Lappeenranta University of Technology
School of Industrial Engineering and Management
PERCCOM Master Program

Fisayo Caleb Sangogboye

Analyzing and Computing the Sustainability Gains of Building Automation

Examiners: Professor Eric Rondeau
Professor Karl Andersson

Supervisors: Professor Olaf Droegehorn
Professor Jari Porras

This thesis is prepared as part of an European Erasmus Mundus programme PERCCOM - Pervasive Computing & COMmunications for sustainable development.

This thesis has been accepted by partner institutions of the consortium (cf. UDL-DAJ, n°1524, 2012 PERCCOM agreement).

Successful defence of this thesis is obligatory for graduation with the following national diplomas:

- Master in Master in Complex Systems Engineering (University of Lorraine)
- Master of Science Degree in Computer Science and Engineering, Specialisation: Pervasive Computing and Communications for Sustainable Development (Lulea University of Technology)
- Master of Science in Technology (Lappeenranta University of Technology)

ABSTRACT

Lappeenranta University of Technology
School of Industrial Engineering and Management
Degree Program in Computer Science

Fisayo Caleb Sangogboye

Analyzing and Computing the Sustainability Gains of Building Automation

Master's Thesis

15 pages, 38 figures, 38 tables, 3 appendixes

Examiners: Professor Olaf Droegehorn
Professor Jari Porras

Keywords: energy usage, energy saving, building automation, automation investment, return on investment, payback time.

Smart home implementation in residential buildings promises to optimize energy usage and save significant amount of energy simply due to a better understanding of user's energy usage profile. Apart from the energy optimisation prospects of this technology, it also aims to guarantee occupants significant amount of comfort and remote control over home appliances both at home locations and at remote places. However, smart home investment just like any other kind of investment requires an adequate measurement and justification of the economic gains it could proffer before its realization. These economic gains could differ for different occupants due to their inherent behaviours and tendencies. Thus it is pertinent to investigate the various behaviours and tendencies of occupants in different domain of interests and to measure the value of the energy savings accrued by smart home implementations in these domains of interest in order to justify such economic gains. This thesis investigates two domains of interests (the rented apartment and owned apartment) for primarily two behavioural tendencies (Finland and Germany) obtained from observation and corroborated by conducted interviews to measure the payback time and Return on Investment (ROI) of their smart home implementations. Also, similar measures are obtained for identified Australian use case. The research finding reveals that building automation for the Finnish behavioural tendencies seems to proffers a better ROI and payback time for smart home implementations.

ACKNOWLEDGEMENTS

First of all, I would like to thank my supervisors, Professor Olaf Droegehorn and Professor Jari Porras, for giving me the opportunity to carry out this work and for their advice, direction and support throughout. Secondly, I would like to thank the people that supported me with the data that was utilized for this thesis, for their contribution, their cooperation and help. Thirdly, I would also like to thank my colleagues in PERCCOM and the administrative staffs of Hochschule Harz, Germany, Lappeenranta University of Technology, Finland, Université de Lorraine, France and Lulea University of Technology, Sweden for their numerous supports. Fourthly, my profound appreciation goes to PERCCOM and Erasmus+ for providing the platform to undertake my Masters studies and for the financial support (Scholarship) during my study period. Finally, I would like to thank my family and friends both in Nigeria and in Europe for all their support.

TABLE OF CONTENTS

LIST OF EQUATIONS

LIST OF FIGURES

LIST OF TABLES

LIST OF SYMBOLS AND ABBREVIATIONS

AV	-	Audio/Video
DMPR	-	Distinct Multi Path Routing Protocol
EEG	-	German Renewable energy policy
EnEV	-	German Energy Conservation Regulations
GA	-	Genetic Algorithm
HMS	-	Home Management System
(H,M,N)SS	-	(High, Medium, No) Smart Strategy
HSI	-	High Smart Investment
HVAC	-	Heating, Ventilation and Air Conditioning
IEEE	-	Institute of Electrical and Electronics Engineers
IT	-	Information Technology
KA	-	Kruskal Algorithm
koe	-	Kilogram of oil equivalent
(k,M,G)Wh	-	(kilo, Mega,Giga) Watt Hour
NPV	-	Net Present Value
NZEB/PEB	-	Negative or Zero net Energy Consumption/ Positive Energy Building
PV	-	Photovoltaic / Solar Panels System
ROI	-	Return on Investment
SAANET	-	Smart home appliance communication protocol
WIFI	-	Wireless Fidelity
WLAN	-	Wireless Local Area Network

1. INTRODUCTION

An automated building is a building that has the capability to adapt itself in certain situation to make areas of the building more comfortable for its occupants while sharing a common interface that links it to systems and services outside the building. This system usually involves the installation of a smart gateway that requires no much hassle into standard homes to make the home smarter. This system alongside a power management features could substantially reduce the power consumption of a home which can in turn reduce the energy cost and carbon emissions of the building (Tejani, et al., 2011). Energy conservation is of particular interest here, because it enable a greener future and it proffer an added advantage to users as a cost-cutting measure.

1.1 BACKGROUND

Today, energy conservation constitutes a major socio-economic discuss amongst committee of nations in the world. This is because, the increasing greenhouse gas emission from industrial activities as led to significant depletion of the Ozone layer and an evident global climate change. One such energy conservation discuss widely known as the Kyoto Protocol was held in Kyoto, Japan in 1997. This discuss was held to extend the commitment of the 1992 United Nations Framework Convention on Climate Change (UNFCCC) of member states to reduce their greenhouse gases. This protocol instruments a common but different responsibilities on participants states by putting more obligations on developed states to reduce their current emissions based on the premise that they are historically responsible for the greenhouse gases (United Nations, 1998).

The European union being an active participant of this protocol identified that buildings constitute 40% of the energy consumption and 36% of CO_2 emission in the EU and it is the largest end-use sector followed by transport (32%), industry (24%) and agriculture (2%). Thus two main legislations that mitigates against emission from buildings were approved by member states (European Commission, 2015). These legislations includes:

1. Energy Performance of Building Directives (EPBD)
2. Energy Efficiency Directives (EED)

These directives serves as a framework for developing the national implementation strategies for member states to significantly reduce the energy consumption at both residential and public buildings. Also a concerted action was launched to enable member states exchange best practices about energy conservation between themselves. Three most significant strategies adopted by both states and individuals are:

1. Building Retrofit:

   Building retrofit is the process of modifying the system or structure of a building at some point after its construction and occupation. This is typically done to improve the amenities and the performance of the building in terms of significant reduction in energy and water usage.

   According to the report in (Ubran Land, 2009),

   > "G*reen retrofits are any kind of upgrade at an existing building that is wholly or partially occupied to improve energy and environmental performance, reduce water use, and improve the comfort and quality of the space in terms of natural light, air quality, and noise—all done in a way that it is financially beneficial to the owner. Then, the building and its equipment must be maintained to sustain these improvements over time."*

2. Renewable Energy Policies:

   Most European states have introduced various schemes and incentives to attract individual investors into the renewable energy source markets and these schemes are fondly guided by legislations and policies that guarantees the mandatory purchase of produced energy by grid operators from these energy producing entities and a fixed feed-in tariff for these purchase. The most widely adopted of these renewable energy policies is the German Renewable Energy Policies. This is because of its huge implementation success and its wide range of provisions for several renewable energy source. Renewable energy source installation are usually adopted to guarantee a zero or negative net energy consumption for building over a specified period of time.

3. Building Automation

   The smart 2020 report given in (Global eSustainability Initiative, 2008) identified that the installation of building management system (smart system) by occupants to automate building functions such as lighting and heating and cooling could offers a major opportunity to reduce the global CO_2 emissions of buildings by a ratio of 15% percent.

   Also according to the report (Energy Star, n.d.), 42% of home energy expenditure comes from house conditioning, however much of this energy expenditure are often used for space conditioning when the home is unoccupied. It was highlighted in (Energy Star, n.d.) that the installation of programmable devices could significantly mitigate against energy wastefulness from negligent occupants and could save approximately 10 to 30% of their overall energy bills.

1.2 STATEMENT OF PROBLEM

Improving the performance of a building through investment in retrofitting or renewable energy source or building automation is associated with a significant investment cost. Results from observations and product research for residential homes indicates that, the investment cost for a PV system usually ranges from 4500 - 12000 Euros (depending on location), while the investment cost for building automation ranges from 500 - 2000 Euros(depending on building type). Several authors have proposed the significant chain of environment degradation (in terms of CO_2 and greenhouse gases reduction) such investment could mitigate and have highlighted the social impact and human consideration of these technologies (in terms of its inherent comfort and control), however:

1. According to the report in (Energy Star, n.d.), it is still unproven and unclear how much these technologies could save in terms of energy and cost
2. There has been no sufficient economic justification for these investments based on some economic metrics (for instance investment return and payback time) and
3. what economic value these investments can proffer?

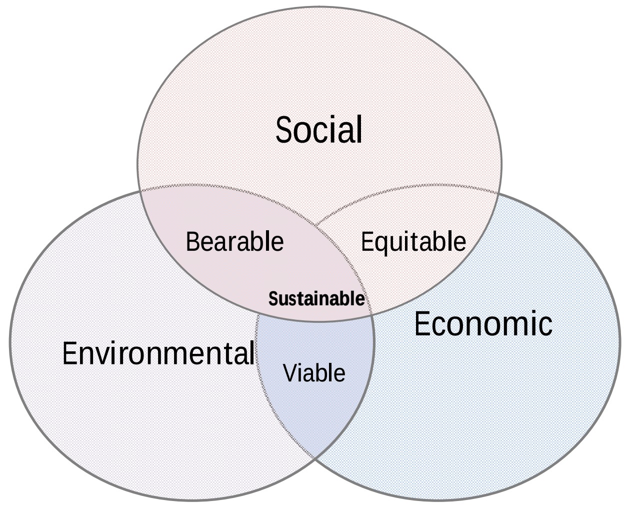


Figure 1.1 Tripod of Sustainable Development

1.3 GOALS

This thesis aims to gather and analyze data from installed building automations to

1. formulate a computational model for different data sets,
2. derive usage patterns and models from analyzed data sets and reuse patterns and models for similar scenarios,
3. compare the energy usage and energy cost for buildings with and without smart system installations, and
4. investigate the return on investment and payback time of building automation investment and PV system installations.

With these economic questions being answered, it is assumed that the equitability, viability and sustainability relations of the economic stand given in figure 1.1 in relation to the sustainability of building automation will be duly exonerated.

1.4 DELIMITATIONS

Buildings can be classified into residential and non residential building. According to (Rapf, 2011) the residential building comprises of 75% of the building block of the total building block in Europe and this represents approximately more than 60% of the total building consumption depending on the state (Odyssee-Mure, 2012). Because of this significant ratios, this thesis will only investigate the energy savings in residential buildings. Also the profile (occupant's behavioural tendencies) of two European countries (Germany and Finland) will be primarily studied to make a comparison that determines the effects of these profiles on the energy consumption and energy savings for each identified types of residential buildings. Also from the analysis that was obtained from a residential building in Australia (Tejani, et al., 2011), the respective cost of the energy saving is compared against a prospective cost of home automation implementations to evaluate its inherent economic gains. Lastly, to estimate the environmental contribution of home automation, it is pertinent to investigate the carbon emission throughout the life cycle of the smart devices, however, the carbon footprint of the production process of these smart devices are not publicly available, thus the measure of the environmental contribution will be limited to the in-use life cycle of these products and the carbon reduction prospects of these smart devices.

1.5 RESEARCH QUESTIONS

This thesis seeks to answer the following research questions:

1. How does human behavioural tendencies affect the building performance (in terms of energy consumption) for both the Finnish and German use cases and scenarios.
2. Does the implementation of home automation optimize the energy consumption in residential buildings in Germany and Finland.
3. What is the financial gain for implementing home automation and renewable energy source.
4. When does the gains of homes automation and renewable energy source repay its investment cost for both the Finnish and German use case.
5. What level of investment is advisable to undertake for home automation to be profitable for end-users in both Finland and Germany
6. What are the environmental and ethical contributions of building automation to sustainable development.

1.6 RESEARCH METHODS

This is a mixed study that integrates both qualitative and quantitative research studies. The quantitative aspect extracts numerical data from the system logs of implemented home automations and these data are used for several numerical computations and statistical analysis. The qualitative aspect utilizes observation and interviews to extract information from home occupants and end-users to corroborate the quantitative data, extract and user behavioural tendencies.

1.7 STRUCTURE OF THE THESIS

This thesis is structured into six chapters. The first chapter introduces the background, goal and delimitations of the study. The second introduces related research works and chapter three introduces the research methodology. Chapter four defines different automation scenarios for identified residential buildings, while chapter five presents the mathematical computation for identified scenarios in chapter four based on the methodology identified in chapter three. Chapter six discusses the result of the various computations in chapter five, concludes the study and recommends further research studies.

2. LITERATURE REVIEW

This chapter presents a review of related works for this study. Related works and cited journal are grouped into five distinct categories which includes home automation system architecture, energy consumption in buildings, energy saving models for home automation, home automation investment models, and national policies for building performance and renewable energy. This review aims to expose the research gap, raise questions, provide counter claims and in some cases continue in a similar tradition of identified related works.

2.1 HOME AUTOMATION SYSTEM ARCHITECTURE

The importance of using information technology for improving energy savings in buildings was highlighted in (Wei & Li, 2011). This paper proposed a systemic framework for enabling energy monitoring and system analysis with the Internet of Things paradigm in order to achieve a real-time energy monitoring, controls and improved energy savings for buildings. This work also highlighted key elements that enables the implementation of a smart building and these includes the perceptual elements, the network layer and the application layer. The perceptual elements comprises of wireless sensors, lighting systems and real-time data acquisition subsystems. The network layer includes the field bus and an industrial control networking and the application layer provides an integration platform to coordinate the operations of the perceptual elements and manage energy consumption. This paper suggests that perceptual elements and the network layer should include subsystems that have attained the IP architecture to communicate on an IP network platform and it proposes a centralized server architectural framework for implementing smart home systems based on Internet of things for managing energy consumptions in buildings. It is observed that major smart home systems utilizes a similar centralized architectural framework for implementing home automation scenarios. These architecture will be duly investigated to propose smart devices and systems that suffices for the three identified core elements and layers for an adequate smart system implementation.

The Finnish AsTEKa-Project given in (Skon, et al., 2011) focused on maximizing the comfort level of occupants and optimizing the energy consumption of home appliances. This was achieved with the design and implementation of a monitoring system that retrieves energy consumption of appliances and indoor air quality data from homes. Eleven different homes were investigated for this study and sensors were deployed to retrieve data from each home and these sensors were coupled with the monitoring system through a data transfer unit. This monitoring system consists of a custom software that retrieves sensory data every minute through a WLAN-router base running a Linux Operating System. Retrieved data were analyzed and analysis results were presented to end users and administrators through the custom designed Silverlight client application interface that displays water usage, heat energy usage and electricity usage according to different predefined energy consumption profiles. Also this interface enables the end users and administrators to query for specific sensory data over a different time ranges and present them using graphs and charts. This paper focused solely on the measurement, storage and presentation of sensory data and analysis result to different audience. This thesis also aims to analyze automation log for periods ranging 6-12 months of home automation deployment and installation. Several descriptive analysis methods will be used to describe and perform data analysis and mathematical computation on retrieved log data and graphical data analysis will be utilized to visualize analysis results.

The design of smart appliances using smart homes technologies and standards to achieve energy conservation was introduced in (Chen, et al., 2009). To enable communication with home appliances, Ethernet and Wi-Fi networks were proposed to fulfil the heavy data traffic demands from AV devices[1] while low speed power line communication was proposed for white goods[2]. To achieve energy conservation, a smart meter was installed to communicate and retrieve power usage of appliances and to orchestrate the operations of smart sensors and appliances. Also the SAANet[3] communication protocol which enables read and write commands for appliances was utilized to enable communication between the smart meter and home appliances. This journal provides an overview of architecture and implementation of smart devices, the communications protocols for smart devices and the integration of an energy conservation module for a smart meter. Also this journal raises an interoperability concern for heterogeneous automation platforms.

---

[1] AV devices are audio/video devices components and capabilities in home entertainment system.

[2] White goods are major household appliances such as stoves, refrigerators that are finished in white enamel

[3] SAANet is a minor weight communication protocol specially defined by SAA. This protocol can be used over power line or wireless systems to achieve communication between smart appliances of different brands.

Due to this interoperability challenge, smart data from the FHEM[4] platform will be adopted for this study because it enables interoperability between several proprietary devices and smart protocols and this platform enables users to define and select the data types that are logged by the smart system. This enables a somewhat easier understanding of log data and data retrieval for data analysis.

A smart home energy management system using IEEE 802.15.4[5] and ZigBee[6] protocols was introduced in (Han & Lim, 2010). This system presents a multi-sensing and lighting control application based on smart energy control for optimized energy cost. To achieve this, smart device descriptions and standard practices were designed for demand response and load management "Smart Energy" applications. This application is recommended for residential or light commercial environments and installation scenarios were formulated for single homes and an entire apartment complex.

This paper proposed the use of two Zigbee networks for device control and energy management respectively to enable the design of a multi-sensing heating and an air conditioning system, an actuation application, a smart lighting control system and an energy production control. Also, a smart control system that includes a smart energy network was proposed to coordinates all smart nodes and this system implements a Disjoint Multi Path Routing protocol (DMPR)[7] based on the Kruskal algorithm (KA)[8] to select nodes with the best KA value through which sensory data are transmitted.

---

[4] Fhem is a GPL'd perl server for house automation. It is used to automate some common tasks in the household like switching lamps / shutters / heating / etc. and to log events like temperature / humidity / power consumption. The program runs as a server, you can control it via web or Smartphone frontends, telnet or TCP/IP directly.

[5] IEEE 802.15.4 is a standard which specifies the physical layer and media access control for low-rate wireless personal area networks (LR-WPANs). It is the basis for the ZigBee, ISA100.11a, WirelessHART, and MiWi specifications, each of which further extends the standard by developing the upper layers which are not defined in IEEE 802.15.4. Alternatively, it can be used with 6LoWPAN and standard Internet protocols to build a wireless embedded Internet.

[6] ZigBee is a specification for a suite of high level communication protocols used to create personal area networks built from small, low-power digital radios. ZigBee is based on an IEEE 802.15 standard.

[7] Multipath routing is the routing technique of using multiple alternative paths through a network, which can yield a variety of benefits such as fault tolerance, increased bandwidth, or improved security. The multiple paths computed might be overlapped, edge-disjointed or node-disjointed with each other.

This paper focused solely on the design and implementation of smart home control systems based on Zigbee 2006 and IEEE 802.15.4 network protocols and standards. Also the implementation promises to save significant energy in home environment and to achieve great level of flexibility and control for building administrators, and significant comfort for the occupants. This thesis views energy conservation, adequate control and comfort for occupant from a higher level of abstraction. While this paper focuses on the enabling technology and protocols for smart system implementation, this thesis builds on these technologies and focuses on embedded intelligence i.e. the definition of scenarios that coordinates the operations of all smart nodes, the retrieval of data measurement from each domain of interest and the analysis of these data to determine if it is worthwhile to invest in building automation and when should an investor expect an investment return for building automation.

2.2 ENERGY CONSUMPTION IN BUILDINGS

The report given in (Odyssee-Mure, 2012) provides a summary of the energy usage for residential and non-residential buildings in EU states and a comprehensive analysis of how the effects of the economic, energy prices and occupant's behaviours affect this energy usage. The analysis in this report are based on the energy usage data and energy efficiency indicators provided by the ODYSSEE database and website. This report identified two types of buildings (the residential and non residential buildings). The residential buildings comprises of single family houses and apartment blocks while the buildings in government service and tertiary sectors are classified as non residential building. The energy usage in buildings may vary per countries, however this consumption represents averagely a total of 41% of the energy usage in the European Union (EU) and from this lot, residential buildings accounts for 65.9% of the total energy usage of EU buildings and 27% of the energy consumption in the EU. For Finland, Spain, Portugal, Cyprus, building energy usage represents 33.33% of their total energy usage while for Germany, Denmark, France, Poland, building energy usage represent 45% of the final energy consumption. Also, while the distribution of building energy consumption between residential and non-residential buildings may vary per country, the share for residential building from the total building

[8] Kruskal's algorithm is a greedy algorithm in graph theory that finds a minimum spanning tree for a connected weighted graph. This means it finds a subset of the edges that forms a tree that includes every vertex, where the total weight of all the edges in the tree is minimized.

consumption for Germany and Finland ranges between 60-70% and the annual consumption per (m^2) for these two countries are 210kWh and 325kWh respectively. This disparity is associated to climatic difference between the two countries by (Odyssee-Mure, 2012). A breakdown of the energy consumption in household for both Finland and Germany in table 2.1 reveals that space heating represents the largest share of the total household energy use.

Table 2. 1 Distribution of building energy consumption per usage category

Distribution	Germany (%)	Finland (%)
Space Heating	75	66.7
Water Heating	12	14
Electric Appliances and Lighting	12	19
Cooking	1	0.3

A comparison of the energy usage for space heating from the year 1990 to 2009 reveals a reduction trend for the EU average usage with a ratio of 30-60%. This reduction was attributed to the implementation of thermal regulations from EU countries for new buildings.

However, the data provided in (Enerdata, 2015) for heat consumption per m^2 at normal climate conditions reveals that between the year 2000 and 2012, Germany recorded a 17.38% decrease in energy usage with figures 17.472koe/m^2 and 12.436koe/m^{2--} respectively while Finland recorded a 2.18% increase with figures 15.583koe/m^2 and 15.923koe/m^2 respectively. This implies a 21% energy usage difference for space heating for Finland and Germany for the year 2012.

Comparing the energy usage for electric appliances per dwelling for the year 2000 and 2012, the data given in (Enerdata, 2015) reveals that Germany recorded a slight 8.81% increase from 2078kWh to 2261kWh respectively and Finland recorded a significant 30.23% decrease from 4548kWh to 3173kWh respectively. This implies a 29% energy usage difference for electricity for Finland and Germany for the year 2012.

2.3 ENERGY SAVING MODELS FOR HOME AUTOMATION

The ecoMOD project by the University of Virginia given in (Foster, et al., 2007) entails the design, construction and evaluation of houses for energy efficiency. This project aims to achieve three objectives which are categorized by the authors as academic, environmental, and social. The academic objective aims to enable a continued research, the environmental aims at reducing energy consumption and careful selection of building materials. The social objective aims at providing affordable and comfortable homes for people living below the poverty line, and to develop a relationship between the community and the university. To achieve energy monitoring, a monitoring system was installed to retrieve sensory and actuation data every second and stores them with timestamps. This monitoring system comprised of cost effective sensors that measure temperature, humidity, air quality, water flow, electric usage for appliances, carbon dioxide level and wind speed. Sensory and actuation data were retrieved through a wireless connection and these were stored on a remotely accessible database. A detailed data analysis was conducted on a 20 day stored data using a custom developed web data-analytical application software and the data analysis results indicates that the HVAC[9] and water heating system constituted the larger portion of the energy consumption with both measuring 38% and 21% total energy consumption respectively. Also the result indicates a 50% and 45% reduction in the envisaged energy consumption of the building. The discrepancies between the envisaged consumption and the analysis result for the hot water heater and HVAC was not justified with measured data, however it correlated with the result of a similar study given in (Global eSustainability Initiative, 2008). This thesis will investigate these assumptions for different home scenarios using real automation data and energy measurements.

Kolokotsa, Rovas et al. (2011) presented a review of the technological developments for every constituent that supports future dynamic development of NZEB/PEB[10]. NZEB/PEB implies that the energy demand for heating and electrical appliances is reduced and the remnant energy demand is met on an annual basis from a renewable-energy source supply. NZEB will not only minimize the energy consumption of the building with passive design methods, but also a building design that balances energy requirement with active energy production techniques from renewable technologies. NZEB/PEB performance of a building is measured and evaluated using various indicators and these includes the net

[9] HVAC (heating, ventilation, and air conditioning) is the technology of indoor and vehicular environmental comfort. Its goal is to provide thermal comfort and acceptable indoor air quality. HVAC system design is a sub discipline of mechanical engineering, based on the principles of thermodynamics, fluid mechanics, and heat transfer. Refrigeration is sometimes added to the field's abbreviation as HVAC&R or HVACR, or ventilating is dropped as in HACR (such as the designation of HACR-rated circuit breakers).

[10] NZEB/PEB refers to a building with a zero or negative net energy consumption over a typical year.

primary energy consumption, net energy costs, and carbon emissions. To illustrate the challenges for energy optimization of a building and the control methodologies for NZEBs, two scenarios were defined. In the first, electricity can be purchased from the grid but cannot be sold. In the second, electricity can be purchased and sold at the same price. A graphic analysis of these scenarios resulted into the electricity generation and consumption curves. The electricity generation curve acted as a baseline while the consumption curve was adapted with proper control decisions to minimize or maximize an appropriate metric. Other identified measurement constraints and models are user thermal comfort and satisfaction, and indoor environmental quality according to CEN recommendations.

This paper identified future prospect which includes the installation of sensors and monitoring equipment to improve the thermal models. The installation of human detection, comfort sensors with a weather forecasting model that communicates with thermal controller were specifically recommended to improve the thermal comfort model. This thesis will design scenarios that incorporates the installation of human detection sensors and thermal control actuators to improve user thermal comfort.

As earlier stated, this paper also investigates scenarios of renewable energy installations. This thesis will continue in a similar light by reviewing various governmental regulations and policies, feed-in policy and all subsidies that can ensure the cost effective installation of renewable energy sources to achieve NZEB/PEB. Also scenarios with both smart system installation and renewable energy source installation will be designed with the aim of achieving NZEB/PEB and an analysis of the pay-back time and ROI of these installation will be duly investigated.

Smart gateways that incorporates power management features to substantially reduce the energy usage, reduce energy cost and carbon emission in residential buildings were introduced in (Tejani, et al., 2011). Alongside these gateways, sensors which communicates directly with the gateway were installed to feed the system with data regarding light intensity, temperature and motion within and outside the apartment. To achieve energy optimization, automation scenarios were designed to prevent human negligence from resulting into energy wastage.

Energy usage of devices were measured when the smart gateway was active and inactive for a year. The energy usage comparison between measurements with and without the smart gateway revealed a significant reduction in energy consumption of lighting, air-conditioner and heater for each room in the apartment. while the energy usage for uncategorized devices(white goods) remained unchanged with/without the gateway. This paper justifies the energy usage optimization capability of HMS for homes and it provides a detailed energy measurement of devices and their comparison with and without the HMS system.

This paper also suggests that the energy usage of some home appliances(e.g. fridges, laptops, desktop computers, pressing iron, vacuum cleaners, washing machine and the garage doors) cannot be further optimised by smart devices, because their energy usage with or without smart system installations are the same. Also the results from this paper suggests that electric fans consumes more energy with smart system installations, hence they should be left out of smart system installation. From the foregoing, it is assumed that all automation scenarios aimed at energy optimization should focus on lightings, air-conditioners and heaters. This thesis will simulate the scenarios presented in this paper to investigate the return on investment and pay-back time of smart system installation.

Also for other residential buildings types presented for this thesis, this thesis will design home automation scenarios to simulate identified user behaviours and smart system requirements; analyze the log files from these scenarios implementation on FHEM HMS; and compute the energy saving of each home appliance and the payback period and ROI for all smart installations.

2.5 HOME AUTOMATION INVESTMENT MODELS

The journal paper presented in (Christina, et al., 2008) proposes a model that enables decision makers to decide on investing in energy efficiency retrofit projects for buildings. This project involves the replacement of inefficient facilities with highly energy efficient ones. To achieve this, a two step approaches was proposed. Firstly, an energy expert carries out an energy analysis of the building and several alternative scenarios are developed and evaluated. Secondly, a multi-objective or multi-criteria decision making tool combined with simulations are applied to assist decision makers to reach a definite decision among the given set of alternatives. Based on this, a model was developed to maximizes energy saving, minimizes payback period of investments and a trade-off between the two. Genetic algorithm[11] was adopted to solve the multi-objective optimization models. Using this algorithm, an initial investment is given and a decision is made to optimize the objectives i.e. energy saving maximization and payback period of investment minimization. These objectives are represented with objective functions $f_1(x)$ *and* $f_2(x)$. $f_1(x)$ represents the ratio of the initial investment cost divided by the savings which resulted from the energy retrofit project. $f_2(x)$ is the sum of products of the quantity of retrofitted facilities and the quantity of energy saved. These objective functions form an optimization problem that is subjected to four constraints namely: the NPV[12], payback period, budget and the energy target. For the analysis, six cases with different budgets were considered and they all had budgets ranging between $62,500 and $375,000. For these cases, 25 energy inefficient facilities were replaced with efficient ones and the analysis result showed that initial investment increased the energy savings and the increase or decrease of payback period actually depended on a particular case under study.

While the focus of this paper was on the replacement of inefficient facilities with efficient ones to achieve energy efficiency for different cases, this thesis will study different smart strategies for different cases and will focus on the installation of smart systems to optimize energy usage and provide comfort and control to occupants. Also the investment gains associated with smart installations, the payback periods and the return on investment will be analyzed to determine which smart investment provides the quickest payback time and better investment return.

The return on investments in Information Technology as presented in (Bruce & Vernon J., 2002), formulates a model to guide future researches in the evaluation of information technology investment. This was achieved by proposing two general frameworks for considering the return on investment in IT that are measured with accounting performance measures (e.g. ROA). The first framework shows how IT has a direct and/or indirect effect on business processes which altogether determine the overall performance of the firm. The second framework categorizes how researchers have measured IT, business process performance and firm's performance. This framework highlights three ways in which IT investments are being examined and these are referred to as IT measures. These IT

[11] a genetic algorithm (GA) is a search heuristic that mimics the process of natural selection. This heuristic is routinely used to generate useful solutions to optimization and search problems.

[12] Net present value (NPV) or net present worth (NPW) is defined as the sum of the present values (PVs) of an entity.

measures includes: difference in the amount of money spent on IT; the type of IT purchased and how IT assets are managed. The authors of this paper referred to these as IT spending, IT strategy and IT management/capability respectively. Also as part of this framework, three paths that illustrates the relation between IT and overall firm performance were identified. The first path is a direct link between IT and firm performance thus bypassing the effects of IT on business processes. The second path describes the effect of IT on business process performance and the third path shows how these business process measures combines to determine the overall firm performance. This paper also identified some contextual factors that determines the links between IT and identified performance measures.

As a recommendation, this paper highlighted some research opportunities that could be further adopted for IT ROI researches from the following observations: Most literatures resulted in measuring the direct relations between IT and firm performance thus bypassing the underlying business processes either due to confounding issues or measurement problems. This approach as highlighted by the authors, is often inappropriate and this paper proposes that future works should demonstrate how IT directly affects the intermediate business processes and how a combination of these intermediate processes impacts firm performances. This paper also proposed an investigation of a triangulation model that singularly address IT in terms of IT spending, IT strategy and IT management/capacity and how a combination of these IT measures determines firms performance.

Taking a clue from this paper with a minimal tweak, the frameworks presented in this paper can be adopted as a methodology by examining the direct and indirect effect of smart investment on device performance and how a combination of device performances affect the overall building performance. Also as suggested, a triangulation model will be proposed to determine the flow of interaction between the smart strategy[13], smart investment[14] and smart management/capacity.

