BUILDING EFFICIENCY

A COMPLEX MODEL FOR SIMULATING OCCUPANTS' ELECTRICITY USE BEHAVIOR WITHIN OFFICE BUILDINGS

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In partial fulfillment of the requirements for the degree of Master of Science in Construction Management and Engineering

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Please note that the report, presentation, model and data can be downloaded from Dropbox. If there are any questions derived from my thesis or simulation model, do not hesitate to contact me on c.visser1989@gmail.com or Linked-in. Please let me know when extended research on my topic or model is done.

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PREFACE

The thesis lying in front of you is the last chapter of my master Construction Management and Engineering (CME), followed at the Technical University of Eindhoven. The municipality of Heerlen joined me in my research by providing me with the data needed for the case study.

The subject regarding building efficiency came first to mind when reading a news article concerning the arrears of the CO2 reduction of the Dutch Government. My curiosity was aroused to find a cost effective solution in times of economic crisis. Completing this thesis has been a long and interesting journey in which I have learned a lot. From the beginning there were several possible challenges but the focus of the research came during the process. With the help and support from my supervisors, family and friend I was able to finish my research. Therefore, before the actual reporting of the thesis begins, I would like to thank some persons for their guidance and help.

First, I would like to thank my supervisors Qi Han, Peter van der Waerden and Joran Jessurun from the TU/e. Han Qi, my first supervisor, thank you for all the guidance, helpful insights but also the patience you had with me on this long journey and helped me several times to get back on the right track. Peter, also thank you for your clear guidance with the questionnaire and great feedback on the NetLogo model. Joran helped me with programming some command which got me through some difficult stages within the NetLogo model.

Secondly, I want to thank Jack Theunissen of the municipality of Heerlen and Martje van Horrik of Centre of Expertise NEBER for providing me the data for the case study and spreading the questionnaire amongst the employees of the City Hall of Heerlen.

Lastly I would like to thank my family and friends. My parents for their support during my whole study. They gave me the opportunity to study and live in Eindhoven. For this my deep appreciation. My friends for all the good memories, the needed distractions and best years of my life. My girlfriend, whom I met during my graduation thesis, for being there for me with the ups and downs, her patience and help. I could not do it without you!

Now I am on the next adventure and energy and energy saving in particular will continue to be my top interest. With this thesis I hope the reader has a better understanding of the possibilities within building efficiency. Especially the steps and factors that need to be taken into account to change the behavior of occupants in regards of using computer and lighting, and help organizations make better and more cost effective energy saving policies.

Enjoy reading my Master's thesis,

Christiaan Visser
Eindhoven, September 2016

SUMMARY

Demand and supply of energy is taking its toll, where energy production and consumption are considered as key contributors for environmental issues. The built environment accounts for approximately 35% of the total Dutch energy consumption. More than half is used in commercial sector such as office buildings. Furthermore 80 percent of CO2 emissions take place during the operational phase of a building when energy is used for heating, cooling, electrical appliances, lighting and others.

Saving energy is increasingly becoming more top priority and vital in mitigating climate change. For the Netherlands, the progress towards energy efficiency has fallen behind the targets of the 2020 climate objective the European Union has agreed upon. The government will emphatically call on municipalities, market leaders and consumer organizations to contribute and work together to bring energy policies into effect. Their strategy is based on the Trias Energetica where energy management, reducing CO2 emission by reducing the demand for energy, is the first and crucial part of this strategy.

Simulation of office building energy use is a very useful tool for studying, planning and managing the energy demand, but failing to predict energy consumption of buildings accurately. There is often a large gap between the predicted energy demand and the actual energy consumption of buildings. Among various factors it is common known that occupants have a major contribution to building fluctuating energy consumption and need to be involved in the energy saving process. Understanding the way occupants interact with building systems, and their impact on building's electricity consumption helps to make better assumptions on user behavior in simulation models. The focus is on energy caused directly by occupants' work activities which influence the energy consumption most namely (1) computer use and (2) lighting use.

This thesis explores the use of agent based modeling as a tool for simulating behavior characteristics of agents, who in this research represent office building occupants, their behavioral change over time, and finally calculates the occupants electricity consumption. An agent based model was developed, where the qualitative behavioral characteristics of occupants are represented in a quantitative way, to simulate stochastic and more accurate electricity use estimations.

A case study was used to validate and test the accuracy of the proposed model to make sure the simulation outcomes are consistent with the actual energy consumption of the City Hall of Heerlen. real-time data was provided about the occupants use behavior and electricity consumption of the building. It showed that with dynamic occupant behavior being properly modeled, energy consumption may change over time. Also the more occupants control the building system of office buildings, the more a change in their behavior affects total energy use. For Power Management an average saving of 15% to 19% can be achieved.

The proposed simulation model serves as a tool that gives insight in the influence of changes in different behavior profiles on the energy consumption of office buildings. It will help organizations to make better energy saving policies by making better informed decisions. This will lead to significant electricity savings over time, while also reduce CO2 emissions. In the end the thesis emphasizes the strengths of using Agent Based Models as a research method for energy management issues.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

"If we each take responsibility in shifting our own behavior, we can trigger the type of change that is necessary to achieve sustainability for our race or this planet. We change our planet, our environment, our humanity every day, every year, every decade, and every millennia."

– Yehuda Berg

1 INTRODUCTION

This chapter give a contextual approach on the relevance of the problem. Global warming is a concerning topic nowadays and saving energy is increasingly becoming more top priority and vital in mitigating climate change. Building efficiency through technical improvements is a widely discussed topic and used in simulation models with the problem that financial limitations discourage organizations to take such actions. Focusing on changing occupant behavior could be a good alternative, but there is lack of insight in behavioral electricity consumption. These problems are discussed to motivate the objective of this research with corresponding research questions. In the third section the structure of the research is defined in a research model and the research method is defined. Also the framework of this thesis is summarized.

1.1 CONTEXT

With no doubt, energy is one of the most important needs of humanity to be able to create a healthy society, whether it is for production of goods, lighting, use of appliances or data traffic. Demand and supply of energy is taking its toll, where energy production and consumption are considered as key contributors for environmental issues. Nearly every environmental pollution, directly or indirectly, is associated with energy consumption. This makes energy and the environment inextricably linked with one another (Warnaar, 2004).

The European Union targets with its 20/20/20 climate objective to have a reduction of 20% of greenhouse gas emissions, 20% more energy efficiency and 20% more renewable energy in 2020 compared to the levels of 1990 (European Commission, 2015). For the Netherlands, the progress towards energy efficiency has fallen behind these targets, despite the considerable policy initiatives to increase energy efficiency (Hieminga, 2013). In accordance, the news brought out recently, to get the CO2 reduction below 17 percent, in spite of climate treaties the Dutch government needs to reduce their CO2 emissions by 2020 by 25 percent compared to the year 1990 (NU.nl/ANP, 2015). To achieve this, they aim at a substantial gain in energy reduction within the built environment and count as an important area for research when it comes for meeting the European Union's 2020 target (Sipma, 2014).

There is a potentially large opportunity to reduce energy demand and CO2 emissions through energy saving initiatives (Apajalahti, et al., 2015). It is currently the central focus of many organizational energy policies, due to its contribution towards a sustainable environment (Netbeheer Nederland, 2015). Energy management strategies should be added to the operational phase (Warnaar, 2004). Whereas this research focuses on building efficiency in the commercial sector, energy management is defined as followed (Grontmij, 2015):

"Energy management is an activity or service with the purpose to come up with the most efficient way to consume energy. It encloses organizational, technical and behavioral measures on how energy cost and environmental loading could be reduced."

So basically energy management is the structural attention for energy within an organization, with the goal of reducing energy use bring immediate benefits to owners (Agentschap NL, 2011). It offers many opportunities to reduce energy costs and improve the comfort for the consumer as can be seen in Table 1.

Table 1Drivers for implementing energy management

Factor	Explanation
Economic	Better energy prices, lower energy costs.
Political	Achieve energy neutrality, increase in business productivity, reduction of exposure to the price of carbon
Environmental	Reduction of greenhouse gasses, reduction of the need for marginal energy supply infrastructure
Social	Health benefits, more energy services for the same amount of energy
Technological	Innovation in energy efficient technological solutions

However, finding feasible solutions to achieve energy saving within buildings is a complex process. Therefor the use of building simulation is becoming inevitable (Hoes, et al., 2009). Technological or operational modifications, such as better insulation or more efficient equipment, are most common used by organizations to save energy but cost a big financial investment. (Davies & Chan, 2001) (Carrico & Riemer, 2011). Instead of implementing more efficient technologies, curtailment of energy demand could also be an important and more cost-effective strategy to achieve the promised targets in the short term (Dietz, et al., 2009) (Ouyang & Hokao, 2009). Consequently the influence of occupant use behavior on the energy demand of buildings increases and is a leading source of uncertainty in predicting building performances (Derijcke & Uitzinger, 2006). This has ensured that there is an increase in attention concerning the modeling of human behavior within building simulations.

1.2 PROBLEM DEFINITION

1.2.1 Problem Statement

In the Netherlands, the demand for energy has grown 1% per year in the last 20 years to 3,500 PJ in 2011 and is expected to continue at this pace until 2030 (Hieminga, 2013). The rise in energy demand, diminishing of natural resources and global warming are driving factors for European countries to save energy in the building sector and meet the 2020 climate objective (Hong, et al., 2015). Especially within the commercial sector, where priority for energy efficient buildings is still low, but accounts for an important contributor to the CO2 emission (Laitner, et al., 2009). Additionally, studies have shown that the role of building occupants play an important role in affecting the energy consumption in buildings (Yan, et al., 2015) (Menezes, et al., 2012).

Building simulation tools have become an accepted method for estimating energy performance during the design process (Hoes, et al., 2009). However most tools only take technical characteristics into account while few studies evaluated that the **influence of the behavioral factor in building energy simulation is evident** and showed that occupants certainly do influence the energy consumption of buildings (Yu, et al., 2011; Hoes, et al., 2009; Rafsanjani, et al., 2015). This becomes more clear when energy efficient measures are investigated and deviations occur between predicted and the actual energy consumption of buildings shown in Figure 1 (Menezes, et al., 2012; Yan, et al., 2015). This shows that occupant behavior is certainly linked to the energy consumption of buildings but fall behind in predicting correctly the energy consumption

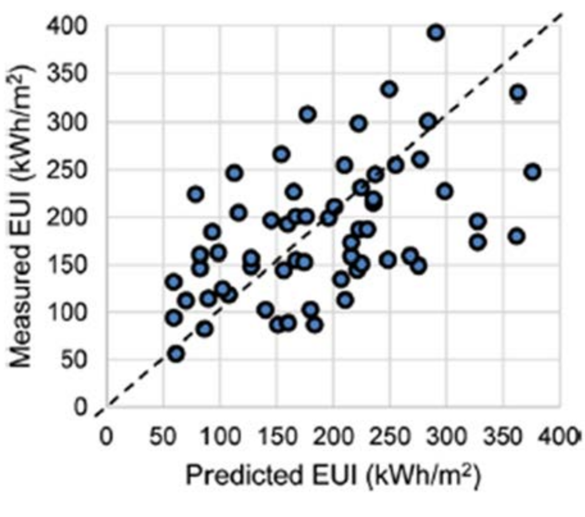

Figure 1 predicted vs actual building energy use Source: (Yan, et al., 2015) of buildings to correspond with actual energy consumption. Studying the way occupants interact with the building systems and their impact on building's energy consumption helps to make better assumptions on occupant behavior in simulation models.

Within the boundaries of this research and based on the problem analysis the research problem can be stated as: "There is still insufficient insight on the amount of influence occupants have on the energy consumption of the building and their potential contribution towards building energy efficiency".

1.2.2 Objective

This thesis focus on the potential energy saving in office buildings through change of occupant behavior. The reason for this is that unlike technological improvements to the building, curtailment of energy demand causing behavioral change can reduce energy use and CO_2 emissions in the short-term and without significant costs. However behavioral factors are not often used when simulating building energy performances. This makes the objective of this research:

Designing a realistic model where behavior of occupants can be investigated to help organizations getting insight in the decision making process of occupants for designing energy efficient strategies. In particular those ones that are low cost, and make proper policies and regulations for meeting the climate objective.

1.2.3 Research Questions

For reaching the 2020 target there is much needed attention for building efficiency. Although there are many building simulation tools for predicting energy performance of buildings, there is still a gap between predicted and actual energy demand. My research indicates that this is caused by lack of insight in the occupant use behavior of the building system. The following main question is formulated to help achieve the purpose of the research:

In what extent is it possible to design a realistic model for predicting energy use behavior of individual occupants and implement cost-effective energy saving measures to help reducing electricity consumption of office buildings?

To provide an answer to the main question, the following sub-questions are formulated according to the themes and will be answered in the coming sections. The main question will be answered at the end of this thesis.

- How is the energy demand regulated in office buildings?
- What defines the behavior of individual occupants? What is the influence of individual occupant behavior on the energy consumption of office buildings?
- What is the current state of building simulation tools?
- What kind of measures are the best solution for changing occupant behavior and reducing energy consumption within office buildings?
- What characteristics need to be integrated into the model to create realistic scenarios? Can the model help create a sustainable policy towards building efficiency?

1.3 RESEARCH DESIGN

1.3.1 Structure

The structure of the thesis can be seen in Figure 2. It shows the steps which will be taken. First an extensive literature study elaborates on the energy consumption of buildings based on the interplay between occupants and energy efficient incentives. Making use of a questionnaire and case studies, will also help to determine the conditions of the model. After the analysis of the gathered data that will provide the characteristics for the design of the model, the model is created in the form of an agent-based model. An agent-based model will be able to simulate the effects of different variables that influence the energy consumption of occupants which result in different scenarios. The model is designed in such way that it can be used by any type of organizations within office buildings. Finally, the model will be tested with various scenarios to create sustainable policies towards building efficiency.

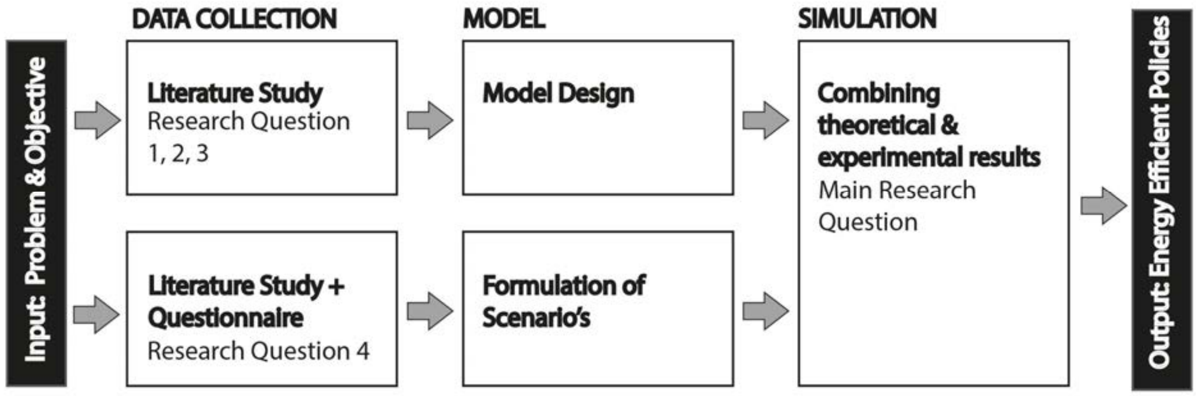

Figure 2 Research Approach

1.3.2 Method

To gain the expected results, a simulation model is a good methodology to represent the complexity of the interaction of occupant behavior on the energy consumption of the built environment. A simulation model may be considered as a set of rules that defines how a system will change over a period of time, given its present state.

Agent-based modelling (ABM) is a form of simulation tool used for simulating agent behaviors and agent interactions with a bottom up approach (Berryman & Angus, 2009). The model is able to simulate a problem in the environment, which changes over time by a set of rules that defines the behavior of the model. This makes ABM very useful for modelling human-social and organizational behavior and in individual decision-making (Osman, 2012). For this thesis, ABM is used to understand how occupant behavior influence energy consumption in the context of building efficiency, by simulating occupants doing their activities and reacting to their environment. In this way it is possible to estimate the influence of various energy efficient incentives on encouraging occupants to change their behavior. This type of quantitative approach could be beneficial in understanding the best possible way to make policies to improve building efficiency.

For designing agent-based models there are several simulation programming platforms with their own pros and cons as shown in Table 2 (Kravari & Bassiliades, 2015). For developing the Agent-based model, Netlogo (Tisue & Wilensky, 2004) is used, especially due to the easy and user friendly programming language, great user interface, but also for its extensive documentation, which was really helpful for learning the programming language. It is a multi-agent programming language for simulating natural and social problems and therefor a useful platform for modelling occupant behavior. By giving independent agents individual instructions makes it possible to explore connections between micro-level behaviors of individuals and macro-level patterns that emerge from their interactions (Tisue & Wilensky, 2004). Many example models are available from which ideas and lines of code can be extracted to implement in an own model, what makes NetLogo such a popular platform.

Table 2 Agent Based Simulation Platforms

Criteria	NetLogo	Repast	Cormas	AnyLogic	SWARM
Programming Language	NetLogo	Java; Python	SmallTalk	Java; UML-RT	Java; ObjectiveC
Popularity	+++	++	-	+	+
Documentation available	+++	++	-	++	++
Modeling Speed	++	---	+++	++	+
Ease to use	+++	---	++	++	+
Simulation Speed	++	+++	---	++	+
GUI features	+++	---	++	+++	---

1.4 EXPECTED RESULTS

The model will provide insight into the use behavior of occupants with the building system of office buildings. By experimentally applying energy efficient measures the influence of the behavior can be observed which should lead to insights in how to best implement energy policies for organizations. The CO_2 reduction resulting from measures should offer additional benefits, to help organizations reaching the 2020 target.

1.5 READING GUIDE

This thesis is organized as shown in Figure 3. Chapter 2 gives an extensive literature review of the energy consumption within the commercial sector, specifically office buildings. Chapter 3 defines the occupants' behavior towards the use of electrical appliances and lighting. The model design and characteristics are determined in Chapter 4. Chapter 5 shows the simulation results and findings of the model. This thesis ends with a conclusion, discussion and recommendations for further research combined in Chapter 6

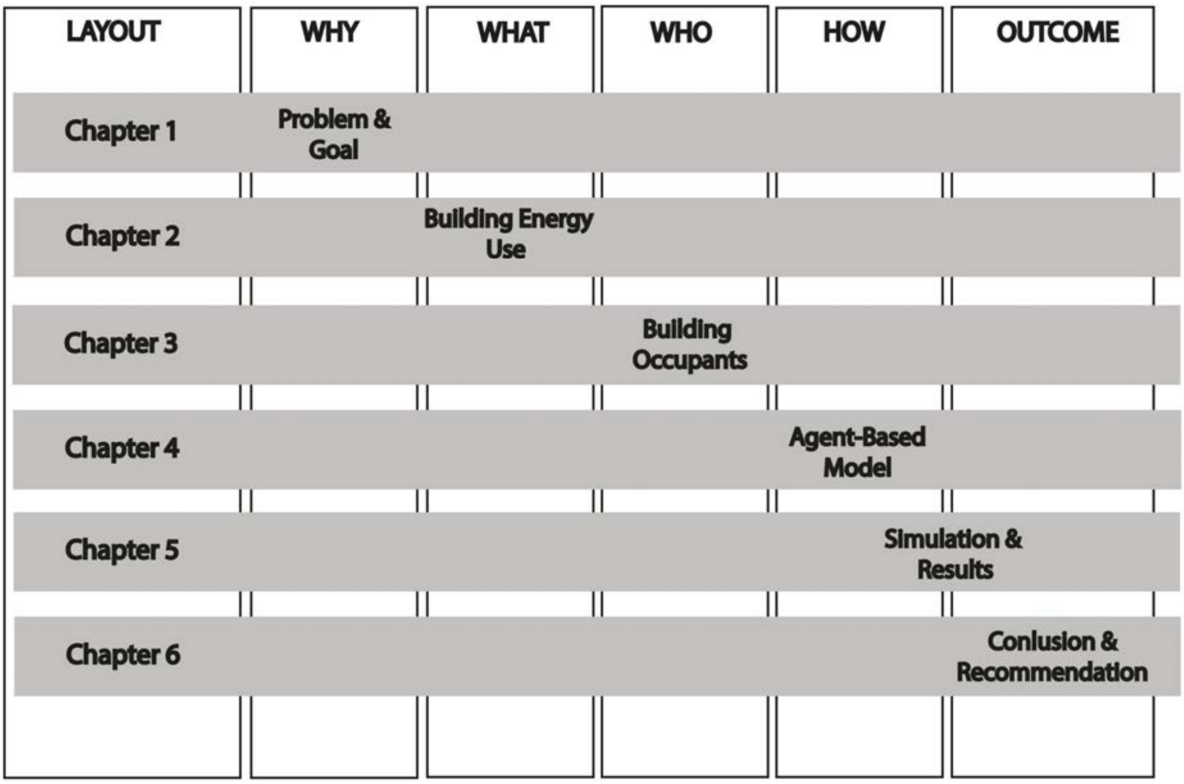

Figure 3 Reading Guide

2 LITERATURE

Energy simulation models are often used during the design phase to estimate future building energy consumption. The outcome of these simulation models typically deviate from actual energy consumption patterns. This inconsistency can mainly be attributed to underestimation of the influence of the occupants within the building have on the total energy consumption. People are individuals and probably have varying energy use characteristics over time, but current simulation models assume they are constant.

Before starting the programming of the ABM, to get insight in occupant integration within building simulation models this chapter gives an extensive literature review by starting with a background on current office energy regulations . Then since this thesis focus is on the influence of occupants on energy consumption of buildings, behavior is defined. Additionally potential changes in their energy use behavior can be attributable to energy efficient strategies, of which an overview is given.

2 OFFICE BUILDING ENERGY REGULATION

With the current increase in the global energy consumption, the focus is not only on how to produce the required energy (e.g. solar, wind, biogas) but also on ways to improve energy efficiency in able to ensure sustainable energy supply and to be able to meet the required demand (Bakar, et al., 2015). In the Netherlands, the built environment, consisting out of residential and commercial sector, is responsible for more than 40% (approximately 1000 PJ) of total energy consumption and CO2 emission (Vreenegoor, et al., 2010) (PBL, 2012). The commercial sector alone contributed with a total gas consumption of 181 PJ and 128PJ of electricity consumption, for over 20% of the total energy consumption (Sipma, 2014). For many organizations, the commercial sector as one of the major energy consumers has become the focus of energy efficient initiatives to meet the 2020 climate objective (Azar & Menassa, 2012).

"1 PJ (Peta Joule) of gas corresponds with 31,6mln m3 gas. 1 PJ of electricity corresponds with 278mln kWh of electricity. With 1 PJ of gas and electricity, 23.000 of households can be provided."

Within the commercial sector, office buildings, is a significant contributors to energy consumption and global CO2 emissions when compared to other sectors, as is shown in Figure 4 (Kristic-Furundzic & Kosic, 2015) (Wade, et al., 2003). Office buildings, are strongly distributed in urban environments and are the largest in floor space in most countries (Nguyen & Aiello, 2013) and seems to have the best potential to achieve energy efficiency (Pérez-Lombard, et al., 2008). Ambitions and policies defined on European and national level must ensure this feasibility of an energy neutral environment (see Appendix 1).

Primarily, energy consumption in office buildings consist of two types (1) gas consumption, and (2) electricity consumption. This thesis will specifically focus on studying the electricity consumption of office buildings, whereas gas consumption not exist is some types of office buildings and occupants major interactions with the building environment uses electricity. Over the life cycle of office buildings, most of the energy is consumed in the operational phase and can be can be characterized as primarily 'building related' and 'user related' energy (Blom, et al., 2011).

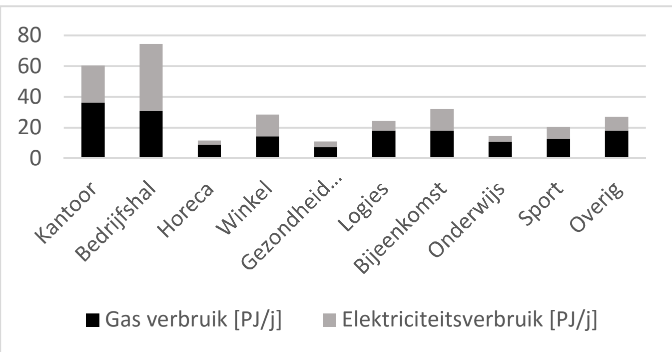

Figure 5 Energy consumption per building type Source: (Sipma, 2014)

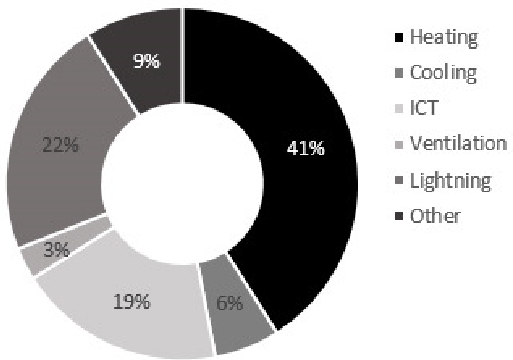

Figure 4 Energy consumption of office services Source: (Geijer, 2014)

Building related energy, mostly gas, provides the indoor thermal comfort for occupants (e.g. heating, hot water, climate systems) where landlord is accountable for. User related energy is caused directly by occupants' work activities (e.g. use of lights and ICT equipment).

Figure 5 shows the percentage scale of the energy consumption of the different components. It is clear that most of the energy consumption includes heating, lightning and ICT (Steinfeld, et al., 2011). Together they represent 88% of the total energy consumption, which makes office buildings of significant importance for meeting the 2020 target set by the Dutch government. Lights and electrical appliances (ICT) used by occupants of office buildings is around 46kwh/year per m2).

However, it is not possible to completely separate energy consumption as there is always an interaction between the building and its users. This makes energy consumption in office buildings a very complex organizational problem involving four important elements, shown in Figure 6 (Zhang, et al., 2011):

- Energy managers of an organization making energy efficient policies and regulations
- Energy efficient technologies installed in the office building
- Types and amount of electrical appliances in the office building
- Occupants' energy use behavior of using the electrical appliances in office buildings

Technology alone cannot achieve optimal energy efficiency, it is a dynamic process between each of the four elements. First energy managers are responsible for constructing energy efficient policies and regulations based on the installed energy efficient technologies in the building (e.g. metering, monitoring, automated sensor technologies). These installed technologies are responsible for the control and/or monitoring of the energy consumed by electrical equipment, and coherently the behavior of energy occupants in the building.

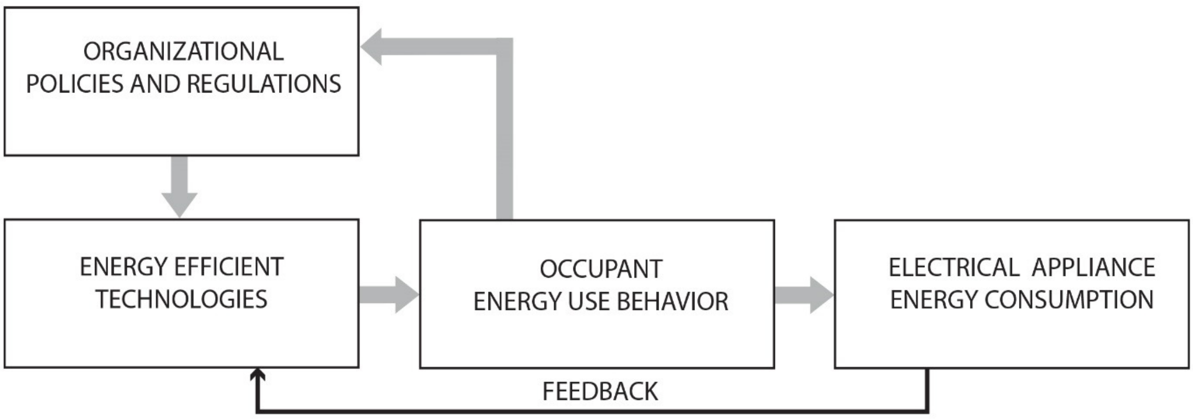

Figure 6 Integrated Process of Energy Management *Adapted from: (Zhang, Siebers, & Aickelin, 2011)*

The behavior of occupants using electrical appliances directly cause energy consumption. Sometimes when new technologies ask for another use approach, occupants need to change their behavior to achieve optimal decrease in energy demand. These behavioral changes are crucial for organizations as they give feedback on how energy efficient improvements is effecting their work.

2.1 Energy Label

An important measuring tool for buildings to know how energy efficient they are is the energy label. The energy label gives insight into the energy performance of a building and should work as basis for other policy instruments that stimulate energy saving in buildings (Rijksoverheid, 2011). For the energy performance of existing commercial buildings the EPA-U (*Energieprestatie advies - utiliteiten*) is prepared.

New buildings need to be at least close to energy neutral as of December 31 2020. Governmental buildings need to achieve this two years sooner. Figure 7 gives an illustration of the energy label. When a building has 'Label A' it means it has a very low energy consumption, whereas 'label G' means the building has a very high energy consumption. Label A^{++} is intended for new buildings. The numbers represent the energy-index of the building that expresses the degree of energy consumption. It is calculated on the basis of the constructional characteristics and building installations. For commercial buildings a recognized expert will monitor the building on a number of characteristics.

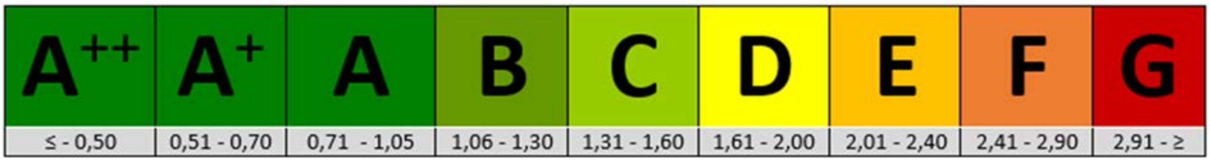

Figure 7 Energy Label

Although the EPA-U is a useful tool for office building management, it only considers building related energy consumption for heating, lighting, ventilation and cooling, and hot water. The behavioral component of energy consumption and energy management policies are not included in the calculation of energy which are very important factors influencing office building energy consumption (Thoolen, et al., 2014).

2.2 Electricity Demand

Owners of office buildings are generally charged for electricity based upon the electricity consumption and peak demand. Peak demand is a term used in energy management that describes a period in which energy demand is expected to be at his maximum for a sustained period at a higher price. The base demand, also called off-peak, is when the demand for electricity is usually low. (Sun, et al., 2013). Even though the peak demand in commercial buildings lasts for a short period of time, it can potentially have a big contribution to the electricity bill (Seem, 1995) (Mathieu, et al., 2011).

The electricity consumption patterns of office buildings are distinctive as they generally vary in regular daily, weekly and seasonal patterns. It counts generally from Monday till Friday, where the weather to a large extend, but also occupant behavior causing the fluctuations in the peak demand. As illustrated in Figure 8 Mathieu et al. (2011) identified notable similarities between typical office building energy profiles on a daily basis:

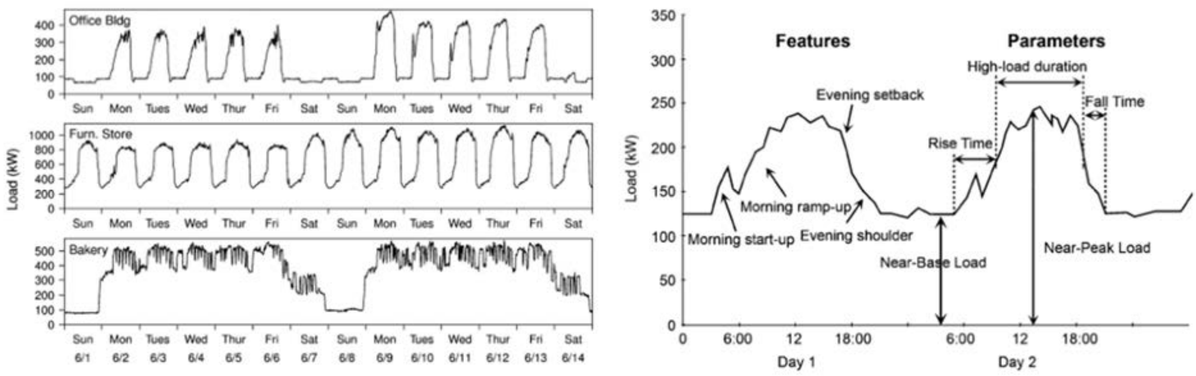

Figure 8 Distinctive electric loads of office buildings (left) and electric load shape features and parameters (right) Source: (Mathieu, Price, Kiliccote, & Piette, 2011)

During the night, a base load is attained where the electricity consumption rarely falls below. In the early morning short-term load spikes called morning ramp-up occurs, which is caused by the HVAC system that switches from nighttime to daytime. As the morning continues, consumption increases (morning ramp-up) with increased occupancy and, in the summer season, with increased outdoor air temperature. Eventually, at some point the building reaches its peak load for the day. When the evening falls, the HVAC system switches back to nighttime operation and the energy consumption quickly decreases, called the evening setback.

