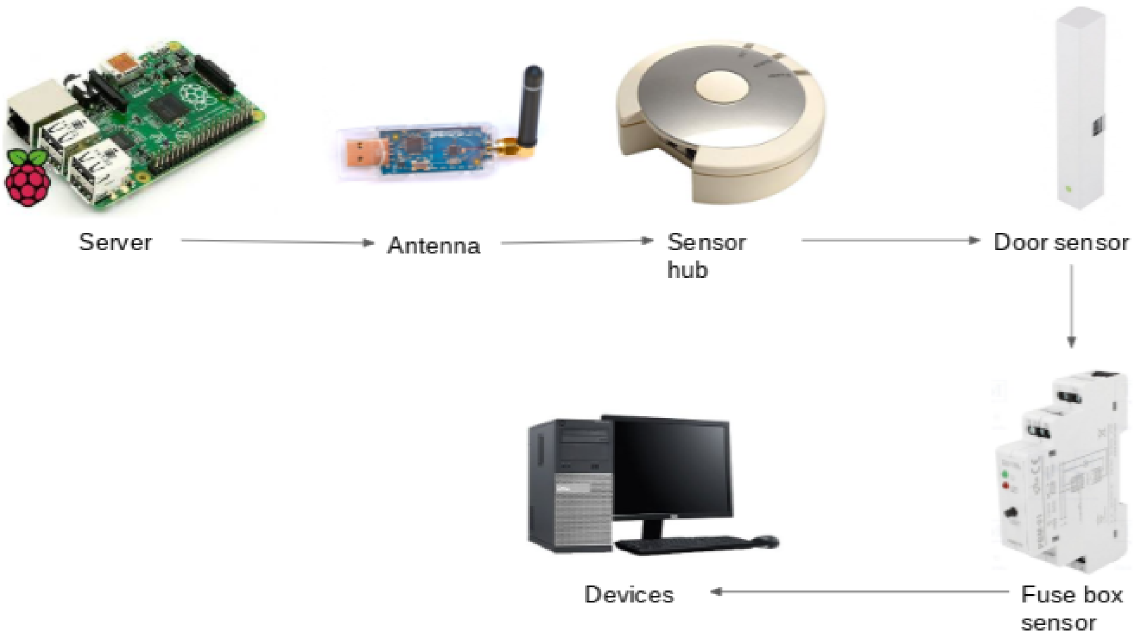

Figure 4.2: University System architecture

4.8 Software

For the system to be set up and monitor properly we need to use software. The devices need to have a way to report the data being captured and this will be done by the running server. There also has to be triggers in place to set of the automated scenarios and this will be discussed below

4.8.1 Automation system

Looking at the software side. We will be using FHEM. FHEM is a perl server that is used for home automation. It allows for common tasks to be automated and the use of triggers to allow for automated change. It can also be controlled fairly easily from a desktop or mobile device to use manual control. FHEM was chosen for use in the implementation phase as it is open source and has a large community. There are many modules and guides online to set up devices. Being open source also means that it is not tied down to one set of devices and the interoperability of the software allows for universities and business to be able to use it even if the devices used in this research are not available to them. With the use of triggers and the sensors we deploy, it should be straightforward to set up a prototype system that allows for the triggers we want to put in place, i.e. time of day or current energy use from devices.

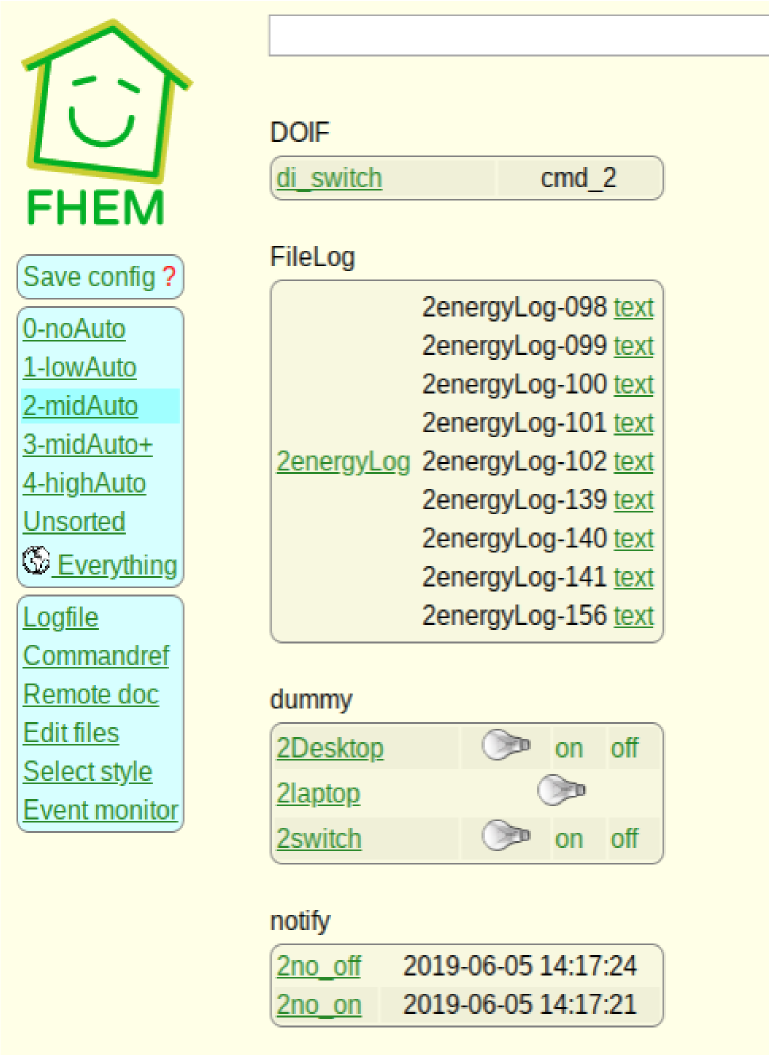

Figure 4.3: FHEM main user interface page

4.8.2 Website creation

Visualizing the data is important for the individual level. It can help show the overall impact that is being made by the company and see the progress that has been made. It will act as a reminder about being sustainable and it will prompt individuals to move towards turning off their devices without an automated system being needed. This should work company wide as people will talk if the results go bad and more energy is being consumed than normal. There is also the impact of users being more forgiving about the less comfortable conditions when they see the positive contributions to reducing electricity and greenhouse emissions.

When looking at how to show the data it is good to remember that most people will only glance at it and it is important to give them as much information in a glance. To do this we will use colour to help them see if the current energy use or the past few days have been good or bad in relation to the base energy consumption. The positives should also be focused on and this can be in the Co2 that has been saved. Many people will find it hard to quantify a number for this metric so we will convey this information in a relatable way, such as car journeys or kettles boiled.

The website needs to be simple and have the ability to have some small customization options. This is due different companies will want to brand it with their own logo's or have certain metrics that they want to show. There also has to be some level of context awareness as different countries might not understand the same visual cues or they will respond better to culture specific/regional ones. This has lead to the decision being made to use simple HTML and jquery. The initial design that has been settled on is a slide show like website that will display the data, in a simple way that is easy to read so that people can read it fast and easy.