[13] Smart Strategy is the rationale for smart installation and the critical issue a system should address
[14] Smart spending is the total cost of smart system implementation and maintenance
Smart management and capacity: management deals with the total operational cost incurred by the smart system after deployment and capacity deals with the capability of the system.

2.6 NATIONAL POLICIES FOR BUILDING PERFORMANCE AND RENEWABLE ENERGY

The database tool presented in (Global Building Performance Network, 2013) is a comparative tool for national building energy polices. The German building policy commonly known as Energy Conservation Regulations (EnEV) provides a mandatory expectation of the primary energy consumptions of both residential and non-residential buildings. Similarly, the Finnish building policy known as the D3 also provides a mandatory monthly energy consumption expectation of residential and non-residential buildings. These regulations both covers Heating, Cooling, Dehumidification, Ventilation, Air tightness, Thermal bridging, Hot water, Technical installations, Lighting, Design, position & orientation of building, Passive cooling, Renewable Energy (solar, PV, others). A comparison of the U-value[15] of the building parts given in table 2.2 shows that the Finnish building are more insulated. However, a look at the HDD[16] and the CDD[17] values in table 2.3 reveals that Finnish buildings requires more energy for heating than the slight reduction posed by the CDD value compared to German buildings. These findings corroborates the energy usage disparity associated climatic difference as given in (Odyssee-Mure, 2012).

Table 2. 2 U-Value of Building Parts

U-Value (W/m²K)		
	Germany	Finland
Roof	0.2	0.09
Wall	0.28	0.17
Floor	0.28	0.09
Window	1.3	1.0
Window2	1.8	-
Others	1.4	-
Overall U-Value	-	-

Table 2. 3 HDD and CDD values of Buildings

	Germany	Finland
HDD(^oC)	3093	5380
CDD(^oC)	245	101

[15] A U value is a measure of heat loss in a building element such as a wall, floor or roof. It can also be referred to as an ‘overall heat transfer co-efficient’ and measures how well parts of a building transfer heat.
[16] Heat degree day is a measurement designed to reflect the demand for energy needed to heat a building. It is derived from measurements of outside air temperature.
[17] Cold degree day is the amount of energy used to cool a building

The Finnish submission for the national policy on renewable energy in (Energy Department, 2010), estimates a 327TWh energy consumption by 2020 and how a renewable energy source policy measures could yield 77TWh of energy by the year 2020.

The wind power is estimated to contribute 6TWh by the year 2020. To actualize this target, the Finnish government legislated in 2011, a market-based feed-in tariff for newly installed wind power plants at the rate of €105.30 per megawatt-hour until the end of 2015. From 2016, these prices will be reduced to € 83.50 per megawatt-hour. However wind power plant that are not on the Feed-tariff scheme will receive a fixed subsidy of €6.9 per megawatt-hour.

As part of the renewable energy quota, the Finnish government will increase CHP[18] production from wood chips to a 28TWh fuel equivalence by 2020. This is expected to gulp up 12 million m^3 of wood chips. Subsidies for this quota is given only for small-sized wood and this subsidy will cost approximately €36 million. A market-based feed-in tariff is introduced for solely electricity production, and this tariff is dependent on the cost of CO_2 emission permit for electricity production. A support of €18 per MWh is given for €10 per ton of CO_2 emission permit. All CHP electricity production not covered by the feed-in-tariff will automatically receive a subsidy of €6.90 per MWh.

A feed-in tariff of €83.50 per MWh is paid for electricity generated from biogas plants. Biogas plants not covered in the feed-in-tariff scheme and all electricity generated from Hydro-power will receive a fixed tariff of €4.20 per MWh.

The German renewable energy policy (EEG) in (Federal Ministry for the Environment, 2007) was introduced in the year 2000 and it is the foremost and most adopted renewable energy act. This is because of its success rate in placing Germany as the leading industrial nations in the renewable energy sector. Six year after its introduction, 12% of the total electricity consumption was supplied from renewable energy sources and over 100 million tons of CO2 emission was reduced. Core to this success is the priority given to electricity generated from renewable sources which mandates an easy connection to the grid system, a compulsory energy purchase for grid system operators and a guaranteed transmission and payment. Also the EEG guarantees a fixed feed-in tariff for electricity fed into the grid

[18] Cogeneration or combined heat and power (CHP) is the use of a heat engine or power station to simultaneously generate electricity and useful heat.

system. This Feed-in tariff is dependent on the type of technology used, the year the plant was manufactured and the size of the plant. Renewable energy source technologies allowed under this scheme includes Photovoltaic(PV), Biomass, Landfill and sewage treatment plant gases, wind power, geothermal and hydroelectric power Systems.

The Feed-in tariff for PV systems ranges from 37.96 - 49.21ct/kWh. Large installation with over 100kWp on open spaces records the lowest rate with 37.96ct/kWh, while small installations into buildings with capacity of less than 30kWp records a rate of 49.21ct/kWh and large installation into buildings with 30kWp-100kWp capacity records a rate of 46.82ct/kWp.

The Feed-in tariff for electricity produced from Biomas power plant with installation capacity of up to 150kW is 10.99ct/kWh; 9.46ct/kWh is paid for installation capacity of up to 500kW; 8.51 ct/kWh is paid for installation capacity of up to 5 MW; and 8.03 ct/kWh is paid for installations capacity of up to 20 MW. For landfill and mines plant with installations of up to 500 kW, a feed-in tariff of 7.33 ct/kWh is paid; with a capacity of up to and greater than 5 MW, a fee of 6.35 ct/kWh is paid.

The Feed-in tariff of a wind plant depends on the location of installation. Plants in less windy inland areas receives higher fee for longer period than those in coastal locations. The basic feed-in tariff for inland installations is 5.9ct/kWh, however for the first five years of installation, this fee is increased by 3.2ct/kWh. For off-shore installations, a basic tariff of 6.19ct/kWh is paid, however for the first twelve years of installation, an increased fee of 9.1ct/kWh is paid.

The Feed-in tariff for geothermal plant installations with a capacity of up to 5MW is 15ct/kWh. Installations of up to 10MW capacity receives 14ct/kWh, while installations of up to 20MW capacity receives 8.95ct/kWh and installations of over 20MW capacity receives 7.16ct/kWh.

The Feed-in tariff for micro hydro-electric power plant installation with capacity of up to 500kW is 9.67ct/kWh and 6.65ct.kWh is paid for a installation capacity of up to 5MW. Hydroelectric power plants with capacity between 5-150MW are considered as large plants and these receives the following rates. 6.44ct/kWh for capacity up to 10MW, 5.92ct/kWh for capacity up to 20MW, 4.42ct/kWh for capacity up to 50MW, and 3.58 for capacity over 50MW.

These details highlights the governmental supports for renewable energy source installation. However, for the residential homes in German and Finnish residential apartments, PV systems are mostly installed to improve the performance of a buildings. Hence, only PV systems will be investigated for these countries and their respective governmental support will be used to compute the ROI and payback time for these installations.

PV systems in Finland are only promoted through the tax system by granting an offset for the household. According to the journal given in (Mikko & Pertti, 2013), this may be due to the common misbelieve that sun does not shine in Northern Europe for PV systems to be lucrative. However the annual irradiation of southern Finland is said to be equal to annual irradiation to northern and mid-Germany. This journal compares the solar energy potential in Finland and in Germany. To achieve this comparison, data are acquired from free-standing crystalline silicon PV panels that are installed at optimal positions with cable and inverter losses of 14% in Finland and Germany. A look at the average electricity production from solar panels at horizontal positions indicates a smaller production for Finland compared to Germany, however at optimal positions, results indicates that the yearly electricity production is 5% more in Turku, Finland than in Hamburg, Germany and with the installation of 2-axis trackers, this production is even 10% more in Turku than in Munich during longer summer days in Finland. Solar panels cannot suffice for the power demand during the winter period (November - March), however from various measurements, it is observed a 2GWp PV installation can mitigate the power demand in Finland by 30% and this projects the solar energy production prospect as a viable energy source for Finland. This thesis will build on this assumption and investigate the economic prospect of PV installation without government incentives.

3. RESEARCH PROCESS

To Investigate the payback time and return on investment for smart home and renewable energy installations, logs from smart home installations are collected and interview are conducted to derive additional information from smart installations and renewable energy sources are issued to users. Log data from smart installations contains time stamped actuations and sensory information from actuator and sensor devices respectively. These logged information are defined and characterized by the functionality set of each smart device and the automation scenarios configured on the smart server. Thus for each actuator and sensory data, it is necessary to understand each smart device specification and capabilities, the log representation for each device's capabilities and analyze the scenario implementation on the smart server in order to understand and meaningfully interpret what actions resulted into the logged data and what actions are a consequence of these log data. Some data analysis methodologies are utilized for data gathering, error-free data preparation and data description using description statistics. These methodologies are discussed later in this chapter.

Home automation like any other system requires a substantial requirement's elicitation to adequately model user's requirements that are implemented as scenarios in the smart system. Also needed for adequate modelling, is an inspection of the domain of interest[19], an understanding of the interaction capabilities between the system, the user and the domain of interest which are modelled into automation scenarios, the rationale behind smart system implementation (smart strategy), the associated cost of smart implementation (smart spending/investment) and an expected gain or benefits(direct/indirect relation between smart systems and building performance) the system will proffer to end-users. These background information are needed to comprehend data patterns and for accurate scenario simulation and investigation. To extract these information, users are observed and actively engage in series of interviews. Information extracted from this process are classified as follows

a. Smart requirement specification
b. Environment of Interest
c. Smart Strategy

[19] Domain of Interest is a specific problem space is implied. It is the environment where the smart system will operate.

3.1 REQUIREMENT SPECIFICATION

The requirement specification for home automation are often influenced by user's behaviour and user's expectation of the smart home system also known as user requirements.

User Behaviour

This comprises of the daily routine and schedules of a user. This information set enable data analyst to understand reoccurring patterns in the automation log. Also since these behaviour is often a major backdrop and rationale for scenario design and implementation, it provides deeper insight into re-elicited user requirements. For example, a typical user behaviour might be the time an occupant is expected to leave and return to the apartment daily.

User Requirement

User requirement is a documentation of user's expectation of the smart home system. This defines explicitly all the necessary features the system should possess and it serves as a guide for designing user-defined automation scenarios and for selecting pre-defined automation scenarios to be implemented in the smart system. Elicited requirements identifies the basic priority of the user (in terms of energy optimization, device control and user comfort) and this helps to determine the smart strategy that suffices for user's expectation of the system.

3.2 DOMAIN OF INTEREST(DOI)

The domain of interest is a contextual factor that influences both the device measures and building performance and it is typically a categorization of apartments types where smart system installation are made. Apartment types contributes significantly to the decision making process of smart device selection and installation. Each apartment types highlights specific smart installation peculiarities (device measures). Two apartments types are considered:

1. The rented apartments and
2. The owned apartments.

Rented Apartment

Rented apartments are often guided by contractual agreements that spans a specified period between the occupant and the landlord. This contractual agreement may differ for different users, however the content of a contractual agreement and its contract period could influence user's decision on the level of modifications and improvements that may be made to the apartment. Generally, a user may prefer to install smart devices that requires less modification to the apartment and less hassle of installation and de-installation. With this constraints, the installation of some smart devices may not be feasible for this apartment type, hence hindering the possible implementation of some scenario that are dependent on the operations of such smart devices.

Owned Apartment

Owned apartments are either leased to users for a lifetime period, built or bought by a user. This apartment type present a clear retrofit advantage over rented apartments and also in terms of smart system and renewable energy source installations. Apart from these advantages, home retrofitting with regards to apartment modification and renovation that focuses on the replacement of energy inefficient parts of a building as explained in (Christina, et al., 2008), are also possibilities that could be adopted to optimize the overall energy consumption of the apartment. This apartment type presents no constraint in terms of the smart devices that could be installed. Also all automation scenarios could experimented and implemented for this DOI.

3.3 SMART STRATEGY

Taking a clue from the recommendations presented in (Bruce & Vernon J., 2002), a triangulation model is being proposed to determine the flow and hierarchy of interaction between the smart strategy, spending/investment and management/capacity. The smart strategy being the rationale for smart system installation determines the selection and definition of automation scenarios that could guarantee the realization of user's intentions. The automation scenarios in turn determines the type and cost of smart devices that are sufficient for an accurate smart implementation. Thus the smart strategy causally determines the smart spending/investment for a smart system. Also since the operational cost and the capabilities of a system are closely related to type of smart devices installed or utilized and the smart strategy determines the type of smart devices that enables an accurate implementation of the automation scenario, thus smart strategy also causally determines the smart maintenance/capacity. From the foregoing, it will be accurate to note that there exist a unidirectional relationship between smart strategy and smart spending, smart strategy and smart management and smart management and smart spending.

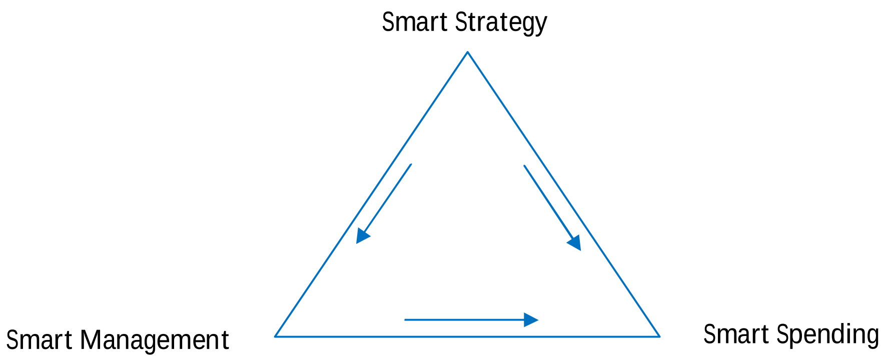


Figure 3. 1 Triangulation of Smart Implementation

Three smart strategies are identified for this study and these are:

1. Low Comfort & Low Energy optimization also known as No smart strategy
2. Medium Comfort & High Energy Optimization also known as Medium smart strategy
3. High Comfort & High Energy Optimization also known as High smart strategy

Based on the rationale of each automation scenario (smart strategy) and the smart spending that enables an accurate implementation of each scenario, the predefined automation scenarios given in appendix AI are grouped into the three identified smart strategies. Also because of the causal relationship between smart strategies and smart spending, these strategies could represents the different degree of smart spending a user can incur. The no smart strategy represents no smart spending, the medium smart strategy represents a medium smart spending/investment and the high smart strategy represents a high smart spending/investment.

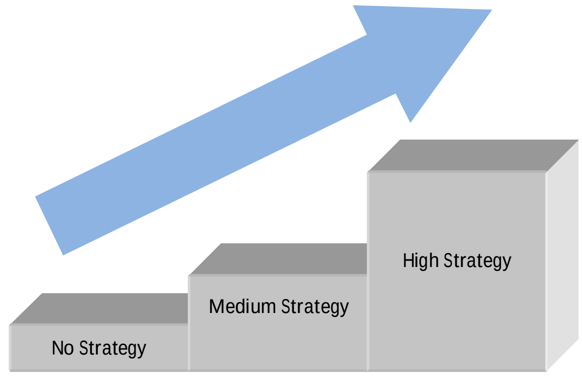


Figure 3. 2 Degree of Smart Spending

The indirect (level of control comfort/ control) relation of each smart strategy to overall building performance is duly highlighted in the scenario categorization given in appendix AII. Also the payback time and ROI (which represents the direct relation of the smart strategy on the building performance) for two smart strategies (the high and medium) will be computed for all domain of interest. The three smart strategies are distinguished as follows:

No Smart Strategy

This case involves no smart installation whatsoever, no cost is incurred, and all appliance controls are made manually by the user. This case gives the user uncomfortable control of appliances and it enables user negligence to result into significant energy wastage and inefficient resource utilization. For this degree of smart spending, scenario simulations will be utilized to compute the energy usage for this case. Prior to this simulation, data analysis will be carried out on collected automation logs to identify the operational patterns of home appliances at certain conditions and this patterns will be modelled mathematically to accommodate the behaviours of users. Also interviews about user's usage behaviour will be conducted for different domains of interest and these behaviours alongside the device models will be utilized to simulate usage scenarios for this case. The scenario simulation for this level of smart spending should yield information about the energy consumption of devices and its relative cost.

Medium Smart Strategy

This represents the first level of smart spending and the objective for a medium investor is to optimize the energy consumption of home appliances and to improve their basic control. Thus a medium smart strategy should enable users to easily control all devices (both heating and other electronic devices) and eliminate possibility of energy wastage due to user's negligence. To achieve this, smart investments for actuators are made to enable basic controls. These actuators are deployed strategically on energy consuming home appliances to significantly optimize their energy usage and reduce energy wastage due to user's negligence.

Also, a medium smart strategy usually implements simpler scenarios that are supported by most smart actuators. In general, it is assumed that a significant level of sensing is not required to achieve medium smart strategy, thus the cost of sensors and sensor installations are usually eliminated. To estimate the ROI and payback time of this investment, the log of all smart devices and home appliances are analyzed to derive their usage period, their energy consumption and their overall energy cost. The derived energy cost is weighted against the energy-cost of the no smart strategy case to derive the gain of investment. This gain alongside the investment cost is utilized to compute the ROI and payback time of this smart strategy.

High Smart Strategy

The high comfort & high energy optimization smart strategy should deliver a highly sophisticated scenario implementation, a full automatic control, and a high level of comfort to users while achieving energy optimization as well. It is assumed that this case is usually sought after by users that have experienced some medium degree of comfort and relative significant energy saving from the medium smart strategy. However to achieve a relatively higher comfort and level of control, additional information must be delivered to the smart system and these information can be guaranteed by the installation of additional sensors and actuators to achieve a more informed automation scenario. These additional sensors and actuators usually raises the initial investment cost and the energy usage of the smart system. These incurred additional costs are added to the Medium smart spending and the energy usage of the new smart devices are subtracted from the Medium investment energy gain. The new figures are used to compute the ROI and payback of the high smart strategy.

3.4 DATA ANALYSIS

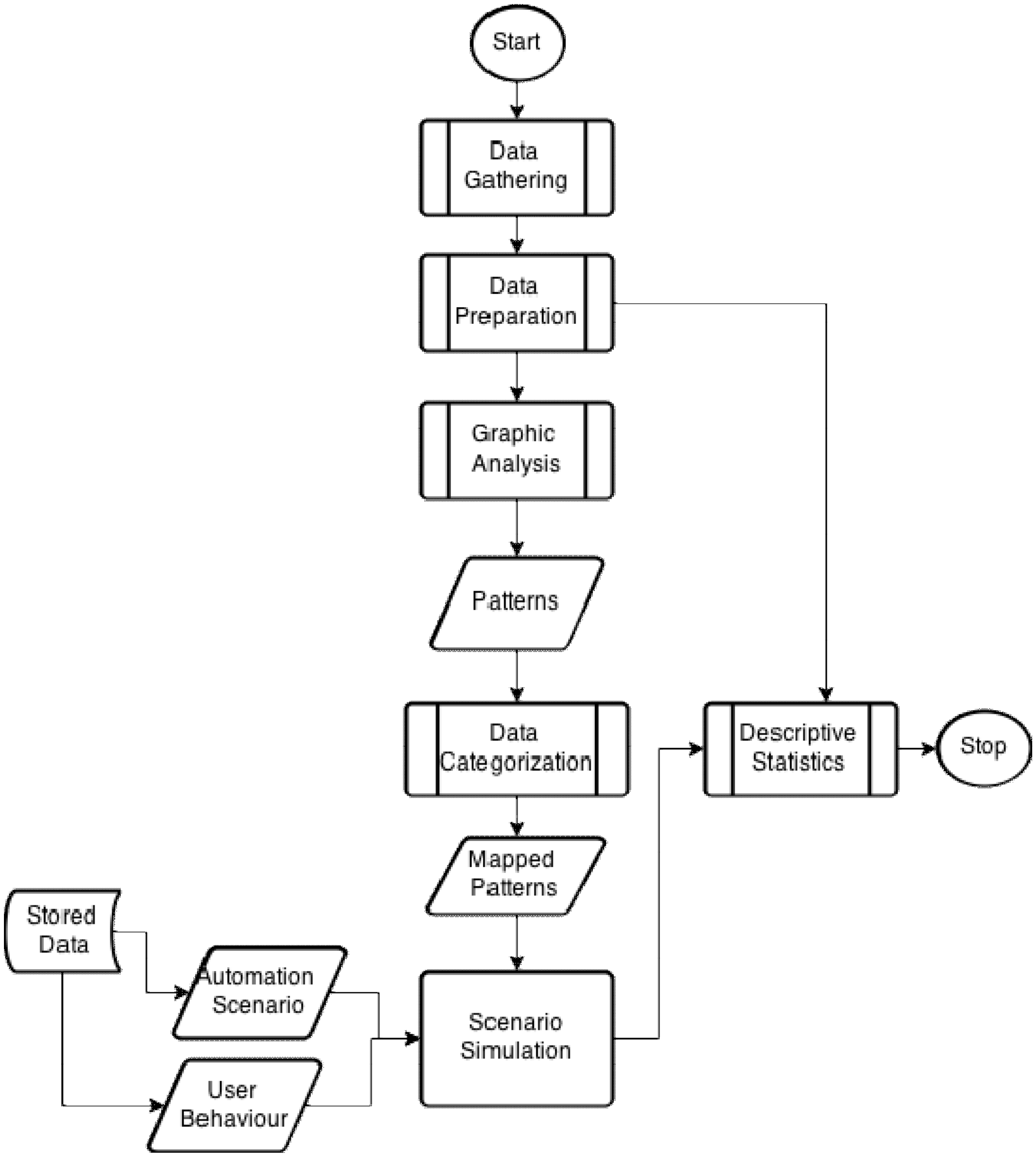


Figure 3. 3 Flow chart Data Analysis

Data analysis is the process of deriving meaningful information from a given data set, the techniques used and the tools that are sufficient for this purpose. Data analysis methodology is explored to describe all the data set presented for this study and to derive patterns associated with automation scenario and device operational specifications. Also mathematical functions are derived for computing the energy consumption of each appliance, the energy cost, the payback time and the return on smart Investment. The following processes and procedure are used for analyzing all data sets used for this study.

3.4.1. Data Gathering

Four data gathering mechanism are employed for this study

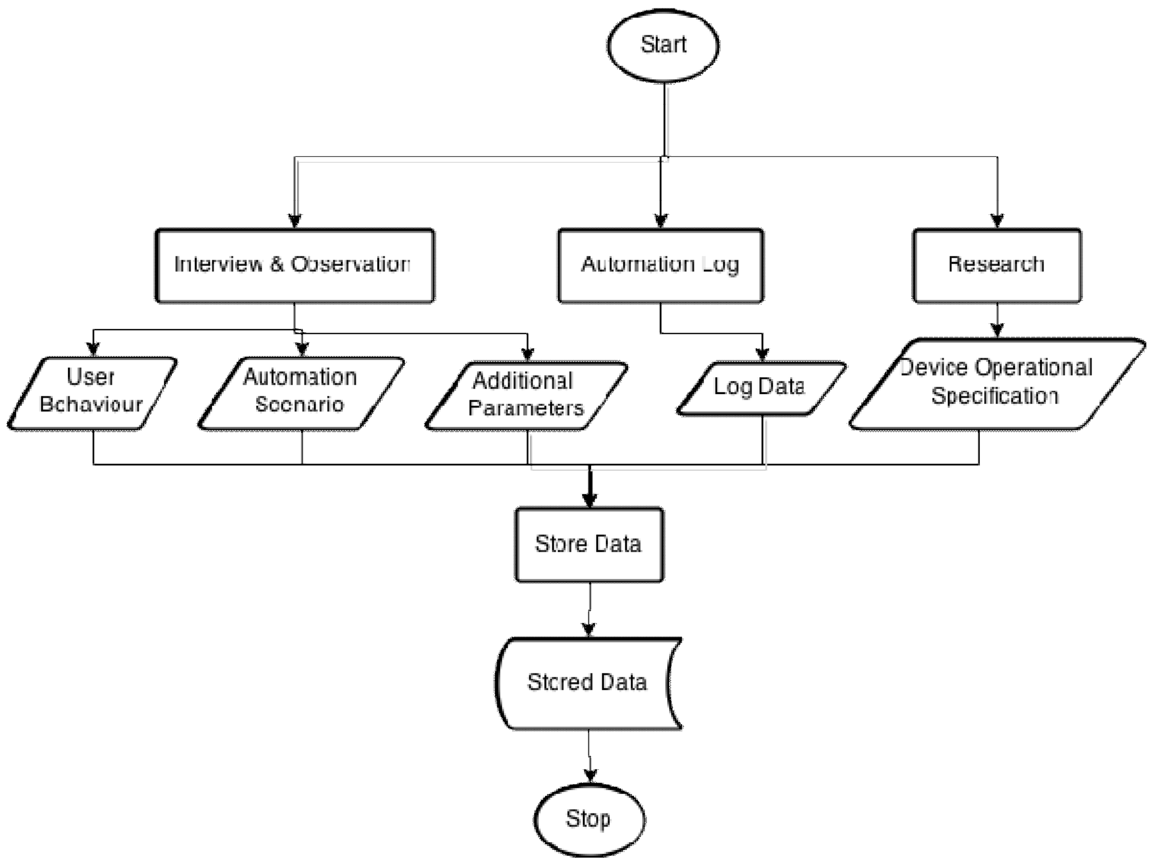


Figure 3. 4 Flow chart Data Gathering

Automation Logs

The automation logs are time stamped measurements of the environment. It stores every measurements and data from all the smart devices (sensors and actuators) that are coupled with the smart server and these data are used to identify device usage patterns, identify relationships and correlations between attributes and to derive the usage period and the energy usage of each device. The log will be the primary source for all mathematical computations for this study.

Interviews

Two kinds of users are interviewed for each domain of interest. These are:

1. User with smart installation: Prior to receiving any automation log, users are interviewed to understand their usage pattern and behaviour, the automation scenarios implemented on the smart system, the utility information of the apartment after smart installation and the smart strategy. This enables a proper understanding of the automation log, the smart devices and what series of events are necessary to cause other events. Also energy specifications for home appliances (wattage of devices in their active and stand-by mode) are collected.
2. Users without smart Installation: user's are observed for usage and behavioural patterns and a detailed interview is conducted to corroboration information gathered from these observations. This enables the creation of an approximate model of user's behaviour and usage patterns for each home appliances. Additionally, user's interest for smart installation are inquired and this helps to determine the smart strategy of their preference.
3. Others: other information gathered from conducted interviews includes concise specifications of home appliances and automation devices, smart installation dates and cost, incentives from government and energy consumption of the apartment and its relative cost. Similar information are gathered for renewable energy installation.

Research

The operational specifications and attributes of some home appliances are studied and documented. This documentation are used to formulate an approximate mathematical model of their operations during scenario simulation.

3.4.2 Preparation

Data preparation involves entering the data into the computer; checking the data for accuracy; transforming the data; and developing and documenting a database structure that integrates the various measures. (Trochim, 2006) This will be used to transform the automation log data into usable attributes.

Identify smart devices:

This involves performing a preliminary reading and understanding of the structure of the data entries in the automation log to identify devices acronyms and the different variables and value attributes associated with these devices.

Extract and Collate data:

Regular expressions are used to separate the data entries of each smart device into different files and these are used for the subsequent data analysis steps.

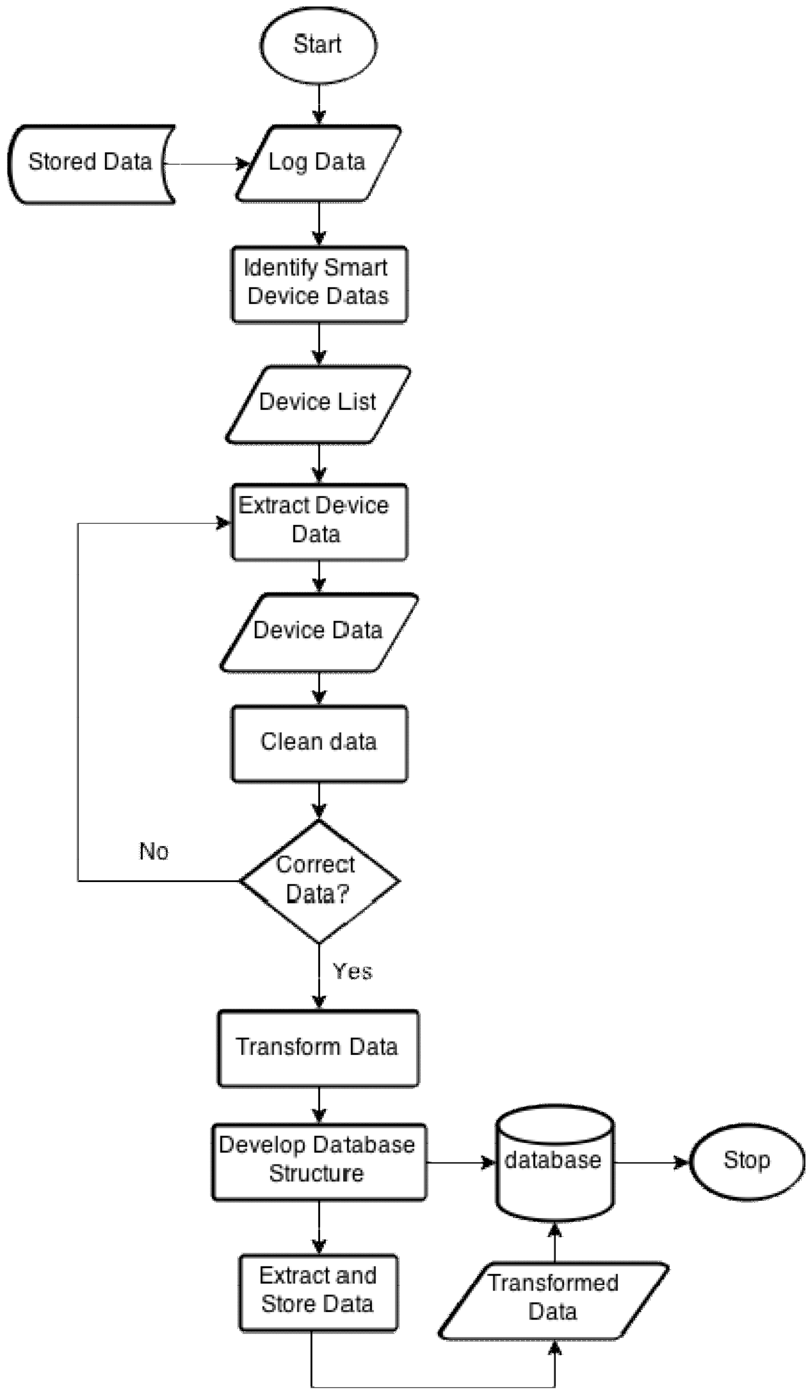


Figure 3. 5 Flow chart Data Preparation

Clean data:

Here, extracted data are checked for errors(or bug information) that could alter the results of data analysis (The Pell Institute for the Study of Opportunity in Higher Education, 2015). Two methods are utilized to check data

1. Eye-balling[20]: Firstly, the data is checked for errors that may have resulted from incorrect regular expressions, coding mistakes and bug information.
2. Spot-Checking[21]: here, that data in each file are correlated with the original log data.