Besides climate changes, occupant electricity demand is also a driving factor contributing to the differences in peak demand of the same building. Acker (2012) studied baseline energy profiles of six office buildings. As can be seen in Figure 9, the profiles were generated on weekday, weekend and holiday. It is clear that during the day the peak load of office appliances contributes to the overall peak load. Buhl (2014) studied all different office appliances separately, seen in Figure 10. It shows the plug load equipment power density for each type of equipment over the course of a typical weekday. Noticeable is the variety of the energy profiles of electrical appliances, where IT equipment load is fairly stable, and personal workstation equipment (e.g. desktop, monitor, task lighting) profile varies depending on use. The energy profiles tend to follow a usage pattern consistent with the standard workday. Also after working hours, the demand of most equipment does not equal to zero, which can contribute to the energy saving dramatically (Webber, et al., 2006).

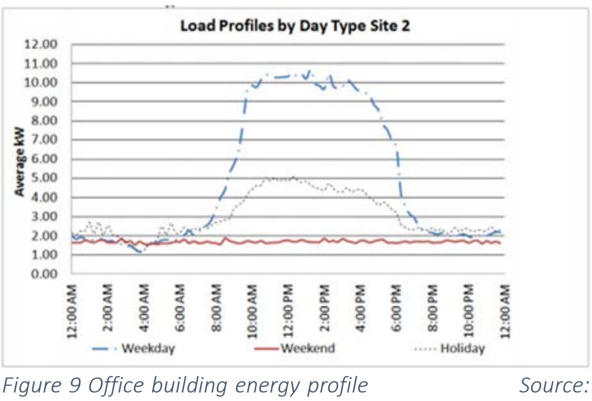

Figure 9 Office building energy profile Source: (Acker, et al., 2012)

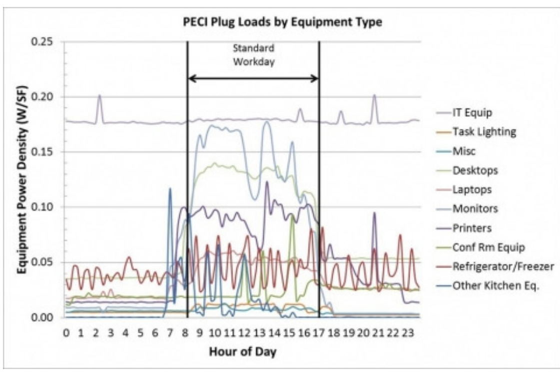

Figure 10 Energy profiles by appliance type Source: (Buhl, 2014)

3 OCCUPANT BEHAVIOR

Building energy simulation models is gaining interest as a cost-effective method to support energy managers to make energy efficient designs and policies for buildings. The International Energy Agency (IEA), Energy in the Buildings and Communities Program (EBC) and Annex 53: Total Energy Use in Buildings identified five factors determining the energy consumption in buildings (1) climate, (2) building envelope, (3) building energy and services systems, (4) indoor design (5) building operation and maintenance, and (6) occupant behavior. Enough research has been done for the first five factors, but methods to define and model occupant energy related behavior in buildings is scarce.

Occupant behavior affects the building energy performance directly and indirectly by interaction with operable lights, electrical appliances, blinds, windows and thermostats. Therefor occupant behavior can be defined as (Page, et al., 2008):

"Any direct or indirect actions made by an individual person in response to external or internal stimulations or to enhance their personal thermal or visual comfort."

The influence of occupant behavior on the building energy performance has been studied in domains as natural sciences, social sciences, and economics. Especially in natural science studies, the focus is on relations between energy-related behavior and the environment influencing this behavior, like solar radiation (Polinder, et al., 2013). But occupant behavior in office buildings is hard to define and quantify due to the complexity and uncertainty of an individuals' actions in relation with the building environment. In reality, an occupant decision to switch on or off lights or computer is based on a number of influencing parameters categorized as physical, biological, psychological, and social (Page, et al., 2008).

Hong et al. (2015) review on energy related behavior has resulted in the DNAs framework Figure 11, which aims to provide understanding of most occupants' behavior and actions that directly or indirectly impacts building energy consumption.

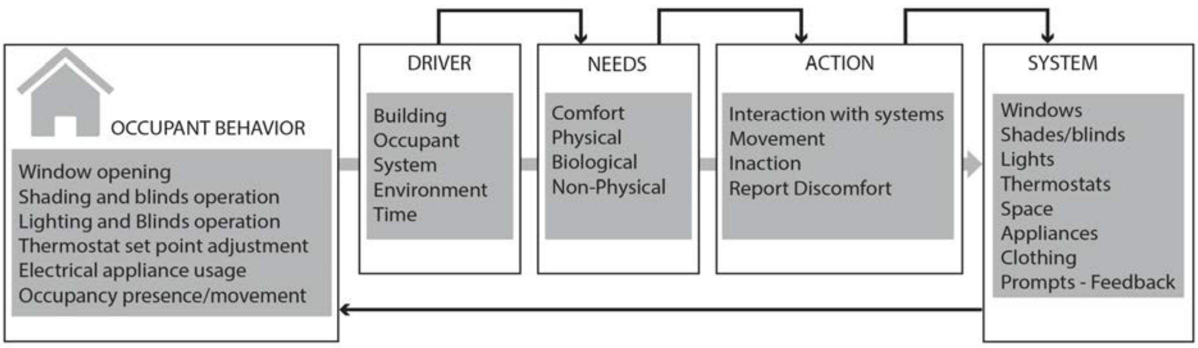

Figure 11 DNAs Framework *Source: (Hong, et al., 2015)*

The behavioral impact on energy consumption can be determined using four main component: (1) Drivers representing the environmental factors determining occupant behavior that influence the building energy consumption. Which are biological, societal, environmental, physical and economical in nature; (2) Needs of occupants that need to be met in order to be satisfied and comfortable with their situation, which are physical or non-physical; (3) actions which occupant take in order to satisfy their needs and: (4) systems where occupant interact with to perform the actions affecting the building energy consumption.

Most of the actions related to energy demand taken by occupants and driven by their needs, are based on their individual attitude towards energy saving. It will decide how occupant interacts with the building systems. When looking at the actions taken, they are often based on routine and habit (Martiskainen, 2007):

A set of situation-behavior sequences that are or have become automatic, so that they occur without self-instruction. The individual is usually not 'conscious' of these sequences

For instance, we leave the computer on standby and lights turned on without the actual need to think about them being carried out, or what the environmental impact could be. Tetlow et al. (2015) argues that, habits are responsible for the energy consumption by occupants' actions. Mckenzie-Mohr (2000) stated that behavior requiring these sort of repetitive actions is more difficult to change than one time changes in behavior, like purchasing more energy efficient lights, and the bigger the chance the rebound effect occurs. A better understanding of the occupant interaction with the building system is needed.

3.1 User-related Energy

To know how occupants influence the electricity consumption through interaction with the building system, it is necessary to know what type of appliances they use, which behaviors take place, and what their difficulty level and energy saving potential is. For this research, the focus is on behaviors which relate to the user related energy caused by occupants' interaction with the building system, which includes the adjustment of lights and the use of electrical appliances.

When the energy consumptions for electrical appliances and lights are considered, large variations are found, which partly relates to psychological parameters such as habits, comfort, but also on the amount of electrical appliances and their efficiency, as well as the use frequency and duration determine the energy consumption.

It should be noted that in most commercial buildings the HVAC system is regulated automatically, and is not taken into account in this research, whereas occupants have no direct influence on the system.

3.1.1 Lights

Lights is one of the major contributors to the electricity consumption in office buildings. The consumption may be reduced by using more efficient lights such as artificial LED lighting or make more use of day light. It highly depends on occupants comfort and can be controlled in two ways, by manual control of artificial lighting or by manual control of blinds (Reinhart & Voss, 2003). When occupants are visually obstructed, they will take actions to improve their comfort. Therefor manual switching lights is strongly correlated to the presence of people. Reinhart (2001) introduced a function regarding the lighting conditions in offices and the probability that occupants would switch the lights on when they arrive in the office. A strong relationship between the affinity of switching the lights off and the length of absence in the room, stating that occupants are more likely to switch off the light when leaving the office for longer periods (Boyce (1980), Pigg (1996)). Additionally, Love (1998) concluded that behavior of using lights is as much dependent on individual as on daylight availability. He observed that occupants who switch the lights on for the duration of the working day, keep it on even in times of temporarily absence. He also mentioned that occupants only use lights when indoor illuminance levels due to daylight are low.

Studies concluded that significant energy savings is feasible by better use of the systems. Parys (2009) evaluated various lights and blind control systems in relation with different types of user behavior in office buildings in Belgium. Results from simulation demonstrated that a reduction in energy of 10% is feasible when occupant behavior accounts for daylight dimming system. Pigg (1996) did research in 63 private offices on what conditions people turn off their lights upon leaving. The results showed that lighting tends to be manually switched off when occupants leave their work place, but also that the length of absence from an office determines the probability that lights are manually switched off shown in Figure 12.

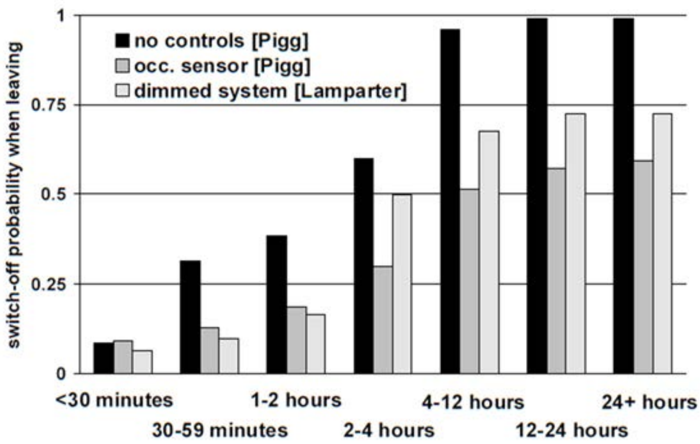

Figure 12 Comparison of measured switch off probabilities for lighting Source: (Reinhart & Voss, 2003)

Table 3 gives an overview of the influences occupant have on switching system of artificial lighting.

Table 3 Overview of occupant influence on lighting system *Source: (Reinhart & Voss, 2003)*

Manual control of artificial lights	Reference
People usually pertain to either of the following two behavioral classes: - People who switch the lights for the duration of the working day and keep it on even in times of temporarily absence and - People who use electric lights only when indoor illuminance levels due to daylight are low	Love 1998
All lights in a room are switched on or off simultaneously	Hunt 1979
Switching mainly takes place when entering or vacating a space	Hunt 1979, Love 1998, Pigg 1998
The switch-on probability on arrival for artifivial lights exhibits a strong correlation with minimum daylight illuminances in the working area	Hunt 1979; Love 1998
The length of absence from an office strongly relates with the manual switch-off probability of the artificial light system	Pigg 1998
The presence of an occupancy sensor influences the behavioral patterns of some people. On the average, people in private offices with occupancy control are only half as likely to turn off their lights upon temporarily departure than people without sensors	Pigg 1998

3.1.2 Electrical appliances

Over the next 20 years, electrical appliances is a growing source of energy consumption (Webber, et al., 2006), and is responsible for about 20% of the primary energy used in commercial buildings. Electrical appliances are primarily controlled by user behavior. On an average workday, occupants are seated at their desk for less than one third, thus more than two third of the year consists of non-working hours where appliances are not used (Metzger, et al., 2012).

The operating time of electrical appliances and their contribution to the energy consumption depends largely on the behavior of the user and what type of appliances are present. User behavior determines the amount of hours per day a device is in use, the amount of hours the device is turned on but inactive, and the amount of hours the device is off. Appliances are on or off because people turned them on or off manually, with some exceptions. For instance some copiers can automatically turn themselves in stand-by mode. The same applies for some computers or laptops that may be set to hibernate manually or automatically when they use power management.

It is often the case that appliances are not shut down properly when done using them. Five energy audits carried out by Masoso & Grobler (2010) showed that more energy was used during non-working hours (56%) than during working hours (44%), caused mainly from occupants' behavior of leaving lights and appliances on at the end of the day, and partly due to poor automatic system controls. Webber confirms this after investigating 11 offices after closing where, on average, only 44% of computers, 32% monitors and 25% of printers were turned off at night. However, although building systems are turned off after working hours, energy is still spilt during the day. An energy audit carried out by Mungwititkul & Mohanty (1997) showed that although electrical appliances are turned off at night and during weekends, they are unnecessarily left on during the day.

3.2 Improving Occupant Behavior

The studies explained in previous section emphasize that occupant actions within the building result in unnecessary energy consumption. To address these issues, many opportunities exist to reduce energy consumption in office buildings through technological improvements, but mostly bare financial costs, that organizations nowadays may not willing to deal with. Change of behavior, on the other hand, has the potential to reduce energy consumption in a cost-effective manner.

Table 4 shows the different behaviors performed by office occupants that have a positive effect on energy conservation and are cost-effective. These energy saving behaviors were chosen based on an earlier qualitative study conducted by Dusée (2004). A distinction is made between easy to change behaviors, and behaviors that are difficult to change, all have a high energy saving potential (> 0.20 Kwh/pp day). Where using power management on desktop; and turning off the lights when enough daylight enters the room are easy adaptable through energy efficient strategies, the behaviors that are difficult to change need more attention because of the strong habitual nature of the behaviors. Thus, changes in these behaviors are expected to take more time and effort to see actual changes in the electricity consumption. Several strategies can be used to reduce energy consumption within commercial buildings. A distinction can be made between investment and curtailment behavior (Han, et al., 2013).

Table 4 Behaviors with high energy saving potential *Source: (Dusée, 2004)*

	Behavior	Energy Saving Potential [kWh/pp day]
Easy to change	Using power management on desktop;	1.13
	Partially or completely turn off the lights in my office when enough daylight enters the room	0.44
Difficult to change	Switching off desktop when leaving the office for more than 20 minutes;	> 0.20
	Switching off lights when leaving the office for more than 20 minutes	> 0.20

3.2.1 Investment behavior

Investment behavior mostly involve improvement of energy efficiency, and consequently use less energy with the same energy demand. They are mostly of a bigger scale, are only performed once and hardly requires behavioral change. Investment behavior can be distinguished into two categories: appliance and control (Gandhi, 2015). Appliance based investment, focuses on the use of less energy by electrical appliances, either by using more efficient ones, or by reducing the amount of installed appliances. This also applies for improvements to insulation, lighting, water, and windows. Control based investment is all about controlling energy use during non-working hours, or when equipment is simply not being used. Adjusting power management settings, setting appliance timers or using tools like power strips are proved examples to lower the energy consumption when mainly appliances are not in use. For this thesis Power Management is further investigated while it is an easy to change behavior to implement

Power Management

Power Management (PM) refers to a set of strategies used to reduce energy consumption of appliances when they are actively in use. PM can be installed on the computer, the printer, and the copier. The program causes that appliances will fall in stand-by mode when not being used, through which energy will be saved. The difference in energy consumption when PM is enabled or disabled represent energy savings.

Kwong (2014) identified the opportunity for energy efficiency improvement of frequently used office appliances in commercial buildings, by focusing on the user behavior and implementation of power management features. The outcome showed that about 19 % of the total energy demand can be reduced when electrical appliances are turned off, unplugged or disconnected. Mungwitikul & Mohnanty (1997) get similar results when studying office buildings in Thailand, where enabling PM can save between 15-26%. However, occupant attitude and habits and appliance characteristic are important variables in determining the success or failure of power management

3.2.2 Curtailment behavior

Curtailment behavior is about reducing the energy consumption by encouraging occupants to use less electricity through behavioral change (Han, et al., 2013) such as turning off the lights in unused rooms or turning off electrical appliances when done using them.

Curtailment behaviors are often associated with additional effort or decreased comfort. They target improvements for usage and operation of the building. Operational measures refer to the controlling of technical issues, whereas building usage refer to the intensity and duration of usage and the user behaviour. It often involve small, simple behavioral changes that have to be repeated over and over again for long time period and continuous attention and effort (Dusée, 2004).

It is important to motivate occupants to engage in energy saving actions. When it comes to changing behavior in an organization, it is important to refer to collective rather than individual interests. Curtailment behaviors are programs or strategies that motivate or make occupants more aware of what energy saving can do, by educating them through workshops, giving them feedback in different ways, or social interaction about energy saving to make behavioral changes (Abrahamse, et al., 2005). In Appendix 2 an overview of all possible strategies can be found adopted from Han, et al. (2013).

Feedback

Feedback is a technique that is proven to result in relevant energy savings (Carrico & Riemer, 2011; Yun, et al., 2013). Feedback of energy use is a necessary step for consumers to understand how to control their energy consumption, by sharing energy use information of the building or work desk. This is especially relevant when there are no financial incentives for participants, as is the case in office buildings (Azar & Menassa, 2012). Savings from direct feedback ranged from 5 – 15 %, while saving from indirect feedback was between the 0 – 10 % (Darby, 2006). In line of these estimations Lasternas (2014) study resulted in a saving of 23%, where occupants were provided with an online interface to view their own energy consumption by individual appliances, create schedules to control devices, and turn off equipment remotely.

A study conducted by Abrahmse (2007) reveals that providing feedback about the reached saving rate is very effective, and appeared to be more effective when such feedback was given more frequent and related to a specific goal. Feedback could increase awareness of occupants' own behavior and its consequences (Lo, et al., 2012).

Regarding communication channels for giving feedback to occupants, email seems to be an effective medium. Kamilaris (2014) studied on how office workers responded to the feedback provided, and users' impact on the energy consumption of their desktop computers. She concluded that emails were considered better communication channels than posters and leaflets.

3 METHOD

A good way to understand what influence occupants have on the energy consumption of their office building and give answer to the main question: *In what extent is it possible to design a realistic model for predicting energy use behavior of individual occupants and implement cost-effective energy saving measures to help reducing electricity consumption of office buildings?* is by developing an agent-based model. This section attempts to develop a decision support tool in the form of an agent based simulation model.

4.1 AGENT BASED MODEL

In recent years, there has been a considerable increase in the attention concerning the modeling of human behavior within building simulations. Despite the increasing attention of occupant behavior, incorporation with simulation models has not sufficiently be developed (Deuk-Woo, et al., 2013). Occupants are normally designed in terms of static schedules, but this approach is too simplistic to properly model the complex influence of occupant behavior on the energy consumption of buildings. They rely on fixed parameters for occupants (e.g. fixed work schedule) and they do not take occupant reactions to the indoor environment (e.g. temperature changes or light state) who also assume that all occupants have the same electricity use behavior and are constant over time (Deuk-Woo, et al., 2013; Yan, et al., 2015).

A good methodology to understand the complexity of the interaction of occupant behavior on the energy consumption of the built environment is agent-based modelling. Agent-based modelling (ABM) is a form of simulation tool, programming language, or prediction model used for simulating agent behaviors and agent interactions with a bottom up approach (Berryman & Angus, 2009). ABM is defined by Macal & North (2010) as:

"Modelling agents – or building occupants – individually to account for effects of the diversity among agents in their behaviors, in the pursuit of understanding the whole system".

Agents act based upon the rules of interaction and relationships with their environment and possibly other agents. It consists of four core elements (Lee & Malkawi, 2013): 1) agents physical environment 2) a set of agents, their attributes, and behaviors (decision making process), 2) a set of agent relationships and methods of interaction, and 4) adoption of new behavior. So agents behave on their own, interact with other agents and with their environment. They are the most important feature and could represent an independent component, such as individuals or organizations, with behavioral states and rules. Besides following their behavioral rules and attributes, agents can learn over time and can have 'rules to change the rules' (Macal & North, 2010). Through adoption of technological and behavioral energy saving policies, their interaction with electrical appliances can be alternated and ultimately form new behaviors. The free open-source NetLogo is used for developing the ABM in this research.

4.1.1 NetLogo

NetLogo is a commonly used ABM simulation program. It is a multi-agent programming language and modelling environment for simulating natural and social problems and thus a useful platform for modelling occupant behavior. By giving independent agents individual instructions makes it possible to explore connections between micro-level behaviors of individuals and macro-level patterns, like CO2 emissions that emerge from their interactions with the environment. (Tisue & Wilensky, 2004). The programs has a 'low threshold', which means that for new users it should be fairly easy to get started.

In Netlogo there exist three different types of agents called, turtles, patches and observer. ‘Turtles’ are the mobile agents that move over a grid of ‘patches’ which are also programmable agents. All of the agents can interact with each other and perform multiple tasks concurrently. The third agent is the ‘observer’ which gives the instructions to the turtles and patches. Besides turtles, all other agents are static and cannot move. An agent consists of a function which describes its behavior and a number of attributes, called agent variables (global, turtle, patch or link). The behavior of each agent depends on their variables, which store the state and motive variable.

An important NetLogo language feature is ‘agentsets’ or collections of agents, enabling the users to create sets of agents based on coordinates, color, size or any other given variable. Different ‘breeds’ of turtles can be defined, and different variables and behaviors can be associated with each breed. In addition, using bars, buttons and tools different sets of variables can be used to see what this does to the model. All these features makes the difference between programming and simulation in NetLogo is small: every change made in the code can directly have an effect on the simulation of the model.

To be able to remake the simulation model, the turtles, patches and agent variables are described, which will be included in the model. A distinction is made between an active agent (turtles) and passive agents (patches). Active agents interact with passive agents when present at the designated location.

4.2 METHODOLOGICAL APPROACH

This research proposes an ABM to understand how individual decisions of occupants interact with other building systems agents and affect the energy consumption in the context of building efficiency. This objective is achieved by taking four steps:

1. Defining the principles of the model
2. Program the ABM
3. Collect data of electricity use behaviors for each energy profile, to import into ABM
4. Validate the model

Defining the principles of the model is based on the conceptual model shown in Figure 13, which shows the most important principles that influence the electricity consumption of office buildings. The system to be observed is the office indoor electricity consumption system. The designed model simulates the energy consumption of the occupants of one commercial building at a time. Electricity consumption in buildings is caused by the operation of different types of electrical appliances. The electricity consumption is defined by occupants’ daily routines and behavioral rules (decision-making process) each time the change of occupants’ state triggers them to think about their next action of interaction. Since daylight plays an important role as a behavioral trigger for the use of lighting, it is taken into account in the model by making use of KNMI data. Through adoption of investment and curtailment energy saving policies, occupant behavior can be changed and eventually form new behaviors.

When the different occupant parameters and factors causing the change in behavior are defined. The programming of the model can start. A set of rules to represent the decision-making processes of agents in the model as they interact with building system components and one another were based on questionnaire and relevant literature. Statistical data about electricity consumption by electric appliances of the City Hall in Heerlen, was used to validate the model and to give an overview of office electricity consumption.

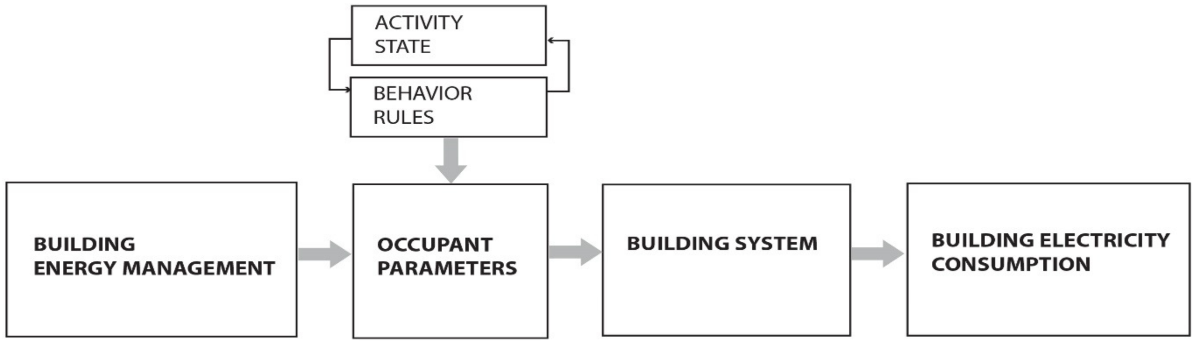

Figure 13 Conceptual Model

4.2.1 Occupant Parameters (Turtles)

The turtles in the NetLogo model represent the occupants of office buildings. Each turtle is designed as an individual, with a set of behavioral variables that define the state of a turtle. In chapter 3 an extensive description is given of occupants' behavior and actions that directly or indirectly impacts building energy consumption. This chapter translates these descriptions into usable data for the model.

4.2.1.1 Occupant occupancy

An individual occupant can only affect the building electricity consumption by taking certain actions which cause electricity consumption when they are presence at work. The occupant working hours affect the time an occupant spends at work. Each individual occupant will have a daily work-schedule that determines the activities that will be performed between arriving at the office and leaving to go home. The reasoning behind this is the fact that occupants can only have impact on the electricity consumption of office buildings when actually present at work. This daily work schedule determines the transition of occupants to a certain location, the time they go to that location, what activity they are doing and how long they are doing that activity. The activities occupants can do during working hours are as followed: working at the work desk (1); go to meeting (2); go to restroom (3) and having a break (4).

The time occupants will perform certain activities is set within a time range reflecting the reality a person usually will need to finish that activity based on predictions of activities found by Tabak & de Vries (2010). Table 5 shows the times used in this model. However the duration of a toilet visit and meeting is an assumption made on own observation, where a toilet visit will usually take around no more than 10 minutes and an efficient meeting should not take longer than an hour (Project Connections, 2016).

Table 5 Average occupant activity duration *Source: (Tabak & Vries, 2010)*

Activity	Duration		Frequency	
	Mean	SD	Mean	SD
Have Lunch	27:42	10:04	0.91	0.29
Go to toilet	07:00	06:00	2.78	1.14
Have a break	08:06	02:36	2.51	1,47
Have a Meeting	20:00	40:00	0.91	0.29

According to their energy profile each occupant will perform electricity demanding activities in order to satisfy their needs. All activities combined will represent the total electricity consumption of that individual occupant, but are not directly translated into actual electricity consumption, as the occupants function according to a decision-making process that triggers to think about their next action, each time they change their state.

4.2.1.2 Behavior rules of building occupants

Based on the article of Linkola et al. (2013) the occupants' use behavior is adapted. This article uses Belief-Desire-Intention framework for human decision making for simulating hourly water-using activities of households. BDI is a common method for simulation modeling that seeks to mimic the practical reasoning processes by which people make the right decisions given the boundaries of their personal values and social norms (UFRGS, 2015). In these method the agents are rational and have certain mental attitudes of belief, desire and intention.

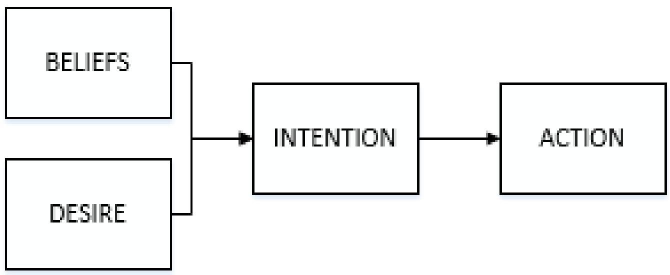

Figure 14 BDI framework

- The belief represents the agent's knowledge, which can be based on information of the real world. Beliefs are updated after the perception of each action
- The desire is the agent's goal. They represent the motivational state of the system
- The intention is a sequence of tasks to achieve the specified goal what the agent has chosen to get.

So, for occupant agents to decide which of the actions to perform (e.g. switch off or leave the computer on) depends on the agents' intention, their daily routines and the level of control over the appliances they have, thus their electricity usage.

Energy Profiles

As was mentioned in the literature study, electricity consumption can change significantly when occupants with different routines are considered (Hoes, et al., 2009; Yu, et al., 2011; Clevenger & Haymaker, 2006). Therefor accounting for different occupancy behavior is essential for developing a realistic decision making model. Based on a study by Accenture (2010), who classified energy consumers from different countries into eight categories based on their attitude toward energy efficient strategies. However, different studies showed that less categories are also adequate for representing the occupant energy consumer (Azar & Menassa, 2012; Zhang, et al., 2011). To elaborate on this theory, four categories of occupants are considered. First, the Big Consumer (BC) representing occupants that do not pay any attention on their energy use. Second occupants that do not make effort towards energy saving but will not over consume energy (e.g. switching off their computer at the end of the day) represent average consumer (AC). The third category are the Energy Savers (ES) that make minimal effort towards energy saving. Lastly, there are the Pro-Environmentalist (PE) representing occupants that are energy efficient in the way they interact with the environment.

The way occupants interact with the environments is the main difference between the defined categories. To know the differences between the energy profiles, it was important to analyze how these categories use each of the main building energy systems such as lighting and computers. Therefor an survey and literature study was carried out was to gather the needed information and understand the different behaviors of each profile. The differences between all the energy profiles is listed in Table 6. Each category has its own values in regard to how they use lighting and computers. For instance, it is assumed that PE switch off their computers whenever they leave the office.

Table 6 Different energy profiles

Parameters		Big Consumer	Average Consumer	Energy Saver	Pro Environmentalist
Occupants		69%	23%	6%	2%
Energy Awareness		0 – 0.20	0.21 – 0.60	0.61 – 0.90	0.91 – 1
Probability		0.2	0.4	0.7	0.95
Computer use	Arriving	Always On when present at the work desk			
	Leaving	If energy-awareness > threshold switch Off if else in stand-by			
Lighting use	Arriving	Always On	On when it is to dark and a probability to leave it off when it is not too dark		Only on when it is too dark
	Leaving	Off			
Light discomfort		0	5 – 15	15 – 30	>30

Each appliance used by an occupant asks a certain energy demand of the building system and to change the perception of which the occupant is present. The activities and heuristic for decision-making are the rules of the occupant behavior. These rules define what type of energy consumer an individual occupant is.

Other factors that are affecting the decision making process is curtailment behavior (e.g. feedback), and organizations values and resulting norms or acceptable electricity use. This forms the individual agent intention to save electricity adopted from a study that investigated the water use of households (Linkola, et al., 2013):

$$I_{Electricity\ Saving} = B_{curtailment} + c \qquad (1)$$

Where

- $I_{electricity\ saving}$ is intention of individual occupant to save electricity
- $B_{curtailment}$ is energy saving awareness if feedback = true. Otherwise B = 0
- c is 0.1 constant to avoid the value of the outcome is 0

The underlying logic is that each occupant would have its own norms of acceptable use of electrical appliances. Studies have shown that mere investment behavior in commercial buildings result in a reduction of electricity use of occupants between 5 and 26% (Mungwititikul & Mohanty, 1997) (Post, 2014). However feedback on electricity can be reduced seem a crucial addition to make individual occupants more aware of the CO2 reduction.

4.2.1.3 Occupant behavior change

As discussed previously occupant might not only have different energy profiles, they can also alter their behavior over a period of time. For this research, feedback and PM are attributable factors causing this change. As feedback, emails are considered to be informational events occurring discretely (ranging from 1 – 3 times a week), that will make occupant in the office building aware of energy saving opportunities, and by that reducing energy demand immediately. In this model each category of occupants is considered to be an adopter by changing their behavior through incentives and adopt new behaviors. Figure 15 shows the different types of conversions where the Big Consumer convert to Average Consumer and so forth, that in the end they become Pro Environmentalist

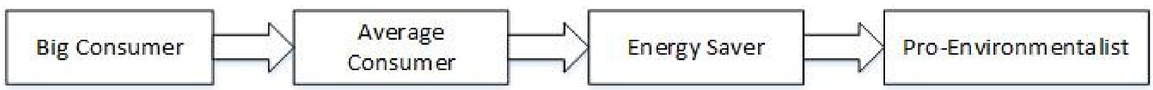

Figure 15 Adoption flow Energy-Profile

As for Power Management, where the relationship between occupant behavior and the state of appliances (on or off) is pretty straightforward, the relationship between the occupant behavior and PM is somewhat more complex. Users control whether PM features are enabled or disabled, and the time it will take before a device set itself in stand-by mode. From literature can be concluded that the shorter the computer is in idle mode and the shorter the delay time is the higher rate of PM operating during the idle mode. Therefor PM operating rate will vary between 5 – 20 minutes (Kawamoto, et al., 2004).