5 RESULTS

This chapter will discuss the results from the implementation phase, specifically the automated scenarios and the energy they used in our scenarios. The chapter will display the results in graphs which will show how we presenting the energy use to the individuals or offices to help aid in energy reduction. The following chapter will go on to discuss them in more details.

5.1 Results discussion

The graphs are in order of the level of automation but before we do any automation we need to find out the normal level of consumption over a normal day. This can be seen in the graph below.

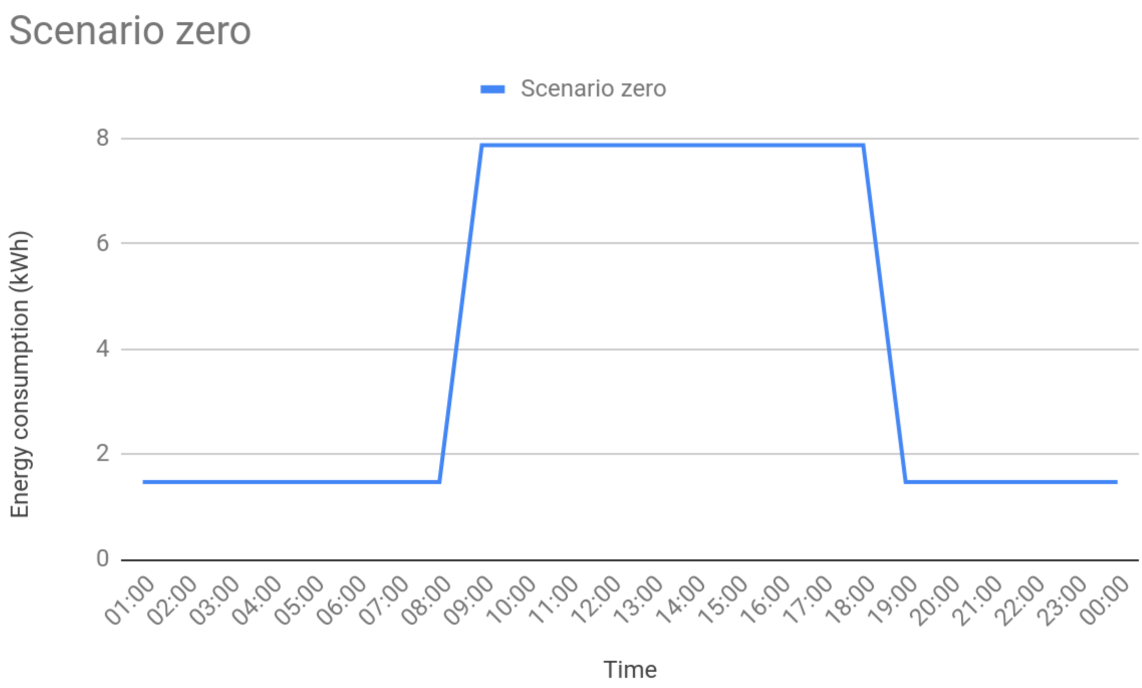

Figure 5.1: Graph of energy consumed without automation

Figure 5.1 has no automation and was completed first, before any other tests were ran. This gives the base of how much energy is used on a day to day basis and with it we can calculated the savings by comparing it to the next tests done. From the graph we can see that it follows the hours of a working day with a rise in the morning and a fall later in the day. We can see the standby power from the energy consumption that is consumed before and after the working period.

When implementing the scenarios, we did not do the scenario for scenario one. This is due to the scenario only turned off devices at the weekend. This would just provide a graph that was the same as above but with a flat line at the weekends. This is however a useful scenario to save energy but it is not worth the time and it will be implemented in Scenario two.

The graph in 5.1 gives us three key things. The maximum energy consumed on this workstation and the energy consumed when the user is not at work. This will be the energy that we are trying to save.

The Scenario to save energy on this time provides the graph seen in figure 5.2.

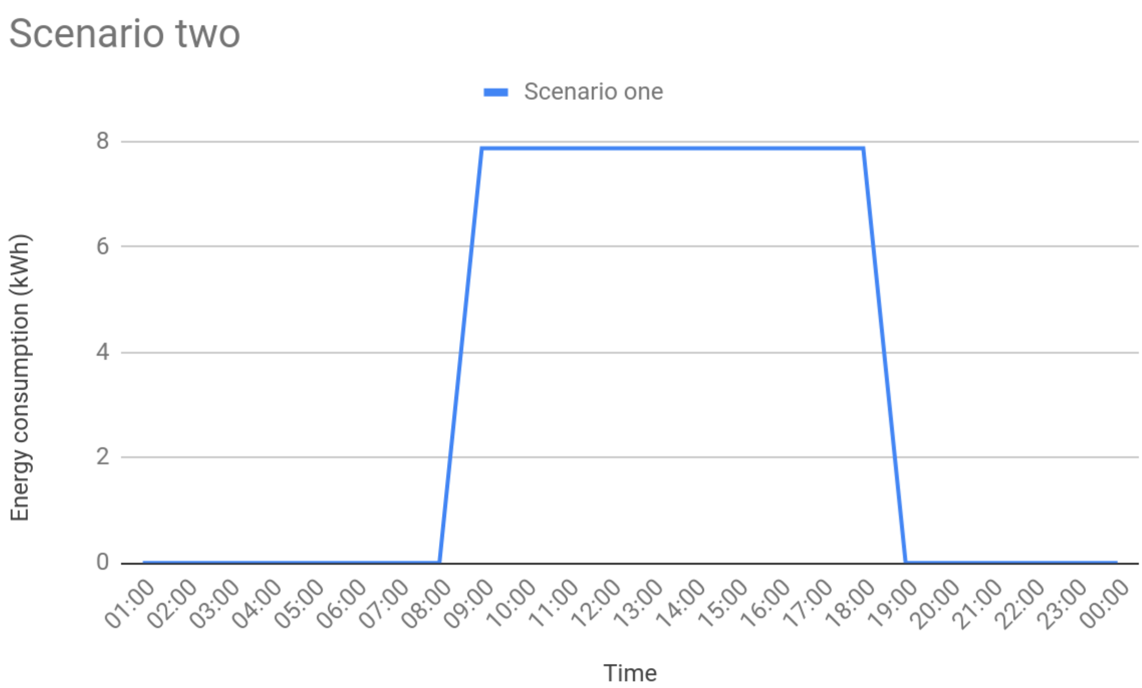

Figure 5.2: Graph of automated scenario two

Looking at the graph we can see that the individual behaviour is the same with work hours being set. But after work hours we can see that there is a drop in energy consumption due to zero die to the system and automation. The graph does go to zero but we have to remember that there is the system itself that is consuming some energy.

Scenario three was similar to the second but it had the extra caveat that it would, based on energy use, turn off the devices earlier than the end of the work day. People leaving early or having a meeting at the end of the day.