Data Transformation:

Here, raw data are transformed into variables that are usable for data analysis and mathematical computation (Trochim, 2006). The cleaned data are closely examined to identify variables, variable attributes and their level of measurement (i.e. nominal, ordinal, Interval or ratio attributes) to determine what statistical analysis and mathematical computation are feasible. Identified variables represents the independent variables because they are direct measurements of the domain of interest by the smart system.

Develop Database Structure:

A database structure is defined according to identified independent variables. An SQL database program(MySQL) is being utilized to store variable attributes because of its high flexibility in data manipulations.

Extract and Enter the data into the database

A Perl program is developed to extract attributes for identified variables and store them into the pre-defined database tables. Spot checking and data summaries are used to identify and correct data entry errors. This steps presents the data in a tabular form and prepares it for various analysis and computation.

[20] This technique involves reviewing the data for errors that may have resulted from a data-entry or coding mistake.
[21] This technique involves comparing the raw data to the electronically entered data to check for data-entry and coding errors.

3.4.3. Analysis

Graphic Analysis

MySQL database management software provides visualization tools for stored data. These tools are utilized to visualize the data of each device to identify patterns. A line graph is utilized to identify the highs and lows of each dataset for its entire entry period and to determine if the pattern that exists are stochastic or regular in nature. If the pattern is stochastic, this may imply that no knowledge may be derived by viewing only the dataset, thus the variable attributes for that dataset may only be relevant for mathematical computations. If a regular graphical pattern exists, this may imply a scenario specification or device operational specification, thus the pattern is compared with implemented automation scenario and documented device operational specification. If there exists a correlation between these, a mapping is created and documented.

Data Categorization

After pattern recognition and data mapping, an algorithm is designed to categorize the log data according to identified mappings. If a dataset is mapped to device operational specification, a further categorization may be necessary according to its mode of operation. Perl programming language is used to implement specified algorithms that disaggregates data according to specified categories. Additionally, eyeballing and logic check[22] are used to verify the correctness and completeness of disaggregation.

Descriptive statistics

Determine Unit of Analysis

The unit of analysis is the level at which analysis is conducted and is the thing under study (Grosshans & Chelimsky, 1992).What is pertinent for the computation of the payback and ROI is the energy usage of each device and the cost rate of energy. Given a particular device type, the variables presented for each case in the log data will determine the sufficiency of the parameters necessary for the computation and what additional parameter obtained from observations and interviews may be needed to corroborate the available

[22] This technique involves a careful review of the electronically entered data to make sure that the answers to the different questions “make sense.

data. A mathematical function is formulated based on presented data and the units of computation to compute the overall energy usage and the incurred cost.

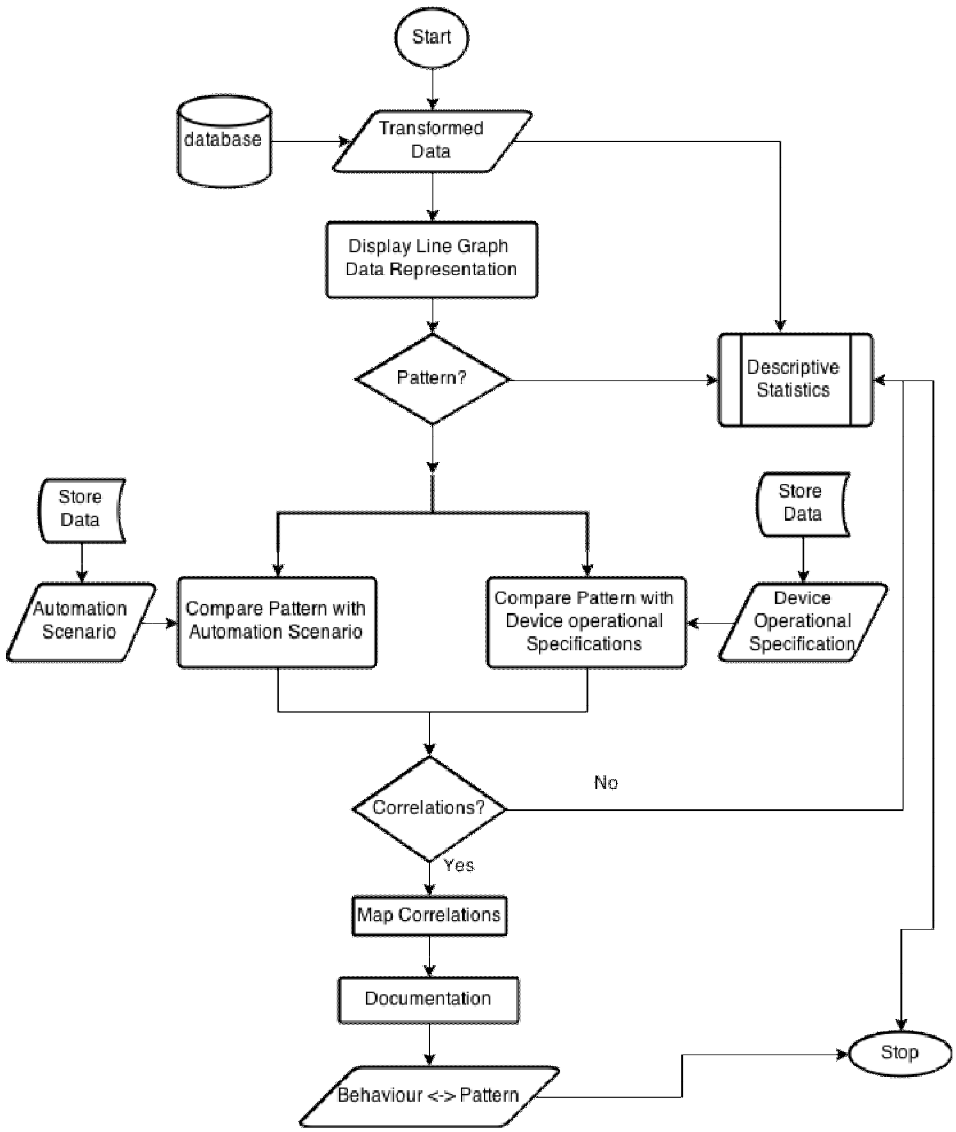


Figure 3. 6 Flow chart Graphic Analysis

Compute Energy Usage, Return on Investment and Payback time

The power consumption and the periods a device was operational as extracted from the log data is utilized to compute the energy usage of each device. The computed energy usage and the cost rate of energy are used to compute the energy usage cost incurred by each home appliance. The summation of all the incurred cost for all devices in an apartment, the energy savings of smart installation and the cost of home automation are used to compute the payback time and the return on smart investment for each apartment.

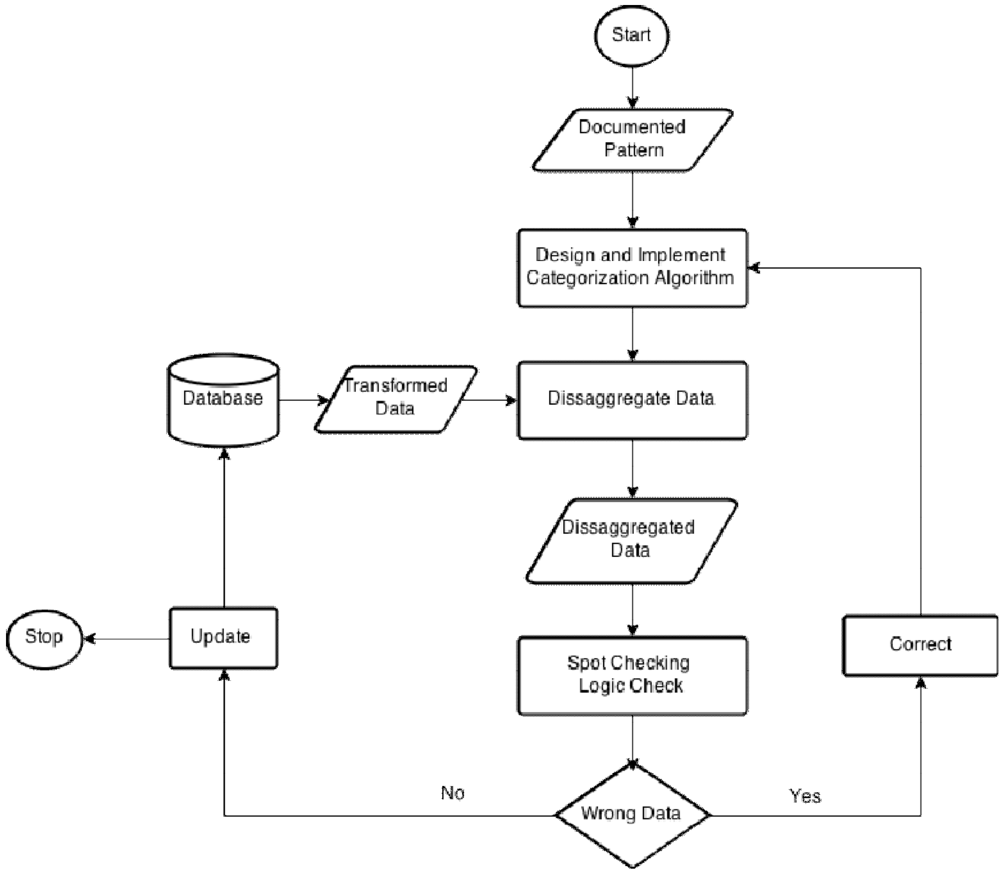


Figure 3. 7 Flow chart Data Categorization

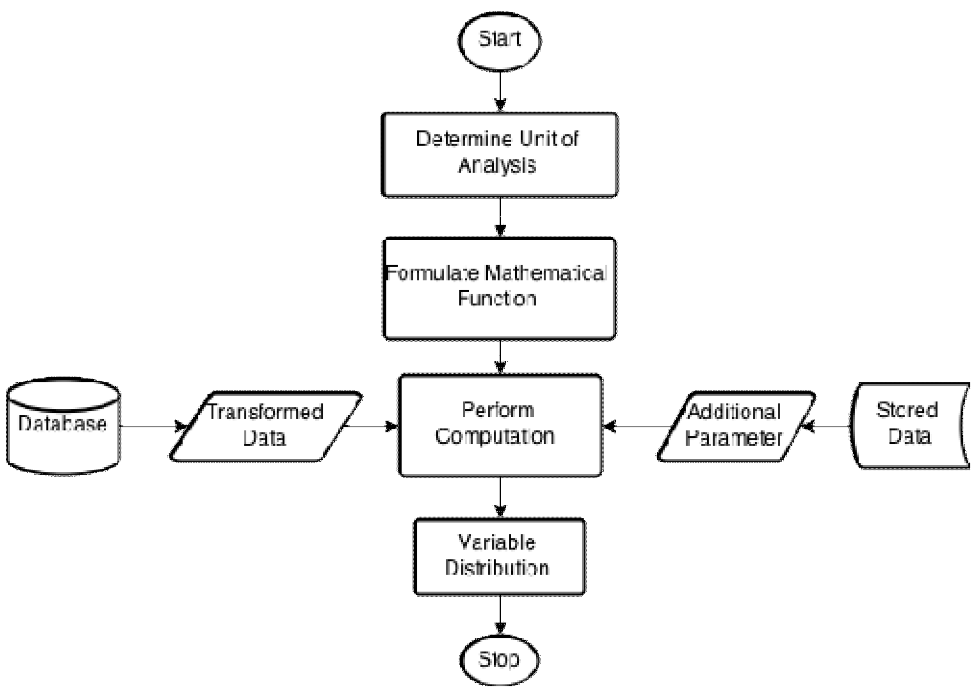


Figure 3. 8 Flow chart Descriptive Statistics

Variable Distribution

Energy cost distribution according to devices:

After the computation of the energy usage and the incurred energy cost for each devices, an energy usage distribution is created to show the variation across device. This is tabulated and a pie chart is utilized to highlight the energy usage proportions of each device in the apartment.

Energy usage distribution of according to week days, weeks of the year and month of the year:

The energy usage for each appliance is summed according to the each category to highlight the days, weeks and months with the most significant energy usage. An histogram chart is used to visualize the distribution of each category.

Cost saving comparison for devices

The energy cost for the three smart strategies for each device is visualised to determine their individual cost saving proportions. An histogram chart is used to visualize this comparison.

3.5 SCENARIO SIMULATION

Scenario simulation involves the reuse and application of documented user behavioural patterns, device operational specification patterns and the data categories identified during the data analysis stage to model similar scenarios. This will proffer an approximate estimate of energy usage of the simulated scenario, compute a smart investment return and payback time based on several educated assumptions.

4. SPECIFICATION OF USE CASES AND USER SCENARIOS

Scenarios are complex applications involving different interacting variables and conditions. According to (Cardoso, et al., 2005),

> *"Scenarios provides a combined 'space-time' understanding of the environment, which maps on a set of factors and parameters of the environmental, temporal, and personal nature."*

To satisfy this goal, ordinary people should be able to specify a set of conditions and/or operating points for environment factors, which determine the way of living in a certain space, at a certain time, with recourse to a library of pre-constructed functional models in the smart system. (Cardoso, Falcão et al., 2005)

It is the specification of these set of conditions and operating points that enables an accurate definition of user defined automation scenarios and the selections of pre-defined automation scenarios.

A complete user's requirement specification for the medium smart strategy and its associated smart spending/investment for the German scenario are presented for this study. Given this documentation, the high smart strategy equivalence for a similar requirement specification is simulated. Users without smart installations (no smart strategy) but with similar domain of interests are observed and interviewed and their respective user behaviours are extracted.

There exist no smart implementation for the Finnish scenario however, if it is assumed that the same smart users were to live in Finland, then the documentations for each domain of interest for the German scenario could be utilized to simulate its Finnish equivalence. However, the distinct average Fin behaviours (for instance sauna usage) extracted from observations and corroborated by interviews should be inculcated into these existing documentations. These behaviours, the automation scenarios and the smart devices that satisfies its implementation and the existing German documentation will constitute the Finnish scenario.

This chapter presents the German and Finnish scenarios for highlighted domains of interests, the three smart strategies for each scenario and their respective smart spending.

4.1. RENTED APARTMENT

The rented apartment selected for this study, comprises of a living room, a bedroom, and a bathroom. Each room contains at least a heat radiator, an electric socket to power electric devices and an overhead lamp. The Finnish scenario additionally comprises of a sauna room. The electronic appliance distribution for the rented apartment is given below.

Table 4. 1 Appliance Distribution for Rented Apartment

SN	Rooms	Devices
1.	Living Room	Lamp Heat Radiator Stereo
2.	Bathroom	Heat Radiator Washing machine
3.	Bedroom	Heat Radiator Wardrobe light
4.	Sauna Room	Lamp Sauna Stove

4.1.1. German Scenario

Requirement Specification

User Behaviour

The user

1. inhabits the apartment for the first four working days i.e. Monday till Thursday.
2. on special work occasions inhabits the apartment over the weekend.
3. often arrive to the apartment on Monday evening and leaves the apartment on Thursday morning.
4. daily leaves the apartment for work in the morning and arrives back in the evening.
5. uses the wash machine once a week for a period of 90 minutes.

User Requirement

The user

1. will require all heating radiators and other electronic devices to be switched off when the apartment is not occupied to avoid space conditioning, device safety and electricity wastage.
2. will require the apartment to maintain an habitable condition (temperature and humidity) when the apartment is occupied.
3. will require a comfortable control of all devices in the apartment.
4. will require an efficient energy usage and monitoring for the apartment.

Smart Strategy

High smart strategy

User-defined Automation Scenario

1. The desired room temperature of the heat radiator controller is set to 23^{o}C and the minimum room temperature is 18^{o}C.
2. The heat radiator controller should maintain the minimum temperature between the hours of 12:00am - 06:00am because the occupant is expected to be asleep.

Predefined Automation Scenario

All scenarios categorized under the High smart strategy are implementable for this case.

Smart Spending

To implement this scenario, the following smart devices are recommended:

Table 4. 2 Smart Spending for High Smart Strategy

SN	Rooms	Automation Devices	Unit Cost(€)	Total(€)
1.	Living Room	***Sensor***		
		1. Motion Detector	39,95	
		Actuator		
		2. Radio Wall Switch	33,95	
		3. Heating control	69,95	
		4. Wireless Switch Socket	39,95	183.8
2.	Bathroom	***Sensor***		

		1. Motion Detector	39,95	
		Actuator		
		2. Heating control	69,95	
		3. Radio Wall Switch	33,95	
		4. Wireless Switch Socket	39,95	183.8
3.	Sleeping Room	***Sensor***		
		1. Motion Detector	39,95	
		Actuator		
		2. Heating control	69,95	
		3. Radio Wall Switch	33,95	
		4. Wireless Switch Socket	39,95	183.8
4.	General	1. TuxRadio	70,00	70.00
TOTAL COST				**621.4**

Medium smart strategy

User-defined Automation Scenario

same as High smart strategy.

Predefined Automation Scenario

All scenarios categorized under the Medium smart strategy for this case.

Smart Spending

The following smart devices are recommended to implement the Medium smart strategy:

Table 4. 3 Smart Spending for Medium Smart Strategy

SN	Rooms	Automation Devices	Unit Cost(€)	Total(€)
1.	Living Room	***Actuator***		
		1. Radio Wall Switch	33,95	
		2. Heating control	69,95	
		3. Wireless Switch Socket	39,95	143.85
2.	Bathroom	***Actuator***		
		1. Heating control	69,95	

		2. Wireless Switch Socket	39,95	109.9
3.	Sleeping Room	***Actuator***		
		4. Radio Wall Switch	33,95	
		5. Heating control	69,95	
		6. Wireless Switch Socket	39,95	143.85
4.	General	2. TuxRadio	70.00	70.00
TOTAL COST				**467.6**

No smart strategy

The user behaviour extracted from observations and corroborated by conducted interviews for this case are as follows:

User Behaviour:

1. All lamps in the apartment are only switched on when they are needed.
2. All lamps are switched-off when the user is asleep.
3. To ventilate the apartment, the user switches off the heat radiator and opens the windows. This is done when the user wakes up and when the user gets back to the room for a period of 30 minutes each.
4. The heat radiator knob is set between 55-60% always.
5. All heat radiators are switched-off when the user will not return to the apartment the same day.

4.1.2. Finnish Scenario

Requirement Specification

User Behaviour

The distinct user behaviour for the Finnish scenario are as follows:

The user

1. reserves and uses the sauna facility for a period of 60 minutes weekly.
2. The sauna room is used during the periods 8:00pm - 10:00pm.

Level of Smart Investment

High smart strategy

User-Defined Automation Scenario

same as German smart strategy.

Predefined Automation Scenario

All scenarios categorized under the High smart strategy are implementable for this case.

Smart Spending

To implement this scenarios, the following devices are recommended:

Table 4. 4 Smart Spending for High Smart Strategy

SN	Rooms	Automation Devices	Unit Cost(€)	Total(€)
1.	Living Room	***Sensor***		
		1. Motion Detector	39,95	
		Actuator		
		2. Radio Wall Switch	33,95	
		3. Heating control	69,95	
		4. Wireless Switch Socket	39,95	183.8
2.	Bathroom	***Sensor***		
		1. Motion Detector	39,95	
		Actuator		
		2. Heating control	69,95	
		3. Radio Wall Switch	33,95	
		4. Wireless Switch Socket	39,95	183.8
3.	Sleeping	***Sensor***		
	Room	1. Motion Detector	39,95	
		Actuator		
		2. Heating control	69,95	
		3. Radio Wall Switch	33,95	
		4. Wireless Switch Socket	39,95	183.8

4.	Sauna Room	***Sensor***		
		1. Motion Detector	39,95	
		Actuator		
		2. ELV FS20 SH Switch module for FS20 DIN rail system	39,95	79,9
5.	General	1. TuxRadio	70,00	70.00
TOTAL COST				**701.3**

Medium smart strategy

User-Defined Automation Scenario

same as High smart strategy.

Predefined Automation Scenario

All scenarios categorized into the Medium smart strategy are implementable for this case.

Smart Spending

Based on the assumptions and user requirements, the following smart devices are recommended to implement this scenario:

Table 4. 5 Smart Spending for Medium Smart Strategy

SN	Rooms	Automation Devices	Unit Cost(€)	Total(€)
1.	Living Room	***Actuator***		
		1. Radio Wall Switch	33,95	
		2. Heating control	69,95	
		3. Wireless Switch Socket	39,95	143.85
2.	Bathroom	***Actuator***		
		1. Heating control	69,95	
		2. Radio Wall Switch	33,95	
		3. Wireless Switch Socket	39,95	143.85
3.	Sleeping Room	***Actuator***		
		1. Heating control	69,95	
		2. Radio Wall Switch	33,95	

		3. Wireless Switch Socket	39,95	143.85
4.	Sauna Room	***Actuator***		
		1. ELV FS20 SH Switch module for FS20 DIN rail system	39,95	39,95
5.	General	2. TuxRadio	70,00	70,00
TOTAL COST				**541.5**

No smart strategy

The user behaviour extracted from observations and corroborated by conducted interviews for this case are as follows:

User Behaviour:

1. All lamps in the apartment are only switched on when they are needed.
2. All lamps are switched-off when the occupant is asleep.
3. To ventilate the apartment, the windows are open while the heat radiator is switched on. This is done every day for a period of one hour.
4. The heat radiator knob is set between 80% always.
5. All heat radiators are switched-off when the user will not return to the apartment the same day

4.2. OWNED APARTMENT

4.2.1 Australian Scenario

The standard apartment for the Australian scenario in (Tejani, et al., 2011) comprises of a living room, a dining room, a kitchen, 3 bedrooms, 2 bathrooms and a garage. The table below highlights the appliance distribution in the apartment.

Table 4. 6 Appliance Distribution for Australian Owned Apartment

SN	Rooms	Appliances
1.	Living Room	1. Air Conditioners 2. Fans 3. Heat Radiator 4. Lights

		5. Television
2.	Dining Room	1. Fan 2. Lights
3.	Master Bed Room	1. Fan 2. Lights 3. Air Conditioner 4. Heater 5. Laptop
4.	Children's Bed Room	1. Fan 2. Lights 3. Air Conditioner 4. Heater 5. Desktop Computer
5.	Guest Bed Room	1. Fan 2. Lights 3. Air Conditioner 4. Heater
6.	Master Bathroom	1. Lights
7.	Common Bath Room	1. Lights
8.	Uncategorized	1. Garage Door 2. Washing Machine 3. Vacuum 4. Iron

The user behaviour, usage pattern and automation scenarios for the devices in the DOI in (Tejani, et al., 2011) are not provided and thus will not be investigated. However, the smart spending for each smart strategy are highlighted as follows:

High smart strategy

Table 4. 7 Smart Spending for High Smart Strategy

SN	Rooms	Automation Devices	Unit	Unit Cost(€)	Total(€)
1.	Living Room	***Sensor***			233.7

		Presence Detector	1	39,95	
		Actuator			
		Radio Wall Switch	1	33,95	
		Wireless Switch Socket	4	39,95	
2.	Dining Room	***Sensor***			
		Presence Detector	1	39,95	
		Actuator			
		Radio Wall Switch	1	33,95	
		Wireless Switch Socket	1	39,95	113.85
3.	Master Bed Room	***Sensor***			
		Presence Detector	1	39,95	
		Actuator			
		Radio Wall Switch	1	33,95	
		Wireless Switch Socket	4	39,95	233.7
4.	Children's Bed Room	***Sensor***			
		Presence Detector	1	39,95	
		Actuator			
		Radio Wall Switch	1	33,95	
		Wireless Switch Socket	4	39,95	233.7
5.	Guest Bed Room	***Sensor***			
		Presence Detector	1	39,95	
		Actuator			
		Radio Wall Switch	1	33,95	
		Wireless Switch Socket	3	39,95	193.75
	Master Bathroom	***Sensor***			
		Presence Detector	1	39,95	
		Actuator			
		Radio Wall Switch	1	33,95	73.9
	Common Bath Room	***Sensor***			
		Presence Detector	1	39,95	
		Actuator			
		Radio Wall Switch	1	33,95	73.9

	Uncategorized	***Sensor***			
		Presence Detector	1	39,95	
		Door window contact	1	22,95	
		Actuator			
		Radio Wall Switch	1	33,95	
		Wireless Switch Socket	2	39,95	
		Wireless Switch Socket repeater	1	49,95	226.7
	General	Raspberry pi		104,00	104,00
	TOTAL				**1253.5**

Medium smart strategy

Table 4. 8 Smart Spending for Medium Smart Strategy

SN	Rooms	Automation Devices	Unit	Unit Cost(€)	Total(€)
1.	Living Room	***Actuator***			
		Radio Wall Switch	1	33,95	
		Wireless Switch Socket	4	39,95	193.75
2.	Dining Room	***Actuator***			
		Radio Wall Switch	1	33,95	
		Wireless Switch Socket	1	39,95	73.9
3.	Master Bed Room	***Actuator***			
		Radio Wall Switch	1	33,95	
		Wireless Switch Socket	4	39,95	193.75
4.	Children's Bed Room	***Actuator***			
		Radio Wall Switch	1	33,95	
		Wireless Switch Socket	4	39,95	193.75
5.	Guest Bed Room	***Actuator***			
		Radio Wall Switch	1	33,95	
		Wireless Switch Socket	3	39,95	153.8
	Master Bathroom	***Actuator***			
		Radio Wall Switch	1	33,95	33.95
	Common Bath	***Actuator***			33.95

Room	Radio Wall Switch	1	33,95	
Uncategorized	***Actuator***			
	Radio Wall Switch	1	33,95	
	Wireless Switch Socket	2	39,95	
	Wireless Switch Socket repeater	1	49,95	123.85
General	Raspberry pi	1	104,00	104.00
TOTAL				**1104.7**

4.2.2 German Scenario

The owned apartment considered for the German Scenario comprises of three bedrooms, a living room, one bathroom and an office area. These rooms contains at least light fittings or an overhead lamp and one heat radiator. Apart from these, the bathroom are equipped with an additional mirror lamp. The Finnish case additionally comprises of a sauna room which contains a sauna stove and a lamp. The appliance distribution for the apartment are summarized in the table below.

Table 4. 9 Appliance Distribution for German Standard Apartment

SN	Rooms	Devices
1.	Living Room	Lighting Heat Radiator
2.	Bathroom	Lighting Heat Radiator
3.	3 Bedrooms	Lighting Heat Radiator
4.	Office Space	Lighting Heat Radiator
5.	Sauna Room	Lamp Sauna Stove

Requirement Specification

User Behaviour

The users

1. inhabits the apartment throughout the week
2. leaves the apartment in the morning by 9:00 and arrives back in the evening by 17:00. This occurs from Monday to Friday.
3. stays at the apartment on weekends all day.

User Requirement

The users

1. will require the heater and all electronic devices to be switched off when the apartment is not occupied to avoid space conditioning and electric energy wastage.
2. will require that the apartment maintains an habitable condition (temperature and humidity) when the apartment is occupied.
3. will require that all the freezers and fridges be switched on at all times.
4. will require a comfortable control of all electronic devices and heat radiator controller in the apartment.
5. will require an efficient energy usage and energy monitoring for the apartment.

Smart Strategy

High smart strategy

User-defined Automation Scenario

Scenario 1: The desired room temperature of the heat radiator controller is set to 21^{o}C and the minimum room temperature is set to 17^{o}C

Scenario 2: On weekdays, all electronic appliances in the occupied area of the apartment should be placed on stand-by and the heat radiator should maintain the desired temperature from 06:00 - 09:00 and from 17:00 - 23:00.

Scenario 3: On weekends, all electronic appliances in the occupied area of the apartment should be placed on stand-by and the heat radiator should maintain the desired temperature from 06:00-22:00.

Scenario 4: The heat radiator controller should be maintain the minimum temperature between the hours of 00:00am - 06:00 because the occupant is expected to be asleep.

Scenario 5 : All fridges and freezers should be switched-on at all times.

Predefined Automation Scenario

All scenarios categorized under the High smart strategy are implementable for this case.

Smart Spending

The following set of smart devices are recommended to implement these scenarios:

Table 4. 10 Smart Spending for High Smart Strategy

SN	Rooms	Automation Devices	Unit Cost(€)	Total(€)
1.	Living Room	***Sensor***		
		1. Presence Detector	39,95	
		Actuator		
		2. Radio Wall Switch	33,95	
		3. Heat radiator control	69,95	
		4. Uniroll	84,95	228.8
2.	Bathroom	***Sensor***		
		1. Presence Detector	39,95	
		Actuator		
		2. Radio Wall switch	33,95	
		3. Heat radiator control	69.95	143.85
3.	3 Bedrooms	***Sensor***		
		1. Presence Detector	39,95	
		Actuator		
		2. Radio Wall Switch	33,95	
		3. Heat radiator control	69,95	
		4. Uniroll	84,95	686.4
4.	Office	***Sensor***		
		1. Presence Detector	39,95	
		Actuator		
		2. Radio Wall Switch	33,95	
		3. Heat radiator control	69,95	
		4. Uniroll	84,95	228.8

5.	General	1. Raspberry pi	104,00	
		2. Optolink	40	
		3. Viessmann Vitotronic	219,00	363.00
TOTAL COST				**1649.85**

Medium smart strategy

User-Defined Automation Scenario

same as High smart strategy

Predefined Automation Scenario

All scenarios categorized under the Medium smart strategy are implementable for this case.

Smart Spending

The following devices are recommended to implement the automation scenario

Table 4. 11 Smart Spending for Medium Smart Strategy

SN	Rooms	Automation Devices	Unit Cost(€)	Total(€)
1.	Living Room	***Actuator***		
		1. Radio Wall Switch	33,95	
		2. Heat radiator control	29,95	
		3. Uniroll	84,95	148.85
2.	Bathrooms	***Actuator***		
		1. Radio Wall switch	33,95	
		2. Heat radiator control	69.95	103.9
3.	3 Bedrooms	***Actuator***		
		1. Radio Wall Switch	33,95	
		2. Heat radiator control	29,95	
		3. Uniroll	84,95	446.55
4.	Office	***Actuator***		
		1. Radio Wall Switch	33,95	
		2. Heat radiator control	29,95	

		3. Uniroll	84,95	148.85
5.	General	1. Raspberry pi	104,00	
		2. Optolink	40,00	
		3. Viessmann Vitotronic	219,00	363.00
TOTAL COST				**1211.15**

No smart strategy

The user behaviour extracted from observations and corroborated by conducted interviews for this case are as follows:

User Behaviour:

1. All Lamps in the apartment are only switched on when they are needed and are switched-off when they are not in use.
2. All lamps are switched-off when the users are asleep.
3. To ventilate the apartment, the windows are open and the heat radiator is switched off. This is done every day for a period of one hour.
4. The heat radiator knob is set at 57.5% when the heat radiator is switched-on.

4.2.3 Finnish Scenario

Requirement Specification

User Behaviour

The user behaviour for this scenario is the same as that of the German scenario however, the Finnish user additionally uses the sauna facility for a period of 60 minutes weekly.