4.3.2 Building system (Patches)

4.3.2.1 Electrical appliance power states and user behavior

For the electricity consumption and energy saving potential of computers the variables that account most for the electricity use are defined such as active mode electricity use, stand-by electricity-use, off mode electricity use, operation hours and power-management enabling rate. The number of computers and power management rate were collected from the organization through expert interview. The operation hours and power consumption were based on industry averages, due to the absent of individual monitoring of the computers.

Table 7 shows average power levels corresponding to on, stand-by and off modes. It should be noted that actual power levels may vary widely between the same type of appliance, depending on specific product characteristics and that almost all new computers and monitors, use some power even when turned off (Webber, et al., 2006). For this research the average power used by each appliance is chosen. It can be concluded that the stand-by mode represent a significant energy saving potential over on power mode.

Table 7 Work desk electrical appliance power use in different modes *Source: (Bray, 2006)*

Appliance	Type	Power use on [W]	Power use off [W]	Power use stand-by [W]	Screen Saver [W]
Computer		75	3	21	155
Monitor	LCD	28	1	1.4	40
Laptop		45	0	15	45
Task Light	Incandescent	60	0	-	-
	LED	8	0	-	-

The operation hours were estimated that when an occupant is present at the work desk it will use the computer. When leaving the work desk to do activities occupant tend to switch off their appliances as can be seen in Figure 16. The dip in midday shows that occupants tend to turn off their appliances when going to lunch and there is a slight reduction in overall electricity use for task lights and monitors. However laptop and desktop computers do not experience a electricity reduction. This suggests that some occupants may leave their work desk during lunch time, causing their monitors to go into sleep mode while their computers remain on. Additionally with Figure 17the extensive use of appliances is examined. For example, computers are typically using about 38% of their maximum power, which suggests that the majority of office occupants are not using their computer very intensively.

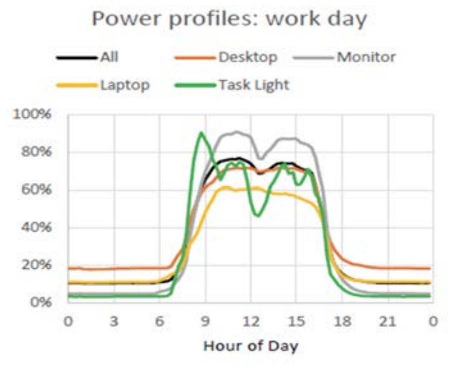

Figure 16 profile of daily power use of office appliances

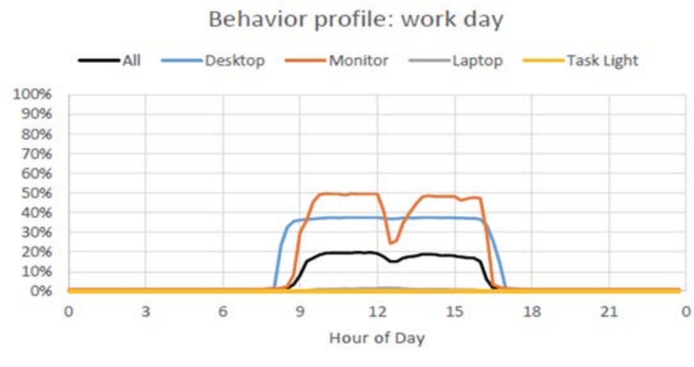

Figure 17 Profile of daily behavior for office appliances

The fluctuation behavior of task lights can be explained with occupants reaction to incoming daylight. At the beginning of the working day most of occupant will turn on the lights. When going to lunch more than half of the occupants will turn off the lights and when coming back turn it back on. At the end of the day most of the task-llights is turned off in contrast to compurers where around 20% of desktops are left on.

4.3.2.2 Building lights power states and user behavior

Lighting should be of sufficient quality to ensure the visual performance to be able to read, write and do computer activities. There are many ways to meet the standard requirements for office lighting. The European Lighting Standard EN 12464-1 deals with room lighting, which provides the illuminance in lux for various application areas. Table 8 shows the lighting level for office buildings.

Table 8 Lighting Level *Source: (EMILUX, 2016)*

Office Space	Lighting Level [lux]
Communal Space	500
Office Space located at window	500
Meeting Room	400
Hallway	200
Cafeteria	200
Restroom	100
Staircase	100

The main variables uses for calculating energy saving potential for the buildings own lighting system are the amount of office space, illumination through day light, the electricity consumption of lighting per square meter, the type of lighting controls available in the building, and operating hours. The amount of office space were collected from buildings blue prints. The lighting control and operating hours were estimated based on expert interview and a questionnaire. The electricity consumption were estimated on industry average data.

Daylight

For daylight, data is gathered of three months (October till January), collected by KNMI. The amount of daylight entering the room is determined by the amount of windows present at the office. To keep the model as simple as possible but yet realistic, I assumed that for each occupant one window is available. The amount of daylight entering the room is then calculated with the following equation:

$$Room\ Daylight = \frac{Solar\ Intensity}{1000} * A * DF \qquad (2)$$

Where

- Room Daylight is the total daylight entering the room in lux
- Solar intensity is the amount of sunlight falling on the earth's surface in MJ/m2
- A is the area of the room
- DF is the daylight factor of 0,05. is the ratio of the light level inside a structure to the light level outside the structure.

In this way the amount of daylight correlates with the area of the room the occupant is present. For example if an occupant is in a room with an area of 30m2 and the solar intensity at that time of day is 390828 MJ/m2. This needs to be divided by 1000 because one lux is around one kWh/m2. This will give a Room daylight of 586 lux, sufficient enough to not use any artificial lighting.

Office overhead light

If there is insufficient possibilities to take advantage of daylight, artificial lighting will provide the answer. To determine the amount of lights that should be needed for a given area or room, the Lumen Method is used, which is valid if light coming out of a uniform layout, the case for most office buildings (Chadderton, 2013):

$$number\ of\ fittings\ \frac{E*A}{LDL*UF*MF} \tag{3}$$

Where

- E is Required Illuminance (lux level)
- A is the area of the workspace in m^2
- LDL average lumens produced from each lamp
- UF is the utilization factor
- MF is the maintenance factor.

The used values are seen in Table 9. The utilization factor is the percent of lumens from the lamp that finds its way to the work desk.

Table 9 Calculation values for lighting

		LDL	Watt	UF	LLF	MF	€/kwh
Overhead Light	TL	2600	40	0.84	0.8	0.9	0.0035
	LED	1100	13	0.55	0.8	0.95	0.0011
TaskLight	Incandescent	228	60	-	-	-	0.0035
	LED	228	8	-	-	-	0.0008

Now the number of lights per occupant is known the illumination can be calculated with the following equation:

$$I = \frac{Li*UF*L_{LF}}{Ai} \tag{4}$$

Where

- I is the illumination (lux, lumen/m2)
- Ll is luminance per lamp (lumen)
- UF is the utilization factor
- LLF is light loss factor
- Al is area per lamp (m2)

For example if 10 TL lamps of 40 W (2600 lumens per lamp) are used in an area of 30 m2 with a UF = 0.84 and Llf = 0.8. Then the illumination in the room will be 582.4 lux.

4.3 UML CLASS-DIAGRAM

UML is a universal language for communicating in the programming world, which makes it very useful to explain the architecture of the NetLogo model. Figure 18 shows the UML class-diagram that contains the different agents, associations and aggregations. It is based on the conceptual model (figure x), but gives a higher detail level of structure of the model. In the model, the occupants, computers and agents are always connected to a workspace. The workspace is always connected to the building.

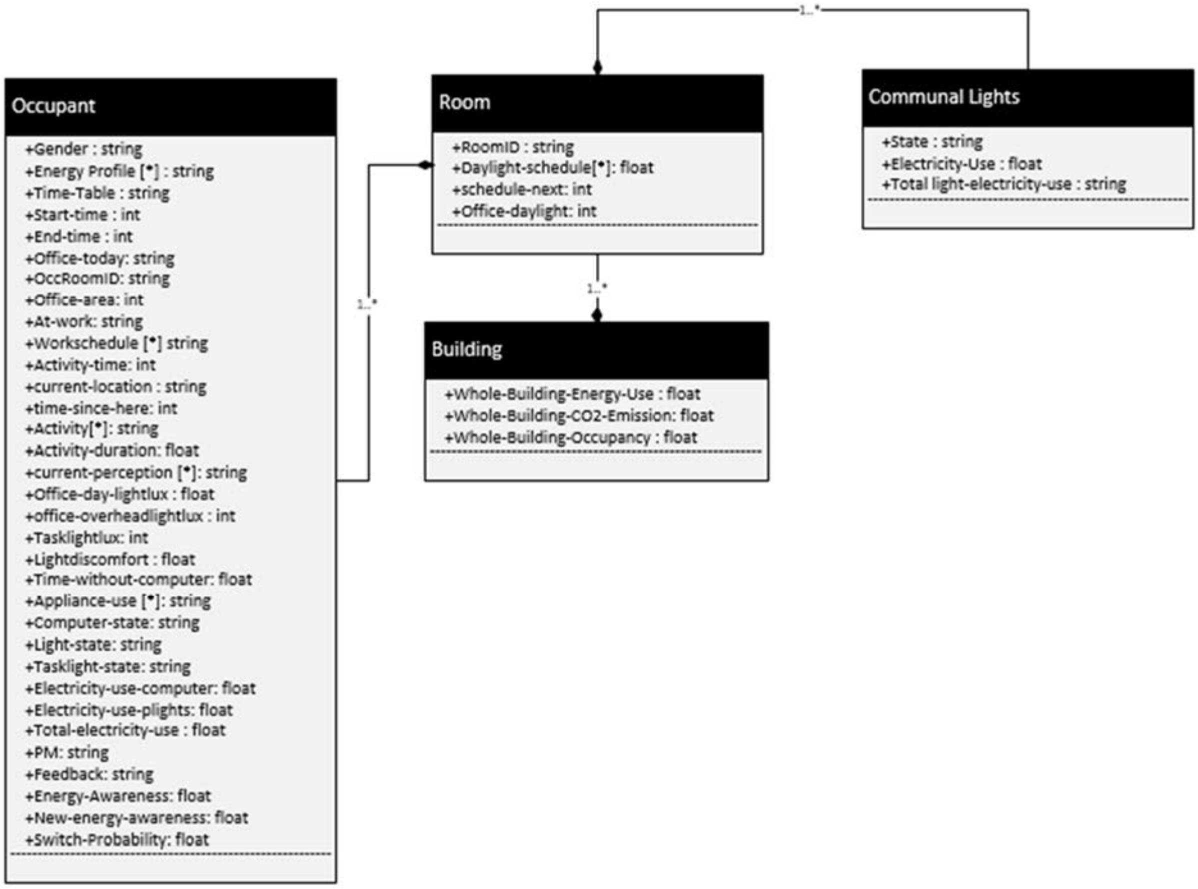

Figure 18 UML Diagram

When combing all the agents described from the UML class-diagram, the NetLogo model will consist out of a building, with rooms and their communal lights, and the occupants that walk through the rooms. The following sections will explain the attributes of all the different agents. This is necessary in order to reproduce the model.

4.4.1 Occupants (Turtles)

In the model the only turtles present are the occupants that move through the building doing their routines. Table 10 gives all the different variables that belong to the occupant.

Table 10 Occupant behavioral variables

OCCUPANTS	Variable	Definition	value
Characteristics	Gender	The gender of the occupant	Male/Female
	Energy-Profile	This is a list containing occupant's values that defines the type of energy consumer the occupant is, describing how the agent is thinking doing current action.	Big consumer/average consumer/energy saver/pro environmentalist
	Occroomid	Determines if the occupant has an own office or not.	True/false
Workschedule	Time-table	Determines if occupant has a strict or flexible working hours	Strict/flex
	Start-time	Hour of day occupant will go to work	hour
	End-time	Hour of day occupant will go home	hour
	Office-today	If current day is the day he is working	True/false
	Office-area	The size of the room occupant work	m2
	At-work	If occupant is at work or home	True/false
	workschedule	A list containing the activities the occupant is doing.	Work/meeting/ restroom/break/home
Action	Activity-time	The time-of-day occupant will do activity	minute
	Current-location	The location the occupant currently stays	Private/ shared/hallway restroom/meeting /cafeteria
	Time-since-here	The time occupant is at current-location	minute
	Activity	The activity occupant is doing	
	Activity-duration	The time a certain activity will take place	minute
Illumination level	Office-daylightlux	Amount of daylight occupant notices	lux
	Office-overheadlightlux	Amount of overheadlight occupant notices	lux
	Tasklightlux	Amount of tasklight occupant notices	
Electrical Appliance	Appliance use	List of appliance used by occupant	
	Computer-state	State of the computer	On/Off/stand-by
	Light-state	State of the light	On/Off
	Task-light-state	State of the task light	On/Off
Perception	Current-perception	The perception of the occupant towards using electrical appliances and lighting	
	Lightdiscomfort	The time an occupant feels uncomfortable	minute
	Time-without computer	The time spend without being behind the computer	minute
	Energy Awareness	Determines how energy conscious an occupant is	0 – 1
	New-energy-awareness	Sets the new level of energy awareness due to direct feedback	0 – 1
	Switch-probability	The probability an occupant will switch off their appliances	0 – 1

Electricity Consumption	Electricity-use-computer	The amount of electricity consumed by computer.	kWh
	Electricity-use-plights	The amount of electricity consumed by light.	kWh
	Total-electricity-use	The total amount of electricity used by occupant	kWh
Behavior Measures	PM	If occupant has PM	True/false
	Feedback	If occupant receives email	True/false

4.4.2 Building System (Patches)

The patches are agents that do not have active behavior and instead their behavior is only triggered by the presence of turtles. Electricity consumption in buildings is caused by the operation of different types of appliances, which are controlled through interaction of the occupants' present in the building. The variables for electrical appliances are shown in Table 11.

Table 11 Building system variables

Patch	Variable	Description	Value
Communal Lighting	State	The state the computer is currently on	On/off
	Electricity use	The amount of electricity used by communal lights	kWh
	Total light electricity use	The total electricity use of the whole simulation	kWh

The Room-Type owns the electrical appliances. Depending on the type of energy consumer, the probability of an appliance to turn on is determined. There are six types of rooms: private (1), shared room (2), Restroom (3), Meeting room (4) and the cafeteria (5) and hallway (6). Table 12 shows the room variables.

Table 12 Room variables

Variable	Description	Value
RoomID	Determines the type of room present in the building	Private/ shared/hallway restroom/meeting/cafeteria
Daylight-Schedule	Daylight schedule for each hour	-
Schedule-next	Determines the hour of day	hour
Office-daylight	Amount of day light entering the room	MJ/m2

4.4.3 Variables

Previous section explained the attributes assigned to each agent in the NetLogo model. The variables are correlated and used for calculating the electricity use of occupants. Two types of variables exist: (1) global variables and (2) adjustable variables. The global variables are necessary for designing a working model. The adjustable variables are observer depended by changing their values. By adjusting the values of the variables, their effect on the occupant behaviour and thus energy consumption become quantifiable. By choosing the adjustable variables, different scenarios can be tested, which help organizations to get insight about the electricity use of occupants and help them designing energy management strategies.

4.4.3.1 Global Variables

In NetLogo, global variables are variables that are necessary for the model to function and are accessible for all agents. All global variables are listed in Table 13

Table 13 Global variables in the Netlogo Model

Variable	Description
Location	There exist 6 locations: Home; hallway; private office; shared office; cafeteria; restroom and meeting room. If an occupant's location is set to one of these option it will move to the corresponding location patch.
Time	The time consist out of minutes hours and what day of the week. Each tick will corresponds to 1 minute in real life. The time is used in occupants work schedule to determine what activities is planned on that time period.
Daylight	The daylight used in the model is collected from the data-set of the KNMI-2016. The values are plotted on an hourly resolution scale. It is through this solar intensity that rooms can calculate the amount of daylight is entering the room.

4.4.3.2 Adjustable Variables

NetLogo enables to program variables in such ways that they can be altered by the user, the adjustable variables. By altering the adjustable variables, different scenarios can be tested on the effect these changes have on the electricity consumption in offices. Table 14 shows the adjustable variables present in this research model.

Table 14 Adjustable variables in the Netlogo Model

	Adjustable Variable	Description
Power Management	Power Management	True/False
	Power Management %	Percentage of computers with PM installed on
	PM-Time	Increase or decrease the time set a computer go's on stand-by when not turned off by the user
Behavior Adjustment	Direct Feedback	True/False
	Feedback Frequency	Increases or decreases the amount of time an intervention is introduced to the occupants. Ranging from once a week to 3 times a week.
	Awareness-Threshold	Value determining occupants will switch on/off the lights
Light Adjustment	LightType	TL/LED/Incandescent
	Light-Control	Manual/Automated/Base case
	Task-Light	True/False
Organization	Occupancy	Percentage of occupant present
	# Big consumers	Percentage of Big consumers
	# Average consumers	Percentage of Average consumers
	# Energy Savers	Percentage of Energy Savers
	# Pro environmentalist	Percentage of Pro environmentalist
	Flex-Worker-%	Percentage of occupants with a strict or flexible working hours
	Male-Occupant	Percentage of male and female occupants
	Number-of-occcupants	The amount of employees an organizations has

4.5 PROGRAMMING OF THE MODEL

Where in previous chapter the conditions of the model where defined, this chapter explains how the model is designed. The findings of the previous chapter are translated into useful formulas. Figure 19 shows the occupant actions at each time step of the NetLogo model, followed by the reasoning behind the working of the model. For a more detailed flowchart see Appendix 3. The complete coding can be found in Appendix 4. At the end of this chapter the final NetLogo model is shown.

It should be noted that to make the model not too complex for this thesis a set of assumptions are made which are listed below:

- Individual decision making process are represented with heuristic and stochastic rules;
- Agents interact with their environment, such as work activities and control of electrical appliances;
- Adaptive behavior is implemented through energy saving strategies.
- The use of the copier, coffee machine, printers and other small plug loads are not simulated in this model; The end-user electricity calculation included only a part of the end-user electricity
- The model will not take special days into account, such as sick days or holidays;
- Due to insufficient data about the amount of lights of each room in the City Hall, they are calculated according the Lumen Method;
- For this model, the orientation of the windows is not taken into account. Each turtle will have the same amount of daylight entering the room;
- Only the light in private workspace, lights in the restroom and meeting room can be controlled manually.
- For computers the intensity of the use by each occupant is the same during the complete simulation;

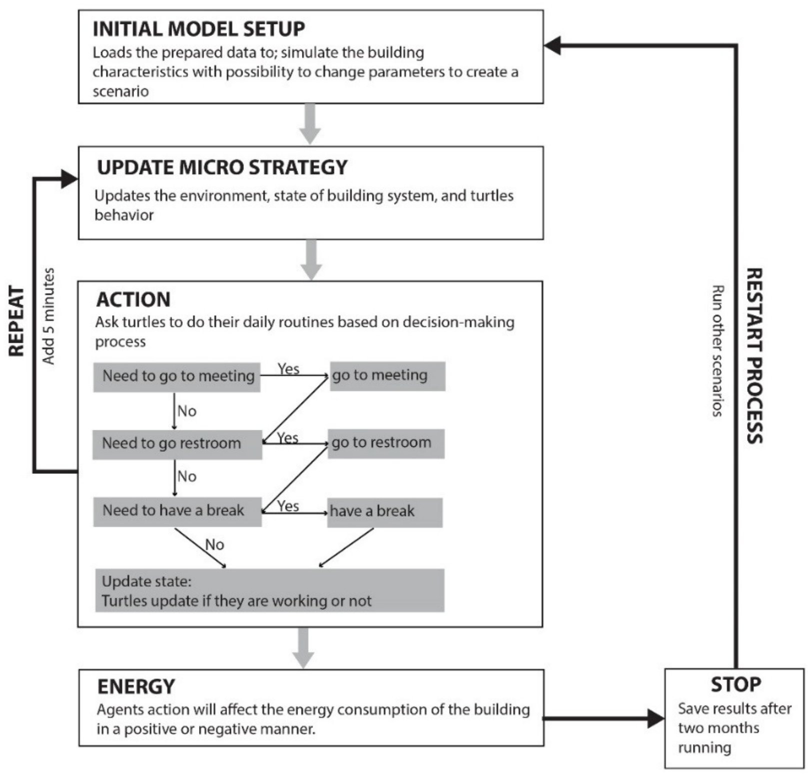

Figure 19Working of the model

4.5.1 Initial Model Setup

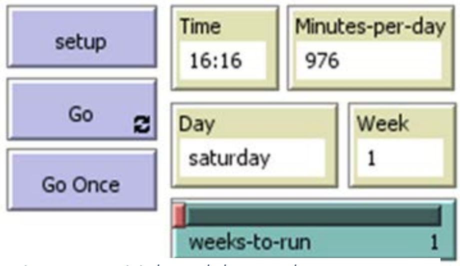

Figure 20 Initial Model Setup layout

The model is divided into two procedures, the *setup* and *go* procedure . The *setup* button set the model in a state from which it can be run. It starts with clearing all previous settings followed by setting up the world by the commands *display-patches* and *display-locations* where occupants can move around. At last other variables are set in a state which are useful during simulation, mainly for setting up the right lighting conditions by importing daylight data into the NetLogo model. An overview of the initial model setup is shown in Figure 20

After pushing the *setup* button, the model starts simulating by pushing the *go* button. The model runs by asking the occupants to execute a set of procedures explained in section 4.5.2 The *go* button including the *forever* sign will run the model during its whole simulation time. The single *go* button is useful when following the behavior during each time-step, where one tick corresponds to one minute. The duration of the simulation can be controlled with the *weeks-to-run slider* ranging from one week to 12 weeks. 12 weeks is chosen, due to the fact that the use behavior of occupants will not deviate that much from month to month. When corresponding week is met the model will stop running, or by pushing the *go* button ones more.

4.5.1.1 Setup Occupants

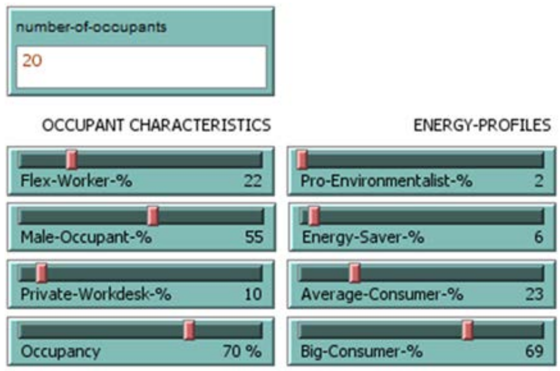

Figure 21Occupant parameters

The turtles in the model represent the different occupant with variables, settings and constraints (Figure 21). With the *setup-occupants* procedure each occupant is assigned with its own individual characteristics defined by the [*random number*] command. What this command does is assigning values to characteristics randomly generated by a deterministic process. A deterministic process means that the same results appear every time, starting with the same random number. This is a necessary and important step for a scientific model, so it can be reproduced where the end result is based on the same starting values, each time. Below is an code example that shows how this is randomly assigned.

Through sliders the percentage of each variable can be adjusted according to the gathered survey data. The sliders under occupant characteristics define the demographic variables, such as gender, type of work desk and type of work schedule (e.g strict or flexible). The sliders under energy-profiles determine the presence of the different types of energy consumers.

<u>CODE</u>

```
to setup-occupants
        let p3 random 100
        ifelse p3 >= 0 AND p3 <= male-occupant-% [ set gender "male"    ]
                                                  [ set gender "female" ]
end
```

4.5.2 Occupant Behavior

The *go* procedure asks all the occupants to execute a set of rules. It will start different sub-procedures that form a part of the *go* command. After all occupants have performed their actions, the model advances a tick. In the next section each of the sub-procedures is explained.

First thing to start with was defining occupancy of the building during each day. At what time occupants will arrive at work, when they are doing other activities during their workday and what time they will leave to go home. The transition between being at home and go to work is determined by the occupants work schedule. Based on working times gathered from survey data, different arriving and leaving times could be randomly assigned to each occupant. At the beginning of each day, corresponding percentage of occupants is asked to determine whether they go to work or go home. This will lead to *n-random* occupants being present at work.

CODE

```
to start-day
        let Occupancy-Percentage (occupancy + random 20)
        ask n-of( int (Occupancy-Percentage / 100 * count occupants)) occupants [
                set office-today true
        ]
end
```

The transition from hallway to their work desk is determined by a time-out between 2 and 5 minutes, which simulates the time that is needed to walk to their work desk. Once arrived at their work desk, their presence can trigger the use of computer and lighting determined by their perception of the room.

CODE

```
to occupant-behavior-computer
        ifelse ( current-location = "PrivateRoom") OR ( current-location = "SharedRoom" )
                [ set current-perception lput "work with computer" current-perception      ]
                [ set current-perception lput "work without computer" current-perception ]
end
```

COMPUTER As can be seen in Figure 22 current perception for computers consist out of two values: (1) work with computer and (2) work without computer. Work with computer is the perception that the occupant is present at their work desk. Due to simplification of the simulation, if an occupant is present at the work desk, the computer will always be switched on, despite what energy consumer it is. This is done within 2 minutes when arrived at the work desk. When the occupant leaves his work desk their current perception will change in “work without computer”. This will trigger the occupant behavior of switching the computer off. The intention for switching the computer off, the transition rule is a threshold. For each occupant it is assumed that they have an own level of awareness towards energy saving, their personal energy awareness parameter, ranging from 0 to 1 based on their Energy-Profile. If the value of occupants energy awareness is greater than the threshold, it has a large probability to switch off the computer when leaving the work desk.

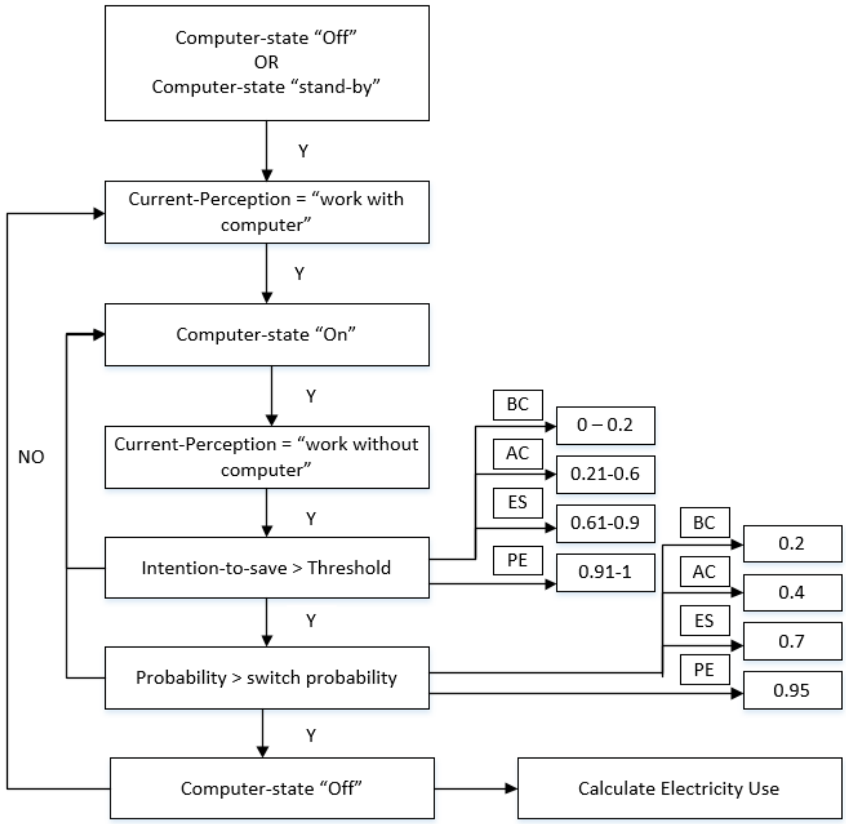

Figure 22 Flowchart occupant computer use behavior

CODE

```
to control-computer
	if at-Work [
		if activity = "work" AND member? "work with computer" current-perception [
		 if (time - time-since-here) >= (3 + random 2) AND computer-state != "On"
			[set computer-state "On"]
	]
	if member? "work without computer" current-perception AND
	intention-to-save-energy > Awareness-Threshold [
		if Energy-Profile = "Big-Consumer"  [
			if switch-probability > 0 AND switch-probability <= 0.2 [ set light-state "Off" ]
		]
		if Energy-Profile = "Average-Consumer" [
			if switch-probability > 0 AND switch-probability <= 0.4 [ set light-state "Off" ]
		]
		if Energy-Profile = "Energy-Saver" [
			if switch-probability > 0 AND switch-probability <= 0.7 [ set light-state "Off" ]
		]
		if Energy-Profile = "Pro-Environmentalist" [
			if switch-probability > 0 AND switch-probability <= 0.95 [ set light-state "Off" ]
	]]
end
```

LIGHT As illustrated in Figure 23 three different levels of light perception are distinguished: (1) too bright (2) normal and (3) too dark. A occupant considers the room too bright when the illumination will rise above the 500 lux. The room is too dark when the illumination level is below 250 lux. In between the 250 lux and 500 lux is usually seen as comfortable for doing office activities.

CODE

```
to calculate-light-comfort
        let x one-of locations with [ ((pxcor = -18) AND (pycor = -5)) ]
        let daylightlux [ office-daylight ] of x

       if current-location = "PrivateRoom" [
               set office-daylightLux ceiling ((daylightlux / 1000) * office-area * Daylight-factor)
                if light-state = "On" [
                       if lightType = "TL" [
                               set office-overheadlightLux floor ( light-per-occupant * illumination )
                       ]
                       if lightType = "LED"  [
                               set office-overheadlightLux floor ( light-per-occupant * illumination )
       ]]]
end
```

Based on current perception defined by the illumination in the room and what energy consumer the occupant is, it will switch the lights on or off. This counts for task-light as well as overhead lights. As can be seen in table x, Pro Environmentalist will only switch on the light if it is too dark. Average consumer and Energy saver will switch on the lights except when the probability will not exceed then they leave the lights on until there light discomfort is met. Then they will switch on the lights. Big consumer will no matter how well the daylight in the room is, it will switch on the lights. When the energy awareness of the occupant is greater than the threshold, there is a probability that they will switch off the light. This probability makes sure that however someone has the intention to switch the lights off there is still a chance he or she will not do it. The probability values are based on own questionnaire and a study done by Zhang et al. (2011) who investigated small electricity consumption in office buildings.