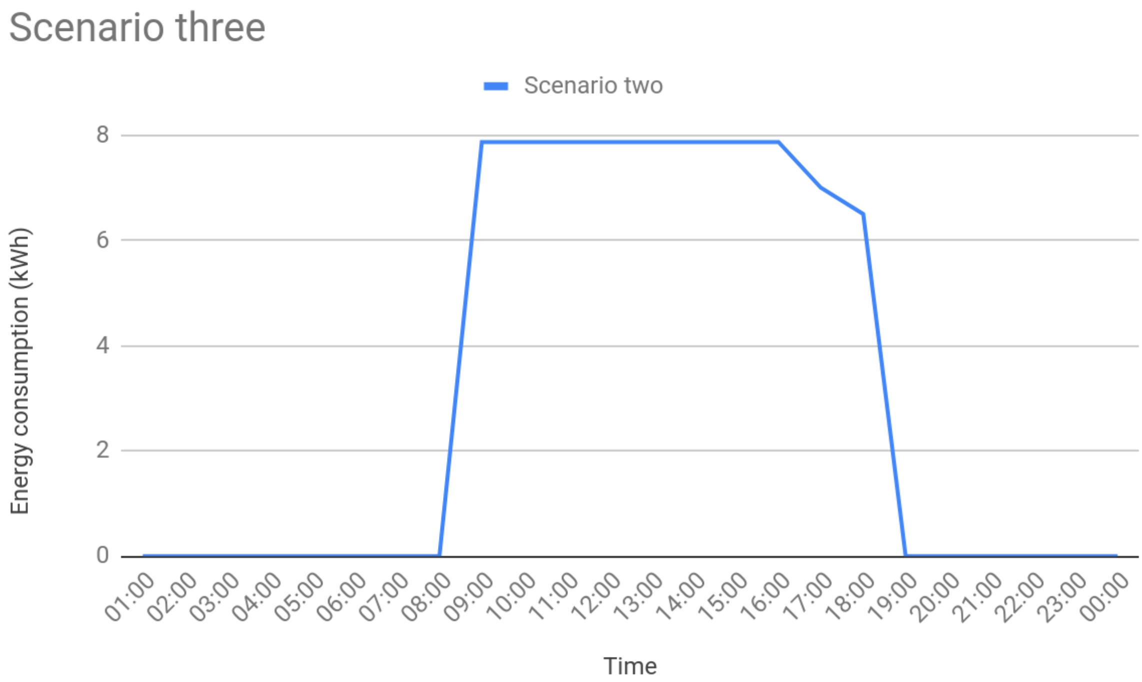

Figure 5.3: Graph of automated scenario three

Looking at the graph we can see that this can save a little more energy each day compared to scenario two. This scenario wouldn't work for all devices but it should be able to save a few Kwh per year with each saving between 1-2 kWh.

Scenario four can be seen as full automation. It will activate when the user goes away from the computer for a set time. This would mainly be used during lunch or if someone leaves the office during the day and forgets to turn off their computer.

Looking at the graph we can see that the peak stays the same as the other scenarios. This is expected but we can see that the dips are lower. This is due to that when devices go

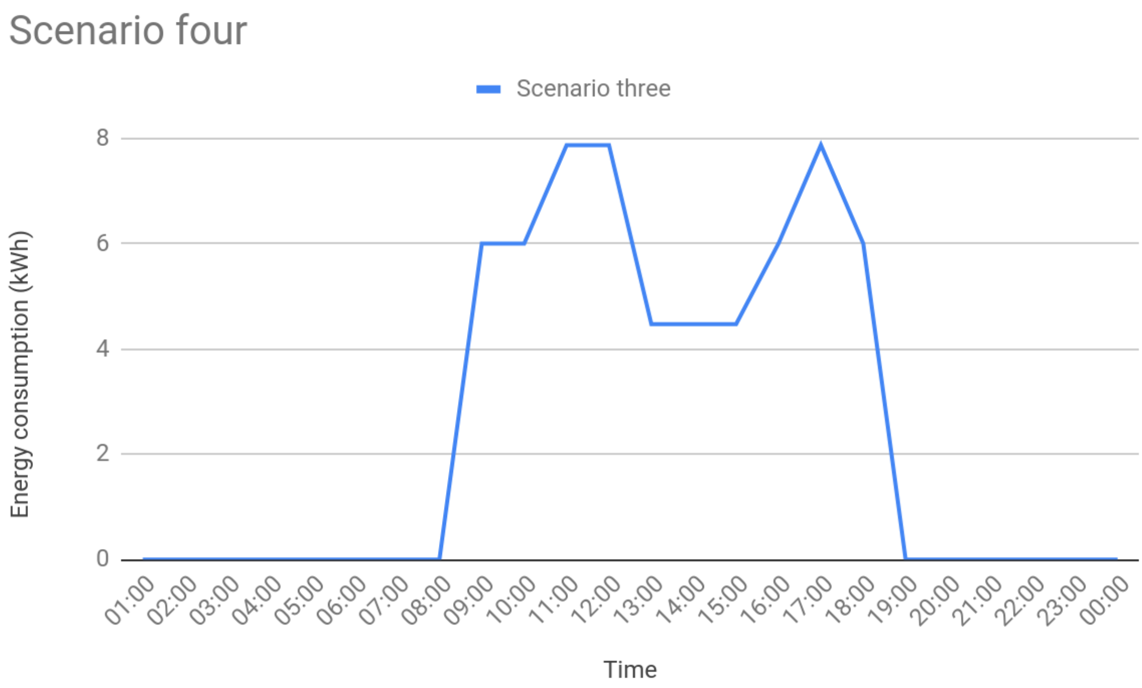

Figure 5.4: Graph of automated scenario four

into standby mode that they will be turned off making the savings higher but we have to consider the user comfort here as when they come back they will need to turn the device back on.

5.2 University results

As mentioned in the previous section the results of this scenario is dependant on the university and the use of the room. taking the same information from the previous scenario and see that we would help reduce the energy consumption with the devices that are in standby after the universities teaching hours, that's along with the teaching hours.

The graph below is an example of what the results would look like:

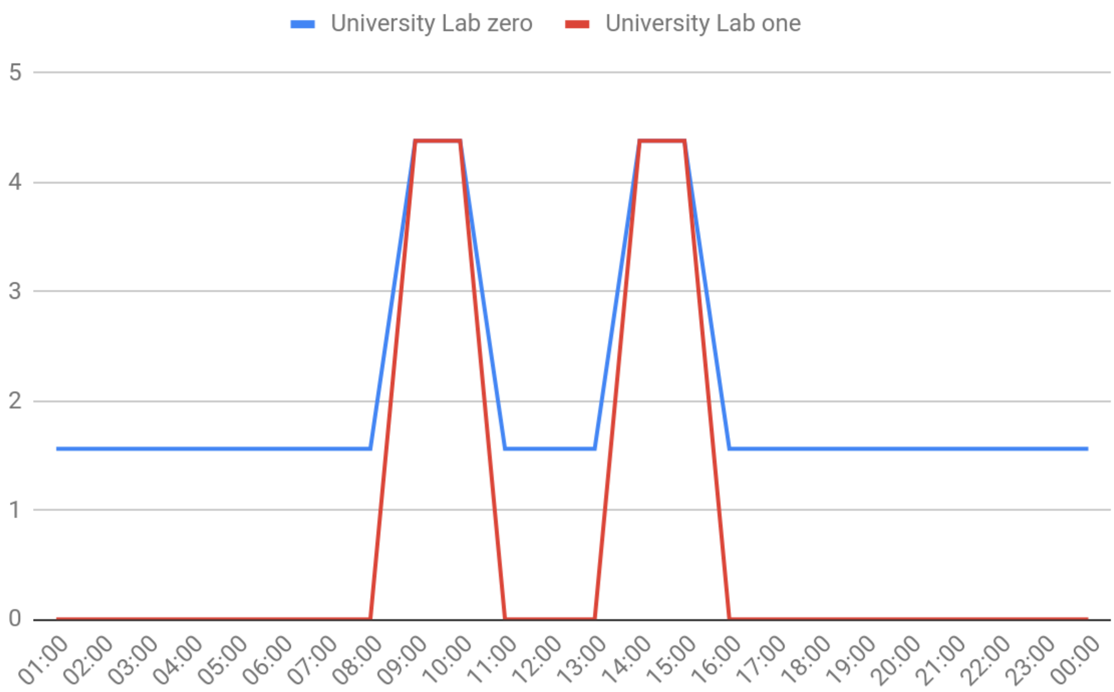

Figure 5.5: Graph of automated University lab

The lab with out any automation consumes electricity at above a standby rate and hits peak consumption when the lab is in use. This is due to that when the lab is locked the devices do not necessarily go to standby mode with most computer being in a low power state with monitors in stand by. The automation system gives the same results as before and limits the power consumption on non occupied hours saving a lot of energy.

6 DISCUSSION

The results chapter does not provide results that can be viewed as surprising. When moving from a system that is dependant on individuals to change their behaviour to one where devices get turned off automatically after work hours, there was always going to be savings in cost and energy but to have quantifiable numbers help for universities and companies to justify the investment and begin to create a smarter work environment.

Looking at the results it is hard to see how they apply to businesses as there are a lot of variables that need to be considered, but the system scales so that more energy is saved in a bigger company than a smaller one. Looking at the results from the small businesses with 50 computers we can see that it will take 286 days to get a return on investment. This depends on the energy use of the company but with the literature to back the scenario's up we can say that this is not far from what is currently happening in Europe and North America.

6.1 Research questions answer

When looking to see the how the overall process and research went we should look at the research questions that were established at the start of the paper and see how well they have been answered and what those answers are.

- How does individual behaviour affect energy consumption in a non-residential building.

This was the first research question that was asked. It was asked to see to what extent individuals in an office affect energy consumption. Before looking into this, it was assumed that people did not take an interest in sustainability behaviour as it only impacted their comfort levels and any positive actions would only benefit the company, which could be seen to be outwith the individuals interests.

After looking at the literature we can see this to be true and there are some additional points. Firstly the behaviour can vary massive across a company or country. This can be due to several factors, one being cultural with studies on this topic giving a different picture between Japan and North America. There is also the position of the employee, with employees being in a higher position having more responsibility to enact company policy and this can be also be extended to the sustainability policy. For universities there is also the same themes where many people where not making a conscience effort to be green but having interactions with some employees that were making an effort to be sustainable would increase their contributions and therefore the whole buildings sustainability.

To conclude on this question we can say that Individual behaviour can greatly affect the energy use of a building greatly but with some culture's, company policies and sustainable employees buildings can see a reduction of energy.

- How much energy is wasted by stand-by devices in commercial buildings in German and Finland

This research question was hard to answer. This was due to commercial buildings having multiple footprints and uses. We can see from the Tabula project (2012) that the creation of a topology for residential buildings was straight forward but commercial buildings are harder due to lack of uniform, different uses and needs for tenants and non-residents, and also over time there can be many changes and retrofits changing the building use and this makes the topology inaccurate.

To get an answer to this question we had to look at two different things. Firstly we look at the general energy consumption of devices in a typical office or from one or more employees. After that we will look at is the number of employees at a typical office. Due to this number having the possibility of ranging from 1 to 10,000+ we created multiple scenarios to reflect a few cases that are most common. We then took the number of employees in an office and calculated the energy use and the cost in both countries to allow us to get an idea of the answer.

- In what way will an automated system affect energy consumption.

This question was looked at in two separate ways. First from a literature stand point and second from our own research where implemented a system to see the effects. Looking at the literature we can see that many automated systems have been put in place in offices and buildings to see the changes in energy consumption. They mainly look at universities as it is easier to set up controlled experiments there, where studies in offices come in the form of surveys. What we can get from these studies is that energy is often saved with the automated systems, but there were times throughout the day where the energy consumed was higher. For example light switches were often turned off sooner in an office with manual control but after office hours they consumed more as one or two would be left on.

As for the implementation of our own system. We had several automated scenarios that had progressively stricter rules to save more energy. We can see in the graph below that each one saves on the previous one and that the savings potential of the system is quite high. But this is at the expense of user comfort and this is something that is outside the scope of this work and it is something that needs to be looked into further.

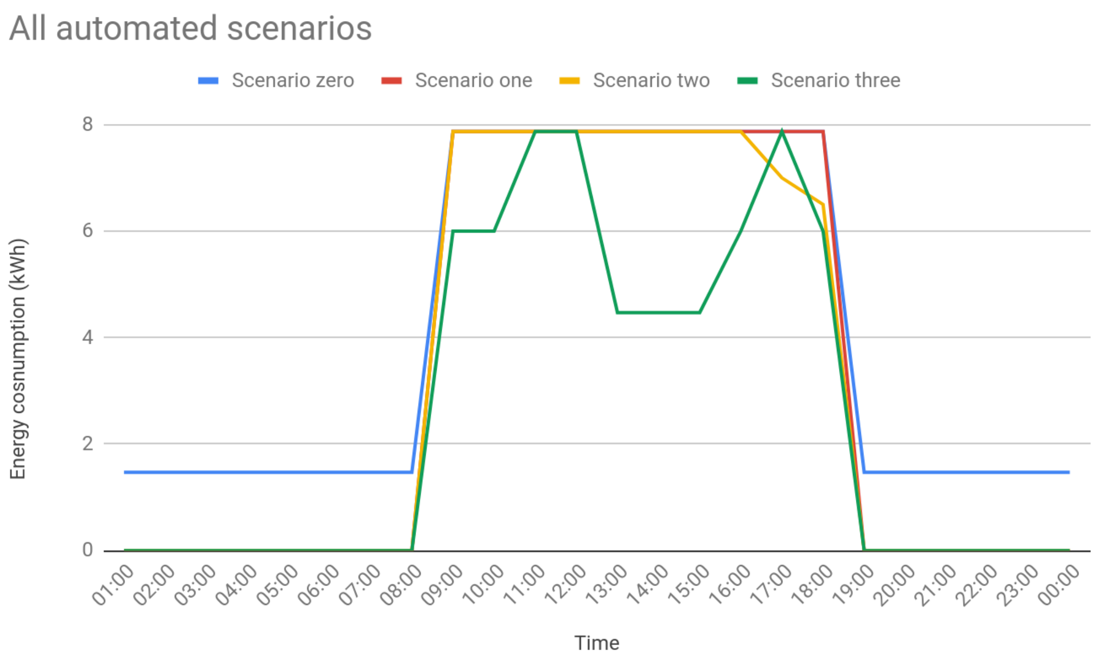

Figure 6.1: Graph of all automated scenarios

- When does the financial gains of a system repay the initial cost.