User Requirement

Same as the German User Requirement

Smart Strategy

High smart strategy

User-defined Automation Scenario

Same as the German user-defined automation scenario for High smart strategy .

Predefined Automation Scenario

All scenarios categorized under the High smart strategy are implementable for this case.

Smart Spending

The following set of automation devices are recommended to implement this strategy:

Table 4. 12 Smart Spending for High Smart Strategy

SN	Rooms	Automation Devices	Unit Cost(€)	Total(€)
1.	Living Room	***Sensor***		
		1. Presence Detector	39,95	
		Actuator		
		2. Radio Wall Switch	33,95	
		3. Heat radiator control	69,95	
		4. Uniroll	84,95	228.8
2.	Bathroom	***Sensor***		
		1. Presence Detector	39,95	
		Actuator		
		2. Radio Wall switch	33,95	
		3. Heat radiator control	69.95	143.85
3.	3 Bedrooms	***Sensor***		
		1. Presence Detector	39,95	
		Actuator		
		2. Radio Wall Switch	33,95	
		3. Heat radiator control	69,95	
		4. Uniroll	84,95	686.4
4.	Office	***Sensor***		
		1. Presence Detector	39,95	
		Actuator		
		2. Radio Wall Switch	33,95	
		3. Heat radiator control	69,95	
		4. Uniroll	84,95	228.8
5.	Sauna Room	***Sensor***		79.9

		1. Motion Detector	39,95	
		Actuator		
		2. ELV FS20 SH Switch module for FS20 DIN rail system	39,95	
6.	General	4. Raspberry pi	104,00	
		5. Optolink	40	
		6. Viessmann Vitotronic	219,00	363.00
TOTAL COST				**1730.75**

Medium smart strategy

User-Defined Automation Scenario

same as High smart strategy

Predefined Automation Scenario

All scenarios categorized under the Medium smart strategy are implementable for this case.

Smart Spending

The following devices are recommended to implement the automation scenario:

Table 4. 13 Smart Spending for Medium Smart Strategy

SN	Rooms	Automation Devices	Unit Cost(€)	Total(€)
1.	Living Room	***Actuator***		
		1. Radio Wall Switch	33,95	
		2. Heat radiator control	29,95	
		3. Uniroll	84,95	148.85
2.	Bathrooms	***Actuator***		
		1. Radio Wall switch	33,95	
		2. Heat radiator control	69.95	103.9
3.	3 Bedrooms	***Actuator***		
		1. Radio Wall Switch	33,95	
		2. Heat radiator control	29,95	

		3. Uniroll	84,95	446.55
4.	Office	***Actuator***		
		1. Radio Wall Switch	33,95	
		2. Heat radiator control	29,95	
		3. Uniroll	84,95	148.85
5.	Sauna Room	***Actuator***		
		1. ELV FS20 SH Switch module for FS20 DIN rail system	39,95	39,95
6.	General	1. Raspberry pi	104,00	
		2. Optolink	40,00	
		3. Viessmann Vitotronic	219,00	363.00
TOTAL COST				**1251.1**

No smart strategy

The user behaviour extracted from observations and corroborated by conducted interviews for this case are as follows:

User Behaviour:

1. All the lamps in the apartment are only switched on when they are needed
2. All lamps are switched-off when the users are asleep.
3. To ventilate the apartment, the windows are open while the heat radiator is switched on. This is done every day for a period of one hour.
4. The heat radiator knob is set at 80% when the heat radiator is switched-on.

5. DATA ANALYSIS AND SCENARIO SIMULATION

This chapter aims to measure the effects (device measures[23]) of identified smart measures on device performance and how the combination of these device measures affects the overall building performance as specified in path 2 and 3 respectively in figure 5.1. A typical measure of device performance is the rate at which energy usage is being optimized or the ease of device control and management. This thesis is primarily concerned about energy optimization measure and how an aggregation of these measures will enable an accurate measurement for building performance.

Path 1 does not provides an in-depth insight into the energy optimisation capabilities of installed smart devices and it will only be utilized when there exists no additional information apart from the overall energy usage of the building with and without home automation, thus this path will be avoided as suggested in (Bruce & Vernon J., 2002).

This chapter will use the data analysis methodology identified in chapter three to compute the device measures and building measures for the domain of interests with smart system installation while scenario simulations will be utilized for the domain of interests without smart installation.

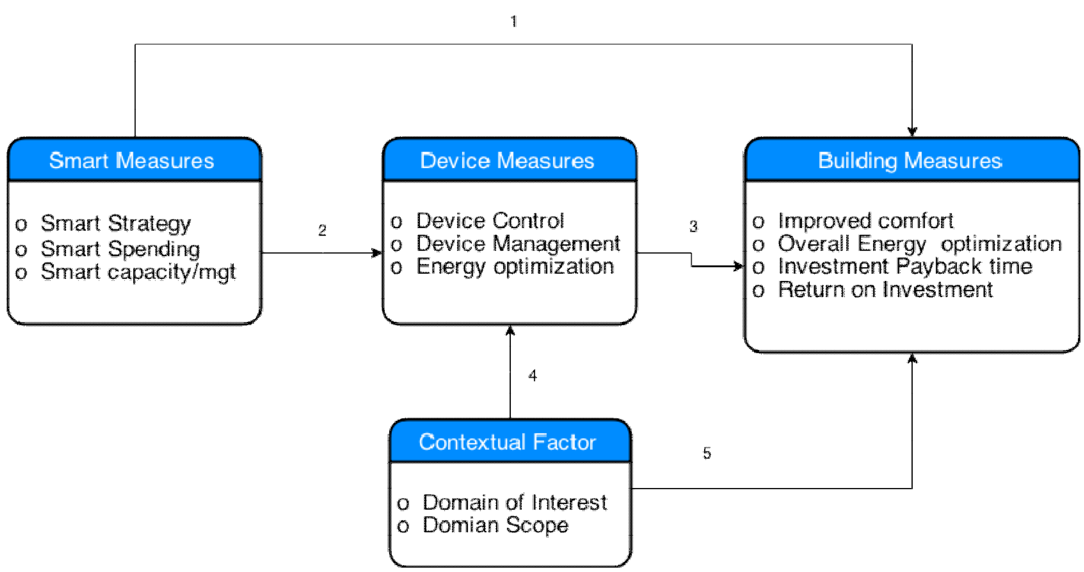


Figure 5. 1 Measures of Entity performance

[23] Measures are the yardsticks for measuring the effects of an entity on another entity.

5.1 RENTED APARTMENT

5.1.1 DATA ANALYSIS

German Medium Smart Strategy

The rate for electricity in Germany is €0.25 per kWh (Eurostat, 2014) and the electricity bill for a year for all electric appliances for the rented apartment with this smart strategy is €391.75. This includes energy usage from white goods (e.g. TV, oven, fridge, cookers) with no energy usage measurements or data log from the installed smart system, hence these appliances will be termed other appliances. Also, the bill for heating for the same period is € 806.60.

Living Room

Lamp:

Graphic Analysis

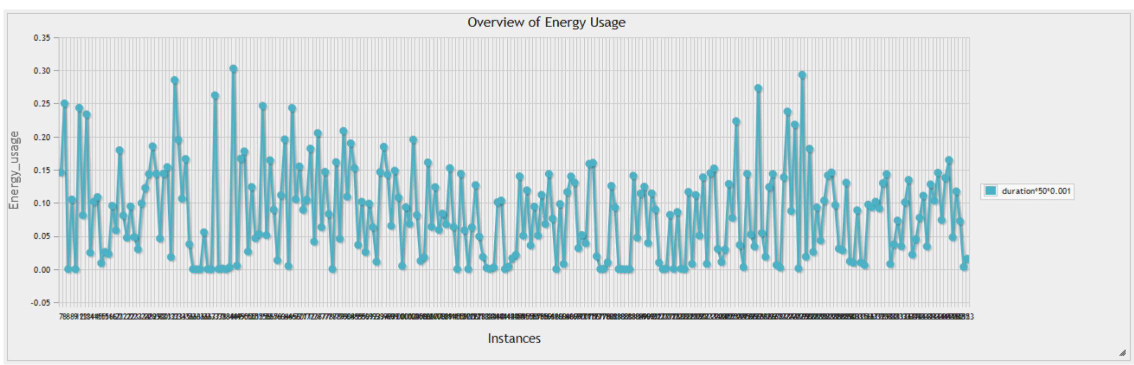


Figure 5. 2 Graphic Analysis for Lamp

No reoccurring pattern is identified from figure 5.2, hence the analysis proceeds to descriptive statistics.

Descriptive Statistics

The smart system logs the periods when the lamp is turned on or off. This is translated into the duration (in hours) of usage for the lamp. This duration alongside the wattage of the lamp and the electricity rate of the country can be used to derive the following:

$$\boldsymbol{Electricity\ usage\ (kWh) = Power\ of\ Device(kW) * Duration\ of\ use\ (hour)}$$

Equation 5. 1 Electricity Usage with Smart Device

$$\boldsymbol{Electricty\ cost\ (€) = Electricity\ usage\ (kWh) * Rate(€/kWh)}$$

Equation 5. 2 Electricity Cost with Smart Device

The wattage of the lamp is $50W$ and its total usage period is $417.4\ hours$ for a period of $160\ day$ for the year under study. Hence,

$$Electricity\ usage\ (kWh) = 50 * 0.001 * 417.4 = 20.872$$

$$Electricity\ Cost\ (€) = 20.872 * €\,0.25 = 5.218$$

The energy usage distribution for the lamp according to the days of the week and month of the year are given in the figures below:

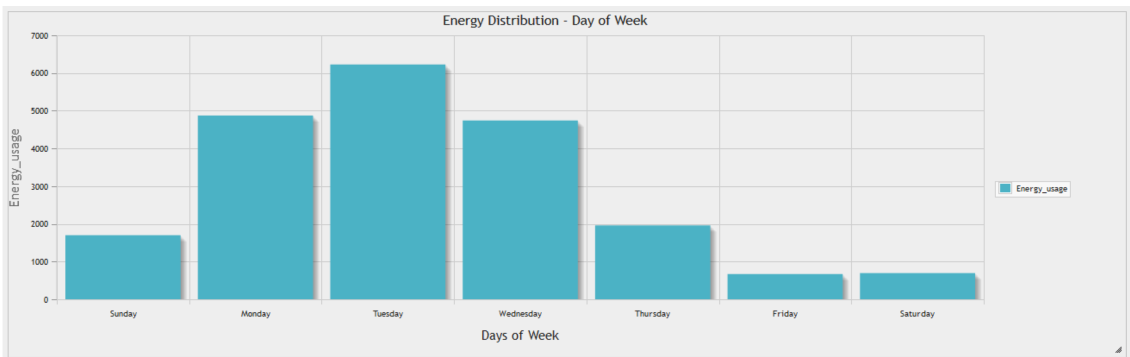


Figure 5. 3 Energy Usage distribution for the Days of the Week

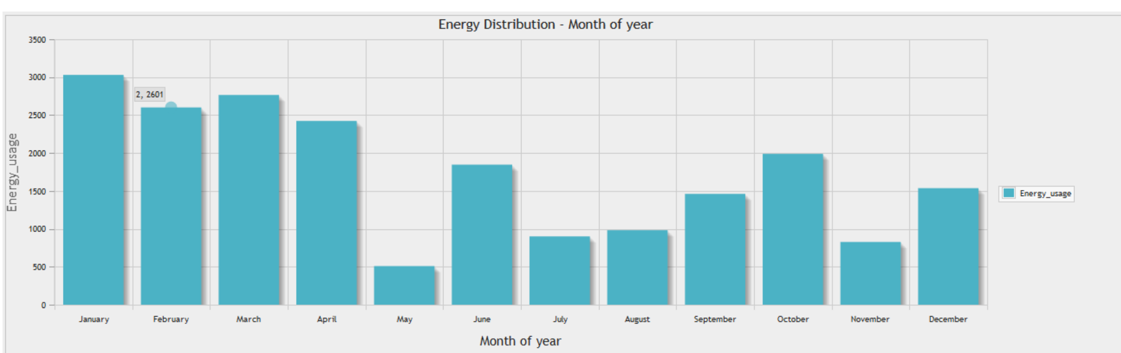


Figure 5. 4 Energy Usage distribution for the months of the year

Heat Radiator:

Graphic Analysis

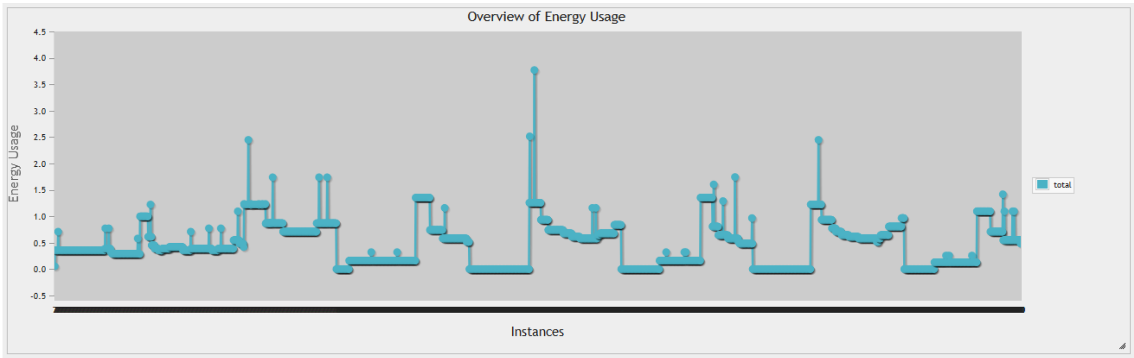


Figure 5. 5 Graphic Analysis for Heat radiator

From figure 5.5, some reoccurring patterns can be seen, these patterns are highlighted in figure 5.6

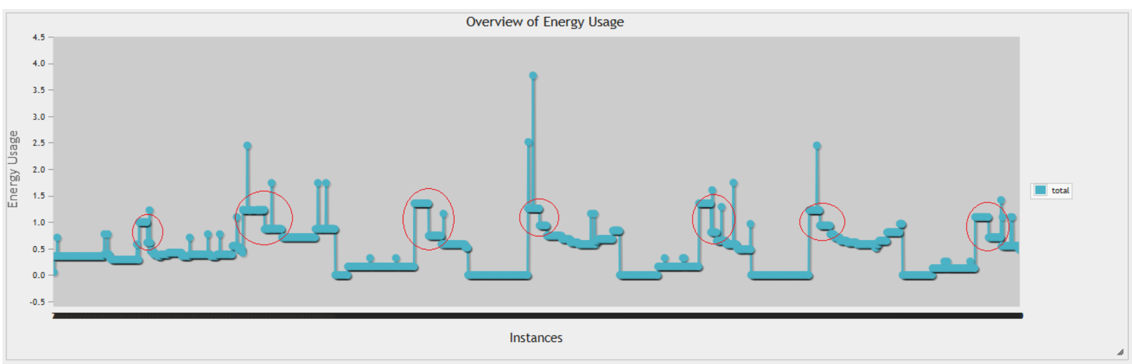


Figure 5. 6 Highlighted patterns for Heat radiator

A closer look at one instance of the pattern in figure 5.7 and 5.8 reveals that this behaviour represents the operational specification of a Thermostat Radiator Valve(TRV) as specified in the appendix AIII, thus the pattern is mapped to the operational specification of a TRV.

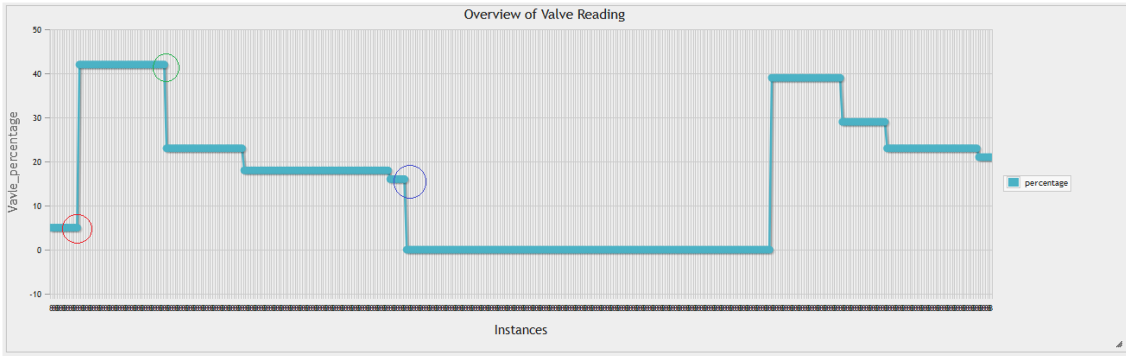


Figure 5. 7 An instance of the identified pattern showing valve position

The valve reading is compared with the desired and measured temperature data

An instance of the identified pattern showing valve position

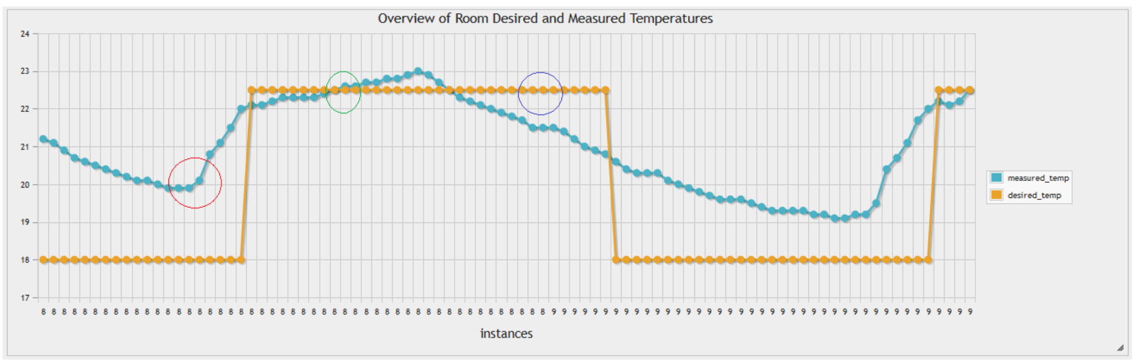


Figure 5. 8 An instance of the identified pattern showing temperature values

The red circle in figures 5.7 and 5.8 indicates the instances at which a new desired temperature was set by the smart system. It can be observed that heat radiator achieved a significant peak valve position of 42% when a desired temperature of 22.5^{o}C was set and this peak value was maintained for a period of 72 minutes until the desired temperature was attained. The green circles indicates the periods when the desired temperature was attained and at this point the TRV tries to maintain the desired room temperature by reducing the valve position to 23% and then to 18% and then to 16%. The blue circle indicates when the TRV was switched off by the smart system. The moments between the blue circle and the next peak represents an automation scenario that switches off the heat radiator when the apartment is not occupied by the user.

Data Categorization

Similar patterns were studied to derive a standard pattern for data categorization. This study shows that for any TRV operation, there are periods when the heat radiator tries to attain the desired room temperature and maintain the attained temperature. These periods are referred to as the peak periods and maintenance periods respectively. For formality, a peak period is between the instance the smart system sets a new desired room temperature and the instance this desired temperature is achieved. The maintenance period is the between the instance the desired room temperature is achieved and the instance the heat radiator is being switched off by the smart system.

A Perl application program and a MySQL query for categorizing the valve position and temperature data for the identified periods (peak and maintenance) according to the algorithm defined in figure 5.9 are given in appendix BI. The Perl program is used to insert the temperature data, instances and durations according to these periods while the MySQL query is used to disaggregate the TRV valve position data according to the temperature periods.

Descriptive Statistics

The smart system logs the periods when the heat radiator changes its valve position, when a new desired room temperature is set and a periodic measurement of the room temperature. From these, the valve reading and the duration for each valve reading can be extracted and be used to formulate the following:

$$\textbf{\textit{S.H.E.(Space Heating Energy) usage}}(\%\boldsymbol{h}) \\ = \textbf{\textit{Radiator Valve Reading}}(\%) * \textbf{\textit{Duration of use}}(\textbf{\textit{hour}})$$

Equation 5. 3 Heat Usage with Smart Device

Given the bill for heating, the cost rate for heat usage and the cost of heating can be derived as follows

$$\textbf{\textit{Rate}}\ (€/\%\boldsymbol{h}) = \frac{\textbf{\textit{Utility Bill}}(€)}{\sum_{0}^{n} \mathbf{S.H.E}\ \textbf{\textit{usage}}(\%\boldsymbol{h})}$$

Equation 5. 4 Rate of Heat Usage

$$\mathbf{S.H.E.}\ \boldsymbol{Cost}(€) = \boldsymbol{Heat\ usage}(\%\boldsymbol{h}) * \boldsymbol{Rate}(€/\%\boldsymbol{h})$$

Equation 5. 5 Heat Cost

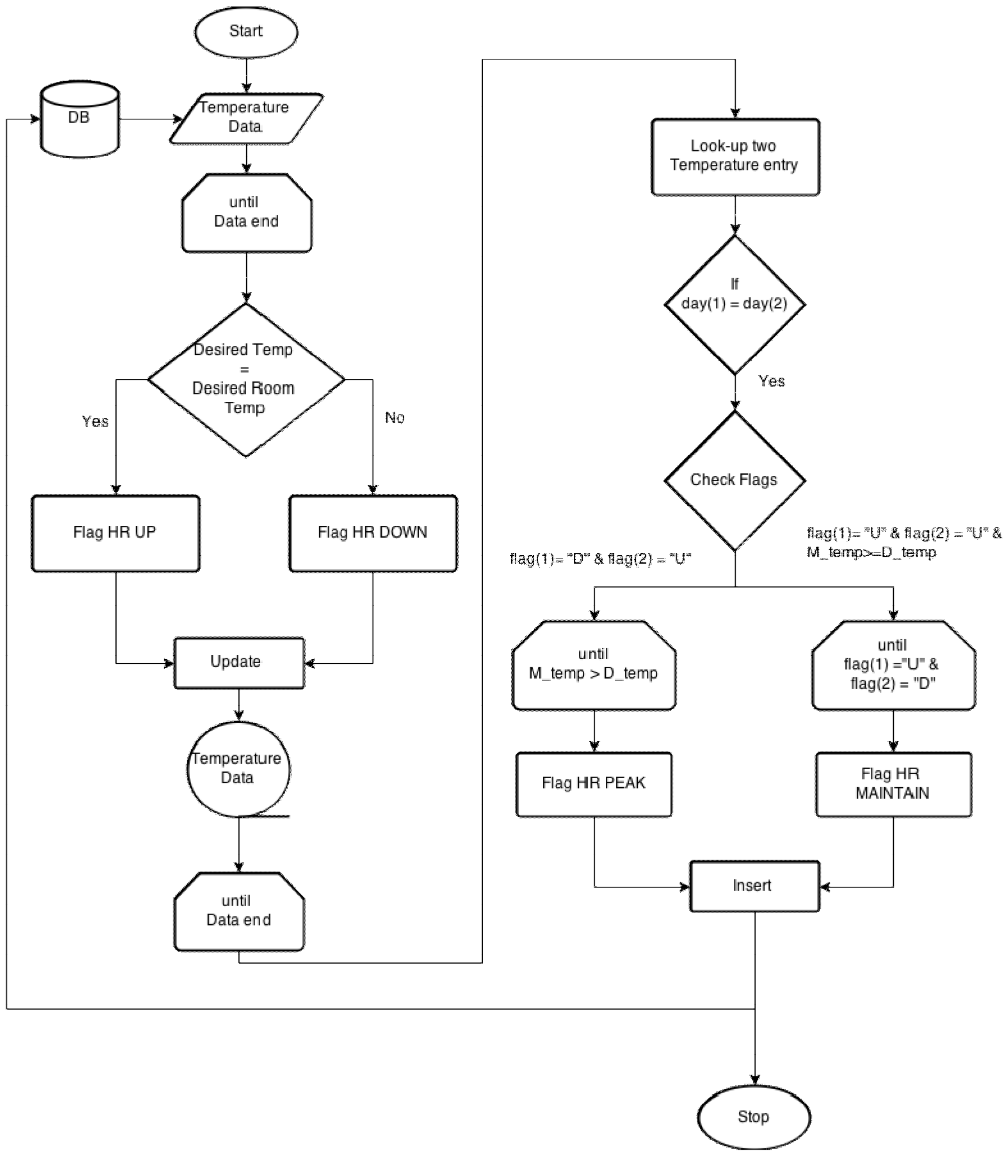


Figure 5. 9 Flow chart for Heat radiator data categorization

The bill for S.H.E. for the period under study is € 806.60 and the total S.H.E. usage for the four heat radiators is 46713.733 $\%h$. Thus the

$$Rate(€/\%h) = 0.017266870972121378991052361642 61 \approx 0.0173$$

$$Duration\ of\ use\ (hrs) = 1851.3225157641573 \approx 1851.3$$

$$\text{S.H.E.}\, usage\ (\%h) = 21812.102016562014 \approx 21812.1$$

$$\text{S.H.E.}\ \ cost\ (€) = 21812.102016562014 * 0.0173$$
$$= 376.6267511507248337099590880 3853 \approx 376.7$$

The S.H.E. usage distribution for the heat radiator in the living room according to the days of the week and month of the year are given in the figures below:

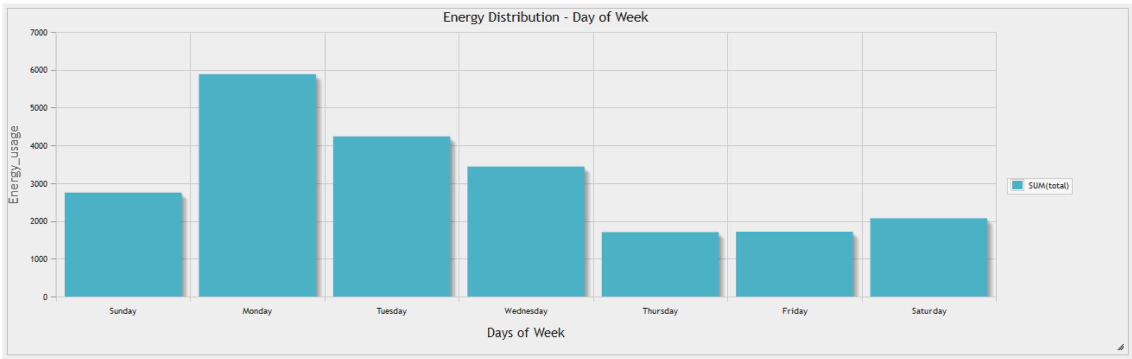


Figure 5. 10 S.H.E. Usage distribution for the Days of the Week

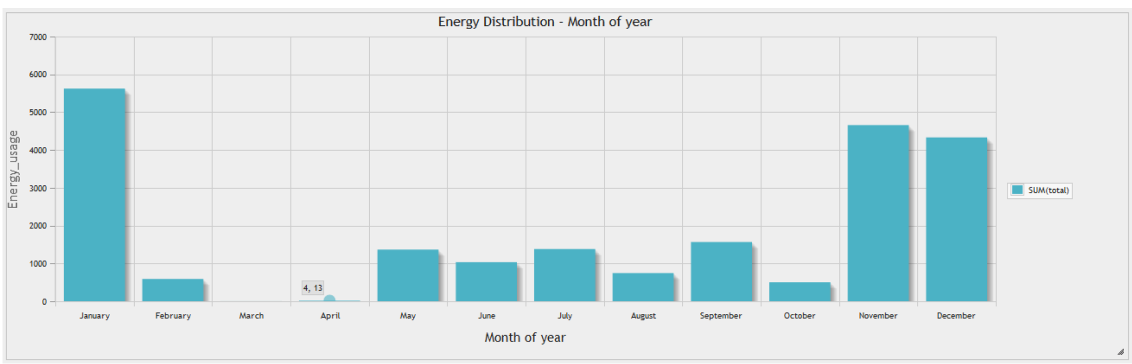


Figure 5. 11 S.H.E. Usage distribution for the months of the year

Stereo:

Graphic Analysis

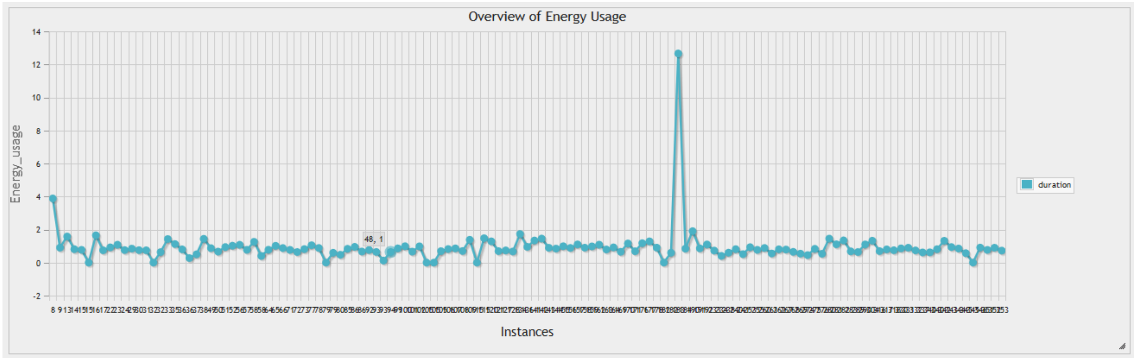


Figure 5. 12 Graphic Analysis for Stereo Electricity Usage

No pattern is identified from figure 5.12, thus the analysis proceeds to descriptive statistics.