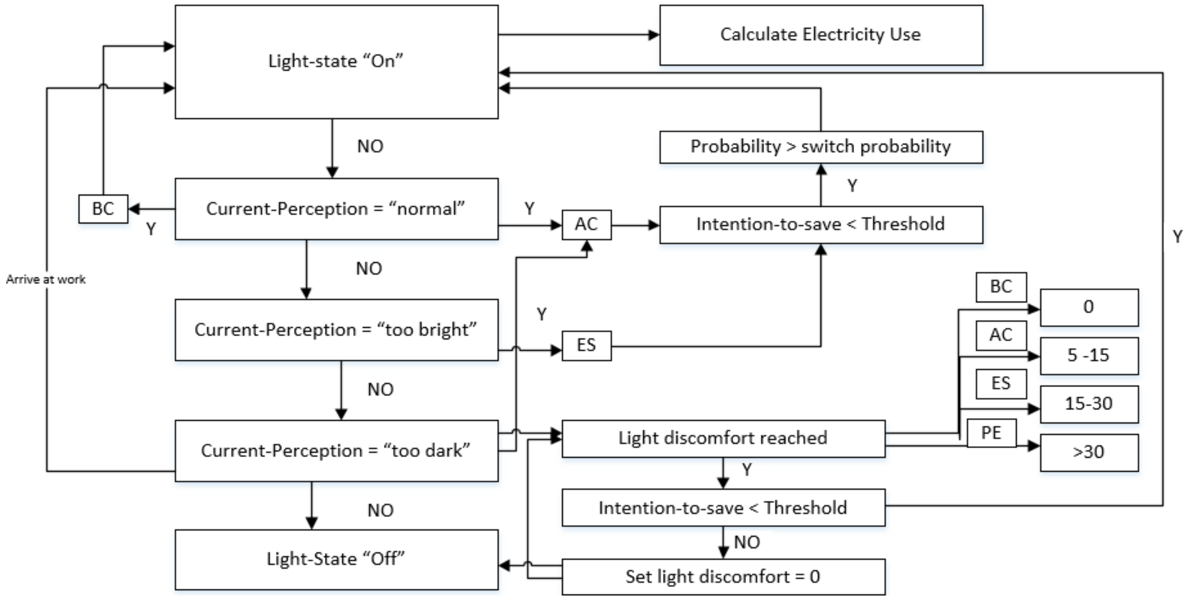

Figure 23 Flowchart occupant light use behavior

CODE

```
to control-light
        if at-Work [
                if activity = "work" AND current-location = "PrivateRoom" AND
                time = (time-since-here + (3 + random 2)) [
                        if Energy-Profile = "Big-Consumer"   [
                                if light-state != "On" [ set light-state "On" ]
                        ]
                        if Energy-Profile = "Average-Consumer" [
                                ifelse NOT ( member? "too dark" current-perception ) [
                                    ifelse  switch-probability > 0.65 [ set light-state "Off"] [
                                        if light-state != "On" [  set light-state "On" ] ] ]
                                                                  [  set light-state "On" ]
                                ]
                        if Energy-Profile = "Energy-Saver" [
                                if member? "normal" current-perception AND
                                switch-probability <= 0.65 [ if light-state != "On" [
                                        set light-state "On" ] ]
                                if member? "too bright" current-perception [
                                    set light-state "Off" ]
                                if member? "too dark" current-perception [
                                        set light-state "On" ]
                        ]
                        if Energy-Profile = "Pro-Environmentalist" [
                                ifelse member?  "too dark" current-perception
                                        [ if light-state != "On" [ set light-state "On" ] ]
                                        [ set light-state "Off" ]
        ]]]
end
```

WORKSCHEDULE During the work day, occupants typically leave their work desk to do other activities. This can happen at any time which makes the transition rule a stochastic event with the probability for it to happen determined by the occupants' arrival and leaving time. For this thesis three kind of leaves are considered based on own observations and experience, namely occupants can leave their work desk to go the restroom, when having a meeting, or for their lunchbreak. The code below will give an impression on how it is implemented in the model. It should be noted that lunch will always be when the occupant is at the half of his work day. When going to the restroom and having a meeting is determined randomly.

CODE

```
to set-workschedule
        ask occupants [
                let p random 10
                if at-work [
                        If current-location = "PrivateRoom" OR current-location = "SharedRoom" [
                        if time = time-since-here AND activity-time = 0 [
                        set activity-time random-time time-since-here ((end-time * 60) + 60)
                        ]

                        if time = activity-time [
                                ifelse p >= 0 AND p <= 3
                                        [ set workschedule lput "meeting" workschedule
                                          set activity "gomeeting"
                                          determine-location ]
                                        [ set workschedule lput "restroom" workschedule
                                          set activity "gorestroom"
                                          determine-location]
        ]]
end
```

LOCATION When 'activity-time' is reached the occupant will go and do the activity by determining the location. The same transition applies for leaving work desk to do other activities as for arriving at the office, by first walk through the hallway.

CODE

```
to determine-Location
         if activity = "golunch" AND current-location != "hallway" [
                 move-to hallway
                set current-location "hallway"
                 set time-since-here time
        ]
        if activity = "golunch" AND current-location = "hallway"  [
                if (time - time-since-here) >= (2 + random 2) [
                move-to cafeteria
                set time-since-here time
                set current-location "cafeteria"
                set activity  "lunch"
                set activity-duration 28 + random 10
        ]]
end
```

4.5.3 Behavior Interventions

For this research the objective was to quantify the energy efficient intervention potential on changing the occupant behavior. As discussed in the theoretical framework and seen in Figure 24several adjustments can be made that will alter the electricity use of occupants.

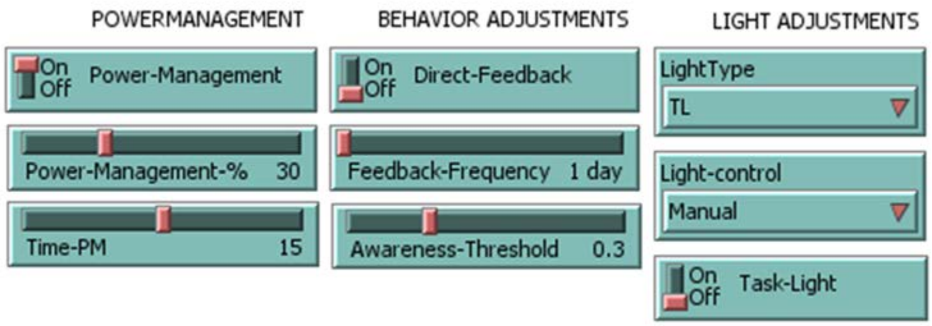

Figure 24 Energy Management Strategies

To start with Power-Management, when the procedure is on with the power-management-% slider the amount of PM users can be adjusted. The Time-PM slider will set the time when PM will be active.

When Direct feedback is on occupants will when they start their workday receive an email. How often they will receive the email can be adjusted with the Feedback-Frequency slider. To simulate the change in behavior attributable to energy efficient incentive, the user can alter the occurrence of these variables. So, for each time step, direct feedback variable is activated only if its actual scheduled for this time step. This state triggers the execution of the code shown below, calculating the flow of occupants becoming more energy conscious. Depending on how often they got in contact with the behavior intervention the more often their energy awareness is updated.

<u>CODE</u>

```
to update-occupant-behavior
    ask occupants [
        if direct-feedback = true [ set feedback true
            if feedback-frequency = 1 [
            if day = 0 [
                if member? "work with computer" current-perception [
                set new-energy-awareness energy-awareness + (0.05 + random 0.05)
                ]
    ]]]
end
```

For lighting the type of lights can be altered. For this research the options TL and LED can be chosen for overhead lights and when the Task-Light procedure is on, the options incandescent and LED can be chosen. These options will affect the amount of power that is needed to light the building. With the Light-control menu. The way occupants control the lights can be altered from Manual to Automated. There is also a Base option that will set the models light control at base scenario.

4.5.4 Calculate Electricity Use

As last is the calculate electricity use procedure, which is made for the electricity consumption of light and computers will show how much electricity each appliance will use at each tick.

<u>CODE</u>

```
to calculate-electricity-use
    ask occupants [
        if computer-state = "On"      [set electricity-use-computer precision (electricity-use-
        computer + (kwhcomp / 60) ) 3 ]
        if computer-state = "stand-by" [
          set electricity-use-computer precision (electricity-use-computer + (0.006  / 60)   ) 3
        ]
        if light-state = "On" [
            if lightType = "TL"  [
              set electricity-use-plights precision (electricity-use-plights + (light-per-
              occupant * 0.04 / 60 )) 3 ]
        if lightType = "LED" [
              set electricity-use-plights precision (electricity-use-plights + (light-per-
              occupant * 0.013 / 60) ) 3 ]
        ]
        if task-light-state = "On" [
            if lightType = "INCANDESCENT" [
            set electricity-use-plights precision (electricity-use-plights + (1 * 0.04 / 60)) 3
        ]
        if lightType = "LED" [
            set electricity-use-plights precision (electricity-use-plights + (1 * 0.09 / 60)) 3 ]
        ]]
end
```

4.5.5 Interface

Shown in Figure 25 is the final interface of the model in NetLogo. At the left are all the model controls to adjust the outcome of each simulation. At the right are all the graphs to monitor the electricity use behavior of the occupants. You can track the number of different energy awareness levels as well as the change in occupant behavior. The total electricity consumption, the costs and also CO2 emission is tracked as well as the state of all appliances. It is also possible to follow one of the occupants behavior by just typing in their occupant identification. In this way you can track his activity movement, their current-perception, what type of consumer and the individual electricity use. Also, in order to give insight in the working of the occupant variables in the NetLogo model an instance-diagram of an occupant is shown in Figure 26. Keep in mind that some of occupant variables can have alternating values during a simulation.

4.5.6 Output

The relation between the occupant and electricity consumption behavior is determined using the NetLogo Behavior Space tool. This tool covers a broad band of possible configurations given certain constraints. In this case it will determine the behavior of occupants multiple times for each incentive. Results are saved to a spreadsheet and table which contain the necessary information from which a relation between behavior and configuration is determined.

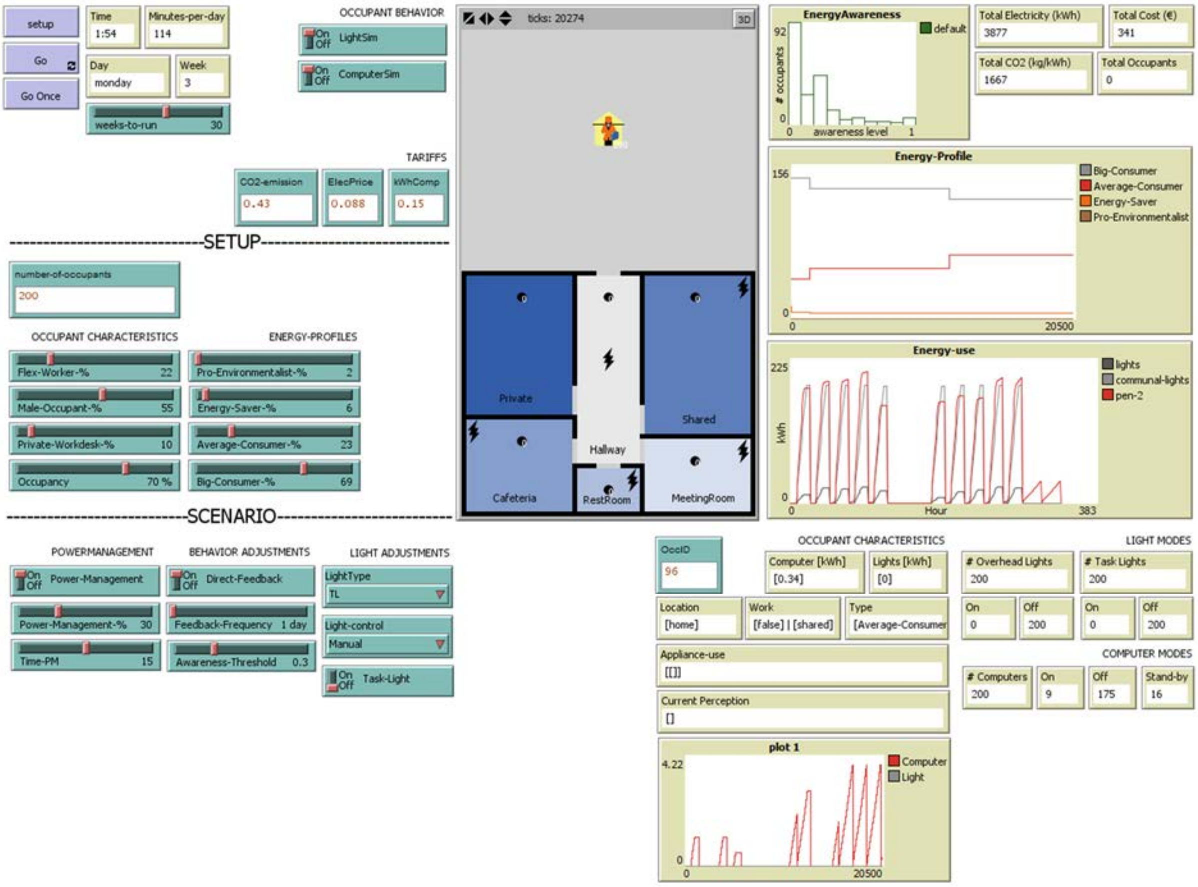

Figure 25 Graphical Interface of NetLogo Model

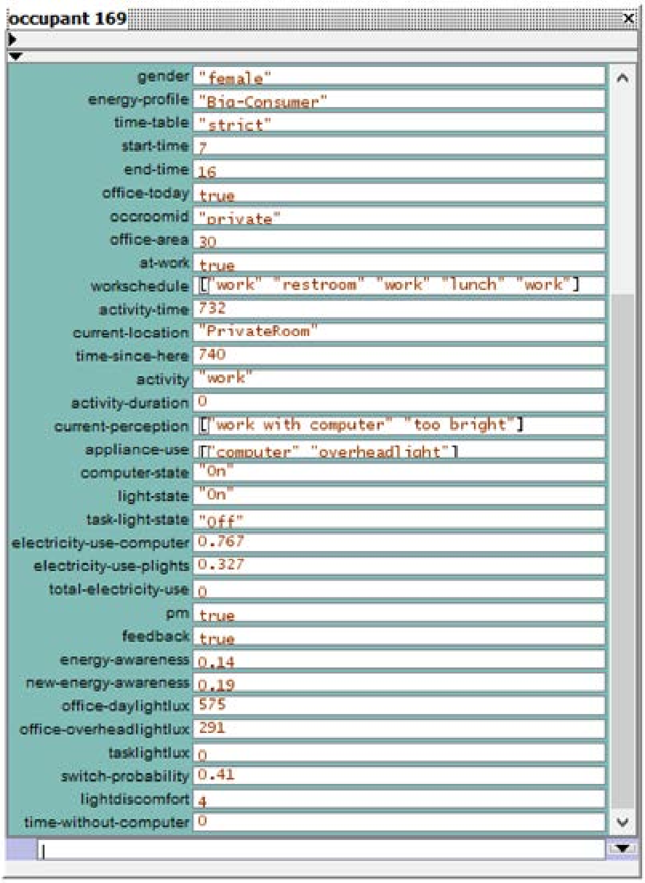

Figure 26 Instance-diagram of an occupant agent

4 SIMULATION & RESULTS

The main objective of this thesis is to designing a realistic model where behavior of occupants can be investigated to help organizations getting insight in the decision making process of occupants for designing energy efficient strategies. Now the model is programmed, the next step consist of simulating occupants' interaction and their potential change in behavior using the developed ABM. Data is collected to test and validate the assumption made about occupants characteristics. Also some scenarios are simulated that shows the influence of the use of different types of occupants

5.1 CASE STUDY: CITY HALL HEERLEN

In the coming years, for Heerlen and Parkstad Limburg region, a transition is taking place to a more sustainable living environment. The governmental and regional goals are ambitious: in 2040 the region should be energy neutral. Therefor the energy consumption needs to be reduced as much as possible. In particular, existing public buildings consume much energy, but are often not sufficient transparent. It is therefore necessary to understand the current situation (baseline). In this context, in December 2013, a research is launched into the current situation of the energy consumption of a number of buildings. The E-KPI project.

Within the project three buildings get monitored for three years in the field of energy and water. With the aim to get insight into the energy characteristics of the buildings. In this way a benchmark can be determined for other similar buildings. The project is implemented in city hall Heerlen, Hogeschool Zuyd and Tarcisiusschool. However, for this research the focus is on the energy efficiency for offices, the city hall Heerlen is only interesting.

One of energy management problems arising at the City Hall is that majority of the lighting in the building are left on unnecessary (think of corridors that are seldom used, or when enough day light enters the space). The other issue is the use behavior of occupants regarding electric appliances. Technically speaking, the amount of electricity used by lights and electric appliances is related to the behavior of the users. Thus changing the behavior could have a positive impact on the energy use of the building.

Focusing on these energy management problems, the following two research questions could be answered: (1) *what is the effect of individual occupant behavior on the energy consumption of commercial buildings,* and (2) *What kind of energy efficient incentives are the best solution for changing occupant behavior and reducing energy consumption within commercial buildings?* Thus, the data from this pilot are very useful for the municipality.

5.1.1 Electricity consumption of City Hall

The City Hall of Heerlen (Figure 27), designed by architect Peutz, was built between 1936 and 1942 and now is a national monument. It is connected to district heating and has not been renovated with regard to energy efficiency. The City Hall of Heerlen is due to its location and orientation associated with the development of Heerlen itself and is the municipal home of some hundreds of employees. The data center of the municipality is located in the city hall and the town takes much annually for cooling.

The characteristics of the rooms and building systems of the City Hall are listed in Table 15. The amount of office space, type of lighting and lighting control of the city hall were collected from blue prints and company records provided by the municipality. The number of appliances and were collected from walkthroughs through the City Hall, expert interviews and a questionnaire.

The electricity consumption data was acquired through existing real time metering of the building. Because it is unclear on which meters what is connected, all electricity consumption is combined into base electricity. The ICT is the only metering which is reliable and know what is connected onto it such as electrical appliances (for the most part computers).

In terms of energy technology, important features are (1) shifting the operating time of the air handling unit from 02:00 to 06:00 to save energy use, (2) reducing the CO2 emission, by covering the roof of the building with 44 photovoltaic cells, producing approximately 10.000kWh per year and, (3) using lighting sensors in toilets to reduce electricity consumption. This means that lights are automatically switched on when occupants enters the restroom and are switched off in 5 minutes after leaving the room. For most part of the building the lights are automatically turned on when the building opens at 07:00 and are turned off at 19:00. For the private offices applies manually controlled lighting. For electrical appliances counts that they are turned on when employees arrive at their workspace, and depending on their use behavior when they are turned off.

Table 15 Building characteristics

Characteristic		Amount
Rooms		71
Total Area [m2]		5408.54
Lights		
Task Lights		5
Computers		175
Monitors		175
Laptops		13
Mobile phones		+- 200
Printers		10
Vending Machines	Coffee	6
	Candy	1
Occupants		+- 200

Figure 27 City Hall Heerlen

5.1.2 Data Collection

Questionnaires are often used to identify the most important factors influencing occupant interactions with the building system: use of lighting and electrical appliances. To calculate the desired number of respondents for a small population a normal approximation to the hypergeometric distribution is used (Morris, 2016). The sample size formula is shown below:

$$n = \frac{N\,z^2\,pq}{(E^2\,(N-1) + z^2\,pq} \tag{5}$$

Where:

- n is the required sample size
- N is the population size
- p and q are the population proportions. (If you don't know what these, are set them each to 0.5.
- z is the value that specifies the level of confidence you want in your confidence interval when you analyze your data. Typical levels of confidence for surveys are 95%, in which case z is set to 1.96.
- E sets the accuracy of your sample proportions, also called margin of error. For example, if you want to know what proportion of individuals are in favor of some policy, with an accuracy of plus or minus 3%, then E is set to 0.03.

As this questionnaire is focused on the impact of the building system on the energy consumption, the target group are occupants of commercial buildings using lighting, computer and miscellaneous appliances. It provides information on, occupants' present routines regarding energy saving, their stated willingness to increase current effort to save energy as well as on socio demographic characteristics. The energy consumption caused by appliances where occupants barely have control over are not considered. Therefor the questionnaire consists out of the four modules: (1) Work profile, (2) Energy profile, (3) Energy efficient strategies and (4) a socio- demographic module. Moreover, it should be noted that it is a cross-sectional questionnaire where questions and information relate to the occupants' current level of knowledge. An explanation of the design of the questionnaire is given in Appendix 5

5.1.3 Descriptive Analysis

This section describes the information drawn from the data of the questionnaire. Information is presented about how user characteristics are divided over the sample, their building system routines and influence of different energy efficient technologies.

5.1.3.1 Research sample description

The questionnaire was distributed amongst occupants of the City Hall in Heerlen, which resulted in 73 completed questionnaire. Only one respondent did only fill in the first part of the questionnaire. Furthermore, three did not indicate their gender, five not their age, and 8 occupants not their function. However it should be noted that all functions are covered with this questionnaire. Table 16 gives an overview of the occupants' characteristics.

Table 16 occupant characteristics

Characteristic	Level	Frequency [%]	Characteristics	Level	Frequency [%]
Gender	Male	57,5	Age	21-30	6,9
	Female	38,4		31-40	23,6
Days occupied	Monday	98,6		41-50	31,9
	Tuesday	97,3		51-60	34,7
	Wednesday	80,8		61-70	2,7
	Thursday	97,3	Type of Work	Managerial	15,4
	Friday	78,1		Supervisor	12,3
Work floor	Ground floor	10,4		Administrative	19,2
	Floor 1	23,9		Technical	8,2
	Floor 2	19,4		Consultant	30.1
	Floor 3	14,9		Other	4,1
	Floor 4	22,4	Sharing a workplace	Yes	90,4
	Floor 5	3		No	9,6
	Floor 6	1,5	Time of going Home	13:00-14:00	4,1
	Floor 7	4,5		14:00-15:00	1,4
Arriving Time at Office	07:00-08:00	46,6		15:00-16:00	5,5
	08:00-09:00	45,2		16:00-17:00	49,3
	09:00-10:00	5,5		17:00-18:00	34,2
	Flexible	2,7		18:00-19:00	2,7
				Flexible	2,7

The respondents were occupants working typical hours and leaving their workplace occasionally for meetings or other activities. The majority of the occupants are male (58%) 51-60 years old (35%), and performing consultancy tasks (30%). When looking at the working hours, most of the occupants arrive on fixed times early in the morning between 7 and 9 o'clock (47% and 45% respectively), and leave the office often at 16:30 (49%). There are only few flexible workers who can arrive between 9 and 13 o'clock (3%). Also known from the questionnaire is that none are working on Saturdays and Sundays.

5.1.3.2 Occupant Energy Profile

This chapter gives a descriptive analysis of the behavior of occupants using the building system during the daily activities. The purpose is to find out the activity routines of the occupants regarding the use of computer and lighting. Important for this research, is in what state occupants leave their electric appliances and lighting when they are not needed during daily activities: meeting, restroom, lunch and going home. To form a clear image of how occupants interact with the building system, each part will be supported with graphs and tables.

<u>OCCUPANT ROUTINE</u> If occupants leave their work desk, the state of their appliances are determined by their own routines. This could mean that a lot of energy is wasted when appliances are still on when not in use. By means of Self-Report Habit Index (SRHI) developed by Verplanken and Orbell (2003) is measured if turning off computers and lighting belongs to habitual behavior and routines of the respondents. Respondents had to answer seven questions for each behavior, which should determine whether there was a matter of automaticity, in support of switching off computers and lighting. The scores of each item was recoded such that high values indicated strong habitual behavior. The Cronbach alpha for

switching off computer and both scenario's for switching off lights (leaving; sufficient daylight) were .90, .83 and .80 respectively, which indicates a high correlation between the items. The mean and, standard deviation of occupants' actions is shown in Table 17. This shows that switching off computer when not needed is a habitual behavior ($t(3)=.132$, $p<.01$). However, this does not corresponds with the results of other questions which is discussed later on. Switching off lights when leaving ($t(2)=.132$, $p>.01$) and when sufficient daylight ($t(2)=-2.389$ $p>.01$) do not belong to their habitual behavior. This is due to the use of automatic lighting in the City Hall, whereas manual control of light is not needed for most rooms.

Table 17 Habit Index Means, standard deviation (SD) and respondents (N)

Behavior	Mean	SD	N
Switching off Computer when not needed	3,66	.876	70
Switch off lights when leaving the work desk	3,01	.821	63
Switch off lights when sufficient daylight at the work desk	2,77	.733	60

A principal component analysis (PCA) without rotation was performed on the seven items of the SRHI for each behavior. For turning off computer only the first component accounted for 61.6% of the variance. Switching off lights when leaving, two eigenvalues were greater than one (4.247 and 1.167), while the first component accounted for 60.7% of the variance and the second for 21% of the variance. For switching off lights when there is sufficient daylight, two eigenvalues were greater than one (4.7 and 1,298) with the first component accounted for 67.2% of the variance and the second 18,5% of the variance. For each behavior the coefficient alpha of the SRHI were: .84 for switching off computer, .78 for switching of lighting when leaving and .84 for switching off lighting when there is sufficient daylight, which indicate high internal reliabilities.

<u>COMPUTER ACTIVITY</u> As can be concluded from Figure 28, the 69% of the respondents never switch off the computer leaving the work desk for more than 20 minutes. In addition, the state of the computer could depend on the length of their absence. From Table 18 it can be concluded on a positive note, that when respondents went home they would switch off the computer (88%). Only three respondents left it on and six put it in stand-by. For the other daily activities, leaving their work desk for a long meeting, their lunch at noon or for a short restroom break, they will never switch off their computer. In fact only one respondent would switch off the computer when going for lunch. The influence of the duration of the absence on computer use is also been asked. When respondents leave their work desk for a meeting (66%) or for lunch (55%), they usually put the computer in standby. For a quick visit to the restroom, most respondents just leave their computer on (68%). A possible explanation for this is that computers will put themselves in stand-by through installed PM. The visit to the restroom will be too short to activate PM. To validate this assumption questions about the use of PM were asked.

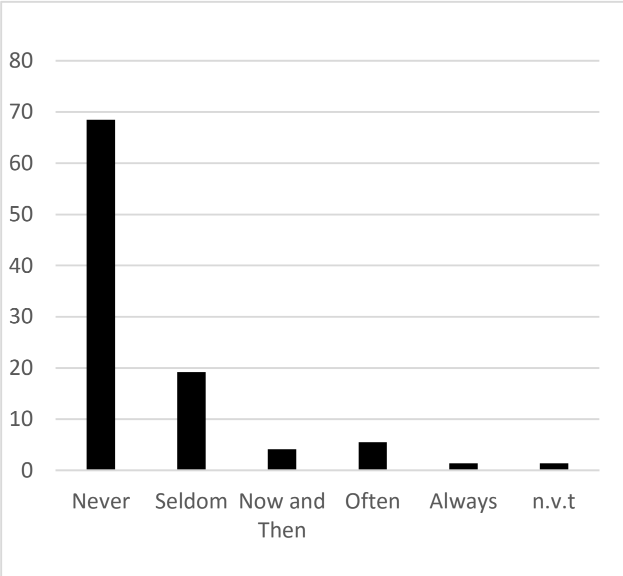

Figure 28 Turn off computer leaving work desk > 20 minutes

Table 18 State of Computer during daily activities

Activity	Mode	Frequency [%]
Meeting	On	34,2
	Off	0
	Stand-by	65,8
	n.v.t	0
Toilet	On	68,1
	Off	0
	Stand-by	30,6
	n.v.t	1,4
Lunch	On	42,5
	Off	1,4
	Stand-by	54,8
	n.v.t	1,4
Home	On	4,1
	Off	87,7
	Stand-by	8,2

As can be concluded from Table 19, the majority of respondents have no PM on their desktop (75%) or monitor (71%). When it is equipped it will be activated after 15 minutes (18% for desktop and 22% for monitor) or 30 minutes (6% for desktop and 7% for monitor). When we relate these results with the stand-by frequency during daily activities it explains the high amount of computers left on when visiting the restroom, where an average visit will take approximate 10 minutes. However, computers equipped with PM are far less than the amount of computers on stand-by during daily activities. This concludes that some respondents are self-aware of putting their computer in stand-by will save energy.

Table 19 Power management activity

Activity	Level [Min]	Frequency [%]	Activity	Level [Min]	Frequency [%]
Activate PM desktop	15	18,1	**Activate PM monitor**	15	22,2
	30	5,6		30	6,9
	45	1,4		45	0
	60	0		60	0
	> 60	0		> 60	0
	n.v.t	75		n.v.t	70,8

<u>LIGHT ACTIVITY</u> Compared to occupants' computer use, lighting is a whole other story. Looking at Figure 29 and Table 20 most off the respondents said switching off lights was not applicable for their situation or that they would never switch off lights. Only few respondents would so now and then switch off the lights. This are the respondents that have a private office. Comparing the lighting use when leaving the room or when there is sufficient daylight, a small difference is noticeable. Respondents will switch off the light more often when sufficient light is entering the room. Also the duration of absence has little to no influence on switching off the lights.

This strange result can all be explained by the fact that most of the lighting in City Hall is controlled automatically which means when occupants arrive at their work desk the lights are already turned on, every day. Only the private rooms and meeting rooms are controlled manually. It should also be noted that respondents could have misinterpreted the question, by choosing never when the lights are controlled automatically. Reactions given by some of the respondents after the questionnaire confirmed this (Appendix 6). Therefor the results are not as reliable. However, literature studies confirmed that controlling lights in an energy saving manner is an area with lots of improving possibilities.

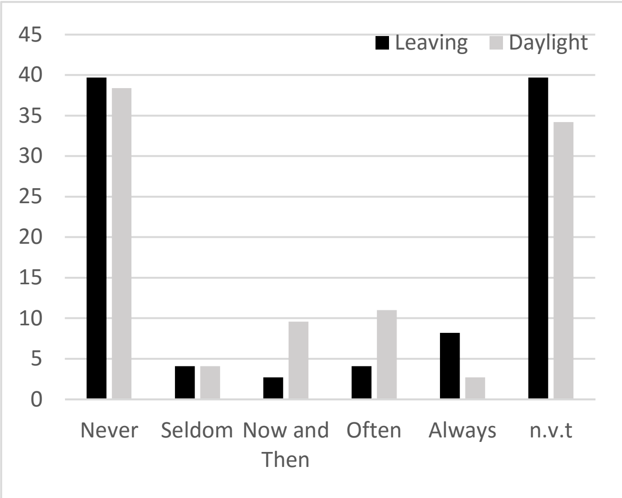

Figure 29 Switch off lighting when leaving the room or daylight is sufficient

Table 20 State of lighting during daily activities

Activity	Mode	Leaving [%]
Meeting	On	39,7
	Off	2,7
	n.v.t	57,5
Toilet	On	42,5
	Off	0
	n.v.t	57,5
Lunch	On	38,4
	Off	4,1
	n.v.t	57,5
Home	On	19,1
	Off	28,8
	n.v.t	51,4

<u>OCCUPANT INTERACTION</u> When in the office, occupants can also interact with others. To see if occupants make each other aware of the energy saving possibilities, questions were asked about their interactions. From looking at Figure 31 it can be concluded that the majority of respondents (56%) never talks about energy saving possibilities. Only 19% will do it so now and then and 4% of the respondents will always make others aware of energy saving possibilities.

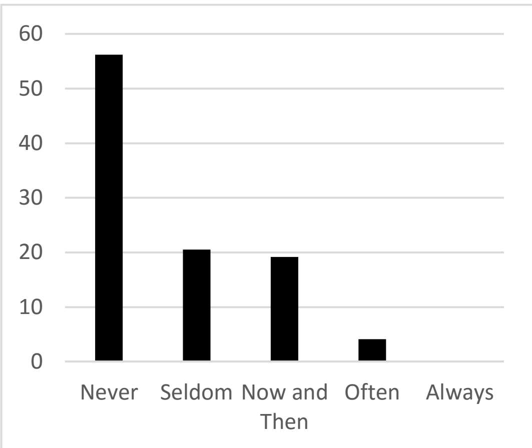

Figure 31 preference Frequency of occupant interaction

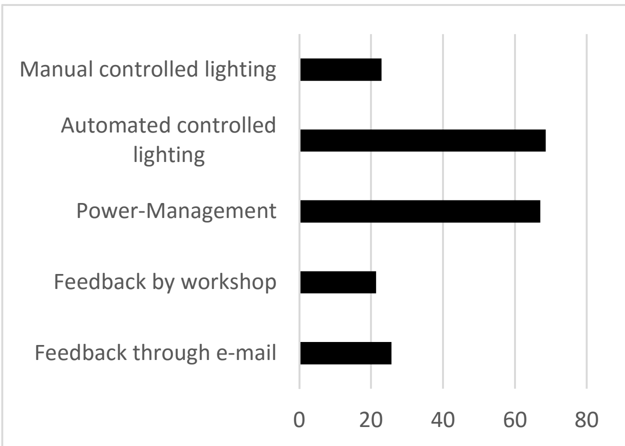

Figure 30 Antecedent interventions

5.1.4 Energy Saving Measurements

One of the goals of this research is to help organizations getting insight in designing energy efficient strategies, in particular those ones that are low cost and aimed to change occupants' behavior. Respondents had to point out what energy saving measures they would think would help the most in changing their routines towards the use of the building system. From Figure 30 it can be concluded that respondents think Power-Management (67%) and automated controlled lighting (69%) are the best ways to save energy. The two interventions have in common that they will not ask much change of respondents behavior, as computer and lighting are controlled automatically. However, some respondents are open to change their behavior.