This is the last research question and it is the question that helps conclude the thesis. This is because once answered we will have the automated scenarios completed, implemented and evaluated. After we answered it we can conclude for what a business should do if they want to implement such a system. Below is the approach taken for implementing the systems and on the ROI.

6.2 ROI from calculations

Looking at the financial gains for an automated system we took two ways of calculating the ROI. We can look at the scenarios of devices used, calculate the energy consumption for the scenarios and then do calculations to estimate the results. For this we take the scenarios above (small, medium and large with the computer composition) and do additional calculations.

Table 6.1: Energy use with different power states

Energy use(kWh)	per day	per week (5 days)	per month (22 days)	per year (261 days)
working day (9-18)	62.96	314.8	1385.12	16432.56
non-office hours(18-9) low power	35.36	176.8	777.92	9228.96
non-office hours(18-9) all standby	5.84	29.2	128.48	1524.24
non-office hours(18-9) hybrid	23.536	117.68	517.792	6142.896

Figure 6.1 shows the energy use for each scenario and there power saving modes per hour. We can see from this that there are drastic difference between the low energy state and the standby power state. This is due to the use of desktop computers and there low power state being relatively high. After this it is useful to get the energy use over time.

Table 6.2: Energy of the small scenario per time

Office Scenario	Energy use(kwh)	Low power energy use(kwh)	Standby power(kwh)
Small	188.88	53.04	8.76
Medium	499.68	114.72	23.76
Large	1081.68	273.36	48.36

Figure 6.2 shows the small scenario and the energy use per working day for each of the models. It makes an assumption of the working day being strict and during the working day devices are on for the total of the 9 hours. After work the devices will go to a low power mode or standby mode. We currently have both of them here as absolutes but this will not be the case for a work environment and the true power consumption will be somewhere in the middle. This has led to the creation of a hybrid model. This model takes information from literature to get the average number of computers turned off and the number of devices that go into standby mode. We can see from Gunay (et al, 2016) that 10$\%$ of all devices will be turned off completely and another 30$\%$ will be put into standby mode. This is what results in the 23.5 Khw per day value for the small scenario.

We would then look at the savings that can be made for this by working out the energy consumption per device. The Homematic devices do not consume much energy and when compared to the hybrid model of 23.5Kw, we use 5.1Kw per day; giving us a saving of 18.4.

$$Savings(Euro) = Electricityusage(kWh) * Energycost(euro/kWh) \tag{6.1}$$

To use this scenario we need to get the cost for energy for each country and put it in the equation, for germany the current cost is 30 cent per kWh €.

$$7.06 = 23.5 * 0.3 \tag{6.2}$$

And we also did this for the Finland, where the cost is 16 cent per kWh. As mentioned above this is close to the EU average, where Germany is an outlier along with Denmark in terms of energy cost.

$$3.76 = 23.5 * 0.16 \tag{6.3}$$

As we have the energy cost per day we can then work out the savings and divide the total cost of the system by this number. To calculate the cost of the system we can then get the total cost. This can be done with the device cost. For a typical system we have one raspberry pi for the server, 1 homematic hub and N main monitors for each power strip.

Table 6.3: Device cost

Raspberry pi	€35
Homematic hub	€80
Homematic switch monitor	€42

As we can see with each switch monitor the price of the system increases but as its cheaper than the hub the average price goes down, meaning the bigger the system the more money can be saved. We can see below the cost totals of the systems for each scenario.

Table 6.4: Total cost and ROI time for small business scenario

Country	Total cost	payback time
Germany	2205	399 days
Finland	2205	748 days

Table 6.5: Total cost and ROI time for medium business scenario

Country	Total cost	payback time
Germany	6405	466 days
Finland	6405	874 days

Table 6.6: Total cost and ROI time for large business scenario

Country	Total cost	payback time
Germany	12705	367 days
Finland	12705	688 days

Looking at these results shows that the payback time is heavily dependant on if the building/office uses more desktop computers or if they use laptops. The medium scenario uses more laptops than the large scenario as an overall percentage and thus the total savings are lower. To get a better understanding of this we will look at the graphs of companies that would use all laptops or all desktops.

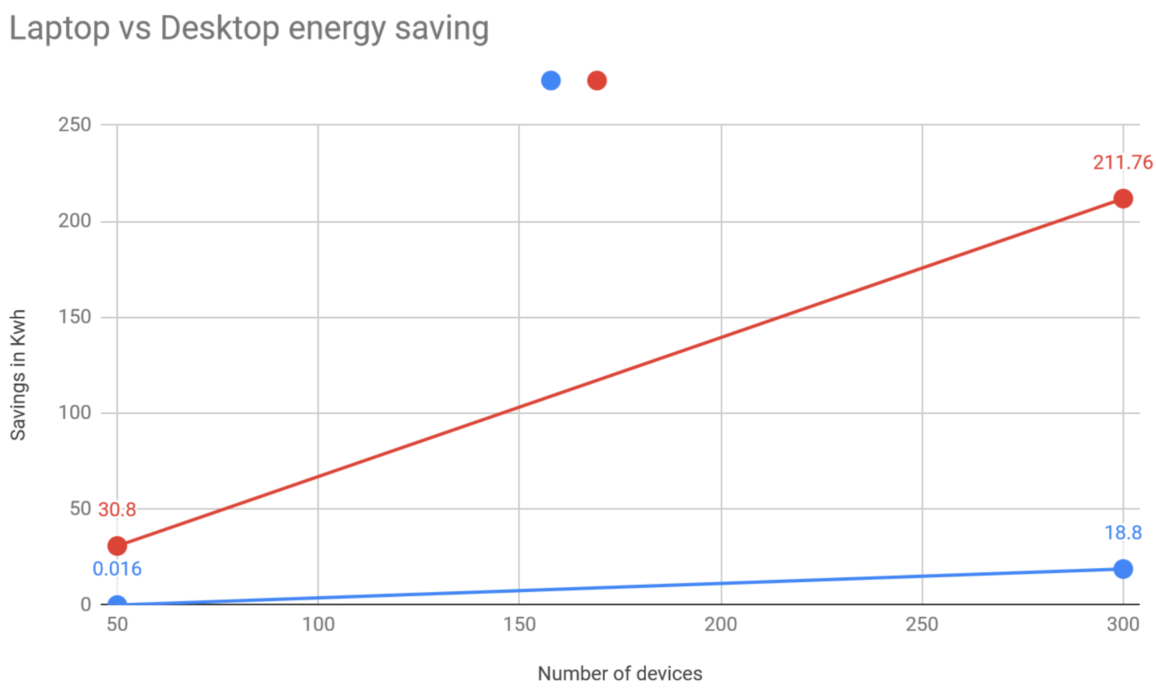

Figure 6.2: Graph of all laptop vs all desktop

This is a graph that shows the energy savings if we chose a scenario that used all laptops and all desktops. This is too say the scenarios of sizes when mapped show the energy saving potential and a real world environment will be somewhere between both lines. We can see that if a company used only laptops for work there will be little value out of running the system design in this research. The desktop savings here are for 200 low end and 100 high end meaning that the savings could be higher if high end desktops where used but this ratio seems fair.