Descriptive Statistics

The wattage of the stereo is $30W$ and the duration of use for the stereo device as extracted from the log data is $125.14\ hour$ for a period of $120\ days$ for the year under study.

utilizing $equation$ 5.1. and 5.2, the

$$Electricity\ usage\ (kWh) = 30 * 0.001 * 125.14 = 3.7542$$

and

$$Electricity\ Cost\ (€) = 3.7542 * 0.25 = 0.93855$$

The energy usage distribution for the stereo device in the living room according to the days of the week and month of the year are given in the figures below:

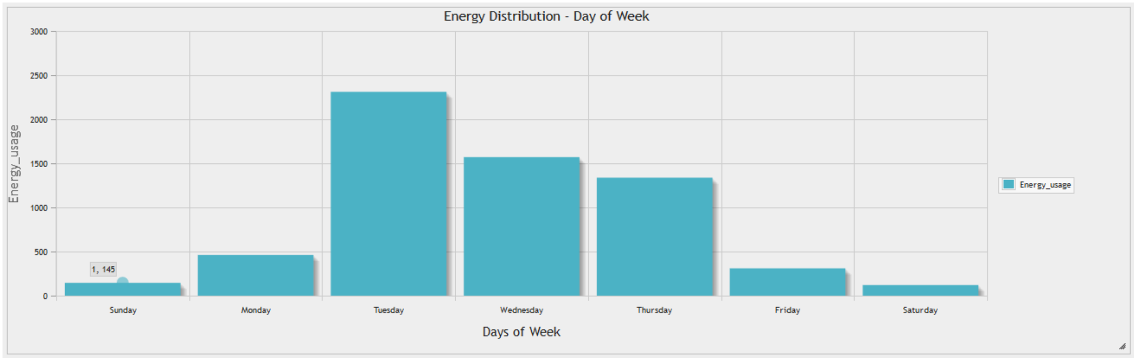


Figure 5. 13 Energy Usage distribution for the Day s of the Week

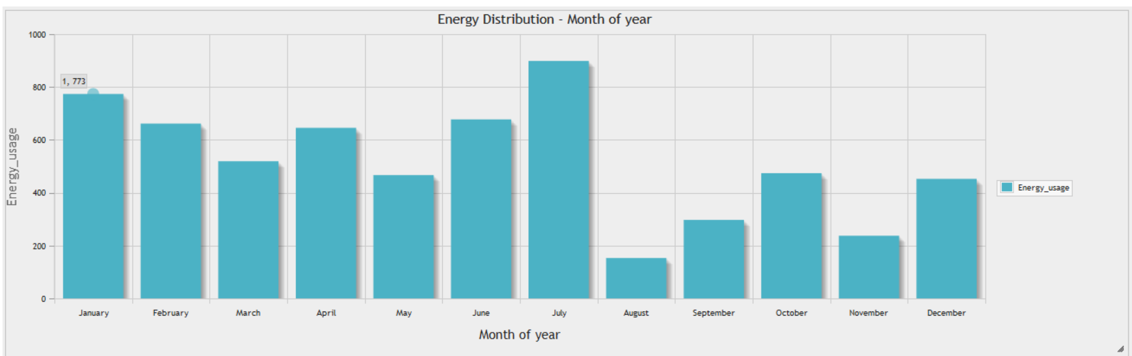


Figure 5. 14 Energy Usage distribution for the months of the year

Bathroom

Heat Radiator

Graphic Analysis

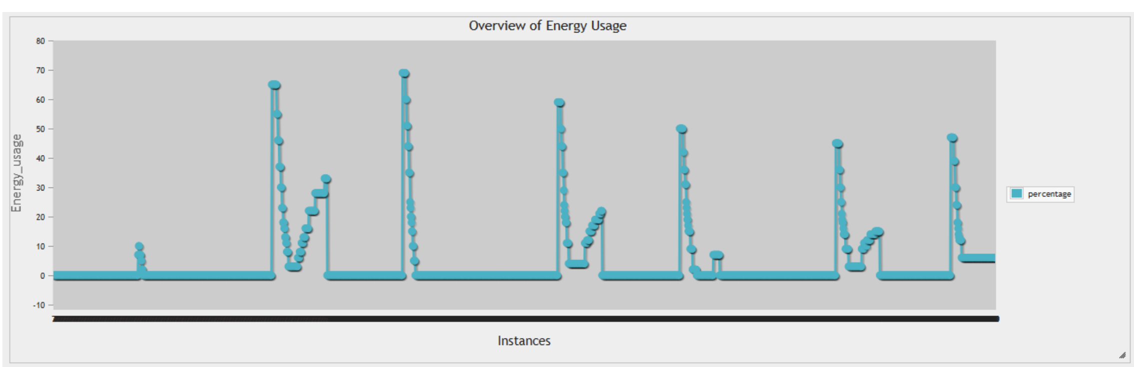


Figure 5. 15 Graphic Analysis for heat radiator

From figure 5.15, it could be observed that there exists some reoccurring patterns, figure 5.16 is used to view an instance of the pattern.

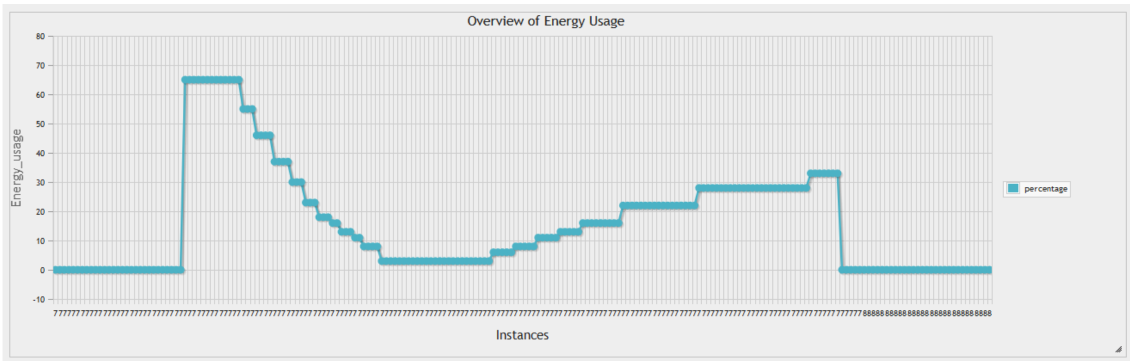


Figure 5. 16 An instance of the identified pattern showing valve position

Figure 5.16 reveals a similar device pattern identified in figure 5.7, hence the algorithm employed for data categorization in the previous case is utilized for this case.

Descriptive Statistics

utilizing equation 5.3 and 5.5

$$\text{S.H.E.}\,usage(\%h) = 14806.618163665757 \approx 14806.6$$

$$\text{S.H.E.}\,cost(€) = 14806.618163665757 * 0.0173 = €\,255.66396536548544 \approx €\,255.7$$

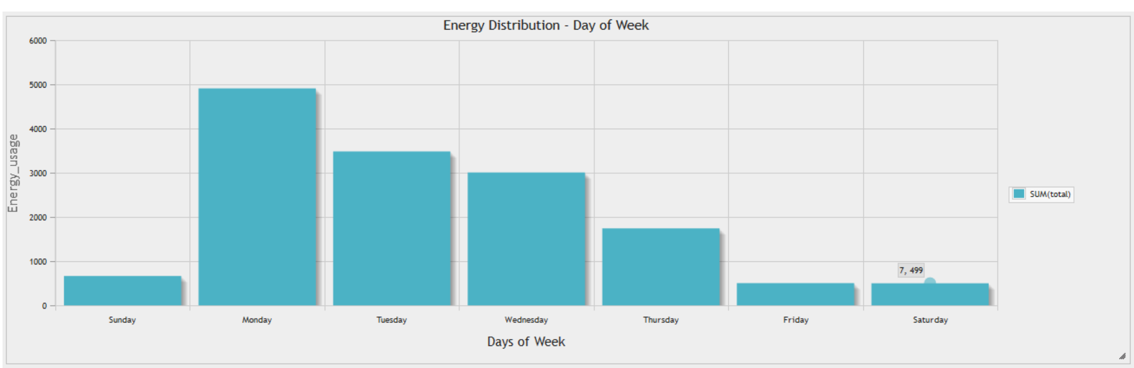


Figure 5. 17 Heat Usage distribution for the Days of the Week

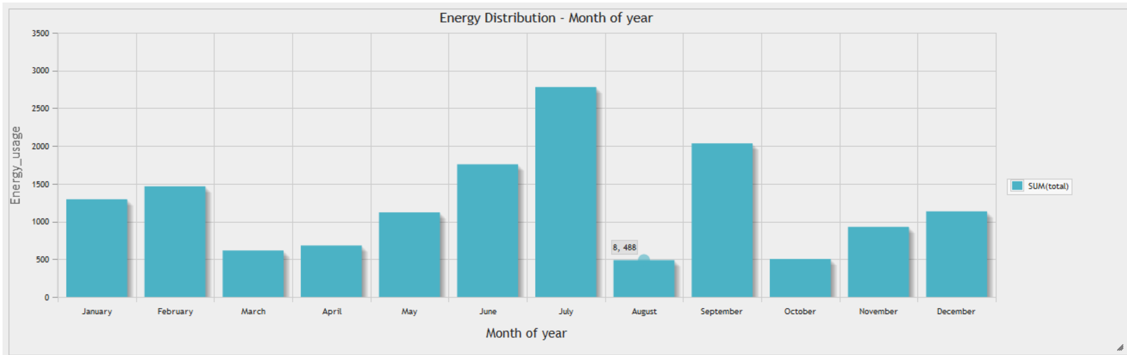


Figure 5. 18 S.H.E. Usage distribution for the months of the year

Washing Machine

There is no automation data for the washing machine, thus it is will be categorized under other appliances.

Bedroom

Heat Radiator

Graphic Analysis

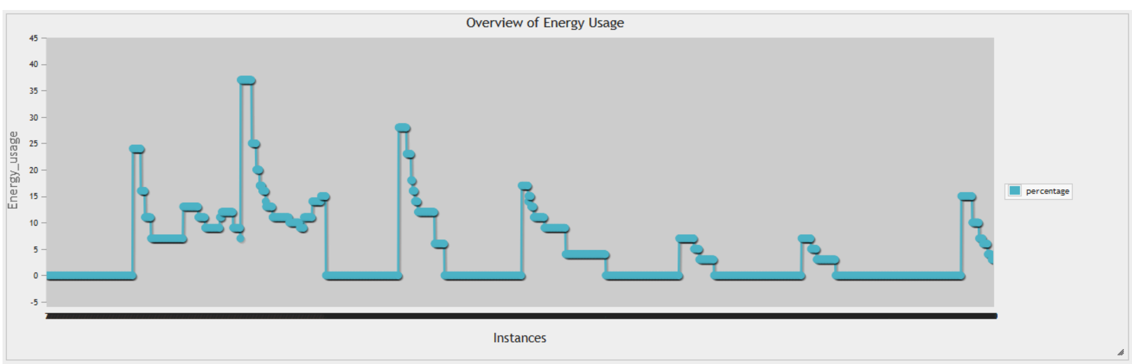


Figure 5. 19 Graphic Analysis for heat radiator

Figure 5.19 displays a similar device behaviour and pattern identified for previously identified radiators, thus the algorithm employed previously are utilized here as well.

Descriptive Statistics

utilizing equation 5.3 and 5.5, the

$$\text{S.H.E.}\,usage\ (\%h) = 10095.012800247641 \approx 10095.0$$

$$\text{S.H.E.}\,cost = 10095.012800247641 * 0.0173$$
$$= €\,174.30928348378974926273178666706 \approx €174.31$$

Wardrobe and Room Lights:

Graphic Analysis

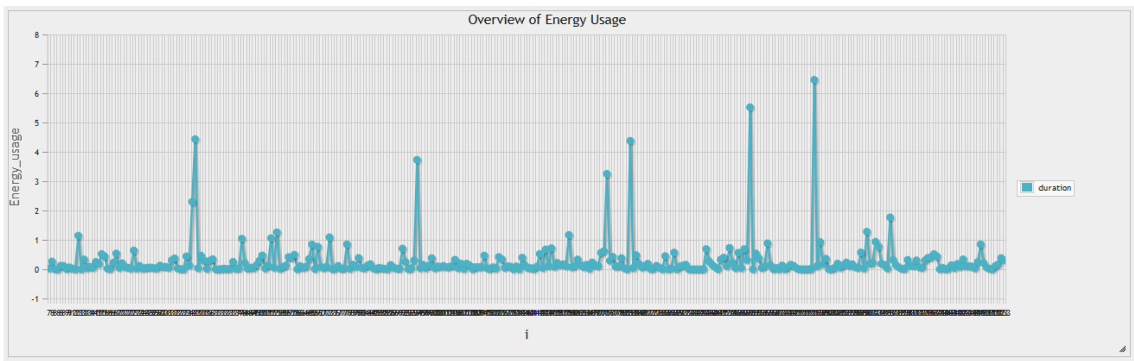


Figure 5. 20 Graphic Analysis for Wardrobe and Room Lights

No reoccurring pattern is identified from figure 5.20, thus the analysis proceeds to descriptive statistics.

Descriptive Statistics

The wattage of the lamps in the bedroom is $80W$ and its usage duration is $91.81\ hours$. utilizing $Equation\ 5.1.\ and\ 5.2$, the

$$Electricity\ usage\ (kWh) = 80 * 0.001 * 91.81 = 7.3448$$

and

$$Electricity\ cost(€) = 7.3448 * €\,0.25 = 1.8362$$

The figures below shows the distribution of the sum of energy usage for days of the week and months of the year.

Smart System

The smart server is powered all the time. This server application is housed in a Tux Radio and its power consumption is 3W. The wattage of other smart devices are in micro-Watts, hence they are negligible for this computation.

utilizing $Equation\ 5.1.\ and\ 5.2$, the

$$Electicity\ Usage\ (kWh) = \ Power\ consumption(kW) * \ 24h * 365days$$
$$= 3 * 0.001 * 24 * 365 = 26.28$$

and

$$Electricity\ cost(€) \ = \ 26.28 \ * \ €\,0.25 \ = \ 6.57$$

Other Appliances

The other appliances in the rented apartment includes a flat screen LCD TV, a microwave oven, an electric cooker & oven, a fridge & freezer, an electric kettle, a vacuum cleaner, a dishwasher, a shaver, a washing machine and internet devices. Amongst these appliances the Flat screen TV and the washing machine are coupled to the smart systems to avoid standby energy consumption when the apartment is unoccupied.

The electricity usage and electricity cost of the other appliances are computed as follows

$$Electricity\ cost\ (€)$$
$$= \ Electricity\ Bill$$
$$- Energy\ cost\ (lamp + stereo + wardrobe\ light$$
$$+ Automation\ system)$$
$$= 391.75 - (5.218 + \ 0.93855 + 1.8362 + 6.57) \ = \ 377.18725$$

$$Electricity\ usage\ (kWh) = \frac{377.18725}{0\ .25} \ = \ 1508.749$$

Summary

Electricity Usage and Cost

Table 5. 1 Summary of Electricity Usage and Cost

S/N	Rooms	Appliances	Energy Usage (kWh)	Energy Cost (€)
5.	Living Room	Lamp	20.872	5.218
		Stereo	3.7542	0.93855

6.	Bedroom	Wardrobe light	7.3448	1.8362
7.	Smart System	Raspberry Pi	26.28	6.57
8.	Other appliances		1508.749	377.18725
9.	Total		1567.22	391.75

S.H.E. Usage and Cost

Table 5. 2 Summary of Energy Usage and Cost for S.H.E.

S/N	Rooms	Appliances	Energy Usage (%h)	Energy Cost (€)
1.	Living Room	Heat Radiator	21812.1	376.7
2.	Bathroom	Heat Radiator	14806.6	255.7
3.	Bedroom	Heat Radiator	10095.0	174.31
4.	Total		46713.7	806.71

$$\boldsymbol{Total\ Energy\ Cost(€)} = \boldsymbol{Electricity\ cost} + \mathbf{S.H.E.}\ \boldsymbol{cost}$$

Equation 5. 6 Total Cost of Energy Used

$$Total\ Energy\ Cost(€) = 391.75 + 806.71 = 1198.46$$

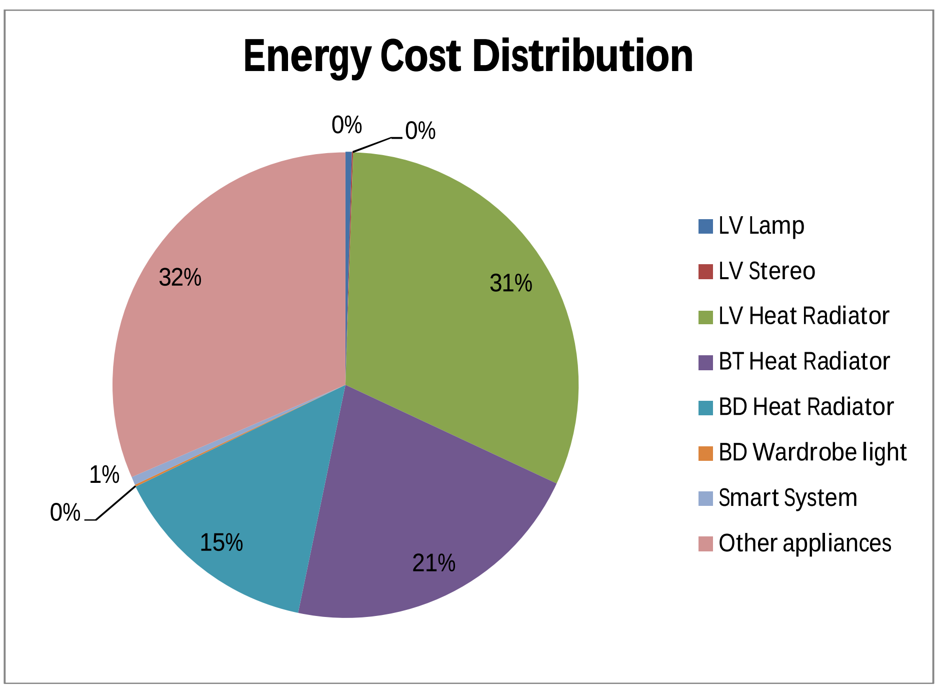


Figure 5. 21 Energy Cost Distribution amongst appliances

5.1.2 Scenario Simulation

German High Smart Strategy

The difference between the high and the medium smart strategy is the energy consumption of installed smart devices to attain a high smart strategy from a medium strategy and how the cost of these devices and the cost of their energy consumption affects the ROI and payback time.

For this case, only battery powered motion detection sensors are deployed to the rooms hence only the cost of the installed device is accrue to the medium smart spending and no energy consumption is accrue to the medium smart strategy.

Thus,

$$HSS\ Total\ Energy\ Cost = MSS\ Total\ Energy\ Cost = 1198.46$$

German No Smart Strategy

Electric Devices

According to the survey conducted in (MINISTERIAL COUNCIL ON ENERGY FORMING, 2006), standby mode is defined as a mode when an appliance is at its lowest power consumption when it is connected to the main power, even if the appliance is turned off. Four standby modes are identified and these are Off-standby, Passive-standby, Active-standby and Delay start-standby. However, not all these modes are relevant for all devices types.

Three electric appliances are prevented by the smart system from the standby power consumption and these are the living room flat screen LCD TV and stereo and the bathroom wash machine.

The electricity usage for all electric appliances for this case will be computed as follows

$$\begin{aligned}\boldsymbol{Electricity\ Usage} &= \boldsymbol{in\_use\ power\ consumption} * \boldsymbol{Usage\ Duration} \\ &+ \boldsymbol{Standby\ power\ consumption} * \boldsymbol{Standby\ Duration}\end{aligned}$$

Equation 5. 7 Electricity Usage for No Smart Strategy Appliances

The stereo performs a secondary function of time display when it is remotely switched-off. This places the stereo device in a passive standby category. It is assumed that the user switches off the wash machine after every in-use period, thus the off standby will only be applicable here. it is assumed that the user remotely switches off the Flat screen TV after every in-use period thus only the passive standby is applicable in this case.

Table 5.3 highlights the power consumption of these three appliances according to different standby modes.

Table 5. 3 Wattage of Home appliances in Standby mode

SN	Device	In use	Standby			
			Off	Passive	Active	Delay
1.	Stereo	50	-	4.2	-	-
2.	Wash machine	2175	0.9	-	-	-
3.	Flat Screen TV	140	-	4.3	-	-

Heat Radiators

The usage pattern of an average German user for the heat radiator clearly states that a user ventilates his apartment daily for a period of one hour and the heat radiator knob is set between 55-60% for the remaining periods of the day. Thus, we take an average of this valve value (57.5%) and the remaining 23 hrs for heating and the distinct number of days each room was heated in the medium smart investment to compute the heat usage.

The Thermostat Radiator Valve:

The categories of data extracted from the pattern identified from the heat radiators in the MSS Case is utilized to create a mathematical model that represents the TRV operational specification for this case:

a. *desired_temp_set*: the timestamp a desired temperature is set
b. *desired_temp_reached*: the timestamp when the measured temperature is greater than the desired temperature after *desire_temp_set.*
c. *min_temp_set*: the timestamp when a minimum temperature was set
d. *period_peak*: This is the period between the desired_temp_set and desired_temp_reached.

e. *sum_period_peak*: From data studies, there may two or more period_peak per day, hence an sum of these period is computed. This also suffice for the NSS usage pattern, because after ventilating the room for a period of 30 minutes, it is assumed that the heat radiator will require another peak to reach the desired temperature of the room.

$$\boldsymbol{sum\_period\_peak(hrs)} = \sum_{\mathbf{0}}^{\boldsymbol{daily}} \boldsymbol{period\_peak(hrs)}$$

Equation 5. 8 Sum of Temperature Peak Period

f. *period_maint*: is the period required to maintain the room temperature after every peak. If the heat radiator is switched-on for 23 hours, then the period_maint is as follows:

$$\boldsymbol{period\_maint\ (hrs)} = \mathbf{23} - \boldsymbol{sum\_period\_peak}$$

Equation 5. 9 Temperature Maintain Period

g. *heat_usage_maint*: Heat usage data for maintaining the room is extracted by queering all valve data between the desired_temp_reached and min_temp_set period.

h. *avg_heat_usage_maint:* Since there can be two or more peak periods per day, hence there can be two or more maintenance period per day, thus to determine a useful *heat_usage_maint* value. a mean of all *heat_usage_maint* value is derived

$$\boldsymbol{avg\_heat\_usage\_maint} = \langle \mathbf{heat\_usage\_maint} \rangle$$

Equation 5. 10 Average Valve value for Temperature Maintain Period

i. *Others*: from data studies, it was observed that there are days where there are peaks and no maintenance or/and vice versa. These peaks might be achieved, when a user abruptly switched-on the heater and the period of usage is within the peak period. Also only temperature maintenances can be achieved when a user decides to be in the apartment for more than a day or decides to maintain a higher minimum temperature. These categories of data will undergo the same computation as the *sum_period_peak* and the *avg_heat_usage_maint* and these will be summed. For the all-day temperature maintenance period, the $period\_maint\ (hrs) = 23$. This data category will be referred to as others

others can assume any of the following depending on the heat radiator usage

$$\boldsymbol{Others}\ (\%\boldsymbol{h}) = \sum_{0}^{m} [\boldsymbol{sum\_period\_peak}(\boldsymbol{hrs}) * \mathbf{57.5\%}\,] + \sum_{0}^{n} [\boldsymbol{avg\_heat\_usage\_maint}\ (\%)\ *\ \mathbf{23}]$$

$$\text{or}\ \ \boldsymbol{Others}\ (\%\boldsymbol{h}) = \textstyle\sum_{0}^{n} [\boldsymbol{sum\_period\_peak}(\boldsymbol{hrs}) * \mathbf{57.5\%}\,]$$

$$\text{or}\ \ \boldsymbol{Others}\ (\%\boldsymbol{h}) = \textstyle\sum_{0}^{n} [\boldsymbol{avg\_heat\_usage\_maint}\ (\%)\ *\ \mathbf{23}]$$

$$where\ m, n\ =\ number\ of\ of\ occurences$$

Equation 5. 11 German Uncategorized Values

j. *heat_usage_TRV*: The total daily heat usage is computed as follows

$$\boldsymbol{heat\_usage\_TRV}(\%\boldsymbol{h}) = \boldsymbol{sum\_period\_peak}(\boldsymbol{hrs}) * \mathbf{57.5\%} + \boldsymbol{avg\_heat\_usage\_maint}\ (\%)\ *\ \boldsymbol{period\_maint}(\boldsymbol{hrs})$$

Equation 5. 12 German Daily Heat Usage

k. *S.H.E. Usage:* The summation of all daily heat usage

$$\mathbf{S.H.E.}\ \boldsymbol{usage}(\%\boldsymbol{h}) = \sum_{0}^{n} \boldsymbol{heat\_usage\_TRV} + \boldsymbol{Others}$$

$$where\ n\ =\ number\ of\ days\ the\ heater\ was\ used$$

Equation 5. 13 Total Heat Usage

Living Room

Lamp:

Same as the medium smart strategy.

TRV Heat Radiator:

Using equation 5.10, 5.11 and 5.12 for this scenario, where $others$ assumes the following

$$Others\ (\%h) = \sum_{0}^{n} [sum\_period\_peak(hrs) * 57.5\%\,] + \sum_{0}^{n} [avg\_heat\_usage\_maint\ (\%) * 23]$$

from data queries,

$$\text{S.H.E.}\ usage(\%h) = 29459.38500946472 + 5395.418753 = 34854.80376246472$$

using equation 5.5,

$$\text{S.H.E.}\,Cost\ (€) = 34854.80376246472 * 0.0173 = 602.99$$

Stereo:

The in-use period for this appliance will be extracted from the automation log to compute in-use electricity usage of the appliance and the remaining hours of the year will be used to compute the passive-standby electricity usage.

$$in_{use}standby\ \ duration\ (hours) = 125.136$$

$$passive\ standby\ duration\ (hours) = 365 * 24 - in\_use\ standby = 8634.86400062288158$$

using equation 5.6,

$$Electricity\ Usage\ (kWh) = 30 * 0.001 * 125.136 + 4.2 * 0.001 * 8634.864 = 40.021$$

using equation 5.2,

$$Electricity\ Cost(€) = 40.021 * 0.25 = 10.005 \approx 10$$

Flat Screen LCD TV:

The in-use duration for the flat screen LCD TV is not given, however it is assumed that the user uses this facility daily for an hour. Hence an hour is multiplied by the number of days the living room was occupied to compute in-use electricity usage of appliance and the remaining number of hours the apartment was unoccupied will be used to compute the passive-standby electricity usage. Only the standby electricity usage will be computed, because the in-use electricity usage is already included in the other devices category.

$$in\_use\ standby\ \ duration\ (hours) = 1\ hours * 163\ days$$
$$= 163\ hours$$

$$passive\ standby\ duration\ \ (hours) = 365 * 24 - in_{use}standby$$
$$= 8597\ hours$$

using equation 5.1,

$$Electricity\ Usage\ (kWh) = 4.3 * 0.001 * 8597$$
$$= 36.9671$$

using equation 5.2,

$$Electricity\ Cost(€) = 36.9671 * 0.25$$
$$= 9.241775 \approx 9.2$$

Bathroom

TRV Heat Radiator:

Using equation 5.10, 5.11 and 5.12 for this scenario, where $others$ assumes the following

$$Others\ (\%h) = \sum_{0}^{n} [sum\_period\_peak(hrs) * 57.5\%\ ] + \sum_{0}^{n} [avg\_heat\_usage\_maint\ (\%) * 23]$$

from data queries,

$$\text{S.H.E.}\ usage(\%h) = 33665.14297844622 + 3420.68419 = 37085.827$$

using equation 5.5,

$$\text{S.H.E.}\ cost(€) = 37085.827 * 0.0173 = 641.59$$

Washing Machine:

The wash machine is utilized for a period of 90 minutes weekly. Thus we extract the distinct number of weeks the user used the bathroom from the automation log to compute the in-use electricity usage and the remaining hours of the year is used to compute off-standby electricity usage. The energy cost of the standby energy usage will be computed only because the in-use energy usage of the wash machine was included in the other devices category in the medium smart spending.

$$in\_use\ standby\ \ duration\ = \ 1.5\ hours * \ 41\ weeks$$
$$= 61.5\ hours$$
$$passive\ standby\ duration\ \ = \ 365 * 24\ -\ in_{use} standby\ \ = 8698.5\ hours$$

using equation 5.1

$$Electricity\ Usage\ (kWh)\ = 0.9 * 0.001 * \ 8698.5$$
$$= \ 7.829$$

using equation 5.2

$$Electricity\ Cost(€)\ = \ 7.829 * 0.25$$
$$= \ 1.957 \approx 2$$

Bedroom

TRV Heat Radiator:

Using equation 5.10, 5.11 and 5.12 for this scenario, where $others$ assumes the following

$$Others\ (\%h)\ = \sum_{0}^{n} [sum\_period\_peak(hrs) * 57.5\%\ ] + \sum_{0}^{n} [avg\_heat\_usage\_maint\ (\%)\ * \ 23]$$

from data queries,

$$\text{S. H. E.}\ \ usage(\%h)\ \ = 7409.367959493412 + \ 1095.99618\ \ = \ 8505.364$$

using equation 5.5,

$$\text{S. H. E.}\ cost(€)\ = 8505.364 * \ 0.0173 = \ 147.143$$

Wardrobe and Room Lights:

same as the energy consumption of the medium smart strategy

Summary

Electricity Usage and Cost

Table 5. 4 Summary of Electricity Usage and Cost

SN	Rooms	Appliances	Energy Usage (kWh)	Energy Cost (€)
1.	Living Room	Lamp	20.872	5.218
		Stereo + Standby	40.0	10
		Flat Screen TV (standby)	36.9671	9.241775
2.	Bedroom	Wardrobe light	7.3448	1.8362
3.	Bathroom	Wash machine (standby)	7.82865	1.9571625
4.	Other appliances		1508.749	377.18725
5.	Total		1621.762	405.440

S.H.E. Usage and Cost

Table 5. 5 Summary of Energy Usage and Cost for S.H.E.