When asking respondents about if they would interact with the building system differently when getting in touch with feedback interventions, changes in behavior are possible. As can be concluded from Figure 32, more than 50% of the respondents are more willingly to turn off their computer. The improvement for light behavior is a lot less, which can be explained that the control of lighting has not changed. The slight changes can be explained by respondents that do not share an office are more willingly to switch off lights or respondents that are more willingly to switch off the lights. These positive results can be used as a guideline for the parameter of presenting interventions to occupants.

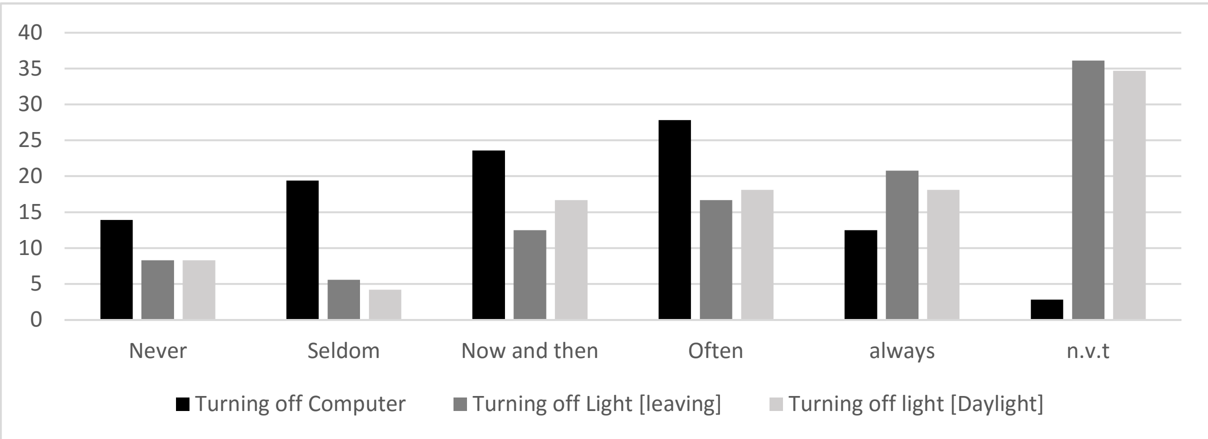

Figure 32 Use behavior of occupants after interventions

5.2. VALIDATION OF THE MODEL

The electricity consumption of the City Hall is measured at different places. However it is unclear for some of the meters what they measure, so they are combined into one large main consumption. Fortunately, the meter which is well known to what it is connected, is the meter that measures the ICT. Figure 33 shows the total electricity consumption of the City Hall during September 2014 to October 2015.

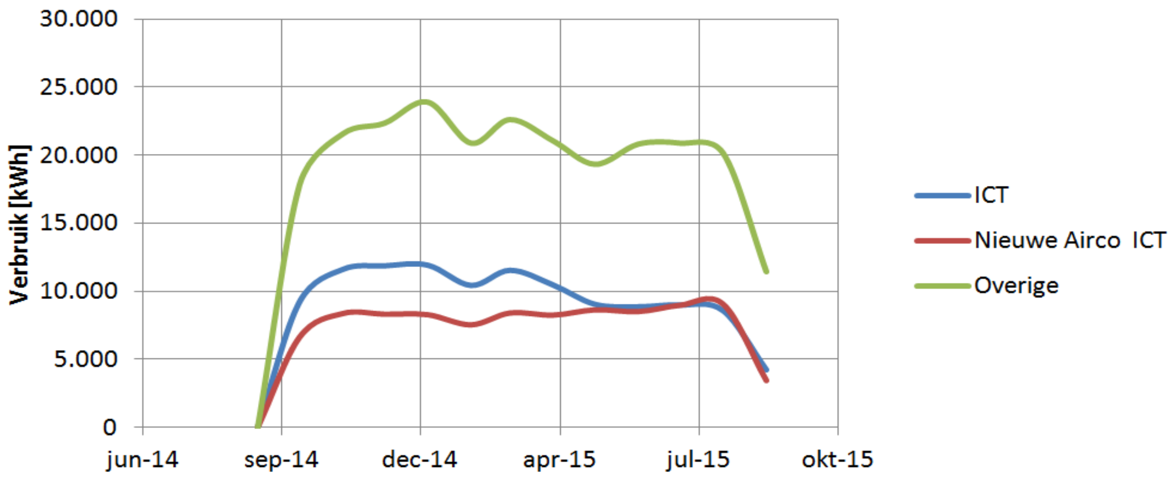

Figure 33 Total electricity consumption of City Hall from September to October 2015

These values themselves provide little insight into the efficiency of the building with regard to electricity consumption, so they are converted to [kWh/m2]. These are listed in Table 22. This makes for the City Hall an average electricity consumption of 45 kWh/year per m2. For ICT alone electricity consumption is an average of 22 kWh/year per m2. To test the validity of the model the outcome of the base scenario needs to be around this number.

As can be seen in Table 21 the kWh/year m2 for the base case scenario is 31% lower than that of the realistic case. This can be explained due to the fact that ICT meter, measures all the electrical appliances available in the building, with one great energy consumer the Data center. However if we compare the simulation results with other scientific studies, where office appliances and lighting combined account for 30 - 40% of total electricity consumption (Junnila, 2007), this is also the case with our simulation. If we compare ICT base case with the real data it is still 25% of the total electricity consumption, which I could argue that it will validate the model.

Table 21 City Hall electricity consumption converted to [kWh/m2]

	Other	ICT	ICT Base Case
Area [m²]	5408,42		
Month	[kWh/m²]	[kWh/m²]	
september-14	0,00	0,00	
oktober-14	3,30	1,71	1,17
november-14	3,99	2,15	1.48
december-14	4,14	2,20	1.47
januari-15	4,42	2,21	1.13
februari-15	3,87	1,93	1.19
maart-15	4,19	2,14	1.25
april-15	3,90	1,94	1.18
mei-15	3,58	1,68	1.17
juni-15	3,85	1,64	1.36
juli-15	3,87	1,67	1.25
augustus-15	3,73	1,59	1.15
september-15	2,12	0,78	1.20
Totaal	**44,96**	**21,64**	**15**

5.2.1.1 Individual computer electricity consumption

From the questionnaire conducted, we can assume that almost everybody held a computer. For the electricity consumption and efficiency potential of computers the variables that account most for the electricity use are used such as active mode electricity use, stand-by electricity-use, off mode electricity use, operation hours and power-management enabling rate. As an extended validation it might be a good thing to know if the electricity consumption of an individual occupant relates to the real world. From an case study done by Murtagh et al. (2013) it can be assumed that electricity used for an occupied work desk can range from 2.02 for a typical usage, to 5.1 kWh when a computer is fully used. These numbers count for a 40h working week. In Figure 34 the electricity consumption of four individual energy consumers is shown. Across all occupants for this baseline the mean electricity use is 4,67 kWh, two times the indicative comparison total of 2,02 but lower that the maximum consumption of 5.1 kWh even though the power used was the maximum of 75W. Other conclusion is that the difference between different energy profiles for computer is very small. This can be explained by the fact that computer is switched on whenever they are present at the work desk.

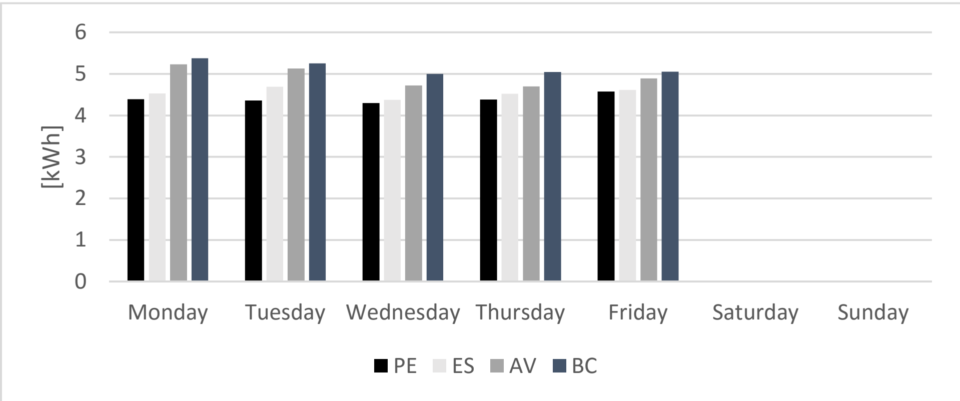

Figure 34 Weekly electricity of different energy consumers

5.3 SCENARIO ANALYSIS

This section discuss the scenario analysis that were performed to test the ABM to changes of the different parameters. While this thesis focus is on the influence of occupant behavior on electricity consumption, the focus of the scenarios on the role of occupants interaction by varying the parameters. With the NetLogo model, The energy efficient potential for the government is estimated by comparing the current electricity consumption of computers and lighting, the base scenario, to the developed energy efficient strategies. Table 22 presents the tested energy efficient actions. The upper part has all the different energy efficient measures listed that can be run in the model, all with a relationship with the use of occupants. The second part shows the types of scenarios ran by the model. For this research, two different simulations can be distinguishedl: (1) Cost Effective and (2) Financial Investment. The outcomes of the simulations will help to design energy efficient strategies for the City Hall and help the City Hall to gain insights about the electricity consumption behavior of occupants in the building. It should be noted that changing the type of light is not a cost effective way of reducing the electricity consumption, but is fairly known as a big energy saving incentives. Therefor it will be used to compare the cost effective incentives with.

Table 22 Simulation Scenarios

Energy Efficient Strategies	Actions	Adjustable variable setting	Description
Computer incentive	A1	Power Management length: 10 minutes	What happens if power management is installed on all computers
	A2	Power Management length: 15 minutes	
Behavioral incentive	B1	Direct Feedback Frequency: 1 day	What happens if occupants receive an email about electricity saving
	B3	Direct Feedback Frequency: 3 day	
Light Incentives	C1	Light Control: Automated	What happens if the light is controlled by light sensors
	C2	Light Control: Manual	
	D1	Light Type: Task-Light	What happens if overhead light is changed to LED task lights.
	D2	Light Type: LED	What happens if overhead lights are replaced with LED lights

	Occupants influence	Type
Cost Effective	Behavioral change	Direct Feedback
	Non Behavioral	Power-Management
Financial Investment	Behavioral change	Automated vs Conrol Task-Light
	Non behavioral	TL vs LED

5.4 Cost Effective Scenario

5.4.1 Behavioral Change: Direct Feedback

After validating the model with real time electricity consumption rates, the next step is to simulate the occupants' interaction with the behavior measures. It is important to motivate occupants to engage in energy saving actions. When it comes to changing behavior in an organization, it is important to refer to collective rather than individual interests. A study conducted by Abrahmse (2007) reveals that providing feedback about the achieved saving rate is very effective, and appeared to be more effective when such feedback was given more frequent and related to a specific goal. Feedback could increase awareness of occupants' own behavior and its consequences (Lo, et al., 2012). Therefor the first parameter that was varied was the occurrence of energy efficient incentives that will influence the use behavior of occupants. The obtained change in electricity consumption behavior of occupants is shown in Figure 35 for the once a week feedback and Figure 36 illustrates the three times a week feedback.

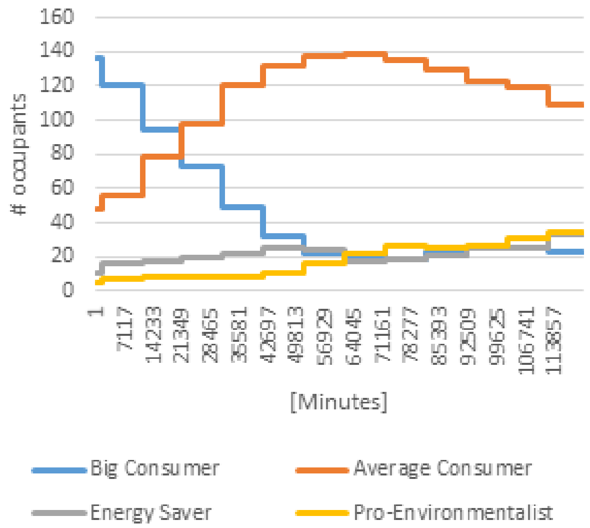

Figure 36 Direct feedback with frequency of once a week

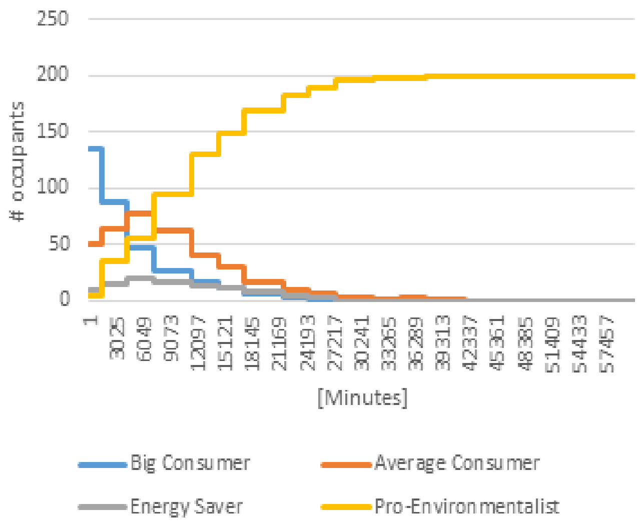

Figure 35 Direct feedback with frequency of three times a week

At the start of the simulation 69% of the occupants were assumed to be BC, 23% Average Consumer, 6% an Energy Saver and 2% an Pro Environmentalist. The occupants were also assumed to read the email once a week or for the other scenario three times a week, encouraging them to reduce their energy consumption and adopt energy saving practices. The efficiency is set at 0,05 which means that after reading all occupants raise their awareness with 0,05 and expected to reduce their energy consumption.

When they only get to see once a week the incentive it is noticeable that after 3 months only 17,5% of all occupants have adopted the most energy conscious behavior as shown in Figure 35. When looking at the accompanied electricity consumption in Table 23, there is a slight decrease of 7% in week 3 this is at that point when more occupants are starting to adopting the most energy conscious behaviors. Although only 17,5% has adopted tot PE, the total electricity consumption decrease over a period of three months is around 13%.

Table 23 Electricity consumption per week when occupant adopt new behaviors

	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	Week 9	Week10	Week 11	Week 12
Computer	5681	5674	5482	5663	5569	563	5705	5663	5649	5565	5607	5583
Lights	1052	887	591	567	437	388	456	470	546	489	441	233
Communal-Lights	554	580	580	563	610	575	581	590	564	567	596	590
Total	7287	7141	6653	6793	6616	6599	6742	6723	6759	6621	6644	6406

As shown in Figure 36, as the simulation time advanced, Occupants are successfully adopting new behaviors until all occupants become an Pro Environmentalist. The change was mainly enhanced at the first week when the third email was sent out, increasing the Pro-Environmentalist from 55 to 95. The same is the case for the second week. After the first email was sent out the Pro-Environmentalist increased from 97 to 130. After that it stagnates a bit, Finally, around the 3.5 week all occupants changed their behavior to Pro-Environmentalist.

By applying these changes on the electricity consumption with an feedback incentive of three times a week, Figure 37 shows where changes in the total electricity consumption over one year study period. It is noticeable that there is a significant drop of 22% in the total electricity consumption. This was expected because the number of Pro Environmentalist was increased over time as the other three energy consumers were converted. By having more Pro Environmentalist in the building, less electricity would be consumed. More occupants get more aware of their usage and their probability to switch appliances of grows.

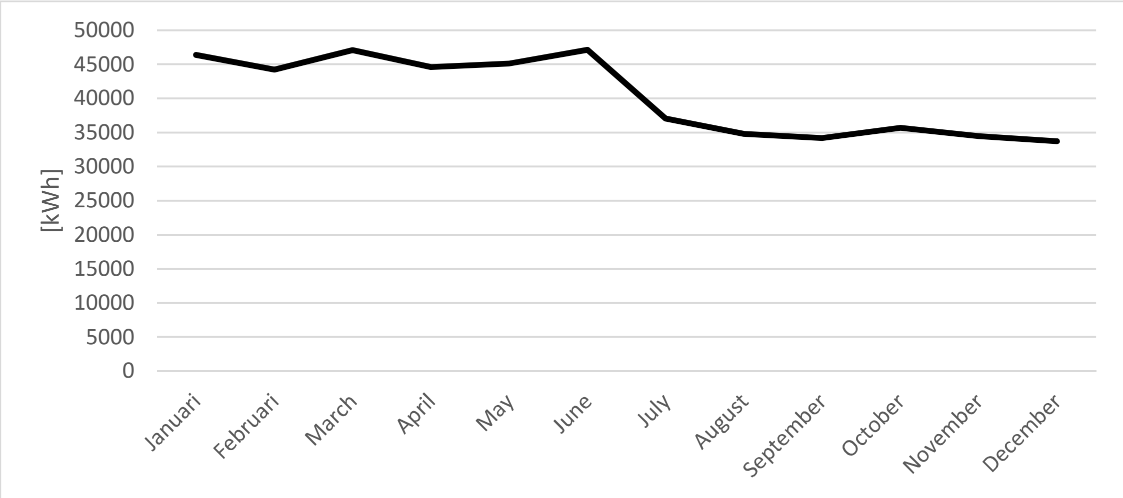

Figure 37 Electricity consumption before and after introduction of Feedback intervention.

The next figure (Figure 38) shows an example that shows the influence of occupant behavior is even more important for predicting electricity use. Two different simulation ran to compare with the base case scenario over a period of three months. The initial conditions for the scenarios are the same as the base scenario except that for one scenario all occupants are Pro environmentalists and one scenario all occupants are big consumers. All other parameters are the same as for the base scenario.

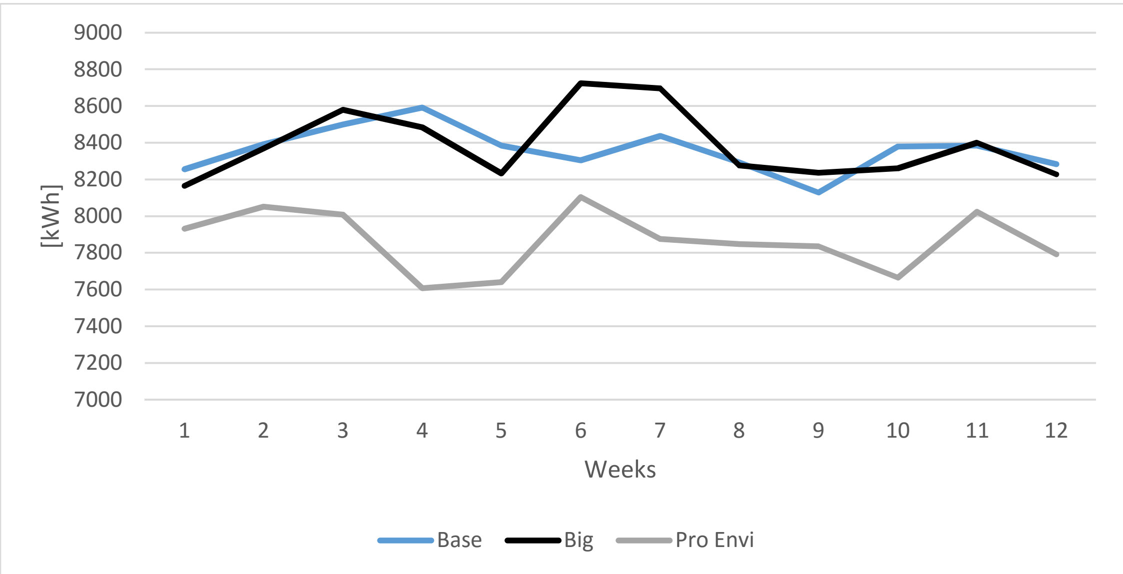

Figure 38 impact of behavior of occupants on electricity consumption

The results shows that when all occupants are Pro Environmentalist electricity consumption successfully is reduced. A reduction over a period of 12 weeks is achieved of 6%. When all occupants are Big Consumers the electricity consumption only increases by 1%. This can be explained by the fact that the base scenario energy profiles almost 69% are already Big Consumers.

5.4.2 Non-behavioral change: Power Management

As can be seen in Figure 39 Power management will have a positive effect on the electricity consumption of occupants. On average the electricity consumption is 15% lower when Power management will set in after 15 minutes. When Power management sets in after 10 minutes the electricity savings is even bigger towards 19%. This can be explained at the fact that most of the occupants does not care about energy saving.

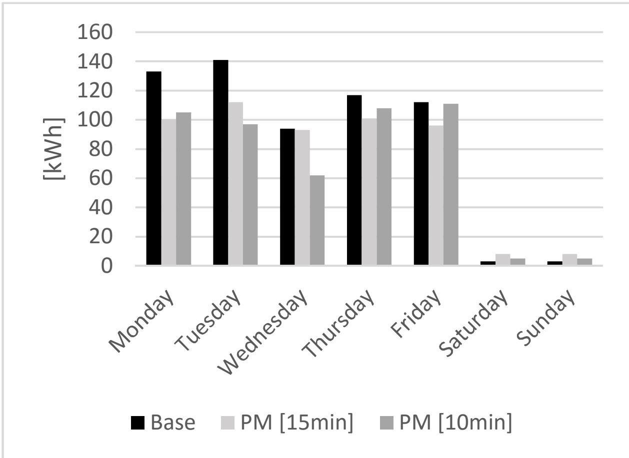

Figure 39 Influence of Power Management

5.5 Financial Investment scenario

5.5.1 Automated compared to manual controlled lighting

Automated and manual lighting have each their advantages in office buildings. Although with manual electricity management the least electricity is consumed, some studies will argue that under manual switching lights were often switched on when enough daylight was entering the room and rarely switched off, regardless of the illumination provided by the daylight. Bourgeois et al. [18] show that under automated lighting control the electricity consumption is much less than that in automated lighting management. However within the City Hall there are occupants that argue that most of the lighting especially in hallways are unnecessary on, due to enough daylight stated from the survey taken. It should be noted that for the City Hall argues that light is automatically switched on when the building opens and is switched off at the end of the day at 19:30 with a good chance everybody was already at home. Therefor for this scenario automated and task-light control are simulated to compare with the base scenario, to see if arguments are true. The reasoning behind the two scenarios is as follows: in the automated lighting control, lights in an office are off 5 min after the last occupying electricity user agent'

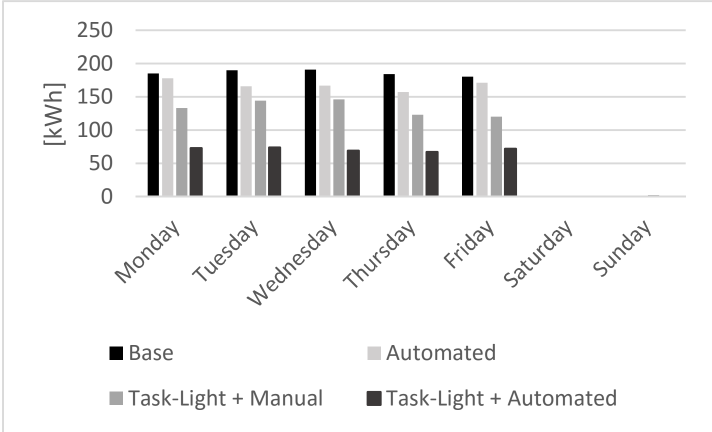

Figure 40 Comparison of light scenarios

leave, while with the manual-controlled lighting, lights in an office are switched off by the last occupant based on their energy profile and a probability. This scenario is also simulated but with the use of Task Lights, the most cost expensive scenario, due to the fact that new appliances have to bought for all work desks. However each occupant, also in the communal spaces can control the light according to their energy awareness. The comparison of the simulations results of the three scenarios are shown in Figure 40 and compared against the base case scenario.

As can be seen is that every energy efficient incentive will save energy. However what is stated earlier on does not count for this model. Automated light control has an electricity saving potential of 10% whereas manual control of the light system combined with task light will give an electricity saving of 29%. This is a strange outcome as most of occupants (70%) are not energy saving conscious and will switch the lights on no matter how well lit the room is. What is even more strange is the fact that when the task light incentive comes into play, combined with automated control of the rest of the building light system, has the most electricity saving potential of 69%. This makes me argue about the role of overhead light in the model. Due to the fact that precise data of the amount of lamps in every room, an estimation formula had to be used. This could explain the strange occurrence.

5.6 DISCUSSION

The scope of the study was limited to occupants' possibilities for energy conservation. It is highly probable that similar or better energy saving measures could be found in other areas of energy management, such as by adjusting the operating hours of HVAC. However, based on the results, it seems that energy efficient measures aimed at changing occupant behavior (involving users in energy conservation by giving them feedback or using automation to take behavior out of the equation) could offer a new opportunity for improving the energy efficiency of office buildings.

Especially, the energy conservation actions involving no investments, such as providing feedback through e-mail or enabling the power management options of electrical appliances, could be highly feasible in the competitive company environment. Although there are some important implications. Modeling occupants with different energy profiles can significantly affect total electricity predictions. The electricity consumption differences are high in case where occupants have control over (22% when feedback) and almost the same when they do not have to change the behavior (PM 15-19%). This argues if organizations have to take the effort to invest in changing behavior, while this is an long process as can be seen when feedback is only send out once a week.

Routines cannot be easily be changed Behavior of individuals is unpredictable with many factor to take into consideration. For example Increasing building efficiency through energy saving initiatives does not mean the energy consumption will be reduced, as it always causes some kind of rebound effect. Rebound effect refers to the negative behavioural responses to energy saving initiatives that may offset the beneficial effect, causing energy demand to increase instead of decline (Geijer, 2014) for example switching of the lighting less often when leaving a room, since LED since LED lighting uses less energy.

On this note, The simulation method used, especially for lights, only give an estimation of the "best case" type of situation for all tested scenarios, in which it is assumed that all the end-users would start to behave according to the scenario In practice, all individuals can hardly ever accomplish such a best case behavior. Fourthly, it seems that the relatively similar results in some of the cases are due to the quality of source data used for calculations. For example, no exact data was available for the amount of light fittings present in the building thus, industry average data based had to be used.

For the use of electrical appliances, many devices capable of PM nonetheless do not successfully enter low power modes. Computer PM is subject to the complex combined effects of operating systems, application software, hardware and networks. Certain operating systems (e.g., Windows NT) effectively prevent PM from functioning. Background network activity may keep computers awake. If computers do succeed in entering low power mode, they may fail to respond to important network activity, which may lead to PM being disabled. (Webber, et al., 2006)

5 CONCLUSION

This chapter presents the conclusion and recommendation of the findings and results of the research. Through literature reviews, developing a NetLogo model and run simulations, knowledge has been gained on the influence of occupant behavior on electricity consumption and the potential of cost-effective energy saving policies. All this is addressed to the specific research questions, and with the findings answer the main research question.

First the conclusion on the main research question is given. Answering this question gives more insight in the problem statement and recommendations on future research can be formulated.

6.1 CONCLUSION

The final result of this thesis for simulating occupant behavior influence on building performance, is based on the City Hall of Heerlen. This all to eventually give answer to the main question:

In what extent is it possible to design a simulation model for predicting energy use behavior of individual occupants? and will implementing cost-effective energy saving measures help reducing electricity consumption of office buildings?

The main question is divided into two parts (1) the value of the simulation model, and (2) the outcome of the model, which will be both answered separately

6.1.1 Value of the simulation model

In what extent is it possible to design a simulation model for predicting energy use behavior of individual occupants

Energy simulation programs are failing to implement and predict energy consumption of buildings (Hoes, et al., 2009; Clevenger & Haymaker, 2006). Implementing occupants in a static way or underestimating the influence occupant have on the actual energy consumption is the main reason why this is happening. Therefor this thesis presented a ABM approach to estimate the occupant behavior in a dynamic way. And to answer the main question, it is indeed possible to develop a model that simulates the behavior in office buildings. A well-functioning NetLogo model is provided using the agent based modeling approach. It provides insight in the decisions individual occupants with their own characteristics, work schedules, and energy profiles make when interacting with user related electricity sources: light and computer.

Potential energy savings and CO2 reduction depends on the occupants' behavior and adoption rate of energy efficient measurements. By using BDI approach to design the human decision process, the model is possible adapt the behavior according the environment, but it should be noted that, despite the variables defining the decision process is based on literature and survey results, still most are subjective. The modeling of the dynamic presence sets this approach apart from others. Where current energy models consider strict schedules, that are similar to operating hours of the building, with no absence from the desk, this developed model made assumption on the duration of absence for each activity. The dynamic schedules are different each day the occupant enters the building. Modeling different types of energy profiles for occupants can significantly influence total electricity predictions

More important, users of the model have the possibility to define the variables in their own insights. This makes this model useful to be implemented for most of office buildings, due to the simplistic layout which covers the characteristics of the buildings. The model can be used to implement in existing energy simulation programs to get better and more reliable energy consumption predictions.

Although it is not possible to perfectly translate occupant behavior into a model., agent based modeling is a good approach to answer energy related problems and model occupant behavior. The model has many applications and is easy to extend to different purposes.

6.1.2 Outcome of the simulation model

Will implementing cost-effective energy saving measures help reducing electricity consumption of office buildings?

Energy saving measures can be implemented to measure the impact on the behavior of occupants and what the intensity is of the change. results from energy efficient incentives showing changes in behavior and also reduction in electricity consumption, they are often neglected by energy managers as technical incentives have a far better result, but also cost much more. As can be concluded from the light change scenario. Therefor the main question is extended with a second question.

In this report three energy efficient measures that influence the occupant behavior are implemented. Feedback, Power-Management, Automated Lights are compared on their saving in electricity use. Because of the assumptions made for the influence of the variables, an advice is given based on the case study and conditions used in the ABM of this report.

The simulation results showed that occupant behavior has significant impact on the electricity use of office buildings. Electricity consumptions differences are high in the case where occupants control the building system and less when building system is controlled automatically. Feedback is a measure that is assumed to result in relevant energy savings. Sharing information about electricity use and how to be more efficient is in particular important when no financial incentives for the occupants are available such as office buildings. From simulations results it can be concluded that it is also a good alternative to save energy. When occupants get to see feedback once a week it takes much longer whereas after three months only 17,% of the occupants use appliances as efficient as possible. This leads to a reduce in electricity consumption of around 7%. For the ideal situation, 22% of total electricity consumption can be reduced when occupants received an e-mail three times a week. It takes approximately 3.5 weeks to converge the last occupant into a Pro Environmentalist. And Although the results showing the conversion of occupants behavior to Pro Environmentalists resulting in less electricity use might seem obvious, most building energy simulation tools do not model these types of interactions. The benefit of this measure is that besides financial investment, which is none, the investment to set it out and occupants to read it is also minim.

With Power-Management the change in behavior of occupants is almost to none. Electrical appliances will go in stand-by after a period of non-use. For occupants it will have no direct effect on their behavior, but will help big consumers to put the computer in stand-by as they are not willing to do this when in long absence. Compared to the base case Power-Management will lead to a reduction of 15-19% when simulation was run. For computers this is maybe not interesting, but when looking at other electrical appliances that have long periods of none-use could save lot of unnecessary electricity consumption. This is the case for printers, copiers and coffee machines for instance.

When automated lighting is compared with manual lighting use it can be concluded that Automated light control has an electricity saving potential of 10% whereas manual control of the light system combined with task light will give an electricity saving of 29%. However due to the fact that precise data of the amount of lamps in every room, an estimation formula had to be used, the outcome of these results are not very trustworthy. Compared to literature Bourgeois, et al. (2006) got a 40% difference between occupants who rely on artificial lights compared to occupants who rather make use of artificial lighting, our predictions are off and better assumption need to be made on the light characteristics.

This model could be used as a decision-making tool that evaluate different behavioral changing strategies in the form of feedback, workshops, financial incentives, power-management, etc.) and helps energy managers make more informed decisions about investing in strategies to effectively reduce energy use. Occupant related energy saving incentives is that the competence gained is linked to the organization and not to the building itself. Even if the end-user moves to new premises, the improved performance in energy management stays with the organization.

7 FURTHER RESEARCH

The agent based model of occupant behavior impact on the electricity consumption of office buildings has potential for further development. The focus is on energy caused directly by occupants' work activities which influence the energy consumption most namely computer use and lighting use. The model can easily be expended with other major behavioral interactions such as using blinds, opening windows, clothing adjustment, water use, use of the door, but also the use of other electrical appliances which are used by more than one person at a time. Implementing more behaviors make the model more complex and give occupants more opportunities to achieve their desired comfort level.