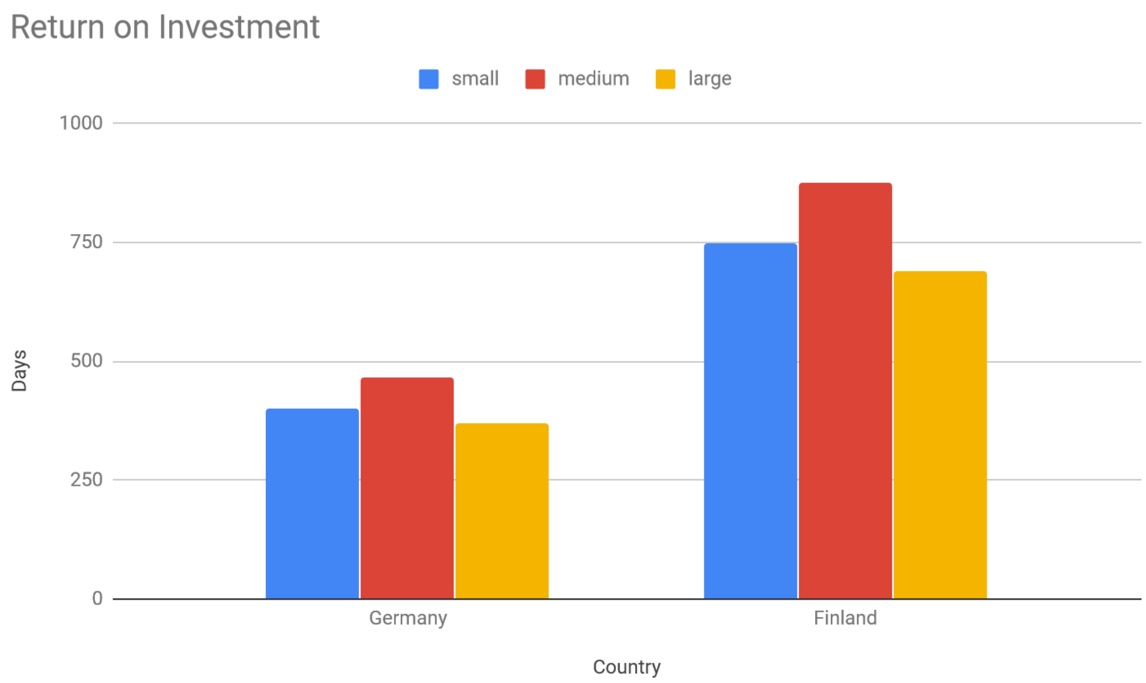

Figure 6.3: Bar chart of ROI in days

This is a bar chart showing the different scenarios and the days to get a return on investment. It is a visual representation of what we discussed in tables 6.3, 6.4 and 6.5. It helps to show that the system is more dependant on the cost of energy than it is on the size of the company. Also device selection is a major contributor to the ROI too.

6.3 ROI University scenario

The university lab scenario is different in design to the previous ones and thus it will give different data. The scenario is a lot cheaper and will give a better ROI, even with the smaller number of devices. This is due to the amount of spare time a computer room is sitting idle and devices are consuming power.

The ROI will need to be done by the university on a per room basis. The number of devices will give a direct correlation to the savings made and it can be said that it is the main factor in the monetary value that could be saved as in general turning off the devices for just the 16 hours that the room is not used will return savings after a set time. The savings are calculated below;

Energy savings per hour = 1.05Kwh. This means that for the standard 16 hours that the devices will be left on will save 16.888kWh. As mentioned earlier this is the minimum energy that the room will save. When looking at the monetary saving we look at the energy costs like above and we get will give a savings of €5.04 for Germany and €2.70 for Finland per day.

The cost of the devices are a lot lower when compared to the previous scenario as we do not need devices for each socket.

Table 6.7: Device costs in lab scenario

Raspberry pi	€35
Honematic hub	€80
Homematic door switch	€35
Homematic fuse switch	€60

This gives a total of €210 for the system. There is the problem that we are not factoring in the value of installing the system. For the previous scenarios it was simple due to the devices being connected at the socket level but for this scenario there will be a need for some rewiring and thus if no one working at the university has the knowledge then someone needs to be contracted to work on it. To repay the system costs though it is relatively fast, as seen in the table below.

Table 6.8: ROI in days

Country	ROI (in days)
Germany	42
Finland switch	78

It should be noted that this is for the 16 hours scenario, if we increase the amount of hours the days will decrease. For example if a lab is only used for 2 hours a day we would get the ROI for Germany down to 30 days.

6.4 ROI from implementation

While we have previous calculated the return of investment from simply turning off devices in a standby mode for different sizes of businesses, by implementing the different automated scenarios we can see further savings.

Looking at the first and second automated scenario's as one due to them being, Turning devices off at the weekend and after work are only timed based and the savings will be similar at both times. The savings are the same as above, and therefore we don't need to calculate the ROI, which is around 400 days.

The third scenario looks at the turn off of devices a few hours earlier due to taking in a smaller energy consumption. This will be used when devices go into standby power late in the day and it is deemed the individual is not coming back. This will lower the value compared the first two scenarios. The reduction is only an extra 2% for a small business and takes the daily consumption from 70.8 to 69.4 kWh. This will give an extra monetary saving of 45 cent a day and the ROI will be reduced by 9 days to 391 days total.

The fourth and last scenario is a more aggressive automation scenario. This should reduce the energy by a lot but there is greater impact on the comfort levels. Looking at the energy saved in the automation scenarios. There is a saving of 83.5% in our tests but this was on one individual and it can be said that there needs to be more research on the behavior of individuals in an office. The kWh will go from 70.8 to 59.15 and this reduces the ROI to 333 days.

6.5 Website discussion

The website was developed and is shown below. It gets the data from * and it displays the information to the user. the figure shows the current energy consumption on a gauge and gives the percentage of the current energy use, with 100% being the base max calculated when no automation scenario was implemented.