SN	Rooms	Appliances	Energy Usage (%h)	Energy Cost (€)
1.	Living Room	Heat Radiator	34854.804	602.99
2.	Bathroom	Heat Radiator	36892.2	641.59
3.	Bedroom	Heat Radiator	8505.364	147.143
4.	Total		80252.37	1391.723

$$Total\ Energy\ Cost(€) = 405.440 + 1391.723 = 1797.163$$

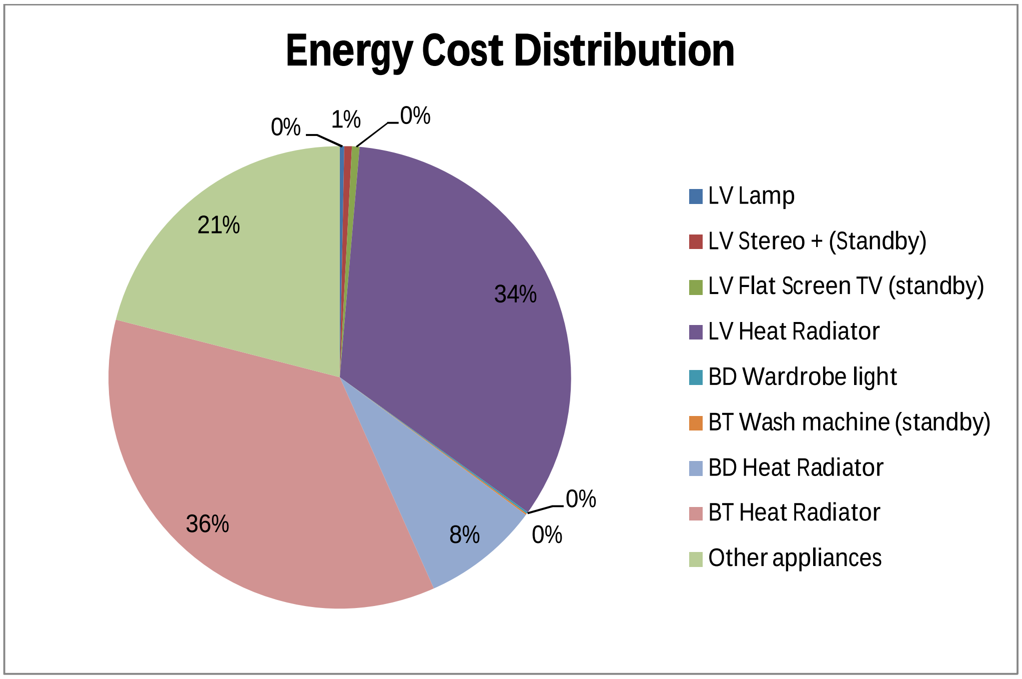


Figure 5. 22 Cost Distribution amongst appliances for NSS

5.1.2.1 Energy Cost Comparison

Electric Appliances

Table 5. 6 Electricity cost comparison between smart strategies

SN	Rooms	Appliances	Smart Strategy		
			No	Medium	High
1.	Living Room	Lamp	5.218	5.218	5.218
		Stereo + Standby	10	0.93855	0.93855
		Flat Screen TV (standby)	9.241775	-	-
2.	Bedroom	Wardrobe light	1.8362	1.8362	1.8362
3.	Bathroom	Wash machine (standby)	1.9571625	-	-
4.	Smart System	Raspberry Pi	-	6.57	6.57
5.	Other appliances		377.18725	377.18725	377.18725
6.	Total		405.440	391.75	391.75

Heat Radiators

Table 5. 7 Cost comparison of S.H.E. between smart strategies

SN	Rooms	Appliances	Smart Strategy		
			No	Medium	High
1.	Living Room	Heat Radiator	602.99	376.7	376.7
2.	Bathroom	Heat Radiator	641.59	255.7	255.7
3.	Bedroom	Heat Radiator	147.143	174.31	174.31
4.	Total		1391.723	806.71	806.71

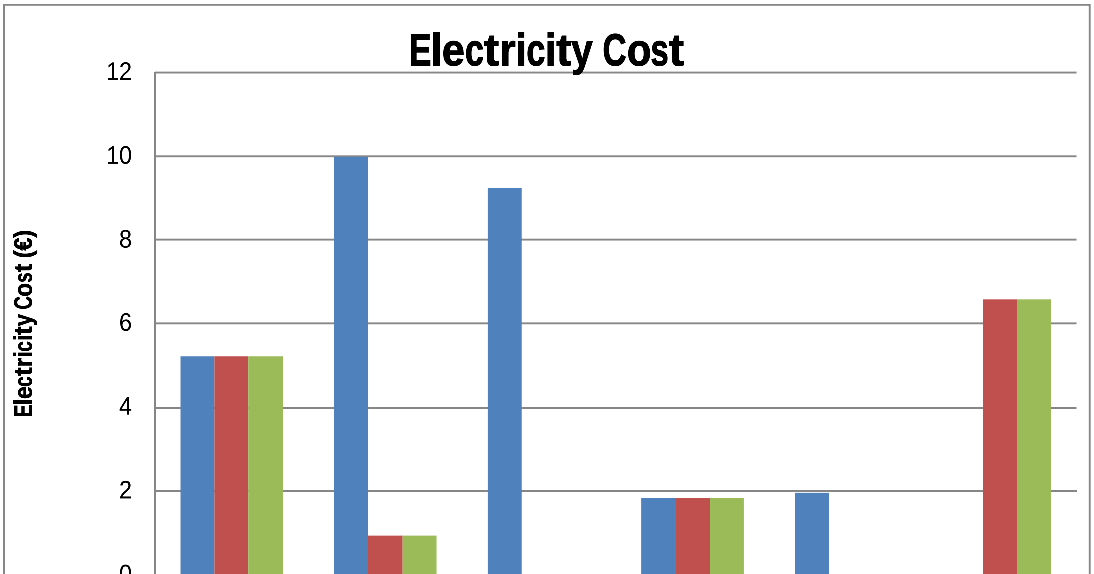
5.1.2.2. Cost Savings

The energy consumption of the High smart strategy is the same with the medium smart strategy, thus there is no cost saving between the two.

$$Electric\ Cost\ Saving\ (€) = 405.440 - 391.75 = 13.690$$

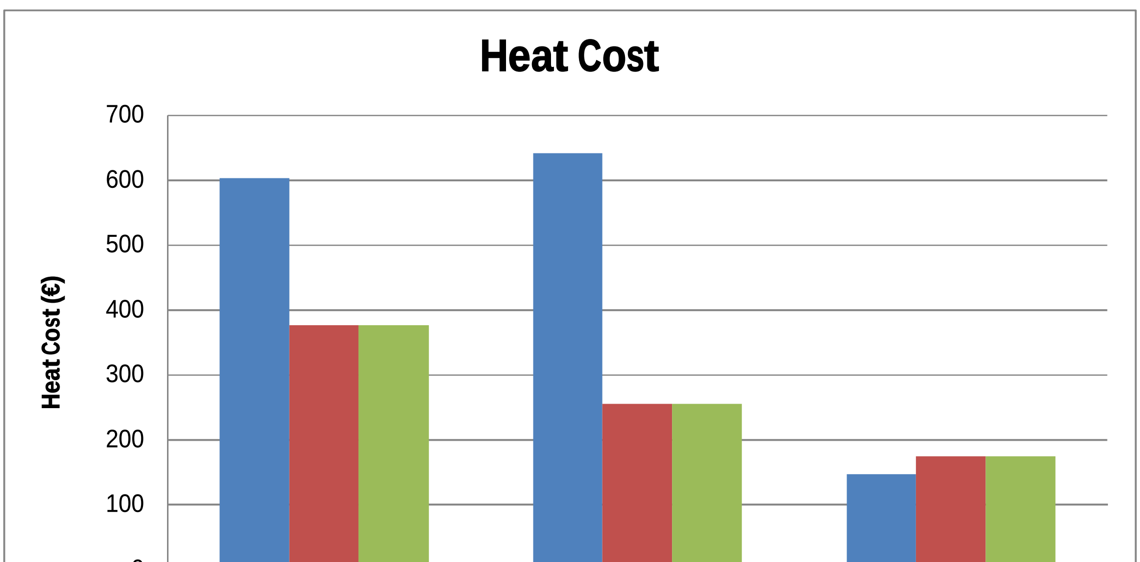
$$Heat\ Cost\ Saving\ (€) = 1391.723 - 806.71 = 585.013$$

$$Total\ Cost\ Saving\ (€) = 13.690 + 585.013 = 598.703$$



	LV Lamp	LV Stereo + Standby	Flat Screen TV (standby)	BD Wardrobe light	BT Wash machine (standby)	Smart System
No	5.218	10	9.241775	1.8362	1.9571625	0
Medium	5.218	0.93855	0	1.8362	0	6.57
High	5.218	0.93855	0	1.8362	0	6.57

Figure 5. 23 Electricity Cost comparison for appliances between Smart Strategies



	LV Heat Radiator	BT Heat Radiator	BD Heat Radiator
No	602.99	641.59	147.143
Medium	376.7	255.7	174.31
High	376.7	255.7	174.31

Figure 5. 24 Cost of heating comparison for comparison between Smart Strategies

5.1.2.3. Environmental Impact

Given that the rate for electricity $1kWh\ is$ € 0.25 and heating $1\%h\ is$ €0.0173, then,

$$1\%h = \frac{€0.0173 * 1kWh}{€0.25} = 0.0692kWh$$

According to (BrightGreen, 2009), the CO2 emission from the electricity generation for Germany is 0.45kg CO2 per kWh and the CO2 emission for heating oil is 3.0 kg CO2 per litre. Given that the one litre of the heating oil produces an equivalent of 10kWh of heat energy and 1%h of space heating is equivalent to 0.0692kWh

Then,

$$\boldsymbol{Oil\ Usage\ for\ S.H.E = S.H.E.usage\ (\%h) * 0.0692\ kWh * 0.1\ l}$$

Equation 5. 14 Oil Usage for S.H.E.

$$\boldsymbol{Carbonfootprint\ \ for\ S.H.E\ (kgCO2) = 3.0kgCO2 * Oil\ Usage\ (litres)}$$

Equation 5. 15 Carbon footprint for S.H.E.

and the

$$\boldsymbol{Carbonfootprint\ for\ Electricity\ Usage\ (kgCO2) = 0.45kgCO2 * Electricity\ Usage\ (kWh)}$$

Equation 5. 16 Carbon footprint for Electricity Usage

thus the carbon footprint for each strategy is given as follow

Table 5. 8 Carbon footprint for Identified Smart Strategies

SN	Energy	Smart Strategy		
		No	Medium	High
1.	Electricity ($kgCO_2$)	729.79	705.25	705.25
2.	Space Heating ($kgCO_2$)	1666.05	969.78	969.78
3.	Total ($kgCO_2$)	2395.84	1675.03	1675.03

$$CO2\ reduction\ for\ Electricity\ Usage\ (kgCO2) = 729.79 - 705.25 = 24.54$$

$$CO2\ reduction\ for\ S.H.E.Usage\ (kgCO2) = 1666.05 - 969.78 = 696.27$$

$$Total\ CO2\ reduction\ (kgCO2) = 24.54 + 696.27 = 720.81$$

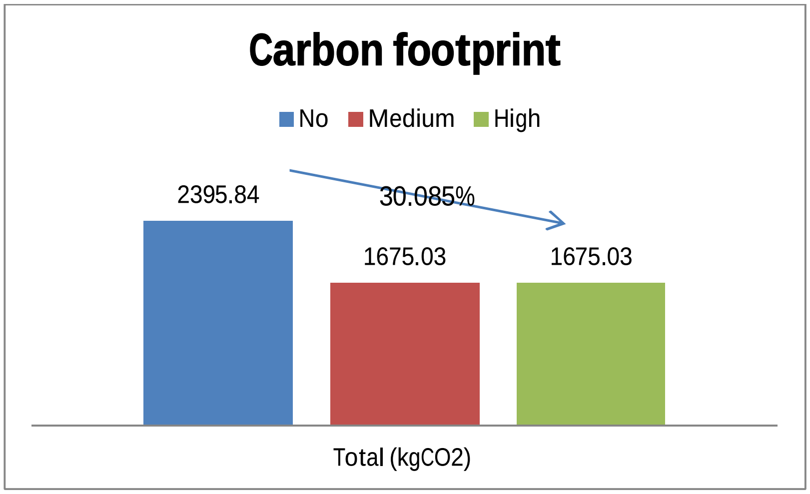


Figure 5. 25 Carbon footprint for Identified Smart Strategies

5.1.2.4. ROI and Payback Computation

$$\textbf{\textit{Return on Investment}}\ (\textbf{\textit{ROI}})\% = \frac{\textbf{\textit{Total Cost saving}} - \textbf{\textit{Smart spending}}}{\textbf{\textit{Smart spending}}}$$

Equation 5. 17 Return on Investment

$$\textbf{\textit{Payback Period}} = \frac{\textbf{\textit{Smart spending}}}{\textbf{\textit{Total Cost saving}}}$$

Equation 5. 18 Payback Time

Medium Smart Investment

$$Smart\ spending = 467.6$$

$$Total\ Cost\ Saving = 598.703$$

$$ROI = \frac{598.703388 - 467.6}{467.6} = 28.04\%$$

$$Payback\ Period = \frac{467.6}{598.703} = 0.781\ years$$

$$\approx 9.4\ months$$

$$1st\ year\ return = 131.103$$

$$2nd\ year\ return = 598.703$$

High Smart Investment

$$Smart\ spending = 621.4$$

$$Total\ Cost\ Saving = 598.703$$

$$ROI = \frac{598.703388 - 621.4}{621.4} = -3.653\%$$

$$Payback\ Period = \frac{621.4}{598.703} = 1.038\ years$$

$$\approx 12.5\ months$$

$$1st\ year\ return = -22.697$$

$$2nd\ year\ return = 598.703$$

5.1.2.5. Monthly ROI after Payback

The table below provides a monthly distribution of the return on investment. The monthly ROI for the TV(standby), wash machine(standby) and the smart system is distributed evenly for each month.

Table 5. 9 Monthly distribution of ROI over home appliances

Device / Month	Living Room				Bedroom		Bathroom		Smart System	others	Total
	Lamp	Stereo	TV	H Radiator	Lamp	H Radiator	Wash M	H radiator	Raspberry	appliance	
January	-	1.120294	0.772	58.3481	-	-3.88632	0.163096875	33.73262	-0.5475	-	89.7022909
February	-	0.958369	0.772	6.114717	-	-0.00696	0.163096875	38.1972	-0.5475	-	45.6509229
March	-	0.751835	0.772	0.022732	-	-0.02966	0.163096875	16.05258	-0.5475	-	17.1850839
April	-	0.935051	0.772	0.138396	-	0	0.163096875	17.78091	-0.5475	-	19.2419539
May	-	0.676087	0.772	14.17604	-	-2.32052	0.163096875	29.20477	-0.5475	-	42.1239739
June	-	0.981036	0.772	10.71308	-	-0.63238	0.163096875	45.80781	-0.5475	-	57.2571429
July	-	1.301554	0.772	14.31358	-	0	0.163096875	72.48968	-0.5475	-	88.4924109
August	-	0.221597	0.772	7.727141	-	0	0.163096875	12.70946	-0.5475	-	21.0457949
September	-	0.43052	0.772	16.25209	-	-0.83466	0.163096875	53.0359	-0.5475	-	69.2714469
October	-	0.686298	0.772	5.207209	-	-0.21544	0.163096875	13.12059	-0.5475	-	19.1862539
November	-	0.343909	0.772	48.32784	-	-15.9249	0.163096875	24.20457	-0.5475	-	57.3390159
December	-	0.655448	0.772	44.94907	-	-3.31616	0.163096875	29.5539	-0.5475	-	72.2298549
Total	-	9.062	9.242	226.29	-	-27.167	1.9571625	385.89	-6.57	-	598.703388

Finnish Medium Smart Strategy

The electricity price for Finland per kWh is €0.158 (Eurostat, 2014), the sauna stove power consumption is 3kW and the sauna switch module consumes 0.2W. From these figures we can compute the energy cost of the energy usage of each appliances plus the Sauna stove. From the user behaviour defined in chapter three, the user uses the sauna room weekly for an hour. Given that the user occupied the apartment for 41 week, thus the usage period for the sauna stove is 41 hours. However, since the sauna switch model is connected to the main electricity switch thus it usage period is 8760 hours.

Electricity Consumption

Table 5. 10 Summary of Electricity Usage and Cost

S/N	Rooms	Appliances	Energy Usage (kWh)	Energy Cost (€)
1.	Living Room	Lamp	20.872	3.297776
		Stereo	3.7542	0.5931636
2.	Bedroom	Wardrobe light	7.3448	1.1604784
3.	Sauna Room	Sauna stove	123	19.434
		Switch module	1.752	0.28
4.	Smart System	Raspberry Pi	26.28	4.15224
5.	Other appliances		1508.749	238.382342
	Total		1691.752	267.3

The utility bill of heat energy usage for the Finnish case is not given however, given that the rate for electricity per kWh is €0.158. An assumption can be made based on the ratio of the rate of electricity to the rate of heating from the German scenario and this ratio can be applied to compute the heat energy consumption in the Finnish case.

The rates of energy in Germany is as follows

$$\text{for electricity: } 1kWh \ = \ € \ 0.25$$

$$\text{for Heatng: } 1\%h \ = \ €0.0173$$

Hence,

$$1\%h \ = \frac{€0.0173 * 1kWh}{€0.25} = 0.0692kWh$$

adopting this value, the rate given in (Storgårds, 2014) can applied to the ratio

$$Finnish\ rate\ for\ Electricity \ = €0.158 \ / \ \text{kWh}$$

Thus,

$$Finnish\ Rate\ of\ Heat\ Energy\ per\ 1\%h = 0.0692kWh * \frac{€0.158}{kWh} = €0.0109336$$

S.H.E. Consumption

Table 5. 11 Summary of Energy Usage and Cost for Heating

SN	Rooms	Appliances	Energy Usage (%h)	Energy Cost (€)
1.	Living Room	Heat Radiator	21812.1	238.48477656
2.	Bathroom	Heat Radiator	14806.6	161.88944176
3.	Bedroom	Heat Radiator	10095.0	110.374692
	Total		46713.7	510.749

$$Total\ Energy\ Cost\ (€) = 267.3 + 510.74891032 = 778.049$$

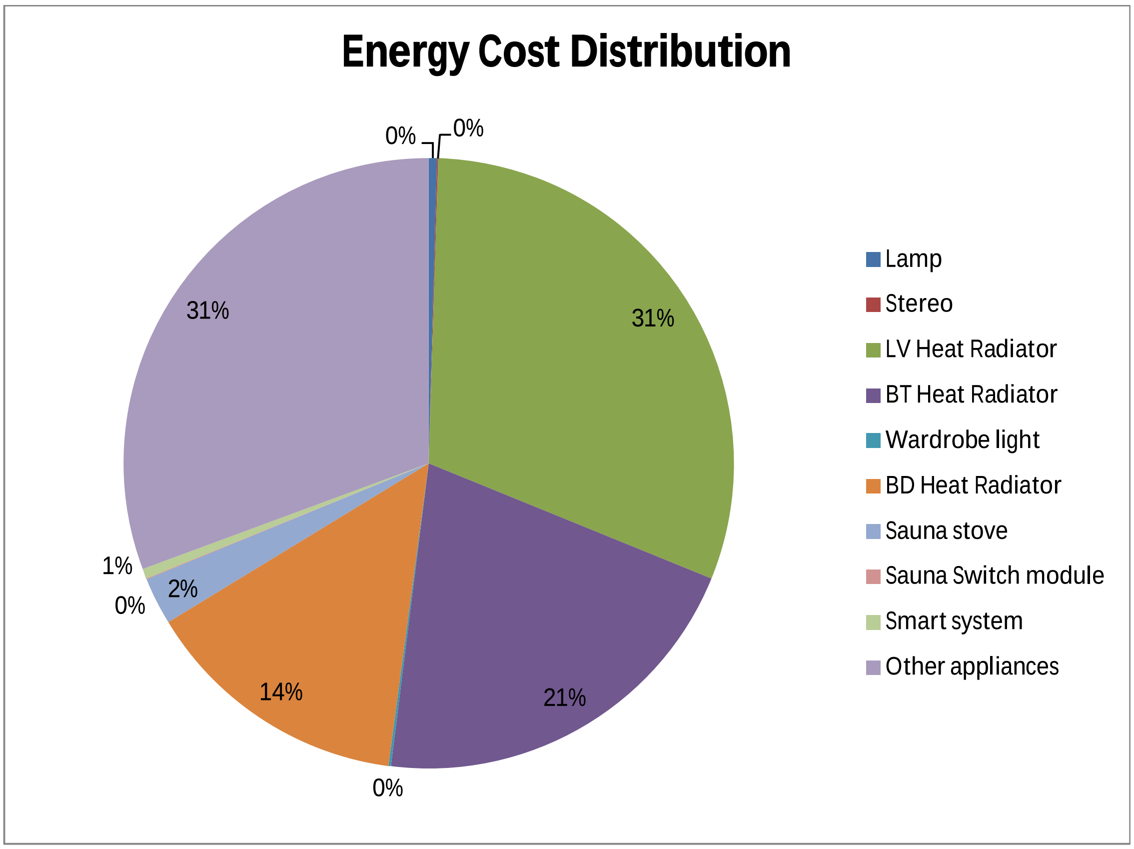


Figure 5. 26 Energy Cost Distribution amongst appliances for MSS

Finnish High Smart Strategy

Only battery powered motion detection sensors are deployed to the rooms hence only the cost of the installed device is accrue to the medium smart spending and no energy consumption is accrue to the medium smart strategy.

Thus,

$$HSS\ Energy\ Cost\ =\ MSSEnergy\ Cost\ =\ 778.049$$

Finnish No Smart Strategy

For this case,

$$the\ Finnish\ NSS\ electricity\ cost\ for\ electric\ appliances$$
$$=\ the\ German\ NSS\ Electricity\ cost\ +\ Sauna\ room\ electricity\ cost$$

The usage pattern for the heat radiator clearly states that the user ventilates the apartment daily for a period of one hour and this is done while the heat radiator is switched on. Also the heat radiator valve is set to 80% at all time.

The Thermostat Radiator Valve (TRV): One typical difference between the German and Finnish usage pattern is that the German usage switches off the heat radiator during room ventilation while the Finnish user keeps the heat radiator switched-on during the one hour ventilation. From the understanding of the operation of TRV, during the time of ventilation, the heat radiator will usually increase hot water flow to the preset maximum valve value which is 80% to maintain the desired room temperature.

This system behaviour creates an additional variable as follows

a. *Energy_vent:* This is energy spent during room ventilation and it is a product of the time of ventilation and the valve percentage for achieving the desired temperature. The time for daily ventilation is one hour and the valve percentage is 80%.

$$\boldsymbol{Energy_{vent}(\%h)}\ =\ \boldsymbol{Time_{vent(\,hrs)}} * \boldsymbol{Valve_{percentage(\%)}} * \boldsymbol{n}$$
$$= 1 * 80 * n$$
$$= 80n$$
$$where\ n\ =\ number\ of\ days\ the\ heater\ was\ used$$

Equation 5. 19 Energy Usage during Ventilation

b. Also peak_valve for the German model will be changed from 57.5% to 80% for the *heat_usage_TRV* and *others* as follows:

$$\boldsymbol{Others}\ (\%\boldsymbol{h}) = \sum_{0}^{n} [\boldsymbol{sum\_period\_peak}(\boldsymbol{hrs}) * \mathbf{80\%}\ ] + \sum_{0}^{n} [\boldsymbol{avg\_heat\_usage\_maint}\ (\%) * \mathbf{23}]$$

$$\text{or} \quad \boldsymbol{Others}\ (\%\boldsymbol{h}) = \sum\nolimits_{0}^{n} [\boldsymbol{sum\_period\_peak}(\boldsymbol{hrs}) * \mathbf{80\%}\ ]$$

$$\text{or} \quad \boldsymbol{Others}\ (\%\boldsymbol{h}) = \sum\nolimits_{0}^{n} [\boldsymbol{avg\_heat\_usage\_maint}\ (\%) * \mathbf{23}]$$

$$where\ n = number\ of\ of\ occurences$$

Equation 5. 20 Finnish Uncategorized Values

heat_usage_TRV: The total daily heat usage is computed as follows

$$\boldsymbol{heat\_usage\_TRV}(\%\boldsymbol{h}) = \boldsymbol{sum\_period\_peak}(\boldsymbol{hrs}) * \mathbf{80\%} + \boldsymbol{avg\_heat\_usage\_maint}\ (\%) * \boldsymbol{period\_maint}(\boldsymbol{hrs})$$

Equation 5. 21 Finnish Daily Heat Usage

c. *S.H.E. Usage:* The summation of all daily heat usage

$$\boldsymbol{Total\_heat\_usage}(\%\boldsymbol{h}) = \sum_{0}^{n} \boldsymbol{heat\_usage\_TRV} + \boldsymbol{Others} + \mathbf{80}\boldsymbol{n}$$

$$where\ n = number\ of\ days\ the\ heater\ was\ used$$

Equation 5. 22 German Total Heat Usage

Living Room

TRV Heat Radiator:

Using equation 5.18 for this scenario, where both cases presented for others are present

$$heat\_usage\_TRV = 34037.5387594647$$

$$Others\ (\%h) = \sum_{0}^{n} [sum\_period\_peak(hrs) * 80\%\ ] + \sum_{0}^{n} [avg\_heat\_usage\_maint\ (\%) * 23] = 5395.419$$

$$80n = 80 * 163 = 13040$$

$$\text{S.H.E.}\,usage(\%h) = 34037.5387594647 + 6632.147003 + 13040 = 53709.686$$

$$\text{S.H.E. } cost(€) = 53709.686 * 0.0109336 = 587.240$$

Bathroom

TRV Heat Radiator:

Using equation 5.18 for this scenario, where $others$ assumes the following

$$heat\_usage\_TRV = 34037.539$$

$$Others\ (\%h) = \sum_{0}^{n} [sum\_period\_peak(hrs) * 80\%\ ] + \sum_{0}^{n} [avg\_heat\_usage\_maint\ (\%) * 23] = 3189.0245$$

$$80n = 80 * 164 = 13120$$

$$\text{S.H.E. } usage(\%h) = 37943.329 + 3189.0245 + 13120 = 54252.355$$

$$\text{S.H.E. } cost(€) = 54252.355 * 0.0109336 = 593.174$$

Bedroom

TRV Heat Radiator:

Using equation 5.18 for this scenario, where $others$ assumes the following

$$Others\ (\%h) = \sum_{0}^{n} [sum\_period\_peak(hrs) * 80\%\ ] + \sum_{0}^{n} [avg\_heat\_usage\_maint\ (\%) * 23] = 1508.0297$$

from data queries,

$$80n = 80 * 83 = 6640$$

$$heat\_usage\_TRV = 34037.539$$

using equation 5.19 and 5.5,

$$\text{S.H.E. } usage(\%h) = 9124.791 + 1508.030 + 6640 = 17272.820$$

$$\text{S.H.E. } cost(€) = 17272.820 * 0.0109336 = 188.854$$

Summary

Electricity usage and cost

Table 5. 12 Summary of Electricity Usage and Cost

SN	Rooms	Appliances	Energy Usage (kWh)	Energy Cost (€)
1.	Living Room	Lamp	20.872	3.297776
		Stereo + Standby	40.0	6.32
		Flat Screen TV (standby)	36.9671	5.8408018
2.	Bedroom	Wardrobe light	7.3448	1.1604784
3.	Bathroom	Wash machine (standby)	7.82865	1.2369267
4.	Sauna Room	Sauna stove	123	19.434
5.	Other appliances		1508.749	238.382342
	Total		1744.762	275.672

Heat usage and cost

Table 5. 13 Summary of Energy Usage and Cost for S.H.

SN	Rooms	Appliances	Energy Usage (%h)	Energy Cost (€)
1	Living Room	Heat Radiator	53709.68	587.24
2.	Bathroom	Heat Radiator	54252.35	593.174
3.	Bedroom	Heat Radiator	17272.82	188.854
	Total		125234.9	1369.268

$$Total\ Energy\ Cost(€) = 275.672 + 1369.268 = 1644.940$$

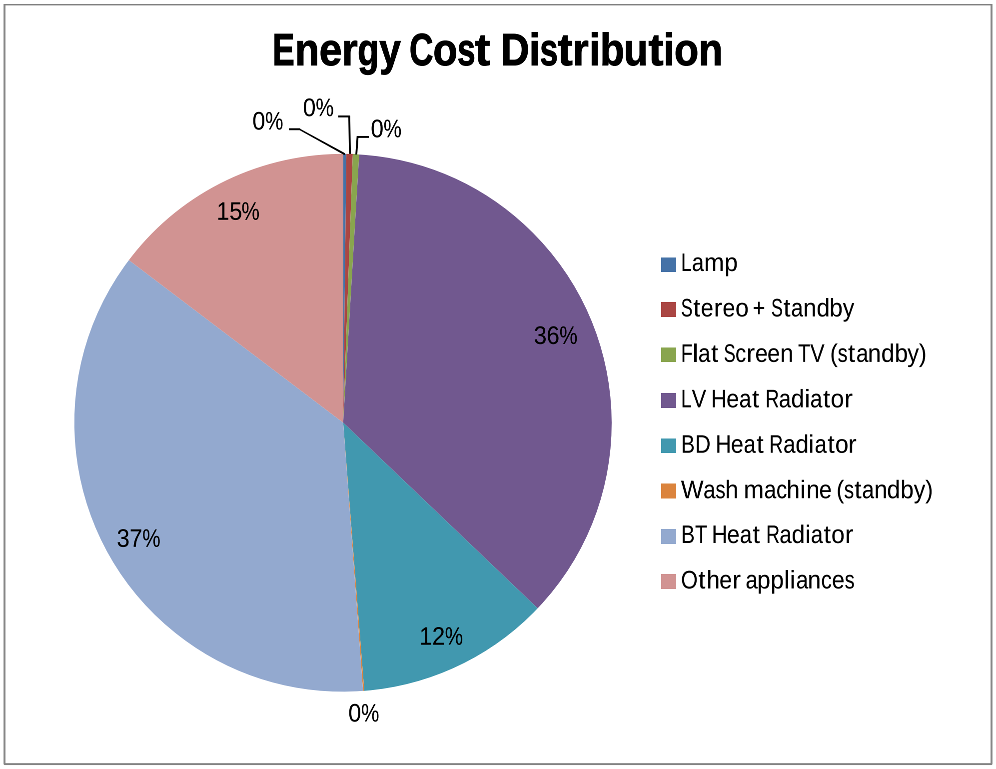


Figure 5. 27 Energy Cost Distribution amongst appliances for NSS

5.1.2.6. Energy Cost Comparison

Electric Appliances

Table 5. 14 Electricity cost comparison between smart strategies

SN	Rooms	Appliances	Smart Strategy		
			No	Medium	High
1.	Living Room	Lamp	3.297776	3.297776	3.297776
		Stereo + Standby	6.32	0.5931636	0.5931636
		Flat Screen TV (standby)	5.8408018	-	-
2.	Bedroom	Wardrobe light	1.1604784	1.1604784	1.1604784
3.	Bathroom	Wash machine (standby)	1.2369267	-	-
4.	Sauna Room	Sauna stove	19.434	19.434	19.434
		Switch module	-	0.28	0.28
5.	Smart System	Raspberry Pi	-	4.15224	4.15224
6.	Other appliances		238.382	238.382	238.382

7.	Total	275.672	267.3	267.3

Heat Radiators

Table 5. 15 Cost comparison of S.H.E. between smart strategies

SN	Rooms	Appliances	Smart Strategy		
			No	Medium	High
1.	Living Room	Heat Radiator	587.24	238.48477656	238.48477656
2.	Bathroom	Heat Radiator	593.174	161.88944176	161.88944176
3.	Bedroom	Heat Radiator	188.854	110.374692	110.374692
4.	Total		1369.268	510.749	510.749

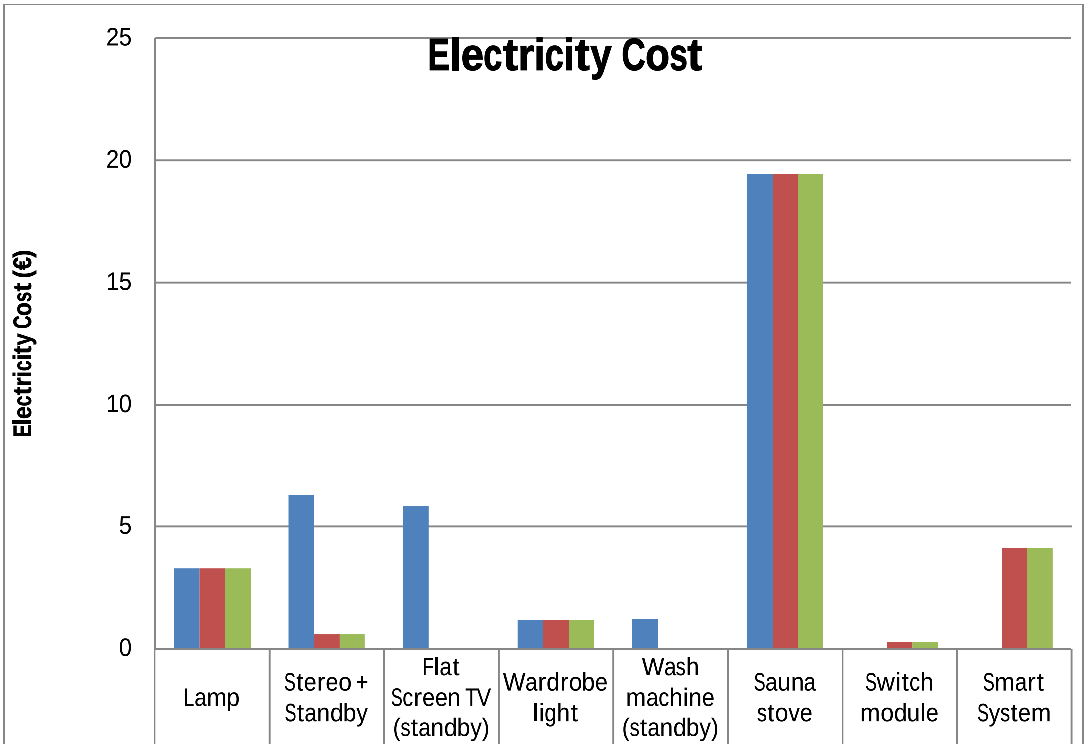
5.1.2.7. Cost Savings

The energy consumption of the High smart strategy is the same with the Medium smart strategy, thus there is no cost saving between the two.

$$Electric\ Cost\ Saving\ (€) = 275.672 - 267.3 = 8.372$$

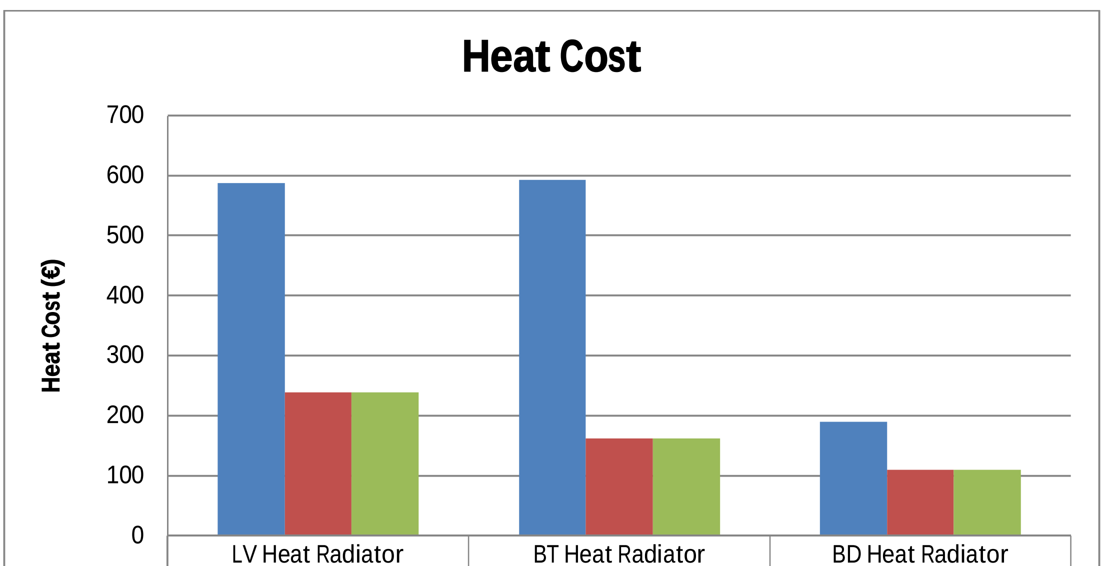
$$Heat\ Cost\ Saving\ (€) = 1369.268 - 510.749 = 858.519$$

$$Total\ Cost\ Saving\ (€) = 8.372 + 858.519 = 866.891$$



	Lamp	Stereo + Standby	Flat Screen TV (standby)	Wardrobe light	Wash machine (standby)	Sauna stove	Switch module	Smart System
No	3.297776	6.32	5.8408018	1.1604784	1.2369267	19.434	0	0
Medium	3.297776	0.5931636	0	1.1604784	0	19.434	0.28	4.15224
High	3.297776	0.5931636	0	1.1604784	0	19.434	0.28	4.15224

Figure 5. 28 Electricity Cost comparison for appliances between Smart Strategies



	LV Heat Radiator	BT Heat Radiator	BD Heat Radiator
No	587.24	593.174	188.854
Medium	238.4847766	161.8894418	110.374692
High	238.4847766	161.8894418	110.374692

Figure 5. 29 Cost comparison of S.H.E. for heat radiators between Smart Strategies

5.1.2.8. Environmental Impact

According to (Climate Friendly, 2011), the CO2 emission from the electricity generation for Finland is 0.134kg CO2 per kWh and the CO2 emission for heating oil is 3.0 kg CO2 per litre.