Now only single behavior is used. But usually, for the same action, occupants have multiple opportunities and behaviors to achieve the same goal. For instance, to change the illuminance level of at the work desk, occupants can use the lighting switch or control the blinds. Sometimes more behaviors are needed simultaneously to achieve the desired comfort, mostly thermal based, or interfere with each other. To make this possible with the model an additional layer needs to address how to combine different behaviors together. This also means that the dataset is also greater, since observation is needed of how each action is taken with respect to other.

Therefor In the future, further analysis of actual energy consumption of electrical appliances and lights through monitoring would be needed in order to have an access to more accurate consumption data. To validate the working of the model, real time data of the whole building is used, but is not accurate enough to exactly capture the electricity consumption per individual behavior. More precise monitoring with the use of plug load sensors and observation help to capture the precise electricity consumption belonging to individual actions occupants take. It will also help to make better estimation on building characteristics which also influence occupant behavior, especially when heating is implanted in the model. Surveys are used to get more insight in the reasoning behind actions taken by occupants. However the value of surveys amongst occupants is not immediately apparent upon the availability of a rich dataset obtained from sensors. There are some fundamental issues including (1) participants knowingly or unknowingly misrepresent their behavior (2) participants may not recall their behavior and the severity of discomfort, and (3) participants may respond the way they think they are expected to. This could be resolved by frequently set out the surveys in which occupants are frequently asked to report their comfort and corresponding behaviors.

Furthermore, occupants in the building now act on their own, without interaction with other occupants. This is also called peer-to-peer where occupants with different energy profile influencing other occupants that share the same building to potential change the electricity consumption behavior. This type of interaction can be very effective in convincing occupants to change their behavior and reduce electricity consumption (Carrico & Riemer, 2011). Adding more psychological factors into the model to study occupants satisfaction and comfort. This type of simulation models has the potential to be developed as an extension for building energy simulations tools which provide organizations with organizational energy policy making advice.

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7 APPENDIX

APPENDIX 1 – POLICY AND AMBITION

Energy saving initiatives is an important means to achieve the climate goals and saving costs. Especially in times of economic crisis and limited budgets. The government will emphatically call on municipalities, market leaders and consumer organizations to contribute and work together to bring energy policies into effect. Their strategy is based on the Trias Energetica (Figure 41) where reducing CO2 emission by reducing the demand for energy is the first and crucial part of this strategy. It can help to reach energy neutral buildings and a sustainable environment (Pérez-Lombard, et al., 2008).

Figure 41 Trias Energetica

With the '*Meerjarenafspraken*' energy-efficiency (MJA), companies and organizations have committed themselves to deliver an effort to improve energy efficiency by 2% per year compared to 2005. The emphasis is on energy conservation and efficiency improvements as primary objective, with the reduction of CO_2 emissions as a derivative effect. Having a full energy management system is a mandatory part of the MJA3 (Agentschap NL, 2011).

Besides MJA 3 there are other policies which more or less acts directly on improving energy efficiency and energy conservation, such as the '*Energie Investeringsaftrek'* (EIA) and the '*Wet Milieubeheer'* (Wm) (ECORYS, 2013)

- The EIA provides deduction of taxable profit or income in order to decrease the cost of energy efficient assets.
- The '*Wet Milieubeheer'* requires that companies are obligated to take responsibility regarding the use of energy. This means basically the obligation to do profitable investments in energy savings with a roughly payback period of 5 years or less.

1.1 Parkstad Limburg

With the agreements made, the government aims to get the necessary energy transition is happening. However this transition to a sustainable environment could only have a chance of succeeding if its given concrete form at regional level. To contribute to the reduction of CO2 emission and becoming an energy neutral region, Parkstad Limburg created the ´*Parkstad Limburg Energietransitie (PALET)'* to state their ambition for 2040 (Parkstad Limburg, 2013):

"In 2040, Parkstad Limburg is energy neutral. This is achieved by reducing our energy consumption with a third and the remaining two third will be generated out of renewable energy sources in the region."

Within this report, Parkstad Limburg focus on the use of renewable energy sources, electric vehicles and, renovating the built environment. Each of these measures has the potential to contribute to the ambition. For this research the implementation of energy efficient measures in the built environment is interesting and already feasible in the short term. The built environment, is responsible for 63% of the total energy consumption in the region, where 25% is consumed by the commercial sector, illustrated in Figure 42 (Parkstad Limburg, 2013). In the residential sector has Energy Label E on average, the commercial sector Energy Label G, thus a lot of improvement is possible. These improvements are, in particular, aimed at reducing the demand for space heating, by improving building characteristics. Saving on electricity asks, not so much technical measures, but more importantly behavioral changes of occupants and investment in renewable energy sources.

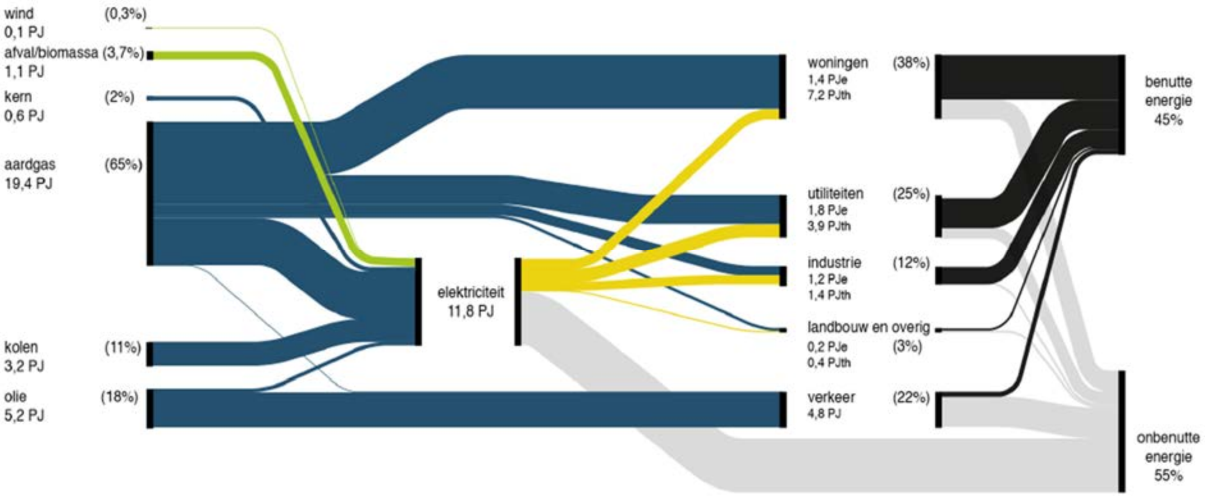
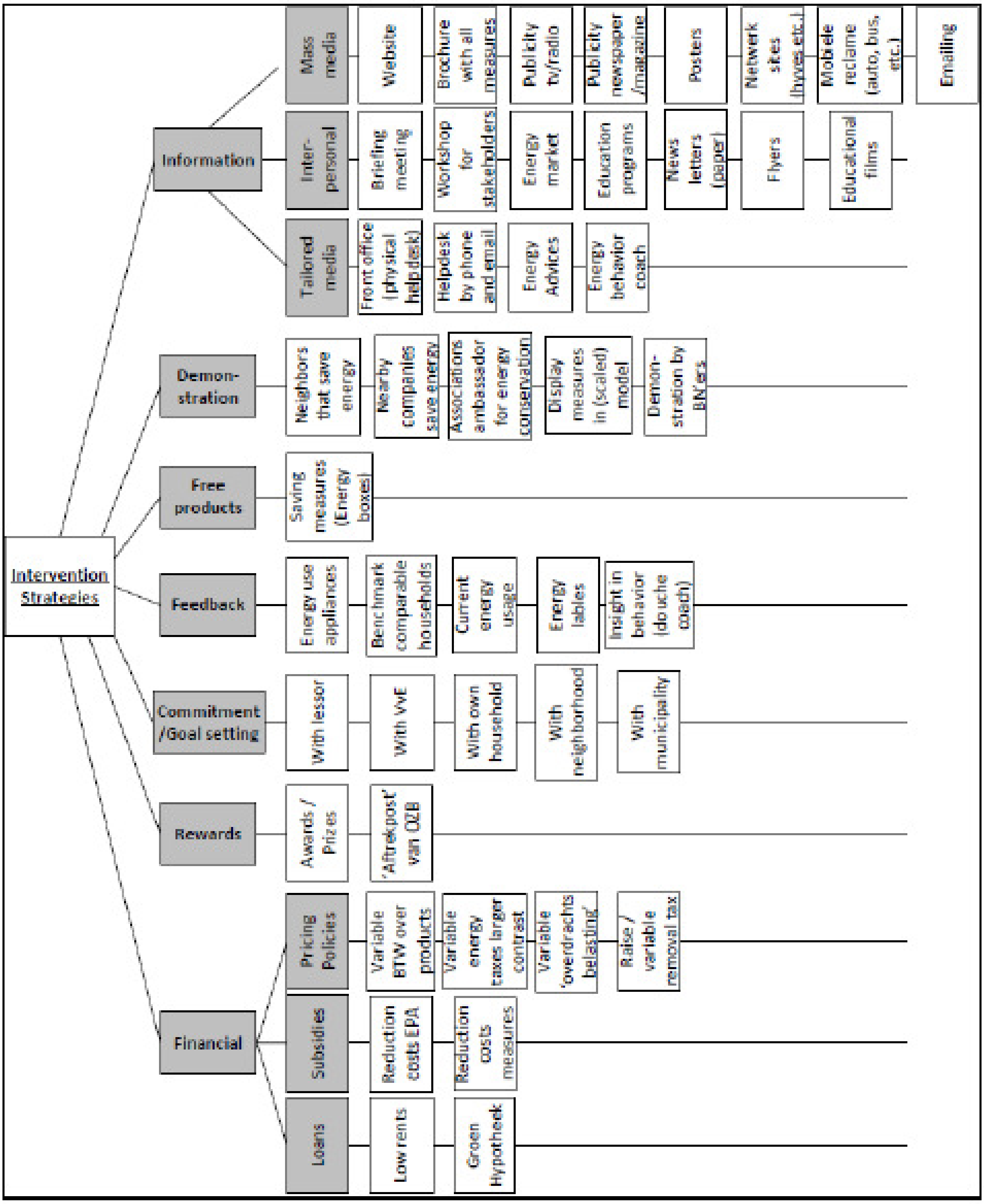


Figure 42 2011 energy mix Parkstad Limburg (29,6PJ) *Source: (Parkstad Limburg, 2013)*

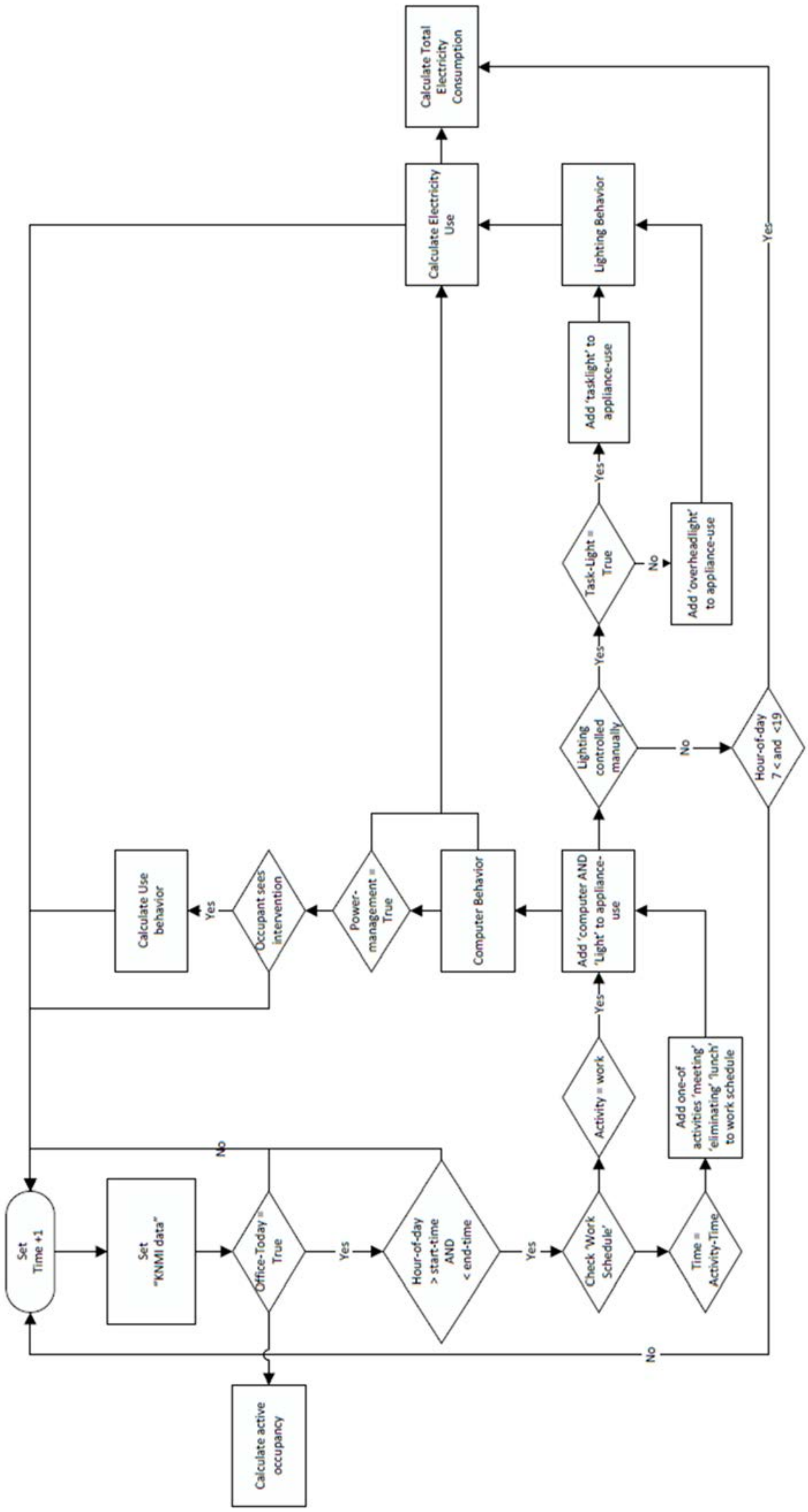
APPENDIX 2 - INTERVENTION STRATEGIES

Intervention strategies adopted from Han et al. (2013)



APPENDIX 3 - FLOWCHART

The flowchart describes the workings of the NetLogo model. It follows the steps the model takes to calculate the electricity consumption every tick (one tick = 1 minute).



APPENDIX 4 – NETLOGO CODING

In this appendix the coding of the NetLogo model is described, which is used for the case study of City Hall of Heerlen. The model executes a range of codes, which simulates the behavior of occupants and the optimization. The code is build up in three parts: (1) model variables (2) setup procedure (3) go procedure and (4) calculation electricity use.

4.1 Model Variables

```
extensions [csv ]

breed [dwellings dwelling]
breed [occupants occupant]
breed [lights light]
breed [communal-lights communal-light]
breed [Locations location]


globals [

;; LOCATION ;;
  privateLocation sharedLocation cafeteria meetinglocation restrooms hallway
  hallway-lights restroom-lights cafeteria-lights meetingroom-lights shared-lights

;; TIME ;;
  minute hour-of-day dayName day days day-of-week week month time

;; LOOKUP ;;
  comfortLux time-light-discomfort Daylight-factor
]

Locations-own [ roomID daylight-schedule schedule-next office-daylight]

occupants-own [
  gender energy-profile

  time-table start-time end-time
  office-today

  occroomID office-area at-work workschedule activity-time
  current-location time-since-here

  activity activity-duration

  current-perception
  office-daylightlux office-overheadlightLux tasklightlux  lightdiscomfort
  time-without-computer

  appliance-use computer-state light-state task-light-state
  electricity-use-computer electricity-use-plights total-electricity-use

  pm feedback

  energy-awareness new-energy-awareness
  switch-probability

]

communal-lights-own [ state electricity-use-lights total-communal-light-electricity ]
```

4.2 Setup Procedure

```
to setup
  clear-all

  setup-occupants
  display-patches
  display-locations

  set-default-shape occupants "person business"
  set-default-shape locations "circle"
  set-default-shape dwellings "house"
  set-default-shape communal-lights "lightning"

  if lightSim = true [
     add-shared-lights
     set comfortLux [250 500]
     set Daylight-factor 0.05

     ask locations with [ ((pxcor = -18) AND (pycor = -5)) ] [
         set daylight-schedule [ ]
         import-daylight-data
         set schedule-next 0
         ]
  ]

  set days [ "monday" "tuesday" "wednesday" "thursday" "friday" "saturday"  "sunday"]
  reset-ticks
end

to import-daylight-data
  file-open "weather.txt"
  set daylight-schedule file-read
  if file-at-end? [file-close]
end

to setup-occupants
  create-occupants number-of-occupants [
      setxy -5 27
      set size 5
      set current-location "home"
      set activity ""
      set workschedule [ ]
      set computer-state "Off"
      set light-state "Off"
      set task-light-state "Off"
      set current-perception [ ]
      set feedback false
      set at-work false
      set appliance-use [ ]
      set time-without-computer 0

;; GENDER ;;
      let p3 random 100
      ifelse p3 >= 0 AND p3 <= male-occupant-% [ set gender "male"   ]
                                                [ set gender "female" ]

;; WORKDESK ;;
      let p4 random 100
      ifelse p4 >= 0 AND p4 <= private-workdesk-% [ set occRoomID "private"
                                                     set office-area 18 + random 19 ]
                                                   [ set occRoomID "shared"   ]

;; SET PERCENTAGE OF OCCUPANTS ARRIVING AT THE OFFICE BUILDING AND WHEN THEY LEAVE THE OFFICE BUILDING ;;
      let p random 100
      ifelse p >= 0 AND p <= flex-worker-% [ set time-table "flex"   ]
                                           [ set time-table "strict" ]
```

```
;;SET PERCENTAGE OF OCCUPANTS ENERGY CONSUMPTION BEHAVIOR ;;
      let p2 random 100
      let ep1 pro-environmentalist-%
      let ep2 (ep1 + energy-saver-%)
      let ep3 (ep2 + average-consumer-%)
      let ep4 (ep3 + big-consumer-%)

      if p2 >= 0 AND p2 <= ep1 [
         set Energy-profile "Pro-Environmentalist"
         set color green
         set Energy-awareness 0.81 + precision (random-float 0.19) 2
         set lightdiscomfort 30 + random 15
      ]

      if p2 > ep1 AND p2 <= ep2 [
         set Energy-profile "Energy-Saver"
         set color yellow
         set Energy-awareness 0.61 +  precision (random-float 0.19) 2
         set lightdiscomfort 15 + random 15
      ]

      if p2 > ep2 AND p2 <= ep3 [
         set Energy-profile "Average-Consumer"
         set color orange
         set Energy-awareness 0.21 + precision (random-float 0.39) 2
         set lightdiscomfort 5 + random 10
      ]

      if p2 > ep3 AND p2 <= ep4 [
         set Energy-profile "Big-Consumer"
         set color red
         set Energy-awareness 0 + precision (random-float 0.2) 2
         set lightdiscomfort 0 + random 5
      ]

;; POWERMANAGEMENT ;;
     let p6 random 100
     ifelse p6 >= 0 AND p6 <= power-management-% AND power-management [ set PM true  ]
                                                                      [ set PM false ]

     type gender type " " type occRoomID type " " type time-table type " " type Energy-Profile type " " type Energy-Awareness type " " print PM
    ]

  print (word (count occupants) "occupants data is populated")
end
```

4.2.1 Patches

```
to display-patches
  ask patches [ set pcolor 8 ]

  ask patches with [ (pycor >= -29) AND (pycor <= -1) AND (pxcor >= -29) AND (pxcor <= -8)]  [set pcolor blue]      ;;private
  ask patches with [ (pycor >= -33) AND (pycor <= -1) AND (pxcor >= 8) AND (pxcor <= 29)]    [set pcolor blue + 1]  ;;shared
  ask patches with [ (pycor >= -49) AND (pycor <= -31) AND (pxcor >= -29) AND (pxcor <= -8)] [set pcolor blue + 2]  ;;cafeteria
  ask patches with [ (pycor >= -49) AND (pycor <= -41) AND (pxcor >= -6) AND (pxcor <= 6)]   [set pcolor blue + 3]  ;;restroom
  ask patches with [ (pycor >= -49) AND (pycor <= -35) AND (pxcor >= 8) AND (pxcor <= 29)]   [set pcolor blue + 4]  ;;meetingroom
  ask patches with [ (pycor >= -39) AND (pycor <= -1) AND (pxcor >= -6) AND (pxcor <= 6)]    [set pcolor grey + 4]  ;;hallway

  ask patches with [ ((pycor = -50) AND (pxcor > -30) AND (pxcor <= 30))  OR
                     ((pycor = 0) AND (pxcor >= -30) AND (pxcor <= -3))   OR
                     ((pycor = 0) AND (pxcor >= 3) AND (pxcor <= 30))     OR
                     ((pycor >= -50) AND (pycor <= 0) AND (pxcor = -30))  OR
                     ((pycor > -50) AND (pycor < 0) AND (pxcor = 30))     OR
                     ((pycor = -30) AND (pxcor >= -29) AND (pxcor <= -7)) OR
                     ((pycor = -34) AND (pxcor >= 7) AND (pxcor <= 29))   OR
                     ((pycor > -24) AND (pycor < 0) AND (pxcor = -7))     OR
                     ((pycor > -28) AND (pycor < 0) AND (pxcor = 7))      OR
                     ((pycor > -35) AND (pycor < -29) AND (pxcor = -7))   OR
                     ((pycor = -40) AND (pxcor >= -6) AND (pxcor <= -3))  OR
                     ((pycor = -40) AND (pxcor >= 3) AND (pxcor <= 6))    OR
                     ((pycor >= -49) AND (pycor <= -40) AND (pxcor = -7)) OR
                     ((pycor > -22) AND (pycor < 0) AND (pxcor = -7))     OR
                     ((pycor >= -49) AND (pycor <= -40) AND (pxcor = 7))  ] [set pcolor black]
end
```

```
to display-locations
  set PrivateLocation patch -18 -5
  ask PrivateLocation [
      sprout-locations 1 [ set color black
                           set size 2
                           set roomID "private"

  ]]
  set sharedLocation patch 18 -5
  ask sharedLocation [
      sprout-locations 1 [ set color black
                           set size 2
                           set roomID "shared"
  ]]

  set cafeteria patch -18 -35
  ask cafeteria [
      sprout-locations 1 [ set color black
                           set size 2
                           set roomID 3
  ]]

  set restRooms patch 0 -45
  ask restRooms [
      sprout-locations 1 [ set color black
                           set size 2
                           set roomID 4

  ]]

  set meetingLocation patch 18 -39
  ask meetingLocation [
      sprout-locations 1 [ set color black
                           set size 2
                           set roomID 5
  ]]

  set hallway patch 0 -5
  ask hallway [
      sprout-locations 1 [ set color black
                           set size 2
                           set roomID 6
  ]]

  ask patches with [(pxcor = 0 and pycor = 30)][
      sprout-dwellings 1 [ set color yellow + 2
                           set size 8
  ]]
end
```

```
to add-shared-lights
  set shared-lights patch 28 -3
  ask shared-lights [
      sprout-communal-lights 1 [ set color black
                                 set size 5
                                 set state ""
                                 set electricity-use-lights 0
  ]]

  set hallway-lights patch 0 -18
  ask hallway-lights [
      sprout-communal-lights 1 [ set color black
                                 set size 5
                                 set state ""
                                 set electricity-use-lights 0
  ]]

  set cafeteria-lights patch -28 -33
  ask cafeteria-lights [
      sprout-communal-lights 1 [ set color black
                                 set size 5
                                 set state ""
                                 set electricity-use-lights 0
  ]]
  set meetingroom-lights patch 28 -37
  ask meetingroom-lights [
      sprout-communal-lights 1 [ set color black
                                 set size 5
                                 set state ""
                                 set electricity-use-lights 0
  ]]

  set restroom-lights patch 5 -43
  ask restroom-lights [
      sprout-communal-lights 1 [ set color black
                                 set size 5
                                 set state ""
                                 set electricity-use-lights 0

  ]]
end
```

4.3 Go Procedure

```
to go
  if ticks >= (weeks-to-run * (7 * 1440)) [stop]
  if time = 0 [ start-day ]
  if time = 1335 [update-day]

  ask locations [
      set label count occupants-here
      set label-color white
  ]

  ask dwellings [
      set label count occupants-here
      set label-color white
  ]

  ;;MAKE SURE ENERGY-AWARENESS IS CONSTRAINED TO < 0 OR > 1 ;;
  ask occupants [ if ( energy-awareness > 0.9 ) [ set energy-awareness 0.9 ]
                  if ( energy-awareness < 0 ) [ set energy-awareness 0 ]

                  if ( time-light-discomfort < 0) [ set time-light-discomfort 0 ]
  ]
  tick
```

```
  if LightSim = true [

    ask locations with [ ((pxcor = -18) AND (pycor = -5)) ] [
      if schedule-next < length daylight-schedule [
         let schedule-item item schedule-next daylight-schedule
         if hour-of-day >= item 0 schedule-item [
            set office-daylight item 1 schedule-item
            set schedule-next schedule-next + 1
         ]
      ]
  ]

 if light-control = "Base" And task-light = false [
    ask communal-lights with [ ((pxcor = 5) AND (pycor = -43)) ] [
        ifelse any? occupants in-radius 6
                [ set color yellow set state "on" ]
                [ set color black set state "off" ]
        ]
    ask communal-lights with [ ((pxcor = 28) AND (pycor = -3)) OR
                               ((pxcor = 0) AND (pycor = -18)) ][
        ifelse hour-of-day >= 7 AND hour-of-day <= 19 AND (Day >= 0) AND (Day <= 4)
                [ set color yellow set state "on" ]
                [ set color black set state "off" ]
        ]
    ask communal-lights with [ ((pxcor = -28) AND (pycor = -33)) ][
        set color black set state "off"
    ]
    ask communal-lights with [ ((pxcor = 28) AND (pycor = -37)) ] [
        ifelse any? occupants in-radius 11
                      [ set color yellow set state "on" ]
                      [ set color black set state "off" ]
    ]
 ]

 if light-control = "Manual" AND task-light = false [
          ask communal-lights with [ ((pxcor = 28) AND (pycor = -3)) OR
                                     ((pxcor = 0) AND (pycor = -18)) ][
              ifelse hour-of-day >= 7 AND hour-of-day <= 19 AND (Day >= 0) AND (Day <= 4)
                      [ set color yellow set state "on" ]
                      [ set color black set state "off" ]
          ]
          ask communal-lights with [ ((pxcor = 5) AND (pycor = -43)) ] [
              ifelse any? occupants in-radius 6
                      [ set color yellow set state "on" ]
                      [ set color black set state "off" ]
          ]
          ask communal-lights with [ ((pxcor = 28) AND (pycor = -37)) ] [
              ifelse any? occupants in-radius 11
                      [ set color yellow set state "on" ]
                      [ set color black set state "off" ]
          ]
 ]
if light-control = "Manual" AND task-light = true [
         ask communal-lights with [ ((pxcor = 0) AND (pycor = -18)) OR
                                    ((pxcor = -28) AND (pycor = -33))] [
             ifelse hour-of-day >= 7 AND hour-of-day <= 19 AND (Day >= 0) AND (Day <= 4)
                     [ set color yellow set state "on" ]
                     [ set color black set state "off" ]
         ]
         ask communal-lights with [ ((pxcor = 5) AND (pycor = -43)) ] [
             ifelse any? occupants in-radius 6
                     [ set color yellow set state "on" ]
                     [ set color black set state "off" ]
         ]
         ask communal-lights with [ ((pxcor = 28) AND (pycor = -37)) ] [
             ifelse any? occupants in-radius 11
                     [ set color yellow set state "on" ]
                     [ set color black set state "off" ]
         ]

]
```

```
 if light-control = "Automated" AND task-light = false [
    ifelse any? occupants with [ current-location = "meetingroom" ]
           [ ask communal-lights with [ ((pxcor = 28) AND (pycor = -37)) ] [
                 set color yellow set state "on" ]
           ]
           [ ask communal-lights with [ ((pxcor = 28) AND (pycor = -37)) ] [
                 set color black set state "off" ]
           ]
    ifelse any? occupants with [ current-location = "SharedRoom" ]
           [ ask communal-lights with [ ((pxcor = 28) AND (pycor = -3)) ] [
                 set color yellow set state "on" ]
           ]
           [ ask communal-lights with [ ((pxcor = 28) AND (pycor = -3)) ] [
                 set color black set state "off" ]
           ]
    ifelse any? occupants with [ current-location = "toilet" ]
           [ ask communal-lights with [ ((pxcor = 5) AND (pycor = -43)) ] [
                 set color yellow set state "on" ]
           ]
           [ ask communal-lights with [ ((pxcor = 5) AND (pycor = -43)) ] [
                 set color black set state "off" ]
           ]
    ifelse any? occupants with [ current-location = "hallway" ] [
           ask communal-lights with [ ((pxcor = 0) AND (pycor = -18)) ] [
               set color yellow set state "on" ]
           ]
           [ ask communal-lights with [ ((pxcor = 0) AND (pycor = -18)) ] [
                 set color black set state "off" ]
           ]
]]

 if light-control = "Automated" AND task-light = true [
    ifelse any? occupants with [ current-location = "meetingroom" ]
           [ ask communal-lights with [ ((pxcor = 28) AND (pycor = -37)) ] [
                 set color yellow set state "on" ]
           ]
           [ ask communal-lights with [ ((pxcor = 28) AND (pycor = -37)) ] [
                 set color black set state "off" ]
           ]
    ifelse any? occupants with [ current-location = "toilet" ]
           [ ask communal-lights with [ ((pxcor = 5) AND (pycor = -43)) ] [
                 set color yellow set state "on" ]
           ]
           [ ask communal-lights with [ ((pxcor = 5) AND (pycor = -43)) ] [
                 set color black set state "off" ]
           ]
    ifelse any? occupants with [ current-location = "hallway" ] [
           ask communal-lights with [ ((pxcor = 0) AND (pycor = -18)) ] [
               set color yellow set state "on" ]
           ]
           [ ask communal-lights with [ ((pxcor = 0) AND (pycor = -18)) ] [
                 set color black set state "off" ]
           ]
]

 simulate-occupant-activity
 simulate-occupant-behavior
 calculate-cost
 SimulateTime
 update-occupant-behavior
end
```

```
to SimulateTime
   set minute            floor (ticks) mod 60
   set hour-of-day       floor (ticks / 60) mod 24
   set day               floor (ticks / 1440 ) mod 7
   set week              1 + (floor (ticks  / (7 * 1440))) mod 52
   set time              floor (ticks ) mod 1440

   set day-of-week       day mod 7
   set dayName item day-of-week days
end
```