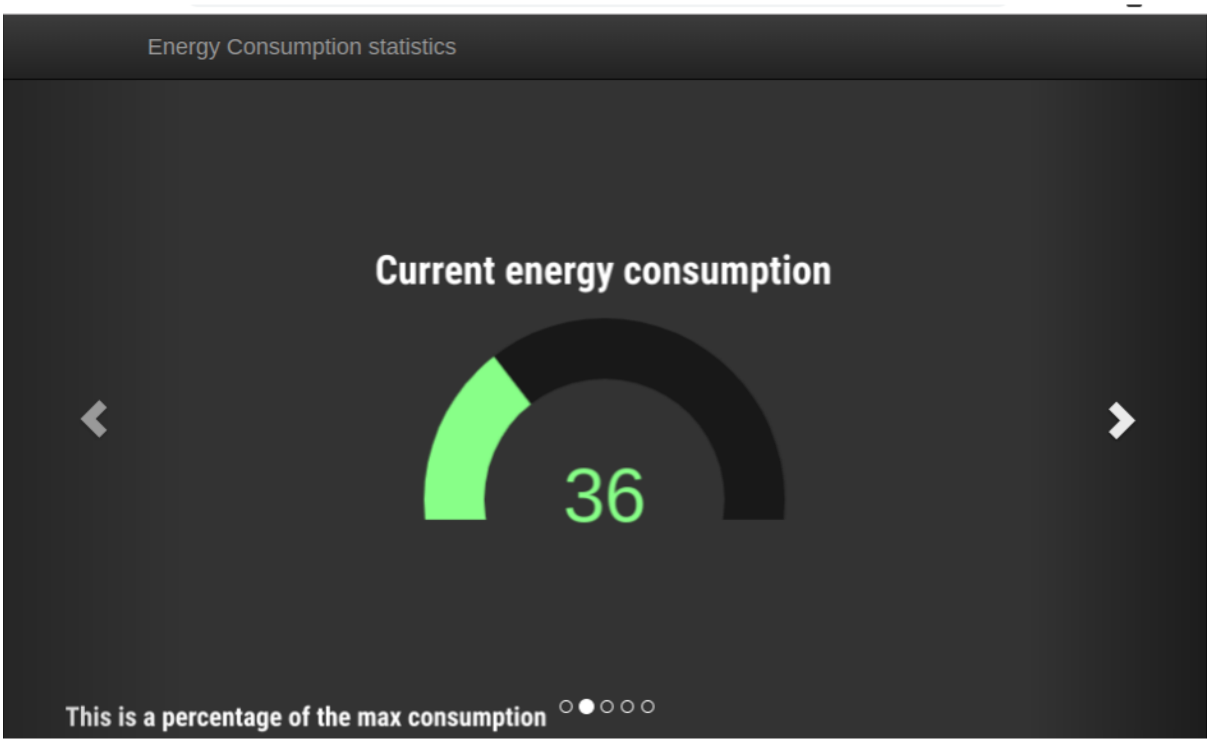

Figure 6.4: Website main page showing current energy consumption

The gauge is green when the system is below a certain threshold and it will become green the closer it gets too 100%Ḟor displaying Co2 we will first take the exact number of energy consumed and see also see how much is saved compared to the max. With this we can get a Co2 in terms of a number but this is vague and thus we can do this with water boiled in a kettle and we can say that over time we can save Co2 in comparison to car or plane trips. Figure 6.5 shows the savings in terms of coffee cups and while this is on a smaller scale it will be able to fit in to all use cases and can be scaled up.

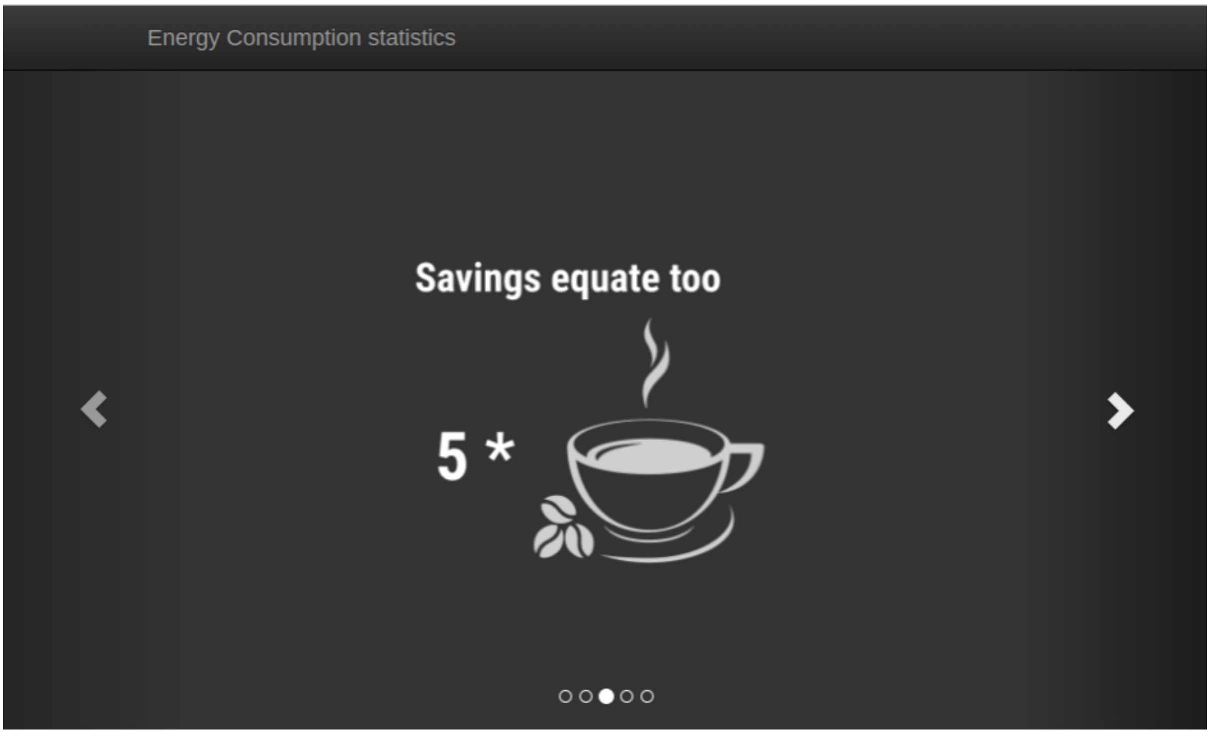

Figure 6.5: Showing Co2 to coffee savings

6.6 Sustainability

When looking at the sustainability of the research we can see that we are lowering energy consumption and therefore reducing Co2 emissions but this is just the high level savings and we can look further into what the system can help to achieve a long with some of the drawbacks.

Along with lowering energy consumption there are a few other areas that the system could help improve. One being that the system allows to see the room usage and if all employees or students could move to a smaller room. Leaving a room with 0 energy needs. The behaviour aspect is something that can be greatly improved. It is discussed in earlier chapters that most individuals have no interest in sustainability for a company as it does not affect them personally but some people do care and it is this caring that can help to form change in others. Behavioural change are always slow and it is often about the formation of habits. This system evokes the user to think about the power state that there devices are in when they leave for work as they know that the devices will turn off. This could lead to the user being more sustainable and then turning off their device if the automated system was withdrawn from the office. There are also the companies themselves which can use such a system to meet there green targets and therefore advertise as a company that cares for the environment and the want for a better planet.