Thus,

$$\boldsymbol{Oil\ Usage\ for\ S.H.E\ =\ S.H.E.usage\ (\%h)\ *\ 0.0692\ kWh\ *\ 0.1\ l}$$

Equation 5. 23 Oil Usage for S.H.E.

$$\boldsymbol{Carbonfootprint\ \ for\ S.H.E\ (kgCO2)\ =\ 3.0kgCO2 * Oil\ Usage\ (litres)}$$

Equation 5. 24 Carbon footprint for S.H.E.

and the

$$\boldsymbol{Carbonfootprint\ for\ Electricity\ Usage\ (kgCO2) = 0.134kgCO2\ *\ Electricity\ Usage\ (kWh)}$$

Equation 5. 25 Carbon footprint for Electricity Usage

thus the carbon footprint for each strategy is given as follow

Table 5. 16 Carbon footprint for Identified Smart Strategies

SN	Energy	Smart Strategy		
		No	Medium	High
1.	Electricity ($kgCO_2$)	233.8	226.7	226.7
2.	Space Heating ($kgCO_2$)	2599.9	969.78	969.78
3.	Total (kgCO2)	2833.7	1196.48	1196.48

$$CO2\ reduction\ for\ Electricity\ Usage\ (kgCO2)\ =\ 233.8\ -\ 226.7\ =\ 7.1$$

$$CO2\ reduction\ for\ S.H.E.Usage\ (kgCO2)\ =\ 2599.9\ -\ 969.78\ =\ 1630.12$$

$$Total\ CO2\ reduction\ (kgCO2) =\ 7.1 +\ 1630.12\ =\ 1637.22$$

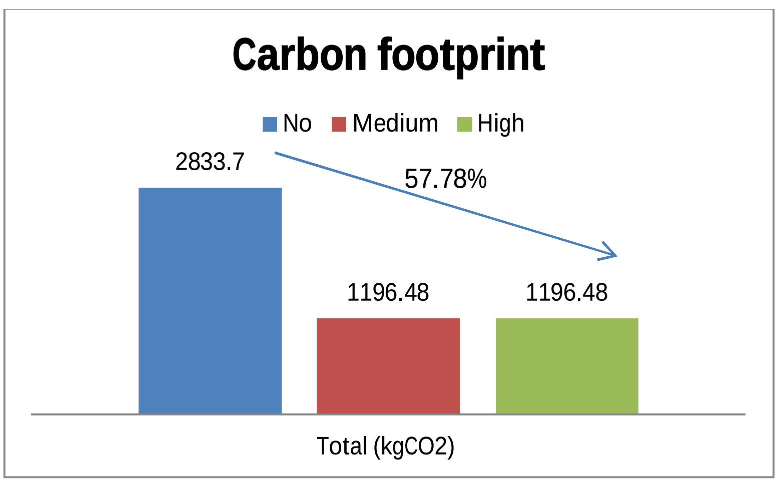


Figure 5. 30 Carbon footprint for Identified Smart Strategies

5.1.2.9. ROI and Payback Computation

Medium Smart Investment

$$Smart\ spending = 541.5$$

$$Total\ Cost\ Saving = 866.891$$

using equations 5:13 and 5:14

$$ROI = \frac{866.891 - 541.5}{541.5} = 60.01\%$$

$$Payback\ Period = \frac{541.5}{866.891} = 0.625\ years$$

$$\approx 7.496\ months$$

$$1st\ year\ return = 325.391$$

$$2nd\ year\ return = 866.891$$

High Smart Investment

$$Smart\ spending = 701.3$$

$$Total\ Cost\ Saving = 866.891$$

using equations 5:13 and 5:14

$$ROI = \frac{866.89141458 - 701.3}{701.3} = 23.61\%$$

$$Payback\ Period = \frac{701.3}{866.891} = 0.809\ years$$

$$\approx 9.70779\ months$$

$$1st\ year\ return = 165.591$$

$$2nd\ year\ return = 866.891$$

5.1.2.10. Monthly ROI after Payback

the table below provides a monthly distribution of the return on investment. The monthly ROI for the TV(standby), wash machine(standby) and the smart system is distributed evenly for each month.

Table 5. 17 Monthly distribution of ROI over home appliances

Device / Month	Living Room				Bedroom		Bathroom		Sauna Room		Smart System	others	Total
	Lamp	Stereo	TV	H Radiator	Lamp	H Radiator	Wash M	H radiator	Sauna Stove	Switch	Raspberry	appliance	
January	-	0.707983	0.487	89.92533	-	11.22671	0.1030772	37.70079		-0.023	-0.34602	-	139.78187
February	-	0.605653	0.487	9.423922	-	0.020115	0.1030772	42.69056		-0.023	-0.34602	-	52.9613072
March	-	0.475131	0.487	0.035034	-	0.085677	0.1030772	17.94094		-0.023	-0.34602	-	18.7578392
April	-	0.590916	0.487	0.213294	-	0	0.1030772	19.87259		-0.023	-0.34602	-	20.8978572
May	-	0.427261	0.487	21.84794	-	6.703453	0.1030772	32.64031		-0.023	-0.34602	-	61.8400212
June	-	0.619977	0.487	16.51086	-	1.826815	0.1030772	51.19646		-0.023	-0.34602	-	70.3751692
July	-	0.822533	0.487	22.0599	-	0	0.1030772	81.01708		-0.023	-0.34602	-	104.12057
August	-	0.140041	0.487	11.90897	-	0	0.1030772	14.20456		-0.023	-0.34602	-	26.4746282
September	-	0.272072	0.487	25.04751	-	2.411146	0.1030772	59.27483		-0.023	-0.34602	-	87.2266152
October	-	0.433714	0.487	8.025283	-	0.622349	0.1030772	14.66405		-0.023	-0.34602	-	23.9664532
November	-	0.217338	0.487	74.48225	-	46.00341	0.1030772	27.0519		-0.023	-0.34602	-	147.975955
December	-	0.414218	0.487	69.27492	-	9.579639	0.1030772	33.0305		-0.023	-0.34602	-	112.520334
Total	-	5.726836	5.841	348.7552	-	78.47931	1.2369267	431.2846		-0.28	-4.15224	-	866.891435

5.3 OWNED APARTMENT

5.3.1 SCENARIO SIMULATION

Australian Smart Strategies

The electricity rate used for computation in (Tejani, et al., 2011) is €0.18 and it is assumed that a Medium smart investment that guarantees basic controls and energy saving is installed for this scenario. Also the identified automation devices for a possible implementation of the MSS and MSS cases does not incur additional electric cost, thus a direct ROI and Payback computation can be made on the values given. A summary of the energy consumption of all appliances with smart installation and without smart installations are given below:

Table 5. 18 Cost comparison of Energy usage between smart strategies

SN	Rooms	Appliances	Energy Consumption (kWh)		
			No	**Medium**	**High**
9.	Living Room	Air Conditioners Fans Heat Radiator Lights Television	4044.596	2780.448	2780.448
10.	Dining Room	Fan Lights	183.553	123.841	123.841
11.	Master Bed Room	Fan Lights Air Conditioner Heater Laptop	3366.062	2736.425	2736.425
12.	Children's Bed Room	Fan Lights Air Conditioner Heater Desktop Computer	2034.359	1404.722	1404.722

13.	Guest Bed Room	Fan			
		Lights			
		Air Conditioner			
		Heater	467.336	322.776	322.776
14.	Master Bathroom	Lights	43.952	37.634	37.634
15.	Common Bath Room	Lights	46.630	39.969	39.969
16.	Uncategorized	Garage Door			
		Washing Machine			
		Vacuum			
		Iron	2516.300	2516.300	2516.300
	Total		**14789.813**	**12023.935**	**12023.935**

From the histogram charts and the power usage of each appliance given in (Tejani, et al., 2011), an approximate energy usage of individual devices are presented for each identified room in table 5.18. This should enable an energy usage percentage for electrical appliances and space conditioning.

Table 5. 19 Approximate Energy Usage of Home Appliance

Rooms	Appliance	Power (kW)	Smart Strategy Energy Usage (kWh)		Energy Saving
			No	Medium & High	
Living Room	Air conditioner	1.799	2140.81	1367.24	773.57
	Fan	0.0513	41.553	61.56	-20.007
	Heater	1.2281	1350.91	994.761	356.149
	Lights	0.1374	163.506	111.294	52.212
	Television	0.1969	356.389	277.629	78.76
Common Bathroom	Lights	0.1374	46.5786	39.9834	6.5952
Uncategorised	Garage Door	0.3417	751.74	751.74	0
	Wash Machine	0.2564	128.2	128.2	0
	Vacuum	0.8198	245.94	245.94	0
	Iron	1.5324	1225.92	1225.92	0

Children Bedroom	Air conditioner	0.731	877.2	650.59	226.61
	Fan	0.0513	35.91	56.43	-20.52
	Heater	1.2281	1350.91	988.6205	362.2895
	Lights	0.1374	164.88	122.286	42.594
	Desktop Computer	0.2174	1282.66	1282.66	0
Guest Bedroom	Air conditioner	0.731	211.99	168.13	43.86
	Fan	0.0513	8.208	13.338	-5.13
	Heater	1.2281	245.62	149.8282	95.7918
	Lights	0.1374	37.785	27.48	10.305
Master Bedroom	Air conditioner	0.731	950.3	657.9	292.4
	Fan	0.0513	35.91	53.865	-17.955
	Heater	1.2281	871.951	577.207	294.744
	Lights	0.1374	178.62	119.538	59.082
	Laptop	0.0851	59.57	59.57	0
Master Bathroom	Lights	0.1374	43.968	37.785	6.183
Dining Area	Fan	0.0513	29.241	22.8285	6.4125
	Lights	0.1374	151.14	97.554	53.586
Kitchen	Fridge	0.1504	1338.56	1338.56	0
	oven	2.2527	225.27	225.27	0
	Microwave	1.0508	210.16	210.16	0
	Lights	0.1374	121.3929	96.18	25.2129
	water kettle	2.6093	260.93	260.93	0

5.3.1.1. Environmental Impact

According to (Climate Friendly, 2011), the CO2 emission from the electricity generation for Western Australia is 0.83kg CO2 per kWh and electricity is used to power electrical appliances and S.H.E devices.

Thus we evaluate only the carbon footprint of total electricity usage as follows:

$$\boldsymbol{Carbonfootprint\ for\ Electricity\ Usage\ (kgCO2)} \\ = \boldsymbol{0.83kgCO2 * Electricity\ Usage\ (kWh)}$$

Figure 5. 31 Carbon footprint for Electricity Usage

thus the carbon footprint for each strategy is given as follow

Table 5. 20 Carbon footprint for Identified Smart Strategies

SN	Energy	Smart Strategy		
		No	Medium	High
1.	Electricity ($kgCO_2$)	12275.55	9979.86605	9979.86605

$$CO2\ reduction\ for\ Electricity\ Usage\ (kgCO2)\ =\ 12275.55 - 9979.866 = 2295.684$$

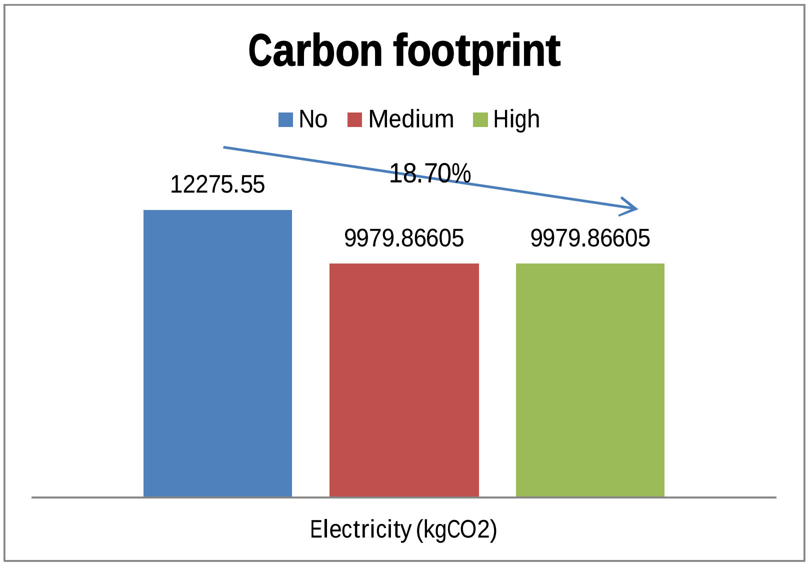


Figure 5. 32 Carbon footprint for Identified Smart Strategies

5.3.1.2. ROI and Payback Computation

Medium Smart Investment

$$Smart\ spending = 1283.8$$

$$Total\ cost\ savings = NSS\ Energy\ Cost - MSS\ Energy\ Cost$$

$$= (14789.813 - 12023.935) * 0.12 = 497.858$$

using equations 5:13 and 5:14

$$ROI = \frac{497.858 - 1104.7}{1104.7}$$

$$= -54.93\%$$

$$Payback\ Period = \frac{1104.7}{497.858}$$

$$Payback\ period = 2.22\ years$$

$$\approx 26\ months$$

High Smart Investment

$$Smart\ spending = 1637.1$$

$$Total\ cost\ saving = NSS\ Energy\ Cost - HSS\ Energy\ Cost$$

$$= (14789.813 - 12023.935) * 0.12 = 497.858$$

using equations 5:13 and 5:14

$$ROI = \frac{497.858 - 1235.5}{1235.5}$$

$$= -59.7\%$$

$$Payback\ Period = \frac{1235.5}{497.858} = 2.48 years$$

$$\approx 29.780\ months$$

German Scenario

The data presented for this scenario are incomplete to evaluate the all device measures hence all evaluation and analysis will proceeds through path 1 to directly compute the building performance. Based on the smart strategy classification, it can be observed that the occupant in this scenario adopted a medium smart strategy thus all data presented for this scenario will be utilized to evaluate the energy usage and cost for this strategy.

German Medium Smart Strategy

Space Heating

The data presented from heating system indicates the total hours the heating system is used. This data with the volume of oil used per hour and the price of the heating oil per litre is utilised to compute the total volume of oil used for heating and the energy cost for space heating.

Where $price\ per\ litre = € 0.82$

$vol.per\ hour = 2.3 ltr$

$$Oil\ Usage\ (ltr) = hours\ of\ usage * 2.3$$

$$Heat\ Energy\ Cost\ (€) = oil\ usage * 0.82$$

The total hour used for heating for this scenario as extracted from the log data is

$$hours\ of\ usage = 549.213$$

thus

$$Oil\ usage (ltr) = 549.213 * 2.3 = 1263.1899$$

$$Heat\ Energy\ Cost\ (€) = 1263.1899 * 0.82 = 1035.816$$

Electricity usage

No data from smart devices are presented for electricity usage, however from data obtained from conducted interviews, the total electricity usage after smart installation is 2000kWh and rate of electricity is 0.25 Euros.

$$Electricity\ Cost = 2000 * 0.25 = 500$$

German High Smart Strategy

Space Heating

same as the medium smart strategy

Electricity usage

same as the medium smart strategy

German No Smart Strategy

Space Heating

The percentage difference between the total energy usage for heating for the no and medium smart strategy in the German rented scenario alongside the energy cost for space heating of the medium smart strategy will be used to compute the space heating for this strategy. This will provide a minimum approximate estimation based on the assumption given in (Tejani, et al., 2011) that the more the number of home occupant the more the energy consumption and that the user behaviour for this strategy is the same with the user behaviour of the German rented apartment.

thus

$$percentage\ difference = \frac{806.71}{1391.723} = 57.965\%$$

$$space\ heating = \frac{1035.815718}{0.57965} = 1786.9675$$

Electricity usage

From the data obtained from conducted interviews, the total electricity usage before smart installation is 2200kWh.

$$Electricity\ Cost = 2200 * 0.25 = 550$$

Table 5. 21 Energy usage summary

SN	Device category	Smart Strategy		
		No	Medium	High

1.	Electricity (€)	550	500	500
2.	Space Conditioning (€)	1786.9675	1035.816	1035.816

Cost Savings

The energy consumption of the High smart strategy is the same with the Medium smart strategy, thus there is no cost saving between the two.

$$Electric\ Cost\ Saving\ (€) = 550 - 500 = 50$$

$$Heat\ Cost\ Saving\ (€) = 1786.9675 - 1035.816 = 751.152$$

$$Total\ Cost\ Saving\ (€) = 50 + 751.152 = 801.152$$

5.3.1.3. Environmental Impact

utilizing equations 5.15 and 5.16 and plugging the electricity and oil usage data obtained for each smart strategy, the carbon footprint for each strategy is as follow

Table 5. 22 Carbon footprint for Identified Smart Strategies

SN	Energy	Smart Strategy		
		No	Medium	High
1.	Electricity ($kgCO_2$)	990	900	900
2.	Space Heating ($kgCO_2$)	6537.69	3789.57	3789.57
3.	Total (kgCO2)	7527.69	4689.57	4689.57

$$CO2\ reduction\ for\ Electricity\ Usage\ (kgCO2) = 990 - 900 = 90$$

$$CO2\ reduction\ for\ S.H.E.Usage\ (kgCO2) = 6537.69 - 3789.57 = 2748.12$$

$$Total\ CO2\ reduction\ (kgCO2) = 90 + 2748.12 = 2838.12$$

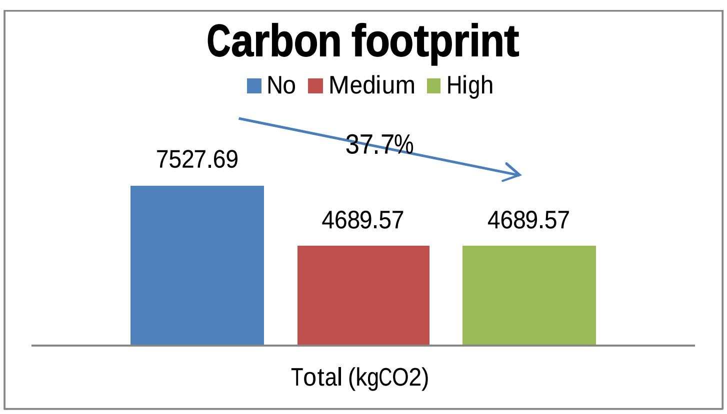


Figure 5. 33 Carbon footprint for Identified Smart Strategies

5.3.1.4. ROI and Payback Computation

German Medium Smart Strategy

$$Smart\ spending = 1211.15$$

$$Total\ Cost\ Saving\ (€) = 50 + 751.152 = 801.152$$

using equations 5:13 and 5:14

$$ROI = \frac{801.152 - 1211.15}{1211.15}$$

$$= -33.852\%$$

$$Payback\ Period = \frac{1211.15}{801.152}$$

$$Payback\ period = 1.5118 years$$

$$\approx 18.14\ months$$

German High Smart Strategy

$$Smart\ spending = 1649.85$$

$$Total\ Cost\ Saving\ (€) = 50 + 751.152 = 801.152$$

using equations 5:13 and 5:14

$$ROI = \frac{801.152 - 1649.85}{1649.85}$$

$$= -51.441\%$$

$$Payback\ Period = \frac{1649.85}{801.152} = 2.059 years$$

$$\approx 24.7\ months$$

Finnish Scenario

The electricity usage in the German scenario plus the electricity used to power the sauna room will be used to compute the electricity consumption for this scenario. Also energy usage for space heating in the German medium smart strategy will b adopted for the Finnish medium strategy and the percentage difference between the total energy usage for heating for the no and medium smart strategy in the Finnish rented scenario alongside the energy cost for space heating of the German medium smart strategy will be used to compute the space heating for this strategy.

Finnish Medium Smart Strategy

Space Heating
same as the German Medium Smart Strategy

Electricity usage
The electricity usage for the sauna room is given below

Table 5. 23 Energy Usage of the Sauna Room

SN	Room	Appliance	Energy Usage	Energy Cost
1.	Sauna Room	Sauna stove	123	19.434
		Switch module	1.752	0.28

$$Electricity\ Cost = 2000 * 0.158 + 19.34 + 0.28 = 335.62$$

Finnish High Smart Strategy

Space Heating
same as the medium smart strategy

Electricity usage
same as the medium smart strategy

Finnish No Smart Strategy

Space Heating

$$percentage\ difference = \frac{510.7489}{1369.268} = 37.30\%$$

$$space\ heating = \frac{1035.816}{0.3730} = 2776.99$$

Electricity usage
The electricity usage for the sauna room is given below

Table 5. 24 Energy usage of the Sauna Room

SN	Room	Appliance	Energy Usage	Energy Cost
1.	Sauna Room	Sauna stove	123	19.434

$$Electricity\ Cost = 2200 * 0.158 + 19.434 = 367.034$$

Table 5. 25 Energy Usage Summary

SN	Device category	Smart Strategy		
		No	Medium	High
1.	Electricity (kWh)	367.034	335.62	335.62
2.	Space Conditioning (l/hr)	2776.99	1035.816	1035.816

Cost Savings

The energy consumption of the High smart strategy is the same with the Medium smart strategy, thus there is no cost saving between the two.

$$Electric\ Cost\ Saving\ (€) = 367.034 - 335.62 = 31.414$$

$$Heat\ Cost\ Saving\ (€) = 2776.99 - 1035.816 = 1741.174$$

$$Total\ Cost\ Saving\ (€) = 31.414 + 1741.174 = 1772.588$$

5.3.1.4. Environmental Impact

utilizing equations 5.15 and 5.16 and plugging the electricity and oil usage data obtained for each smart strategy, the carbon footprint for each strategy is as follow

Table 5. 26 Carbon footprint for Identified Smart Strategies

SN	Energy	Smart Strategy		
		No	Medium	High
1.	Electricity ($kgCO_2$)	311.3	311.52	311.52
2.	Space Heating ($kgCO_2$)	10159.7	3789.57	3789.57
3.	Total (kgCO2)	10471	4101.09	4101.09

$$CO2\ reduction\ for\ Electricity\ Usage\ (kgCO2) = 311.3 - 311.52 = -0.22$$

$$CO2\ reduction\ for\ S.H.E.Usage\ (kgCO2) = 10159.7 - 3789.57 = 6370.13$$

$$Total\ CO2\ reduction\ (kgCO2) = -0.22 + 6370.13 = 6369.91$$

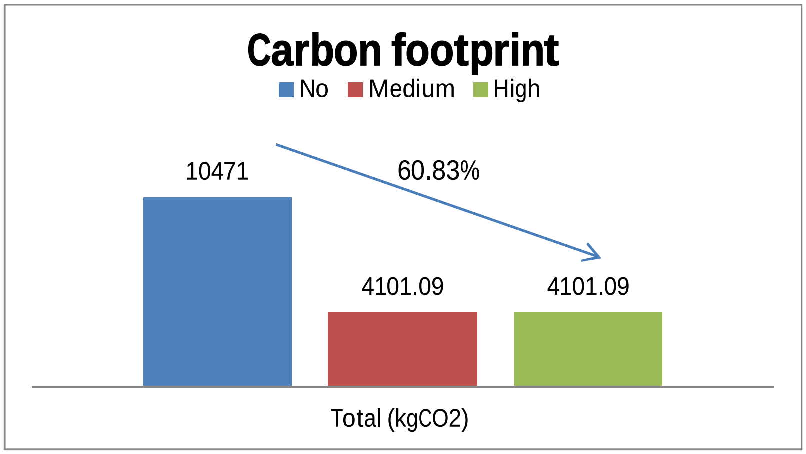


Figure 5. 34 Carbon footprint for Identified Smart Strategies

5.3.1.5. ROI and Payback Computation

Finnish Medium Smart Strategy

$$Smart\ spending = 1251.1$$

$$Total\ Cost\ Saving\ (€) = 31.414 + 1741.174 = 1772.588$$

using equations 5:13 and 5:14

$$ROI = \frac{1772.588 - 1251.1}{1251.1}$$

$$= 41.68\%$$

$$Payback\ Period = \frac{1251.1}{1772.588}$$

$$Payback\ period = 0.706 years$$

$$\approx 8.4\ months$$

Finnish High Smart Strategy

$$Smart\ spending = 1730.75$$

$$Total\ Cost\ Saving\ (€) = 31.414 + 1741.174 = 1772.588$$

using equations 5:13 and 5:14

$$ROI = \frac{1772.588 - 1730.75}{1730.75}$$

$$= 2.417\%$$

$$Payback\ Period = \frac{1730.75}{1772.588} = 0.976 years$$

$$\approx 11.717\ months$$

5.4 RENEWABLE ENERGY INSTALLATION

PV Systems

All irradiation data are adopted from (EU Institute for Energy and Transport, 2014) and the total energy generated from solar radiation is calculated as follows

$$\boldsymbol{E = A * r * H * PR}$$

Equation 5. 26 Solar Energy Output

Where

$$E = Solar\ Energy\ Output$$
$$A = Total\ Surface\ Area(m2)$$
$$r = Solar\ Panel\ yield(\%)$$
$$H = Annual\ Average\ Solar\ Radiation$$
$$PR = Performance\ Ratio = 0.75$$

Germany Owned Apartment

The annual average irradiation for Stuttgart, Germany where this apartment is located is 1323.05kWh/m^2 and the expected peak power (i.e. kW-peak) for this apartment is 3kW. The total surface area that is sufficient to capture adequate solar radiation to achieve this peak is 30m^2.

Table 5. 27 Monthly energy output for PV-system

Month	Irradiation (Wh/m^2/day)	Monthly Solar Energy (kWh/m^2)	Electricity (kWh)
Jan	1370	41.1	92.475
Feb	2280	63.84	143.64
Mar	3890	120.59	271.3275
Apr	4930	147.9	332.775
May	5070	157.17	353.6325
Jun	5490	164.7	370.575
Jul	5420	168.02	378.045
Aug	4990	154.69	348.0525
Sep	4200	126	283.5
Oct	2900	89.9	202.275
Nov	1690	50.7	114.075
Dec	1240	38.44	86.49
Year	3630	1323.05	2976.8625

Thus

$$r = 10\%, A = 30m2, H = 1323.05, PR = 0.75$$
$$E = 2976.9\ kWh/an$$

0.4675 Euros is paid for electricity sold to the grid while 0.25 Euro is paid for electricity used from the grid thus the amount for

$$Electricity\ used = 2000 * 0.25 = 500$$

and

$$Electricity\ generated = 2976.9 * 0.4675 = 1391.70075$$

the gain from PV installation

$$gain(€) = 1391.70075 - 500 = 891.7$$

ROI and Payback Computation

$$cost\ of\ PV\ system\ (€) = 16000$$

$$gain(€) = 891.7$$

using equations 5:13 and 5:14

$$ROI = \frac{891.7 - 16000}{16000}$$

$$= -94.4\%$$

$$Payback\ Period = \frac{16000}{891.7}$$

$$Payback\ period = 18\ years$$

Finnish Owned Apartment

The annual average irradiation for Lappeenranta, Finland is 1105.95kWh/m^2 and the expected peak power (i.e. kW-peak) for this apartment is 3.5kW. The total surface area that is sufficient to capture adequate solar radiation to achieve this peak is 40m^2.