4.3.1 Work schedule

```
to start-day
  ask occupants [
      set at-work false
      set office-today false
      set workschedule [ ]
      set activity-time 0
      set activity-duration 0
      set time-without-computer 0
      set office-daylightlux 0
      set time-light-discomfort 0
      set new-energy-awareness 0

      if office-today = false [ set computer-state "Off" set light-state "Off" set task-light-state "Off"]

;; SET ARRIVAL TIME AND LEAVING TIME EACH DAY OF OCCUPANT ;;
      if time-table = "flex" [
         set start-time random-time 7 13
         set end-time random-time start-time 18
      ]
      let p random 100
      if time-table = "strict"[
         if p >= 0 AND p <= 8     [ set start-time 9 ]
         if p > 8 AND p <= 51    [ set start-time 8 ]
         if p > 51 AND p <= 100 [ set start-time 7 ]

         if p >= 0 AND p <= 4    [ set end-time 13  ]
         if p > 4 AND p <= 5     [ set end-time 14  ]
         if p > 5 AND p <= 11    [ set end-time 15  ]
         if p > 11 AND p <= 62   [ set end-time 16  ]
         if p > 62 AND p <= 96   [ set end-time 17  ]
         if p > 96 AND p <= 100 [ set end-time 18  ]
      ]
  ]

  ask locations [ set schedule-next 0 ]
  let Occupancy-Percentage occupancy
  ;let Occupancy-Percentage (occupancy + random 20)
  ask n-of( int (Occupancy-Percentage / 100 * count occupants)) occupants [
      set office-today true
  ]
end

to set-workschedule
   ask occupants [
       let p random 10
       if at-work [
          if current-location = "PrivateRoom" OR current-location = "SharedRoom" [
             if time = time-since-here AND activity-time = 0 [
                set activity-time random-time time-since-here ((end-time * 60) + 60)
             ]

             if time = activity-time [
                ifelse p >= 0 AND p <= 3
                       [ set workschedule lput "meeting" workschedule
                         set activity "gomeeting"
                         determine-location ]
                       [ set workschedule lput "restroom" workschedule
                         set activity "gorestroom"
                         determine-location]
             ]
          ]
```

```
            if activity != "golunch" [
               if activity = "meeting" [
                  ifelse activity-duration = 0 AND time = lunch-time
                         [ set workschedule lput "lunch" workschedule
                           set activity "golunch"
                           determine-location ]
                         [ if time = (end-time * 60 + start-time * 60) / 2
                              [ set workschedule lput "lunch" workschedule
                                set activity "golunch"
                                determine-location]
                         ]
             ]

             if time = (end-time * 60 + start-time * 60) / 2
                [ set workschedule lput "lunch" workschedule
                  set activity "golunch"
                  determine-location]
            ]
         ]
   ]
 end

 to-report lunch-time
   let lunch-time-prob ( (end-time * 60 + start-time * 60) ) / 2
   report lunch-time-prob
 end

to simulate-occupant-activity
  let $currenttime time
  ask occupants [
    ifelse ((office-today AND (Day >= 0) AND (Day <= 4) AND ($currenttime >= start-time * 60 ) AND ($currenttime <= end-time * 60  )))
           [if (not at-work) [GoWork]   ]
           [if (at-work)     [GoHome]   ]

    MoveToOwnWorkdesk
    set-workschedule
    determine-Location
  ]
end
```

4.3.2 Location

```
to GoWork
 set activity "goWork"
 if current-location = "home" [
    move-to hallway
    set at-work true
    set current-location "hallway"
    set time-since-here time

 ]
end

to GoHome
  set activity "leaving"
  ifelse current-location != "hallway"
         [ move-to hallway
           set current-location "hallway"
           set time-since-here time
          ]
         [ if (time - time-since-here) > (2 + random 2) [
              move-to one-of dwellings
              set at-work false
              set current-location "home"
              set activity "relax"
              set time-since-here 0 ]
         ]
end
```

```
to MoveToOwnWorkdesk
  let _myroomID occRoomID

  if at-work AND activity = "goWork" AND current-location = "hallway" [
     if (time - time-since-here) > (2 + random 2) [
         move-to one-of locations with [RoomID = _myRoomID]

         if _myRoomID = "private" [
            set current-location "PrivateRoom"
            set activity "work"
            set time-since-here time
         ]

         if _myRoomID = "shared"  [
            set current-location "SharedRoom"
            set activity "work"
            set time-since-here time
         ]

         set workschedule lput "work" workschedule
     ]
  ]
end

to determine-Location
;; LUNCH ACIVITY ;;
  if activity = "golunch" AND current-location != "hallway" [
     move-to hallway
     set current-location "hallway"
     set time-since-here time
  ]

  if activity = "golunch" AND current-location = "hallway"  [
     if (time - time-since-here) >= (2 + random 2) [
         move-to cafeteria
         set time-since-here time
         set current-location "cafeteria"
         set activity  "lunch"
         set activity-duration 45 + random 15
     ]
  ]

  if current-location = "cafeteria" [
     set activity-duration activity-duration - 1
     if activity-duration = 0 [
        move-to hallway
        set activity "goWork" set current-location "hallway"
        set time-since-here time
        set activity-time 0
     ]
     MoveToOwnWorkdesk
  ]
```

```
;; RESTROOM ACIVITY ;;
  if activity = "gorestroom" AND current-location != "hallway" [
     move-to hallway
     set current-location "hallway"
     set time-since-here time
  ]

  if activity = "gorestroom" AND current-location = "hallway"  [
     if (time - time-since-here) >= (2 + random 2) [
         move-to restrooms
         set time-since-here time
         set current-location "toilet"
         set activity "takingashit"
         set activity-duration 7 + random 13
     ]
  ]

  if current-location = "toilet" [
     set activity-duration activity-duration - 1
     if activity-duration = 0 [
        move-to hallway
        set activity "goWork"
        set current-location "hallway"
        set time-since-here time
        set activity-time 0
     ]
     MoveToOwnWorkdesk
  ]

;; MEETING ACTIVITY ;;
  if activity = "gomeeting" AND current-location != "hallway" [
     move-to hallway
     set current-location "hallway"
     set time-since-here time
  ]

  if activity = "gomeeting" AND current-location = "hallway" [
     if (time - time-since-here) >= (2 + random 2) [
         move-to meetingLocation
         set time-since-here time
         set current-location "meetingroom"
         set activity "meeting"
         set activity-duration 20 + random 40
     ]
  ]

  if current-location = "meetingroom" [
     set activity-duration activity-duration - 1
     if activity-duration = 0 [
        move-to hallway
        set activity "goWork" set current-location "hallway"
        set time-since-here time
        set activity-time 0
     ]
     MoveToOwnWorkdesk
  ]
end
```

4.3.3 Occupant Behavior

```
to simulate-occupant-behavior
  ask occupants [
    ifelse at-work [
           set current-perception [ ]
           set appliance-use [ ]

;; COMPUTER SCENARIOS ;;
           if ComputerSim = true [
              occupant-behavior-computer
              if current-location = "PrivateRoom" OR current-location = "SharedRoom" [
                 if time = time-since-here [ set switch-probability precision random-float 1 2 ]
              ]
           ]
;; LIGHT-CONTROL SCENARIOS ;;
        if LightSim = true [
           if light-control = "Base" AND task-light = false [
              occupant-behavior-light
              calculate-light-comfort
              if current-location = "PrivateRoom" AND time = time-since-here [ set switch-probability precision random-float 1 2 ]
           ]
           if light-control = "Automated" [
              ifelse current-location = "PrivateRoom"
                     [ set light-state "On"  ]
                     [ set light-state "Off" ]
           ]
           if light-control = "Manual" AND task-light = false [
              occupant-behavior-light
              calculate-light-comfort
              if current-location = "PrivateRoom" AND time = time-since-here [ set switch-probability precision random-float 1 2 ]
           ]
           if light-control = "Manual" AND task-light = true [
              occupant-behavior-task-light
              calculate-light-comfort
              if (current-location = "PrivateRoom" OR current-location = "SharedRoom") AND time = time-since-here [ set switch-probability precision random-float 1 2 ]
           ]
        ]
    ]
    [ set appliance-use [ ] set current-perception ""]

;; POWER-MANAGEMENT SCENARIO ;;
      if PM AND at-work [
         ifelse ( member? "work without computer" current-perception) [
                   if computer-state = "On" [
                      set time-without-computer time-without-computer + 1 ]
         ]
         [control-computer]
      if time-without-computer >= time-PM AND computer-state != "Off" [ set computer-state "stand-by" ]
      if member? "work with computer" current-perception [ set time-without-computer 0]
      ]
  ]
end
```

4.3.4 Light Comfort

```
to calculate-light-comfort
   let x one-of locations with [ ((pxcor = -18) AND (pycor = -5)) ]
   let daylightlux [ office-daylight ] of x

   if current-location = "PrivateRoom" [
      set office-daylightLux ceiling ((daylightlux / 1000) * office-area * Daylight-factor)
      if light-state = "On" [
            if lightType = "TL" [
               set office-overheadlightLux floor ( light-per-occupant * illumination )
            ]
            if lightType = "LED"  [
               set office-overheadlightLux floor ( light-per-occupant * illumination )
            ]
      ]

      if task-light-state = "On" [
            if lightType = "TL" [
               set tasklightlux ( 1 * 228 )
            ]
            if lightType = "LED"  [
               set tasklightlux ( 1 * 228 )
            ]
      ]
   ]

   if current-location = "SharedRoom" [
      set office-daylightLux ceiling ((daylightlux / 1000) * 25 * Daylight-factor)
      if task-light-state = "On" [
            if lightType = "TL" [
               set tasklightlux ( 1 * 228 )
            ]
            if lightType = "LED"  [
               set tasklightlux ( 1 * 228 )
            ]
      ]
   ]

   if light-state = "Off" [ set office-overheadlightLux 0 ]
   if task-light-state = "Off" [ set tasklightlux 0 ]

end
to-report light-per-occupant
  if lightType = "TL" [
     let A office-area
     let lux 500
     let LDL 2600
     let UF 0.84
     let MF 0.9
     report A * lux / (LDL * UF * MF)
  ]

  if lightType = "LED" [
     let A office-area
     let lux 500
     let LDL 1100
     let UF 0.77
     let MF 0.95
     report A * lux / (LDL * UF * MF)
  ]
end
```

```
to-report illumination
  if lightType = "TL" [
     let LDL 2600
     let Cu 0.55
     let Llf 0.8
     let A office-area
     report (LDL * CU * Llf) / A
  ]

  if lightType = "LED" [
     let LDL 1100
     let Cu 0.77
     let Llf 0.95
     let A office-area
     report (LDL * CU * Llf) / A
  ]
end

to-report total-lux-workdesk
  report (office-DaylightLux + office-overheadlightLux + tasklightlux)
end
```

4.3.5 BDI

```
to occupant-behavior-computer
  ;;BELIEF;;
  if activity = "meeting" [
     set current-perception lput "presentation" current-perception
  ]

  ifelse ( current-location = "PrivateRoom") OR
         ( current-location = "SharedRoom" )
           [ set current-perception lput "work with computer" current-perception    ]
           [ set current-perception lput "work without computer" current-perception ]

   ;;DESIRE;;
   if ( empty? current-perception = false) [
        if ( member? "work with computer" current-perception) OR
           ( member? "work without computer" current-perception) [
                     set appliance-use lput "computer" appliance-use
           ]
           if member? "presentation" current-perception [
                      set appliance-use lput "misc" appliance-use
           ]
   ]

   ;; INTENTION
   if ( empty? appliance-use = false) [
              if member? "computer"  appliance-use [ control-computer ]
   ]
end
```

```
to occupant-behavior-light
  ;;BELIEF;;
  let $perceivedlux ( [total-lux-workdesk] of self )
  ; if not windowsBlindOpen? [ set $perceivedLux ($perceivedLux - [zoneDaylightLux] of myself) ]
  ifelse ( current-location = "PrivateRoom") OR
         ( current-location = "meetingroom") OR
         ( current-location = "toilet"    ) [
           if ( $perceivedlux >= first comfortlux AND $perceivedlux <= last comfortLux ) [
                                set current-perception lput "normal" current-perception
           ]
           if ( $perceivedlux > last comfortLux) [
                               set current-perception lput "too bright" current-perception
           ]
           if ( $perceivedlux < first comfortLux) [
                               set current-perception lput "too dark" current-perception
           ]
  ]
  [ set current-perception lput "no illumination" current-perception ]

  ;;DESIRE;;
  if ( empty? current-perception = false) [
       if ( member? "too dark" current-perception) OR
          ( member? "too bright" current-perception) OR
          ( member? "normal" current-perception) OR
          ( member? "no illumination" current-perception ) [
                    set appliance-use lput "overheadlight" appliance-use
       ]
  ]

  ;;INTENTION;;
  if ( empty? appliance-use = false) [
       if member? "overheadlight" appliance-use [ control-light ]
       if member? "task-light" appliance-use    [ control-task-light ]
   ]
end

to occupant-behavior-task-light
   ;;BELIEF;;
   let $perceivedlux ( [total-lux-workdesk] of self )
   ifelse ( current-location = "PrivateRoom") OR
          ( current-location = "SharedRoom" ) OR
          ( current-location = "meetingroom") OR
          ( current-location = "toilet") [
            if ( $perceivedlux >= first comfortlux AND $perceivedlux <= last comfortLux ) [
                                 set current-perception lput "normal" current-perception
            ]
            if ( $perceivedlux > last comfortLux) [
                                set current-perception lput "too bright" current-perception
            ]
            if ( $perceivedlux < first comfortLux) [
                                set current-perception lput "too dark" current-perception
            ]
   ]
   [ set current-perception lput "no illumination" current-perception ]

   ;;DESIRE;;
   if (empty? current-perception = false) [
              if ( member? "too dark" current-perception) OR
                 ( member? "too bright" current-perception) OR
                 ( member? "normal" current-perception) OR
                 ( member? "no illumination" current-perception ) [
                        if ( current-location = "PrivateRoom" ) [
                           ifelse probability intention-to-save-energy
                                  [ set appliance-use lput "task-light" appliance-use ]
                                  [ set appliance-use lput "overheadlight" appliance-use  ]
                        ]
                        if ( current-location = "SharedRoom" ) [
                           set appliance-use lput "task-light" appliance-use
                        ]
                        if ( current-location = "meetingroom") OR
                           ( current-location = "toilet") [
                           set appliance-use lput "overheadlight" appliance-use
                        ]
                        if ( current-location = "hallway") OR
                           ( current-location = "cafeteria") [
                           set appliance-use lput "task-light" appliance-use
                           set appliance-use lput "overheadlight" appliance-use
                        ]
              ]
```

```
    ]

    ;;INTENTION;;
    if ( empty? appliance-use = false ) [
               if member? "task-light" appliance-use    [ control-task-light ]
               if member? "overheadlight" appliance-use [ control-light ]
    ]
end

to-report probability [x]
  let trial Awareness-Threshold
  ;if time = time-since-here [ set trial random-float 1 ]
  ifelse x > trial [report true] [report false]
end
```

4.3.6 Appliance Use

```
to control-computer
  if at-Work [
     if activity = "work" AND member? "work with computer" current-perception [
        if (time - time-since-here) >= (3 + random 2) AND computer-state != "On" [set computer-state "On"]
     ]

     if member? "work without computer" current-perception AND intention-to-save-energy > Awareness-Threshold [
        if Energy-Profile = "Big-Consumer"   [
              if switch-probability > 0 AND switch-probability <= 0.1 [ set light-state "Off" ]
           ]
           if Energy-Profile = "Average-Consumer" [
              if switch-probability > 0 AND switch-probability <= 0.3 [ set light-state "Off" ]
           ]
           if Energy-Profile = "Energy-Saver" AND intention-to-save-energy > Awareness-Threshold [
              if switch-probability > 0 AND switch-probability <= 0.65 [ set light-state "Off" ]
           ]
           if Energy-Profile = "Pro-Environmentalist" AND intention-to-save-energy > Awareness-Threshold [
              if switch-probability > 0 AND switch-probability <= 0.95 [ set light-state "Off" ]
           ]
        ]


     if activity = "leaving" [
        ifelse intention-to-save-energy > Awareness-Threshold
             [ set computer-state "Off"]
             [ ifelse random 100 <= 5
                     [ set computer-state "stand-by" ]
                     [ set computer-state "Off"]
             ]
     ]
  ]
end

to control-light
   if at-Work [

      if ( member? "too dark" current-perception) [
          set time-light-discomfort 0
          set time-light-discomfort time-light-discomfort + 1
      ]
      if ( member? "too dark" current-perception) [
          set time-light-discomfort time-light-discomfort - 1
      ]
      if ( member? "too bright" current-perception) [
          set time-light-discomfort 0
          set time-light-discomfort time-light-discomfort + 1
      ]

     if activity = "work" AND current-location = "PrivateRoom" AND time = (time-since-here + (3 + random 2)) [
        if Energy-Profile = "Big-Consumer"   [
           if light-state != "On" [ set light-state "On" ]
        ]
        if Energy-Profile = "Average-Consumer" [
           ifelse NOT ( member? "too dark" current-perception )
                [
                  ifelse  switch-probability > 0.65 [ set light-state "Off"] [ if light-state != "On" [  set light-state "On" ] ] ]
                [  set light-state "On" ]
        ]
        if Energy-Profile = "Energy-Saver" [
           if member? "normal" current-perception AND  switch-probability <= 0.65 [ if light-state != "On" [ set light-state "On" ] ]
           if member? "too bright" current-perception AND switch-probability >= 0.65  [ set light-state "Off" ]
           if member? "too dark" current-perception [ set light-state "On" ]
        ]
        if Energy-Profile = "Pro-Environmentalist" [
           ifelse member?  "too dark" current-perception
                [ if light-state != "On" [ set light-state "On" ] ]
                [ set light-state "Off" ]
           ]
     ]
```

```
    if activity = "work" AND time > time-since-here [
      if current-location = "PrivateRoom" OR
         current-location = "SharedRoom" [
      if ( member? "too dark" current-perception) AND task-light-state != "On" AND time-light-discomfort >= lightdiscomfort [
         if Energy-Profile = "Big-Consumer" [
            if intention-to-save-energy < Awareness-Threshold [ set task-light-state "On" ]
         ]
         if Energy-Profile = "Average-Consumer" [
            if intention-to-save-energy < Awareness-Threshold [ set task-light-state "On" ]
         ]
         if Energy-Profile = "Energy-Saver" [
            if intention-to-save-energy < Awareness-Threshold [ set task-light-state "On" ]
         ]
         if Energy-Profile = "Pro-Environmentalist" [
            if intention-to-save-energy < Awareness-Threshold [ set task-light-state "On" ]
         ]
      ]

      if ( member? "too bright" current-perception) AND task-light-state = "On" AND intention-to-save-energy > Awareness-Threshold [
         if Energy-Profile = "Big-Consumer"  [
            if switch-probability > 0 AND switch-probability <= 0.1 [ set task-light-state "Off" ]
         ]
         if Energy-Profile = "Average-Consumer" [
            if switch-probability > 0 AND switch-probability <= 0.3 [ set task-light-state "Off" ]
         ]
         if Energy-Profile = "Energy-Saver" AND intention-to-save-energy > Awareness-Threshold [
            if switch-probability > 0 AND switch-probability <= 0.65 [ set task-light-state "Off" ]
         ]
         if Energy-Profile = "Pro-Environmentalist" AND intention-to-save-energy > Awareness-Threshold [
            if switch-probability > 0 AND switch-probability <= 0.95 [ set task-light-state "Off" ]
         ]
     ]]]

     if activity = "leaving" AND task-light-state = "On" [ set task-light-state "Off" ]

     if activity != "leaving" AND ( member? "no illumination" current-perception ) AND task-light-state = "On" [
        if intention-to-save-energy > Awareness-Threshold [ set task-light-state "Off" ]
     ]

  ]
end
       set time-light-discomfort time-light-discomfort + 1
    ]

    if activity = "work" AND time = (time-since-here + (3 + random 2)) [
      if current-location = "PrivateRoom" OR
         current-location = "SharedRoom" [
            if Energy-Profile = "Big-Consumer"   [
               if task-light-state != "On" [ set task-light-state "On" ]
            ]
            if Energy-Profile = "Average-Consumer" [
               ifelse NOT ( member? "too dark" current-perception )
                    [ ifelse  switch-probability > 0.65 [ set task-light-state "Off"] [ if task-light-state != "On" [  set task-light-state "On" ] ] ]
                    [ set task-light-state "On" ]
            ]
            if Energy-Profile = "Energy-Saver" [
               ifelse NOT ( member? "too dark" current-perception )
                    [ if member? "normal" current-perception AND  switch-probability < 0.65 [ if task-light-state != "On" [ set task-light-state "On" ] ]
                      if member? "too bright" current-perception [ set task-light-state "Off" ]
                    ]
                    [  set task-light-state "On" ]
            ]
            if Energy-Profile = "Pro-Environmentalist" [
               ifelse member?  "too dark" current-perception
                    [ if task-light-state != "On" [ set task-light-state "On" ] ]
                    [ set task-light-state "Off" ]
            ]
      ]
    ]
      if ( member? "too bright" current-perception) AND light-state = "On" AND intention-to-save-energy > Awareness-Threshold [
          if Energy-Profile = "Big-Consumer"  [
             if switch-probability > 0 AND switch-probability <= 0.1 [ set light-state "Off"
                                                                     if ( member? "too dark" current-perception) [ set time-light-discomfort time-light-discomfort + 1 ]
                                                                     if ( member? "normal" current-perception) [ set time-light-discomfort time-light-discomfort - 1 ]
             ]
          ]
          if Energy-Profile = "Average-Consumer" [
             if switch-probability > 0 AND switch-probability <= 0.3 [ set light-state "Off"
                                                                     if ( member? "too dark" current-perception) [ set time-light-discomfort time-light-discomfort + 1 ]
                                                                     if ( member? "normal" current-perception) [ set time-light-discomfort time-light-discomfort - 1 ]
             ]
          ]
          if Energy-Profile = "Energy-Saver" AND intention-to-save-energy > Awareness-Threshold [
             if switch-probability > 0 AND switch-probability <= 0.65 [ set light-state "Off"
                                                                      if ( member? "too dark" current-perception) [ set time-light-discomfort time-light-discomfort + 1 ]
                                                                      if ( member? "normal" current-perception) [ set time-light-discomfort time-light-discomfort - 1 ]
             ]
          ]
          if Energy-Profile = "Pro-Environmentalist" AND intention-to-save-energy > Awareness-Threshold [
             if switch-probability > 0 AND switch-probability <= 0.95 [ set light-state "Off"
                                                                      if ( member? "too dark" current-perception) [ set time-light-discomfort time-light-discomfort + 1 ]
                                                                      if ( member? "normal" current-perception) [ set time-light-discomfort time-light-discomfort - 1 ]]
          ]
      ]
    ]

    if activity = "leaving" AND light-state = "On" [ set light-state "Off" ]

    if activity != "leaving" AND ( member? "no illumination" current-perception ) AND light-state = "On" [
       if intention-to-save-energy > Awareness-Threshold [ set light-state "Off" ]
    ]
  ]
end
```

4.3.7 Behavioral Measurements

```
to update-occupant-behavior
ask occupants [
  if direct-feedback = true [
     set feedback true

     if feedback-frequency = 1 [
        if day = 0 [
           if member? "work with computer" current-perception [
              set new-energy-awareness energy-awareness + (0.05 + random 0.05)
           ]
        ]
     ]
     if feedback-frequency = 2 [
        if day = 0 [
           if member? "work with computer" current-perception [
              set new-energy-awareness energy-awareness + (0.05 + random 0.05)
           ]
        ]
        if day = 2 [
           if member? "work with computer" current-perception [
              set new-energy-awareness energy-awareness + (0.05 + random 0.05) / feedback-frequency
           ]
        ]
     ]
     if feedback-frequency = 3 [
        if day = 0 [
           if member? "work with computer" current-perception [
              set new-energy-awareness energy-awareness + (0.05 + random 0.05)
           ]
        ]
        if day = 2 [
           if member? "work with computer" current-perception [
              set new-energy-awareness energy-awareness + (0.05 + random 0.05) / feedback-frequency
           ]
        ]
        if day = 4 [
           if member? "work with computer" current-perception [
              set new-energy-awareness energy-awareness + (0.05 + random 0.05) / feedback-frequency
           ]
        ]
     ]
  ]
]
ask occupants with [ energy-awareness <= 0.20] [
    set energy-profile "Big-Consumer"
    set color red ]

ask occupants with [ energy-awareness >= 0.21 AND energy-awareness <= 0.60] [
    set energy-profile "Average-Consumer"
    set color orange ]

ask occupants with [ energy-awareness >= 0.61 AND  energy-awareness <= 0.80] [
    set energy-profile "Energy-Saver"
    set color yellow ]

ask occupants with [ energy-awareness >= 0.81] [
    set energy-profile "Pro-Environmentalist"
    set color green ]
end

to update-day
 ask occupants [
    set  total-electricity-use  ( precision (total-electricity-use + (electricity-use-computer + electricity-use-plights )) 3)
    if direct-feedback = true AND office-today = true [
       if feedback-frequency = 1 AND day = 0 [
          set energy-awareness new-energy-awareness
       ]
       if feedback-frequency = 2 [ if day = 0 OR day = 2 [
          set energy-awareness (energy-awareness + new-energy-awareness)
       ]]
       if feedback-frequency = 3 [ if day = 0 OR day = 2 OR day = 4 [
          set energy-awareness (energy-awareness + new-energy-awareness)
       ]]
    ]
 ]

 ask communal-lights [
    set total-communal-light-electricity precision ( total-communal-light-electricity + electricity-use-lights ) 3
 ]
end
```

```
to-report intention-to-save-energy
  let A  energy-awareness
  ;let B  0
  let F  0.1
  if Direct-Feedback = true [set A  energy-awareness + new-energy-awareness ]
  ;if Power-Management = true [set B 0.4]
  report a + f ;(a + b + f)
end
```

4.4 Calculate Electricity Use

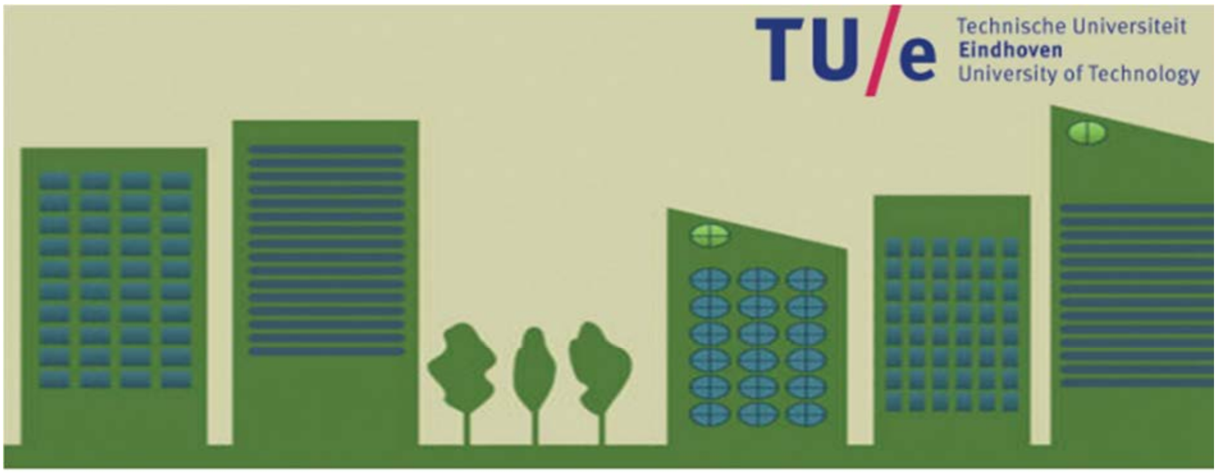
```
to calculate-cost
  ask occupants [
     if computer-state = "On"       [set electricity-use-computer  (electricity-use-computer + precision (kwhcomp / 60) 4 )  ]
     if computer-state = "stand-by" [set electricity-use-computer  (electricity-use-computer + precision (0.006  / 60) 4   )    ]


  if light-state = "On" [
     if lightType = "TL"  [
        set electricity-use-plights  (electricity-use-plights + precision (light-per-occupant * 0.04 / 60 ) 4) ]
     if lightType = "LED" [
        set electricity-use-plights  (electricity-use-plights + precision (light-per-occupant * 0.013 / 60) 4 )  ]
  ]

  if task-light-state = "On" [
     if lightType = "TL" [
        set electricity-use-plights  (electricity-use-plights + precision (1 * 0.06 / 60) 4)  ]
     if lightType = "LED" [
        set electricity-use-plights  (electricity-use-plights + precision (1 * 0.09 / 60)  4) ]
  ]


  if time mod 1440 = 0 [
     set electricity-use-computer 0
     set electricity-use-plights 0]
  ]

  if Simulation = "Whole Building" [
    ask communal-lights with [ ((pxcor = -28) AND (pycor = -33)) ] [
       ifelse color = yellow [
              if lightType = "TL" [
                 set electricity-use-lights precision (electricity-use-lights + (((90 * 200 / (2600 * 0.84 * 0.9)) * 2 * 0.04) / 60) ) 3 ]
              if lightType = "LED" [
                 set electricity-use-lights precision (electricity-use-lights + (((90 * 200 / (1100 * 0.77 * 0.95)) * 2 * 0.013) / 60) ) 3 ]
              ]
              [ if time mod 1440 = 0 [ set electricity-use-lights 0 ] ]
    ]
    ask communal-lights with [ ((pxcor = 0 ) AND (pycor = -18)) ] [
       ifelse color = yellow [
              if lightType = "TL" [
                 set electricity-use-lights precision (electricity-use-lights + (((2100 * 100 / (2600 * 0.84 * 0.9)) * 0.04) / 60) ) 3 ]
              if lightType = "LED" [
                 set electricity-use-lights precision (electricity-use-lights + (((2100 * 100 / (1100 * 0.77 * 0.95)) * 0.013) / 60) ) 3 ]
              ]
              [ if time mod 1440 = 0 [ set electricity-use-lights 0 ] ]
    ]
    ask communal-lights with [ ((pxcor = 28) AND (pycor = -3)) ] [
       ifelse color = yellow [
              if lightType = "TL" [
                 set electricity-use-lights precision (electricity-use-lights + (((800 * 500 / (2600 * 0.84 * 0.9)) * 0.04 ) / 60) ) 3 ]
              if lightType = "LED" [
                 set electricity-use-lights precision (electricity-use-lights + (((800 * 500 / (1100 * 0.77 * 0.95)) * 0.013) / 60) ) 3 ]
              ]
              [ if time mod 1440 = 0 [ set electricity-use-lights 0 ] ]
    ]
    ask communal-lights with [ ((pxcor = 28) AND (pycor = -37)) ] [
       ifelse color = yellow [
              if lightType = "TL" [
                 set electricity-use-lights precision ((electricity-use-lights + ((20 * 0.04 ) / 60)) ) 3 ]
              if lightType = "LED" [
                 set electricity-use-lights precision ((electricity-use-lights + ((20 * 0.013)  / 60)) ) 3 ]
              ]
              [ if time mod 1440 = 0 [ set electricity-use-lights 0 ] ]
    ]
```

```
  ask communal-lights with [ ((pxcor = 5) AND (pycor = -43)) ] [
      ifelse color = yellow [
             if lightType = "TL" [
                set electricity-use-lights precision ((electricity-use-lights + ((26 / 10 * 2) * 0.04) / 60))  3 ]
             if lightType = "LED" [
                set electricity-use-lights precision ((electricity-use-lights + ((26 / 10 * 2) * 0.013 ) / 60))  3 ]
             ]
             [ if time mod 1440 = 0 [ set electricity-use-lights 0 ] ]
  ]]

if Simulation = "Manual" [
   ask communal-lights with [ ((pxcor = 28) AND (pycor = -37)) ] [
      ifelse color = yellow [
             if lightType = "TL" [
                set electricity-use-lights precision ((electricity-use-lights + ((20 * 0.04 ) / 60)) ) 3 ]
             if lightType = "LED" [
                set electricity-use-lights precision ((electricity-use-lights + ((20 * 0.013)  / 60)) ) 3 ]
             ]
             [ if time mod 1440 = 0 [ set electricity-use-lights 0 ] ]
  ]
  ask communal-lights with [ ((pxcor = 5) AND (pycor = -43)) ] [
      ifelse color = yellow [
             if lightType = "TL" [
                set electricity-use-lights precision ((electricity-use-lights + ((26 / 10 * 2) * 0.04) / 60))  3 ]
             if lightType = "LED" [
                set electricity-use-lights precision ((electricity-use-lights + ((26 / 10 * 2) * 0.013 ) / 60))  3 ]
             ]
             [ if time mod 1440 = 0 [ set electricity-use-lights 0 ] ]
  ]]

end
```

4.4.1 Plot

```
to-report total-electricity
 report ( (sum [ total-electricity-use ] of occupants ) + (sum [total-communal-light-electricity] of communal-lights))

end

to-report total-CO2
 report ( ((sum [ total-electricity-use ] of occupants) + (sum [total-communal-light-electricity] of communal-lights)) * CO2-emission )
end

to-report total-cost
 report ( ((sum [ total-electricity-use ] of occupants) + (sum [total-communal-light-electricity] of communal-lights)) * Elecprice )
end

to-report total-occupancy
  report count occupants with [ at-work = true ]
end

to-report computer
  if ticks mod 60 = 0 [
  report precision sum [electricity-use-computer] of occupants with [who = occID] 2]
end
             ]
             [ if time mod 1440 = 0 [ set electricity-use-lights 0 ] ]
  ]]

end
```

APPENDIX 5 - QUESTIONNAIRE



Energiebesparing voor kantoren

Geachte Heer/Mevrouw

Deze enquête is onderdeel van een afstudeerproject wat gaat over de handelingen en voorkeuren met betrekking tot energiebesparing tijdens het gebruik van kantoor apparatuur en verlichting.