As for the negative aspects of the system. the system has many devices depending on what the company or university choose to do. These devices need to be manufactured and can be be costly if we look at the full life cycle of the devices. Electronics use a lot of hazardous materials and these devices are hard to recycle properly, which is not often the case with many ending up in a landfill and polluting the land and air. The system also consumes energy and if it is implemented haphazardly then it can just add to the energy costs.Along with this the behavioural changed mentioned above could also become negative as if the comfort of the individual is impacted too much then they will begin to dislike the system and not want to be reduce energy and look at ways to avoid using the system. Engaging people in a negative will also bring that mentality into other aspects of their life be it work or leisure. These positive and negatives are better represented in figure 6.6 below. (Porras, et al, 2017)

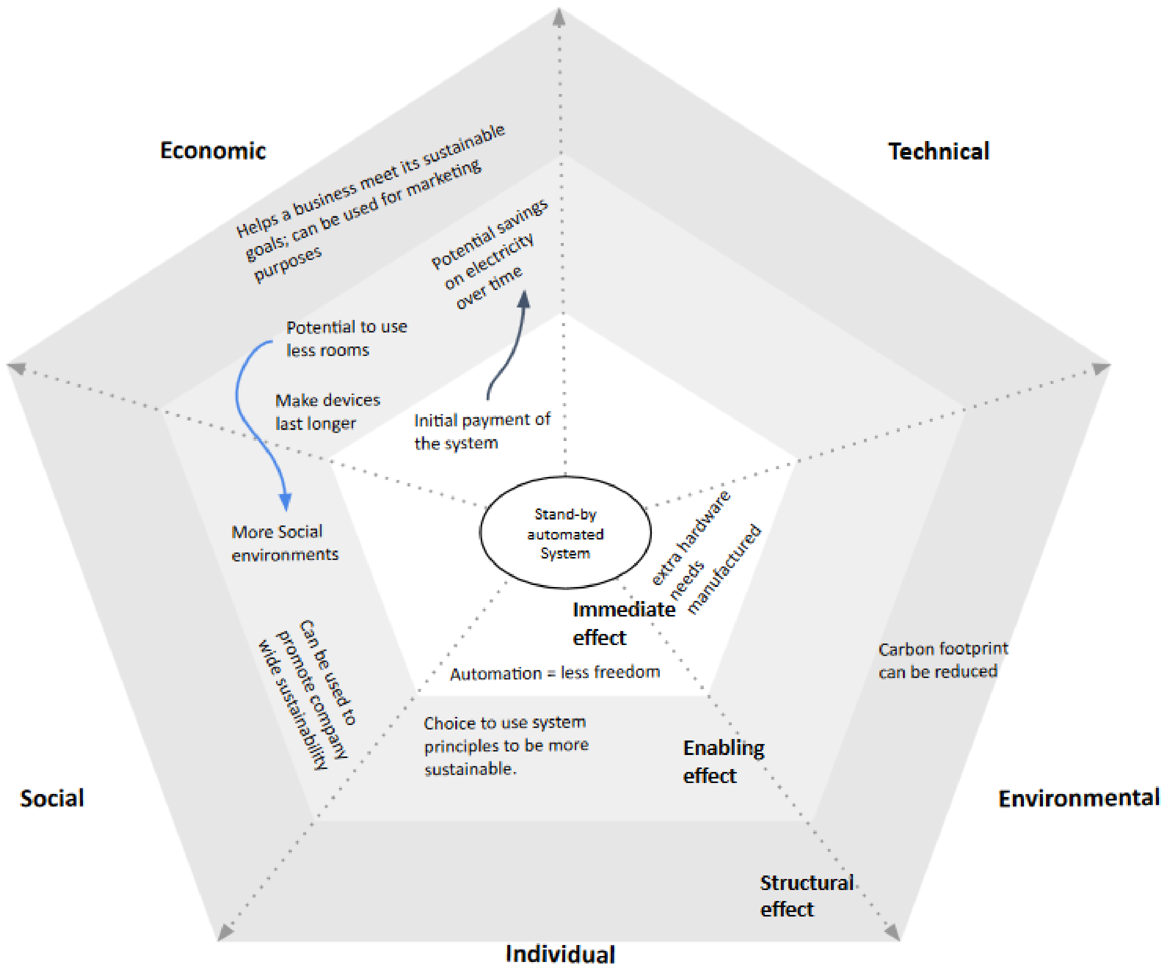

Figure 6.6: Sustainability pentagon

6.7 Ethics

The research itself did not have any human interaction. This drastically decreases the ethical considerations of the thesis. If we did further work we would likely look into testing the system developed in an office or building and this would need some consideration, along with the surveys and interviews that would be taken after.

The only Ethics we need to be sure to adhere by is the use of data from other research papers. For the creation of the scenarios we have used data that other researchers have obtained we need to make sure that we state clearly that this data is not our own and that we have used it in an ethic manor with the proper citations.

6.8 Final thoughts

Looking at the research done here we can draw some final thoughts and conclusions. The research gives us a monetary value for the return on investment if a business invested into an automated system. We can see the the payback time is dependant on the country and it can be drastic between countries due to energy costs. This can be lowered though if the company is happy to raise the automation's control or lower the comfort of the individuals by increasing automation.

This system would be highly suitable for a business that has a high number of desktop computers, preferable over 3/5. With companies moving towards a composition that is more laptop than desktop, increasing the ROI in days to where there will become a problem with the longevity of the devices. But this does make the system suited to more formal companies, such as call centers.

As for the university lab scenario. If a university has a computer lab then it is worth implementing the system, but some universities are moving away from this type of system though and are moving towards a thin client system and this takes away the desktop from the room and therefore the main energy drain. There is also the fact that most students will bring laptops to university too

7 CONCLUSIONS AND FUTURE WORK

As mentioned at the beginning of this thesis, over time low power and standby modes that devices come with have provided energy savings over old devices which do not have the option but as the number of devices we use increase these savings are negated. This is a trend that seems to increase with more devices needing to be on to function fully, via wifi or bluetooth. To break out of this cycle we need to start to think of standby mode as a power using mode and not a power saving mode. The research set out to turn off power saving devices, see how much energy could be saved and the time taken to get a return on investment. The aim was to provide a value to help businesses and universities make the decision to invest in more sustainable practices and technology.

We aimed to use automation to help with the turning off devices as there is a needless waste of energy when it comes to devices being left on over time. Using data got from literature we created scenarios that mimic the real word in office size; the number of employees and the number of devices that would be used. This allowed us to get the value of energy used and calculate the return on investment with others being able to use this information to see which scenarios relate to their own company and then see how long they would be waiting until they would see a profit.

Looking at the work done for this research we can see that there are some areas that could be explored to help further improve the energy that can be saved. Firstly extending the range of devices such as servers. Network devices are increasingly common in offices and universities with them often having specific server rooms running their own software systems. These systems are a major energy drain and thus have a good potential for savings. We can also look at other common elements such as lights and HVAC, these are not necessary devices that go on standby but they are on a lot when they are not needed and implementing them into some of the scenarios would not be very hard.

Further work could also be done on implementing what was done here in an office and evaluating the outcomes. A key component of the research was trying to limit the impact of user comfort but without implementing the scenarios individually and getting feedback from users it is hard to say the true impact on comfort. It would also be nice to see this in an business environment as there is fewer studies on it than university buildings and getting more data on that to compare if the behaviour is the same in both environments would be useful for determining if the solutions can be used in both domains.

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