Thus

$$r = 10\%, A = 40m2, H = 1105.95, PR = 0.75$$

$$E = 2903.12\ kWh/an$$

The electricity usage after home automation for the apartment is

$$Electricity\ usage = 2000 + 123 + 1.752 = 2124.752kWh$$

There is no feed-in tariff for PV systems in Finland, hence any electricity generated cannot be sold, however it is assumed that only electricity generated and produced into the grid can be used from the grid without users having to pay. Hence from Table, it can be observed that the total energy generated is greater than the energy used.

Table 5. 28 Monthly energy output for PV-system

Month	Irradiation ($Wh/m^2/day$)	Monthly Solar Energy (kWh/m^2)	Electricity(kWh)
Jan	693	20.79	54.57375
Feb	1970	55.16	144.795
Mar	3070	95.17	249.82125
Apr	4690	140.7	369.3375
May	5600	173.6	455.7
Jun	5430	162.9	427.6125
Jul	5530	171.43	450.00375
Aug	4220	130.82	343.4025
Sep	2720	81.6	214.2
Oct	1510	46.81	122.87625
Nov	530	15.9	41.7375
Dec	378	11.718	30.75975
Year	3030	1106.598	2904.8198

Also the Finnish renewable energy Act offsets household taxes for households with PV installations. The annual tax rate for household is calculated based on the NPV of the apartment and it is approximately 0.60–1.35% of this NPV. It is assumed that the value of this apartment is 135,680 Euros and the tax rate is 0.975%, hence the house tax is 1322.88 Euros.

Thus

$$gain\ (€) = \ cost\ of\ energy\ savings\ +\ household\ tax$$

$$= 2124.752 * 0.158 + 1322.88 = 1658.6$$

ROI and Payback Computation

$$cost\ of\ PV\ system\ (€) = \ 20000$$

$$gain(€) = 1658.6$$

using equations 5:13 and 5:14

$$ROI = \frac{1658.6 - 20000}{20000}$$

$$= -92\%$$

$$Payback\ Period = \frac{20000}{1658.6}$$

$$Payback\ period = 12.06\ years$$

6. CONCLUSION

To conclude this thesis work, the cost of electricity usage and space heating for each smart strategy for the identified domains of interest are highlighted to verify the claims given in (Odyssee-Mure, 2012). Secondly, the energy saving prospect of each smart strategy are clearly highlighted and compared to the claims given both in (European Commission, 2015) and (Global eSustainability Initiative, 2008). Thirdly, the payback time and ROI of all presented smart strategies for each domain of interest are highlighted and a profitable smart investment approach is recommended for each domain of interest. Fourthly, a comparison of the ROI and payback time of PV system installations for Finland and Germany are highlighted to investigate the claims given in (Mikko & Pertti, 2013). And lastly, in the summary, a general concluding statement is made and some recommendations about future works are presented.

6.1 FINDINGS

Energy cost distribution

German Rented Apartment

The cost of energy usage for the No smart strategy is 1797.1634 Euros and 77% and 23% represents the cost contribution of space heating and electricity usage respectively. While the cost of energy usage for the Medium and High smart strategy is 1198.46 and 67% and 33% represents the cost contribution of space heating and electricity usage respectively.

Finnish Rented Apartment

The cost of energy usage for the No smart strategy is 1644.940 Euros and 85% and 15% represents the cost contribution of space heating and electricity usage to the total cost respectively. While the cost of energy usage for the Medium and High smart strategy is 778.05 and 66% and 34% represents the cost contribution of space heating and electricity usage to the total cost respectively.

Comparing these percentage distribution with the figures given in (Odyssee-Mure, 2012) where water heating, electric appliances and lighting and cooking are considered as electricity usage, the energy usage for the No smart strategy for the German rented apartment seems to approximately aligns with the figures given in the report. However, for the Finnish rented apartment, there is a significant difference, this might be because the German energy usage for electronic appliances and lighting and water heating and cooking were adopted for Finnish scenario due to insufficient data, whereas in real life, the irradiation in Finland is lesser compared to Germany thus the energy used for lighting will be relatively higher and for climatic reasons, the energy used for water heating will also be relatively higher.

Also, these findings reveals that there is a cost distribution realignment with the adoption of a smart strategy and this realignment favours the percentage reduction in the cost of heating and home conditioning significantly. This implies that a smart investment for heat energy optimization proffers better cost reduction capabilities and tendencies for heat and home conditioning than for other home electric appliances. However the measure of this reduction can only be ascertained by the energy saving distribution

Energy saving distribution

German Rented Apartment

Standby Energy Saving

The total electricity usage in kWh for the no smart strategy is 1621.76155 and its relative cost is 405.440388 Euros while the electricity usage for both the medium and high smart strategy is 1567.22 and its relative cost its 391.75. Thus the electricity saving for both medium and high smart strategy is 54.54155 kWh and its relative cost 13.69 Euros. This represents a 3.46% percentage reduction in energy usage for electric appliances.

Space Heating

The total energy usage for heating in %h for the no smart strategy is 80252.37 and its relative cost is 1391.723 Euros while the electricity usage for both the medium and High smart strategy is 46713.7 and its relative cost is 806.71 Euros. Thus the heat energy saving for both the medium and high smart strategy is 33538.67 and the relative cost of this saving is 585.013 Euros. This represents a 42.04% percentage reduction in the energy usage for heat radiators.

Finnish Rented Apartment

Energy Saving from Standby

The total electricity usage in kWh for the no smart strategy is 1744.76155 and its relative cost is 275.6723249 Euros while the electricity usage for both the medium and high smart strategy is 1691.752 and its relative cost its 267.3. Thus the electricity saving for both medium and high smart strategy is 53.00955 kWh and its relative cost 8.3723 Euros. This represents a 3.04% percentage reduction in energy usage for electric appliances.

Energy from Space Heating

The total heat energy usage in %h for the no smart strategy is 125234.9 and its relative cost is 1369.268 Euros while the heat energy usage for both the medium and High smart strategy is 46713.7 and its relative cost is 510.74891032 Euros. Thus the heat energy saving for both the medium and high smart strategy is 78521.2 and the relative cost of this saving is 858.51908968 Euros. This represents a 62.7% percentage reduction in the energy usage for heat radiators.

These values corroborate the earlier cost reduction realignment assumption and reveals that the smart investment for heat usage in the German scenario contributed a 97.7% energy reduction to the total energy reduction of this apartment. While the smart investment for heat usage in the Finnish scenario contributed a 99% energy reduction to the total energy reduction of this apartment.

Also from these values, it can also be observed that inefficient use of space heating contributed 52% and 33% to the total energy usage of the Finnish and German rented apartment respectively. While the standby energy usage for electric appliance contributed 0.509% and 0.762% only to the total energy usage of the Finnish and German rented apartment respectively. These figures reveals that the installation of smart home systems achieved significantly more than the 10-30% energy usage reduction prediction given in (Energy Star, n.d.).

6.2 DISCUSSION

German Rented Apartment

The return on smart investment or spending for a year period for the medium and high smart strategy are 28.04% and -3.653% and their respective payback times are 9.4 months and 12.5 months. The value for this return for the first and second year (given there are no significant differences in environmental factors from the first year) for a medium smart strategy is 131 and 598 Euros respectively while the value for this return for the first and second year for a high smart strategy is a loss of 23 Euros and a gain of 598 Euros. Depending on the preference of an investor, a payback time of 12.5 months for a high smart strategy might be appropriate for the level of comfort and control the automation scenarios this smart strategy proffers. However from an economic standpoint, it is advisable to progressively invest in a medium smart strategy for the first year and then a high smart strategy for the second year. This is to enable the investor get some returns of 131.1 Euros for the first year, before investing another some of 153.8 Euros to attain a high smart strategy to both achieve a higher level of control and comfort and a smart investment return of 576.0 Euros.

Finnish Rented Apartment

The return on smart investment or spending for a year period for the medium and high smart strategy are 60.01% and 23.61% and their respective payback times are 7.5 months and 9.71 months. The value for this returns for the first and second year (given there are no significant differences in environmental factors from the first year) for a medium smart strategy are 325.4 and 866.9 Euros respectively while the value for this returns for the first and second year for a high smart strategy are 165.6 Euros and 866.9 Euros respectively. From an economic standpoint, the high smart strategy can be implemented from the beginning, this is because a progressive investment for a medium strategy for the first year and high strategy for the second year will yield the same investment return as the initial high smart spending over a two year period.

Australian Owned Apartment

The return on smart investments for a year period for the medium and high smart strategy are -54.93% and -59.7% and their respective payback times are 26 months and 29.7795 months. From an economic perspective, these investments might not be good investments to undertake for investors that are looking for an investment return within a two year period. However from a closer look at the data given in (Tejani, et al., 2011), approximately 90% of energy saving was made on space conditioning, if the smart investments for the medium smart strategy are solely made for space conditioning, the payback for this strategy could be reduced for 20 months.

German Owned Apartment

The return on smart investment or spending for a year period for the medium and high smart strategy are -33.852% and -51.441% and their respective payback times are 18.14 months and 24.7 months. From an economic standpoint, the medium smart strategy represents a smart investment choice for end-users because of its relative shorter payback time and better ROI thus it is advisable to progressively invest in a medium smart strategy and then to a high smart strategy.

Finnish Owned Apartment

The return on smart investment or spending for a year period for the medium and high smart strategy are 39.17% and 0.6023% and their respective payback times are 8.62 months and 11.93 months. Both strategies provides a positive ROI and payback time under a year period, however the large difference between the ROI of the medium and high smart investment makes the medium smart investment a better bargain thus from an economic standpoint, thus it is advisable to progressively invest in a medium smart strategy for the first year and then a high smart strategy for the second year.

PV system Installation

The ROI for PV system installation in Germany that enables an NZEB/PEB for the Owned apartment is -94.4% and its payback time is 18 years while the ROI and payback for this installation in Finland are -92% and 12.06 years respectively. This figures clearly overrides the assumption that PV installations is more profitable in Germany than in Finland and it further supports the claims given in (Mikko & Pertti, 2013) that power production from PV systems is a viable energy source for Finland and can be regarded as a long-term profitable venture.

6.3 ENVIRONMENTAL CONTRIBUTION

German Rented Apartment

From table 5.8, it can be observed that the same carbon footprint distribution is recorded for the energy consumption of both the medium and high smart strategies, thus the same total CO2 reduction is derived between the medium and no smart strategies and the high and no smart strategy. The CO2 exhaled by both the no smart strategy and the other strategies are 2395.84 kgCO2 and 1675.03 kgCO2 respectively and the CO2 reduction between these strategies is 720.81kgCO2. This figure represents a 30.085% total reduction of CO2 emissions.

Finnish Rented Apartment

The carbon footprint for the Finnish use case presented in table 5.17 and figure 5.29 for all smart strategies reveals a total CO2 percentage reduction of 57.78% from the no smart strategy to the medium and to high smart strategy where the carbon footprint for these strategies in kgCO2 are 2833.7, 1196.48 and 1196.48 respectively.

Australian Owned Apartment

The total CO2 reduction for the Australian case presented in (Tejani, et al., 2011) from the no smart strategy to the medium and the high smart strategies is 2295.68 kgCO2 and this implies an 18.70% CO2 emission reduction.

German Owned Apartment

The German use case for the owned apartment recorded a 37.7% total carbon footprint reduction with a value of 2838.12kgCO2. This was obtained by comparing the no smart strategy to the medium and high smart strategy with 7527.69, 4689.57 and 4689.57 kgC02 emission respectively.

Finnish Owned Apartment

The Finnish use case for the owned apartment recorded a 60.83% total carbon footprint reduction from the no smart strategy to the medium and high smart strategy with 10471, 4101.09 and 4101.09 C02 emission respectively.

The smart 2020 report in (Global eSustainability Initiative, 2008) predicted that the introduction of smart systems to buildings may mitigate 15% of the global CO2 emission. However, out of nine measure identified to yield this mitigation, only five of these measures are covered in this thesis and this represent 9.9% total mitigation of global CO2 emission.

From the data highlighted above, it can be observed that the Australian owned apartment use case yielded the least CO2 reduction amongst the owned apartment use case. This is because, the source of energy for both electric appliances and appliances for space conditioning is electricity and while the CO2 rate for the electricity production in Australia is relatively higher compared to Germany and Finland, this rate is relatively more environmentally efficient than the rate of the fuel used for space heating in German and Finland.

Comparing both the Finnish and German use cases, if the oil usage adopted by the German use case for space heating is also adopted by the Finnish use case, the Finnish use case will accrue a higher CO2 emission simply because of the higher energy consumption accrued for space heating. However, if natural gas or electricity is utilized as energy source for space heating for the Finnish use case as this is the case for most Finnish homes and apartments and oil is utilized for the German use case, the CO2 exhaled by the Finnish use case will be relatively lower than that of the German use case.

6.4 ETHICAL CONTRIBUTION

"*An ethical approach to sustainability suggests that society has an obligation to restrain wasteful uses of resources among the affluent, but it also has a special obligation to foster economic development for the poorest of the poor, all while maintaining environmental resource protection*." (Warner & DeCosse, 2009)

Firstly, this thesis informs home occupants of the eminent wastefulness that can result from user's negligence and other causes. Also it clearly highlights that the environmental and economical consequence of these wastefulness clearly supersede a tailored cost of its prevention. The results from this thesis present an alternative energy usage profile for home occupants to adopt and it presents a justification for this adoption from an economic and environmental perspective with increased home comfort-ability and home appliance control.

Secondly, while there may be no laws or directives that implores home occupants to adopt building automation for energy resource optimization, the results from this thesis presents a justification for the consideration of a concerted effort or directives because of the resource wastefulness mitigation prospects, the economic development of the building automation sector and the development of human capacity in this sector. Also, such effort or directive will facilitate the awareness of the inherent capabilities of this technology and it will accelerates its adoption by home occupant.

6.5 SUMMARY

This thesis aims to investigate the energy usage tendencies in residential buildings in Germany and Finland and to measure and compare the energy saving prospects of both countries with the installation of home automation. Also for both countries, it investigates the gains of home automation investments and it proffers an investment approach for every identified domain of interest. Lastly, to ensure a NZEB/PEB this thesis investigates and compares the gains of installing PV system in both countries. To achieve these aims, user behaviours for both countries are observed and interviews are conducted to corroborate user observation. Secondly log data from home automation installations are collected and analysed for various mathematical computations and pattern derivation. Also automation scenarios are grouped into smart strategies and a cost estimation for implementing these smart strategies were made and the energy saving associated with each smart strategy was computed. Fourthly, based on the cost of investment and cost of energy savings, the gains of home automation were calculated for each smart strategy. Lastly, to enable an NZEB/PEB, the cost and gains of installing PV systems for both countries were analysed and a comparison between the two were made.

From the foregoing, it can be observed that the installation of both home automation and PV systems for the Finnish usage tendencies seems to proffers a better ROI and payback time than for the German usage tendencies. Also while a German investor should initially adopt a medium smart strategy before a high smart strategy for early profitability, a Finnish investor may have the liberty to adopt any of these smart strategies and still accrue a desired profit.

Highlighted below are recommendations for future research works:

1. A large share of the energy consumption in buildings is driven by occupancy behaviour. Thus, it is pertinent to develop a standard framework:
   - that models occupancy behaviour
   - that predicts future occupancy with respect to historic, real-time and future data
   - and estimate the energy usage associated with building occupancy.

2. Quantification of the energy optimisation capabilities of home retrofitting and computation of its ROI and payback time with acute investigation and modelling of the relationship between space heating and the R-value of buildings.

APPENDIX A

AI: PREDEFINED SCENARIOS

ELECTRICITY OPTIMIZATION (E)

1. The system should automatically turn on/off lights.
2. The system should automatically place A/V appliances on standby or switch on/off.
3. If room is occupied, perform E1 on and E2 standby.
4. If the house is not occupied, perform off of E2 and place all desktop computers on standby.
5. The Electricity smart monitor should daily measure and report the overall energy consumption of the apartment, including its CO_2 emissions.

HEAT OPTIMIZATION (H)

1. The heat system should be switched on if the house is occupied.
2. If a room is occupied, the heat radiator controller should maintain the desired room temperature
3. If a room is not occupied, the heat radiator controller should power down and maintain the minimum temperature
4. If the window is open, the heat radiator should be switched-off
5. if the entrance door is open for a certain amount of time, the heat radiator should be switched-off
6. If the heat radiator is switched-on the house heater should be switched-on else it should be switched-off.
7. if the sauna room is occupied, maintain the preset high temperature else the sauna stove should be switched off.

COMFORT (CC)

1. The remote control and mobile app should be configured to perform E1,E2,E3,E4, H1,H2 and H3.
2. The system should be configured to enable mobile apps and web app to control and check the status of all appliances and security systems (if Installed) remotely.
3. Automatically regulate room temperature to maintain the desired temperature according to weather forecast or outdoor temperature (if installed).
4. Adjust the brightness of a room according to user requirement.
5. Adjust A/V system mode according to user requirement.
6. In the living room, when the user turns on the DVD player, adjust the room brightness, then, place the A/V system to start in the DVD mode.
7. Early rush: With a single click, the coffee machine should prepare a coffee.
8. Detect motion or presence in all room to perform turn on/off the light and the heating system, maintain desired or minimum temperature.

9. Automatically Unlock/lock entrance door using the system.
10. Unlock/lock entrance door with remote control and mobile app.
11. Adjust the brightness of a room based on the current intensity of illumination.
12. When someone comes home turn on certain lights for convenience.
13. In the living room, When the telephone rings, the A/V system should be paused if playing.

SECURITY (S) (Cellini, 2015)

1. Perform E1 on for Security lights when motion is sensed around the house
2. Alarms should be sounded when a person tries to unlock the doors to the house for more than a minute
3. When an exterior motion sensor detects body presence, security cameras should be switched-on and should start to record.
4. Send email notification when the security system is armed, disarmed, or when there's an alarm.
5. Notify the user if garage door is left open and provide option to remotely open/close it.
6. Notify the user if entrance doors to the house are left open.
7. If someone walks up onto the house during "quiet hours", give alarm warning and take a photo.
8. Archive photos/video footage immediately before or/and after security system is tripped, or when doorbells are rung.
9. When someone rings your doorbell pause all playing media in the living room if it was playing. Turn TV to security camera's channel to see who's by the door.
10. During emergency, flash porch lights to attract attention of your neighbours or guide police/fire trucks to your home.

MODES (M) (io-homecontrol, 2015)

1. Holiday: Simulate user presence in the home: the roller shutters should go up and down automatically (if installed) and the lights should go on and off.
2. Good Morning: When a user wakes in the morning, the system should turn on the bedroom lights and adjusts its brightness to 40%, then to 60% a few minutes later. The bathrooms and living areas should warm up automatically to the desired temperature or/and the roof window should open up to ventilate the area, also all the roller shutters should open up (if installed).
3. Good night mode: With a single click on the remote control or the mobile app, the lights should go off and also the minimum room temperature should be maintained. The roller shutters should be closed (if installed), the front door should be locked and the alarm should be set (if security system is installed). A green light on your remote control or an acknowledgement on the mobile app should display that everything is okay.

4. Party Nights: Turn ambient lighting to highlight your entertainment area. Turn on the background music.
5. In wintertime: the roller shutters should go up in order to allow the sunlight naturally heat the house. At nightfall, the roller shutters should automatically go down to prevent heat in the apartment from escaping, and the lights should be switched on.
6. Summer period: In the summertime, as the sun heats the façade and the roof, the sun protections should automatically roll down or shut to keep the apartment cool.
7. Welcome home: With a single click of the remote control, your house welcomes you: the gate opens, the lights come on, the front door unlocks, the garage door opens and the security system is disarmed.
8. Refreshing Nights: At nightfall, the roof windows and shutters should open wide in order to let the cool evening air ventilate the house. The air-conditioning or ventilation system should only be switched on later.
9. You have to go out for a short while? Close the whole house with a single click: the front door is locked, the windows are closed, lights go off, the garage door and the gate are closed.
10. When the user leaves the apartment, mobile app should request the time of return, This will enable the system to set the rooms at a desired temperature an hour before arrival. Before switching the heating system on, the system should notify the user via available media.

AII: SCENARIO CATEGOIZATION

Scenario	SMART STRATEGY			
	No	**Medium**	**High**	**Optional**
E1		X	X	
E2		X	X	
E3		X	X	
E4		X	X	
E5				X
H1		X	X	
H2		X	X	
H3		X	X	
H4		X	X	
H5			X	
H6		X	X	
H7		X	X	
CC1		X	X	
CC2		X	X	
CC3		X	X	
CC4			X	
CC5			X	
CC6			X	
CC7				X
CC8			X	
CC9				X
CC10				X
CC11				X
CC12		X	X	
CC13				X
S1				X
S2				X
S3				X
S4				X
S5				X
S6				X
S7				X
S8				X
S9				X
S1O				X
M1		X	X	
M2		X	X	
M3		X	X	
M4			X	
M5			X	
M6			X	
M7			X	
M8			X	
M9		X	X	
M10		X	X	

AIII: DEVICE OPERATIONAL SPECIFICATION

THE THERMOSTAT RADIATOR VALVE:

This valve regulates the flow of water to the radiator which controls the amount of heat given off by the a radiator which also controls the temperature of the room (Judge Electrical Limited, n.d.). TRV consists of a thermostat (in form of a tiny metal spring or gel) which controls the valve, when the room temperature is higher than the preset temperature, this spring or gel expands to reduce the water flow into the radiator and when the room temperature drops, the metal spring or gel contracts and this allows water flow into radiator. (plumberparts, 2011)

THE NORMAL VALVE:

The normal valve allows the influx of water into the radiator without any control or regulation. (plumberparts, 2011)

APPENDIX B

BI: INTERVIEW QUESTIONS FOR SMART HOME INSTALLATIONS

General Information

1) Name:____
2) Country:____
3) Contact
   Email:____
4) Type of Apartment (Rented, Owned Apartment, Hotel, Others) Category:______________
5) Date of Survey:_______________________ Date of installation:______________________

Please kindly upload your log to: https://www.mediafire.com/folder/ta9gykt8dj1qi//Documents

Purpose for Installation:

	Low	Medium	High
Control			
Energy Saving			
Comfort			

***High Control**: A fully automatic control of device and implementation of highly intelligent scenarios*
***Medium Control**: A basic control of appliance that requires user input or acknowledges*
***Low Control**: No automatic control at all.*

Energy Consumption

6) Period (How many months or years):
   ____

	Before Automation		After Automation(kWh)	
	(kWh)	Euro	(kWh)	Euro
Electricity				
Heating				

Cost of Smart Installation:

7) Installation Cost :____
8) Government Incentives or Subsidy for installation:__________________________________

Details About Apartment, Home Appliances and Automation Devices

9) Number of Room:____
10) Automation Platform(FHEM, Zigbee, MAX!, etc):__________________________________

	Room	Appliances	Automation Devices	Power (W)	
				Appliance	Device

Comments:

BII: INTERVIEW QUESTIONS FOR PV SYSTEM INSTALLATIONS

General Information

1) Name: ______________________________
2) Country: ______________________________
3) City: ______________________________
4) House Category: ______________________________
5) Date of Survey: ______________________________
6) Date of RES installation:______________________________
7) Type of RES: ______________________________

Device Details:

If Solar PV Systems

8) Surface area per unit(m^2): ______________________________
9) Number of Installed Units:______________________________
10) Expected Power(kW-peak): ______________________________
11) Solar Panel yield (%):______________________________

Installation Cost

12) Cost of RES: ______________________________
13) Government Incentives or Subsidy for RES installation: ______________________________

Electricity Cost

14) Electricity Rates per kWh: ______________________________
15) Average Electricity Cost (Before RES installation): per period ______________________________
16) Average Electricity Cost (After RES installation): per period ______________________________

Benefits of RES Installation

17) Electricity Savings: ______________________________
18) Electricity sold to Electricity grid: ______________________________
19) CO_2 Reduction: ______________________________

APPENDIX C

CI: URL FOR DATA ANALYSIS CODES AND QUERIES

Link: http://goo.gl/qUy1P7

CII: URL OF HOME AUTOMATION LOG

Rented Apartment

Link: http://goo.gl/YLtJ6f

Owned Apartment

Link: http://goo.gl/kE9myK

BIBLIOGRAPHY

BrightGreen, 2009. *Your Persoonal Carbon Footprint Calculator,* England: s.n.

Bruce, D. & Vernon J., R., 2002. Returns on Investments in Information Technology: A Research Synthesis. *Journal of Information Systems,* 16(1), pp. 7-30.

Cardoso, F. J. A. et al., 2005. Defining scenarios in home and building automation: CANopen and the virtual entities approach. *iCC CAN in Automation,* pp. 7-14.

Cellini, S., 2015. *Home Automation Scenarios (list).* [Online]. [Accessed 20 March 2015]
Available at: http://iseebots.com/home-automation-scenarios-current-and-planned/.

Chen, C.-Y., Tsoul, Y.-P., Liao, S.-C. & Lin, C.-T., 2009. *Implementing the design of smart home and achieving energy conservation.* Cardiff, Wales, IEEE.

Christina, D., Evangelos, G. & Dionyssia, K., 2008. *Towards a multi-objective optimization approach for improving energy efficiency in buildings.* Chania, Crete, Greece, Elsevier B.V..

Climate Friendly, C., 2011. [Online]. [Accessed 30 January 2015]
Available at: http://www.climatefriendly.com/personal/calculators/electricity/.

Enerdata, 2015. [Online]. [Accessed 02 February 2015]
Available at: http://www.indicators.odyssee-mure.eu/online-indicators.html.

Energy Department, M. o. E. a. t. E., 2010. *Finland's national action plan for promoting energy from renewable sources pursuant to Directive 2009/28/EC,* Helsinki: Finnish Government.

Energy Star, E., n.d.. *ENERGY STAR for Programmable Thermostats,* s.l.: s.n.

EU Institute for Energy and Transport, I., 2014. *Photovoltaic Geographical Information System (PVGIS solar data) - Interactive Maps.* [Online]. [Accessed 02 February 2015]
Available at: http://re.jrc.ec.europa.eu/pvgis/apps4/pvest.php.

European Commission, E., 2015. [Online]. [Accessed 02 March 2015]
Available at: http://ec.europa.eu/energy/en/topics/energy-efficiency/buildings.

Eurostat, E. C., 2014. [Online]. [Accessed 02 February 2015]
Available at: http://ec.europa.eu/eurostat/statistics-explained/index.php/File:Half-yearly_electricity_and_gas_prices,_first_half_of_year,_2011%E2%80%9313_(EUR_per_kWh)_YB14.png#.

Federal Ministry for the Environment, N. C. a. N. S. (., 2007. *EEG – THE RENEWABLE ENERGY SOURCES ACT - The success story of sustainable policies for Germany,* Berlin: Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU).

Finnish Energy Industries, F., 2015. [Online]. [Accessed 2 February 2015]
Available at: http://energia.fi/en/home-and-heating/district-heating/price-district-heating.

Foster, S., Tramba, A. & MacDonald, L., 2007. *ecoMOD: Analyzing Energy Efficiency in Affordable Housing.* Charlottesville, VA, IEEE.

Global Building Performance Network, G., 2013. [Online]. [Accessed 15 January 2015] Available at: http://www.gbpn.org/databases-tools/bc-detail-pages/germany#Type%20of%20Building%20Code.

Global eSustainability Initiative, G., 2008. *SMART 2020: Enabling the low carbon economy in the information age,* UK: Global eSustainability Initiative.

Grosshans, W. & Chelimsky, E., 1992. *Introduction.* 1st ed. Washington D.C.: United States General Accounting office.

Han, D.-M. & Lim, J.-H., 2010. *Smart home energy management system using IEEE 802.15.4 and zigbee.* Kongju, South Korea, IEEE.

io-homecontrol, 2015. *io-homecontrol adapts to your needs.* [Online]. [Accessed 30 January 2015] Available at: http://www.io-homecontrol.com/en/all-scenarios.html.

Judge Electrical Limited, J., n.d. *Thermostatic Radiator Valve (TRV).* [Online]. [Accessed 04 February 2015] Available at: http://www.judgeelectrical.co.uk/central-heating/radiators/thermostatic-radiator-valve.html.

Kolokotsa, D., Rovas, D., Kosmatopoulos, E. & Kalaitzakis, K., 2011. *A roadmap towards intelligent net zero- and positive-energy buildings.* Crete, Greece, Elsevier Ltd.

Mikko, P. & Pertti, S., 2013. Prospects of Photovoltaic Systems in Finland. *Lappeenranta University of Technology (Finland),* pp. 208-211.

MINISTERIAL COUNCIL ON ENERGY FORMING, M., 2006. *APPLIANCE STANDBY POWER CONSUMPTION STORE SURVEY 2005/2006 - FINAL REPORT,* Australia: s.n.

Odyssee-Mure, O., 2012. *Energy Efficiency Trends in Buildings in the EU.* [Online]. [Accessed 02 March 2015] Available at: http://www.odyssee-mure.eu/publications/br/Buildings-brochure-2012.pdf.

plumberparts, 2011. *Thermostatic Radiator Valves.* [Online]. [Accessed 30 January 2015] Available at: https://www.youtube.com/watch?v=2aLBOzqvosE.

Rapf, O., 2011. *Europe's Buildings under the microscope - A country-by-country review of the enegy performance of buildings,* s.l.: s.n.

Skon, J., Kauhanen, O. & Kolehmainen, M., 2011. *Energy consumption and air quality monitoring system.* Adelaide, SA, IEEE.

Storgårds, L., 2014. *Prices of heating energy in Juni 2014.* [Online]. [Accessed 02 February 2015] Available at: http://www.stat.fi/til/ehi/2014/02/ehi_2014_02_2014-09-18_tau_003_en.html.

Tejani, D., Al-Kuwari, A. & Potdar, V., 2011. *Energy conservation in a smart home.* Daejeon, IEEE.

The Pell Institute for the Study of Opportunity in Higher Education, P., 2015. [Online]. [Accessed 20 January 2015] Available at: http://toolkit.pellinstitute.org/evaluation-guide/analyze/enter-organize-clean-data/.

Trochim, William M.K., 2006. *Descriptive Statistics.* [Online]. [Accessed 29 01 2015] Available at: http://www.socialresearchmethods.net/kb/statdesc.php.

Trochim, W. M., 2006. *Data Preparation.* [Online]. [Accessed 29 January 2015] Available at: http://www.socialresearchmethods.net/kb/statprep.php.

Trochim, W. M., 2006. *Research Methods Knowledge Base,* s.l.: William M.K. Trochim.

Ubran Land, U., 2009. *Building Retro.* [Online]. [Accessed 02 March 2015] Available at: http://www.esbnyc.com/sites/default/files/uli_building_retro_fits.pdf.

United Nations, U., 1998. *KYOTO PROTOCOL TO THE UNITED NATIONS FRAMEWORK CONVENTION ON CLIMATE CHANGE,* Kyoto: s.n.

Warner, K. D. & DeCosse, D., 2009. *Lesson Four The Ethical Dimension of Sustainability.* [Online]. [Accessed 20 April 2015] Available at: http://www.scu.edu/ethics/practicing/focusareas/environmental_ethics/lesson4.html.

Wei, C. & Li, Y., 2011. *Design of energy consumption monitoring and energy-saving management system of intelligent building based on the Internet of things.* Zhejiang, IEEE, pp. 3650,3652.