De enquête bestaat uit vier modules en zal ongeveer 10 minuten duren. De verschillende modules worden hieronder kort uitgelegd.

Module 1: Stelt een aantal vragen over uw huidige werksituatie.
Module 2: Gaat over uw huidige gebruik van computers en verlichting op uw werkplek.
Module 3: Behandelt uw reactie op energiebesparende maatregelen.
Module 4: Stelt een aantal korte vragen over uw persoonlijke situatie.

Ik vraag u even de tijd te nemen om de vragen in te vullen. Beantwoord alstublieft alle vragen, ook wanneer het lijkt alsof vragen zich herhalen.

Alvast hartelijk dank voor uw deelname!

Uw gegevens zullen vertrouwelijk worden gebruikt en zullen niet op persoonsniveau worden verwerkt.

Doorgaan »

5% voltooid

Module 1: Work Profile

This module defines the work profile of each respondent through questions about the work situation. The outcome gives insight in the occupancy rate of the building by knowing when an occupant arrives and leaves his work place. This helps to define parameters for different work profiles. Respondents are also asked what floor they work on, if they have an own office or share one. Also to get an assumptions about the amount of appliances a single occupant uses, a question is related to the type of electrical appliances are present at their work desk.

Energiebesparing voor kantoren

Module 1: Werk Profiel

Geef aan op welk tijdstip u gemiddeld gezien aankomt op kantoor.

	07:00 - 08:00	08:00 - 09:00	09:00 - 10:00	10:00 - 11:00	11:00 - 12:00	12:00 - 13:00	Ik heb geen vaste tijden
Tijd van aankomst	○	○	○	○	○	○	○

Geef aan op welk tijdstip u gemiddeld gezien het kantoor verlaat.

	11:00 - 12:00	13:00 - 14:00	14:00 - 15:00	15:00 - 16:00	16:00 - 17:00	17:00 - 18:00	18:00 - 19:00	Ik heb geen vaste tijden
Verlaten van kantoor	○	○	○	○	○	○	○	○

Op welke dagen bent u gemiddeld gezien aanwezig op kantoor? U kunt meerdere dagen aanvinken.

- ☐ Maandag
- ☐ Dinsdag
- ☐ Woensdag
- ☐ Donderdag
- ☐ Vrijdag
- ☐ Zaterdag
- ☐ Zondag

Op welke verdieping bevindt zich voornamelijk uw werkplek?

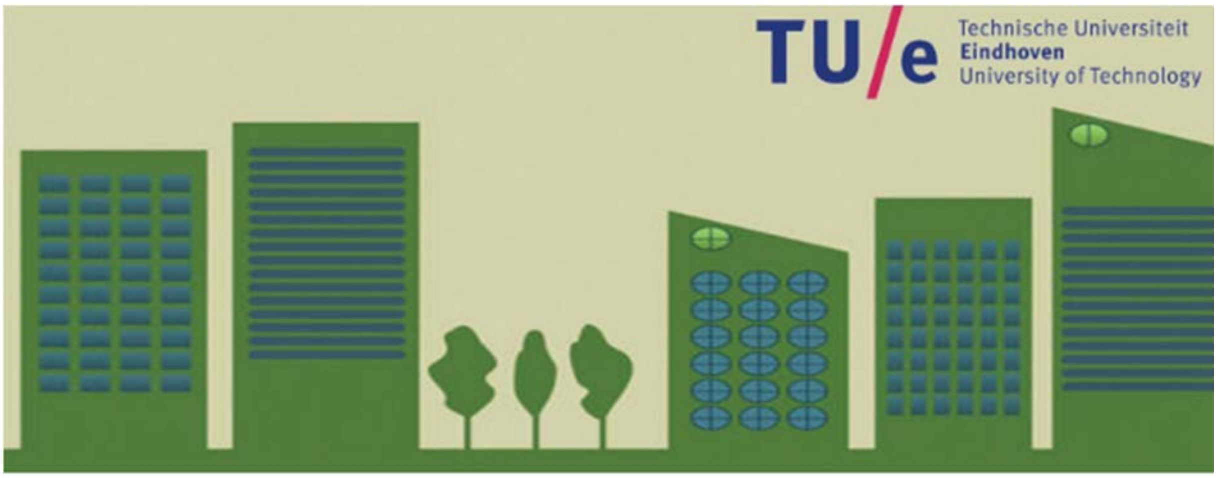
- ○ Begane Grond
- ○ Verdieping 1
- ○ Verdieping 2
- ○ Verdieping 3
- ○ Verdieping 4
- ○ Verdieping 5
- ○ Verdieping 6
- ○ Verdieping 7

Deelt u uw werkplek met andere collega's?

- ○ Nee ik heb een werkplek voor mij alleen
- ○ Ja, ik deel mijn kantoor met één of meerdere collega's

« Vorige | Doorgaan »

11% voltooid



Energiebesparing voor kantoren

Module 1: Werk Profiel

Geef aan welk en hoeveel van de onderstaande elektrische apparaten aanwezig zijn op uw werkplek. Wanneer een bepaald apparaat niet op uw werkplek aanwezig is wilt u dat aangeven met een 0.

Desktop Computer

Monitor

Laptop

Mobiele Telefoon

Bureau Lamp

« Vorige   Doorgaan »

16% voltooid

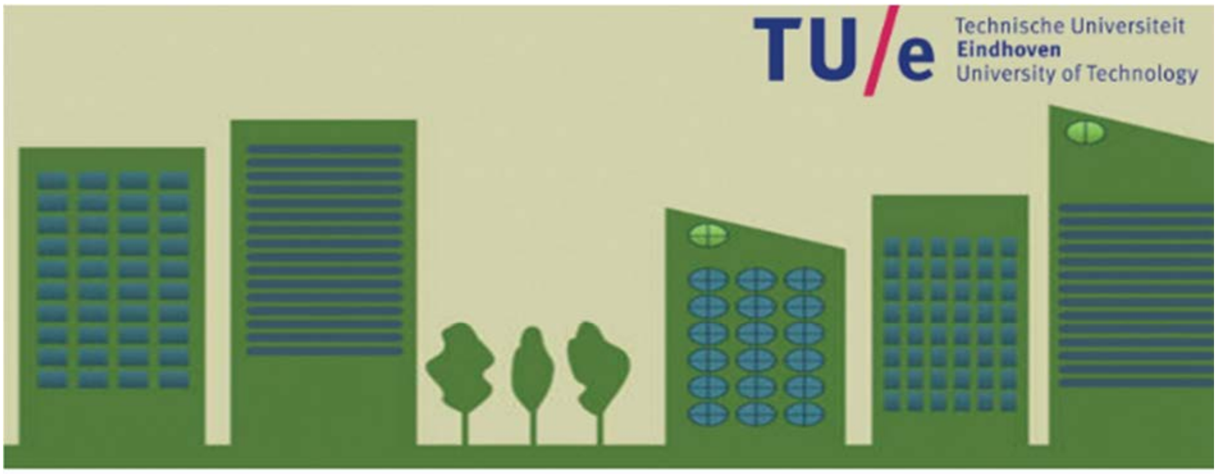
Module 2: Energy Profile

This module defines the energy profile of each respondents, which describes what type of energy user respondents are. The energy profile is based on two factors: (1) the current developed habits regarding the use of electrical appliances and (2) interaction with other occupants. Based on findings of Tetlow et al. (2015) who identified that habits or routines of occupants towards the use of electrical appliances as a significant influence on whether or not an occupant turns off appliances when not in use, and therefor only taken into account in this questionnaire. This is also in the case of the use of lighting, which depends highly on the routines of occupants present when controlled manually.

If occupants are absent, the states of their appliances are determined by their use habit. This could mean that a lot of energy is wasted when appliances are still on when not in use. Therefor a question is included related to the state of appliances when occupants are absent. Four states of absence were defined: having a meeting, going to the restroom, noon break and done working. Three options could be selected for the state of computer (e.g. normal operation, standby, and shutdown) and two for lighting (e.g. on and off).

Also for lighting activity as well as computer activity, questions are asked about the frequency of switching them off. These three questions were scored on a 5-point Likert scale ranging from “never” to “always”.

The Self-Report Habit Index (SRHI) developed by Verplanken and Orbell (2003) is recommended as a useful tool for measuring habitual pro-environmental behavior (Tetlow, et al., 2015). These seven questions were scored using a 5-point Likert scale ranging from “totally agree” to “totally disagree”. The scores for each question were added together to provide a range of scores for the construct of habit from + 14 to – 14. An example of the SRHI regarding turning off computers when not in use is shown in Table x.



Energiebesparing voor kantoren

Module 2: Energie Profiel

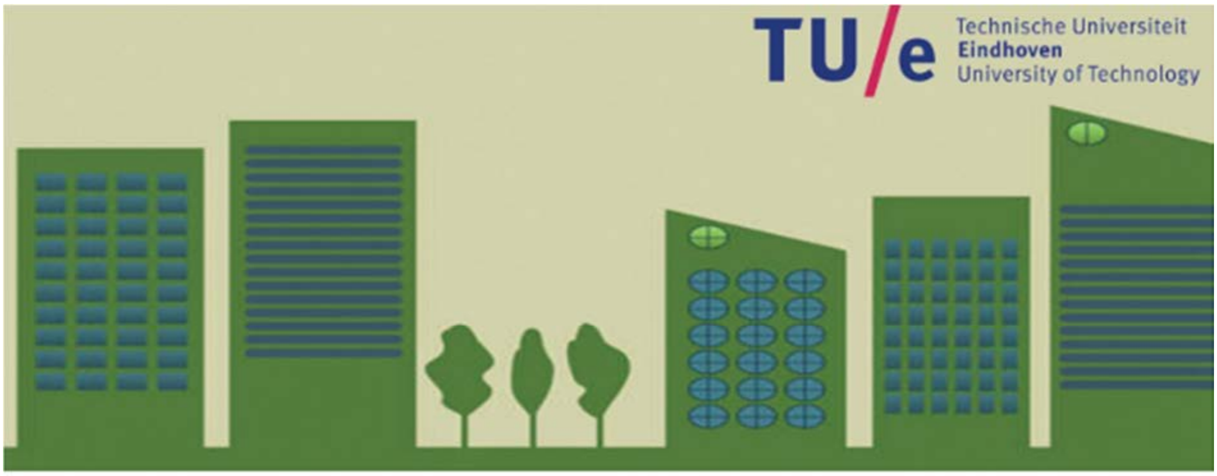
De volgende vragen hebben betrekking op uw gebruik van computers op de werkplek. U kunt n.v.t. kiezen wanneer een vraag niet van toepassing is op uw huidige situatie.

Hoe vaak zet u uw computer uit wanneer u langer dan 20 minuten weg bent?

- Nooit
- Zelden
- Af en toe
- Vaak
- Altijd
- n.v.t.

« Vorige   Doorgaan »

22% voltooid



Energiebesparing voor kantoren

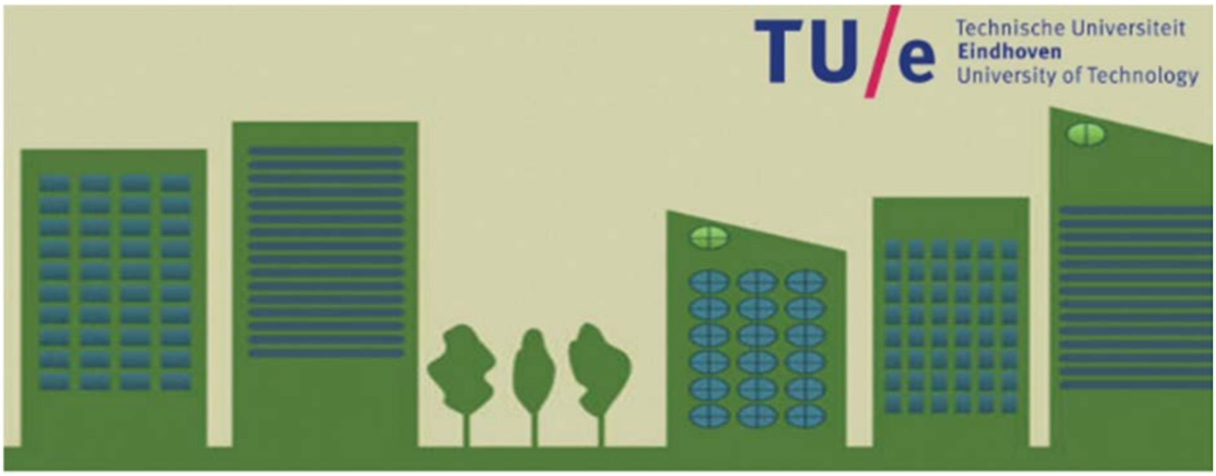
Module 2: Energie Profiel

Op welke stand laat u meestal uw computer achter, wanneer u uw werkplek verlaat voor...

	Aan	Uit	Stand-by	n.v.t.
Een vergadering	○	○	○	○
Een bezoek aan toilet	○	○	○	○
Een lunch pauze	○	○	○	○
Vertrek naar huis	○	○	○	○

« Vorige   Doorgaan »

27% voltooid



Energiebesparing voor kantoren

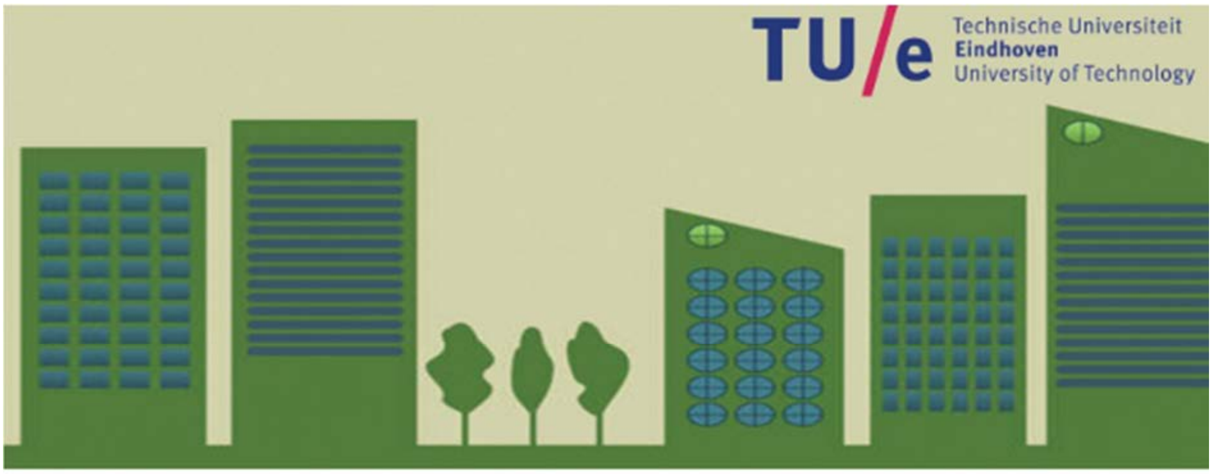
Module 2: Energie Profiel

Het uitzetten van mijn computer wanneer ik deze niet meer gebruik is iets...

	Totaal mee oneens	Oneens	Neutraal	Eens	Totaal mee eens
wat ik automatisch doe					
wat ik bewust doe					
waar ik over moet nadenken					
wat hoort bij mijn dagelijkse routine					
wat ik doe zonder dat ik het door heb					
wat ik moeilijk zou vinden om te doen					
waar ik niet over hoef na te denken om te doen					

« Vorige   Doorgaan »

33% voltooid



Energiebesparing voor kantoren

Module 2: Energie Profiel

De volgende vragen hebben betrekking op uw gebruik van verlichting op de werkplek. U kunt n.v.t. kiezen wanneer een vraag niet van toepassing is op uw huidige situatie.

Voorbeeld: Als het licht automatisch wordt geregeld, dan is er voor u geen mogelijkheid om het licht aan of uit te zetten. Kies dan voor n.v.t.

Hoe vaak doet u het licht uit als u uw werkplek verlaat?

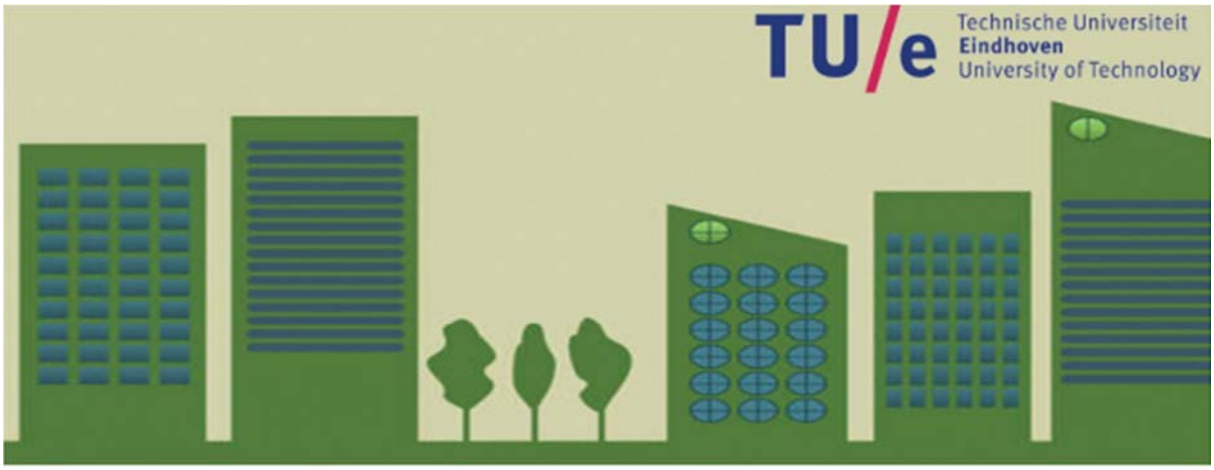
- Nooit
- Zelden
- Af en toe
- Vaak
- Altijd
- n.v.t.

Hoe vaak doet u het licht uit als er voldoende daglicht uw werkplek binnenkomt?

- Nooit
- Zelden
- Af en toe
- Vaak
- Altijd
- n.v.t.

« Vorige | Doorgaan »

38% voltooid



Energiebesparing voor kantoren

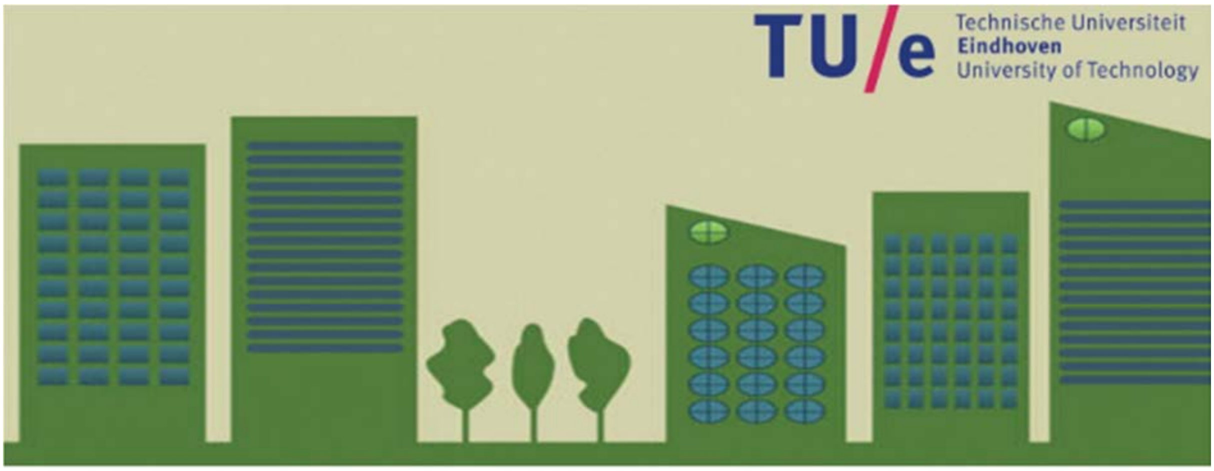
Module 2: Energie Profiel

Op welke stand zet u het licht meestal, wanneer u uw werkplek verlaat voor...

	Aan	Uit	n.v.t.
Een vergadering	○	○	○
Een bezoek aan het toilet	○	○	○
Een pauze	○	○	○
Vertrek naar huis	○	○	○

« Vorige   Doorgaan »

44% voltooid



Energiebesparing voor kantoren

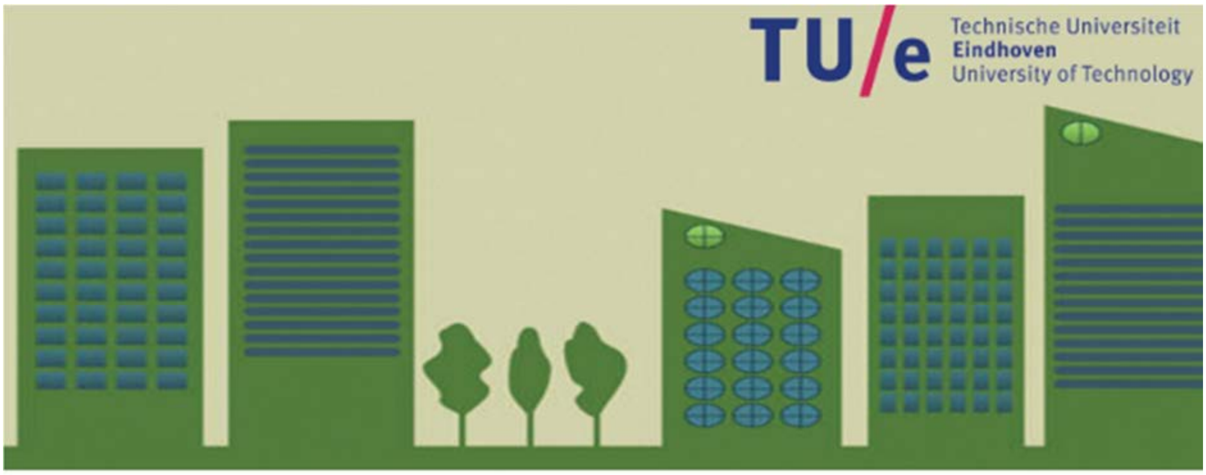
Module 2: Energie Profiel

Het licht uitdoen wanneer ik mijn lege werkplek verlaat is iets...

	Totaal mee oneens	Oneens	Neutraal	Eens	Totaal mee eens
wat ik automatisch doe	○	○	○	○	○
wat ik bewust doe	○	○	○	○	○
waar ik over moet nadenken	○	○	○	○	○
wat hoort bij mijn dagelijkse routine	○	○	○	○	○
wat ik doe zonder dat ik het door heb	○	○	○	○	○
wat ik moeilijk zou vinden om te doen	○	○	○	○	○
waar ik niet over hoef na te denken om te doen	○	○	○	○	○

« Vorige | Doorgaan »

50% voltooid



Energiebesparing voor kantoren

Module 2: Energie Profiel

Het licht uitdoen wanneer voldoende daglicht binnenkomt is iets...

	Totaal mee oneens	Oneens	Neutraal	Eens	Totaal mee eens
wat ik automatisch doe					
wat ik bewust doe					
waar ik over moet nadenken					
wat hoort bij mijn dagelijkse routine					
wat ik doe zonder dat ik het door heb					
wat ik moeilijk zou vinden om te doen					
waar ik niet over hoef na te denken om te doen					

« Vorige   Doorgaan »

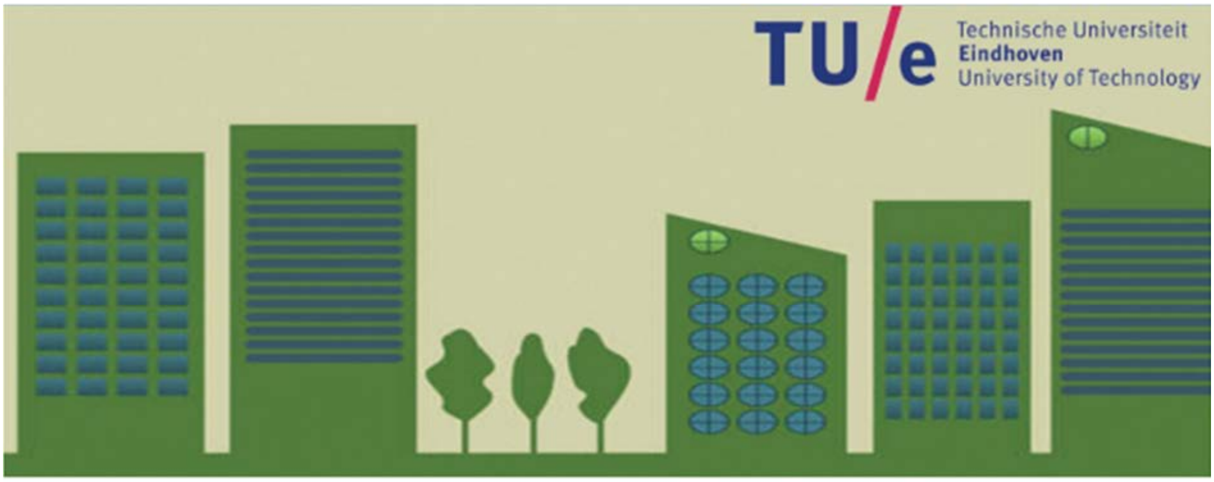
55% voltooid

Module 3: Energy efficient strategies

The awareness of electricity use of respondents is questioned. Therefor scenarios are presented to the respondents that show energy saving interventions. The types of interventions used in this research are based on outcomes of various literature studies that have proven positive outcomes when implementing them in commercial buildings. These questions are used to support the simulation scenarios. The question includes a scenario to give respondents an idea of the feedback information that could be presented to them which could affect the occupants' willingness to save electricity through altered behavior.

In developing behavioral strategies to increase the number of computers turned off rather than left in stand-by or on when not in use, Lockton et al. (2013) offer a useful intervention mapping approach which accounts for the 'rule of thumb' that may keep people from turning off their computer and therein can be used to help identify possible strategies to increase the rate of computers turned off.

To find out whether occupants are willing to change their user behavior by means of these interventions, the respondents are asked to evaluate their behavior towards the use of electrical appliances. The respondents were asked to answer these questions on a 5-point Likert scale, ranging from "every time" to "never".



Energiebesparing voor kantoren

Module 3: Energie besparende maatregelen

De volgende vraag gaat over energie besparende maatregelen die helpen gebruikers te motiveren om hun gebruiksgedrag te veranderen om energie te besparen. Energie managers kunnen verschillende maatregelen daarvoor nemen.

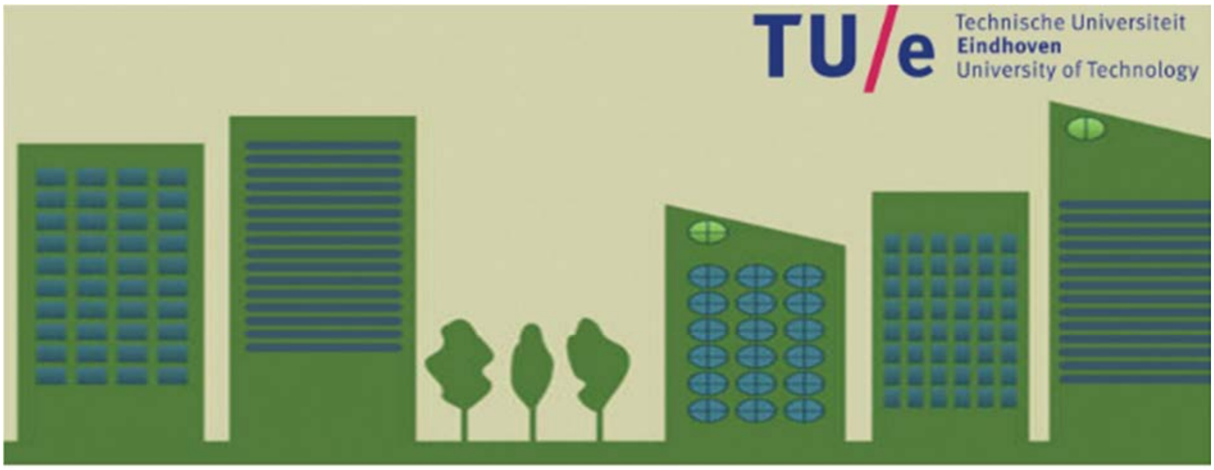
Welke van de onderstaande energie besparende maatregelen denkt u dat kan helpen bij energiebesparing door de gebruiker? Meerdere antwoorden zijn mogelijk.

- ☐ Geven van feedback interventies aan gebruiker door e-mail
- ☐ Geven van feedback interventies aan gebruiker door energy manager
- ☐ Toepassen van Power-Management*
- ☐ Volledig automatiseren van verlichting (bijv licht sensors)
- ☐ Verlichting volledig laten controleren door de gebruiker

*Power Management:
Een software programma waarmee u energie kunt besparen. Power-Management zorgt ervoor dat wanneer u het apparaat niet gebruikt het apparaat in de "stand-by" mode wordt geschakeld om energie te besparen Een screensaver behoort niet tot power management

« Vorige   Doorgaan »

66% voltooid



Energiebesparing voor kantoren

Module 3: Energie besparende maatregelen

De volgende vragen gaan dieper in op het inzetten van feedback interventies. Het geven van feedback kan op verschillende manieren:

[1] Informatie geven over energie besparing:
Geeft algemene tips over hoe energie te besparen op de werkplek. Het beschrijft de meest ontbrekende energie besparingspotentieel van de gemiddelde collega.

[2] Inzicht in energieverbruik:
Geeft een overzicht van de totale wekelijkse als ook de gemiddelde dagelijkse energieverbruik van elektrische apparaten en verlichting op uw kantoor van de voorgaande week.

[3] Doelen stellen:
Geeft doelen die haalbaar zijn voor de komende week.

[4] Vergelijking met collega's:
Laat zien hoe uw energieverbruik is ten opzichte van andere collega's.

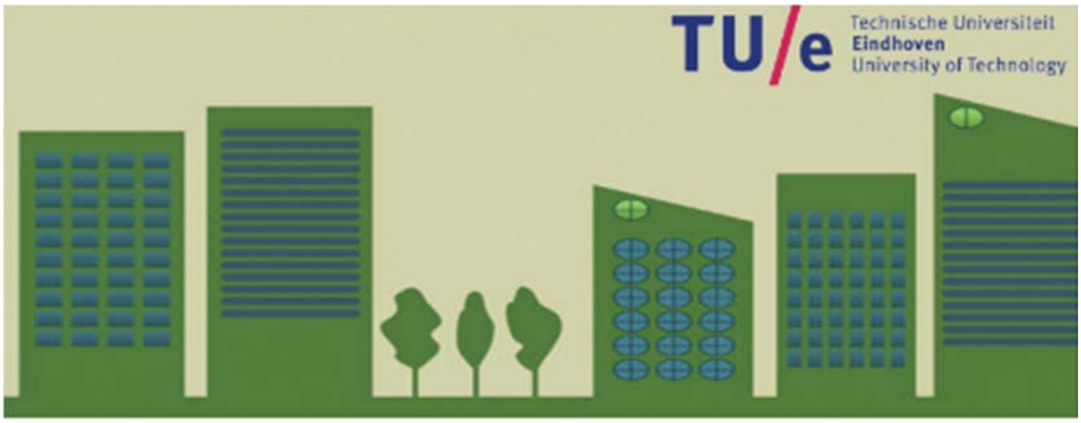
Voor dit onderzoek geldt het volgende scenario:

Uw organisatie is van plan om u een wekelijkse e-mail te sturen, om u te attenderen op de mogelijke energie besparingen die u met veranderingen in uw gebruiksgedrag kunt behalen. De e-mail bevat feedback gericht op uw energie prestatie.

Beantwoord de volgende vragen die betrekking hebben op u energie besparend gedrag als reactie op energie besparende maatregelen.

« Vorige   Doorgaan »

72% voltooid



Energiebesparing voor kantoren

Module 3: Energie besparende maatregelen

Kunt u in onderstaande tabel de mate van inlvoed aangeven die de verschillende vormen van feedback zou kunnen hebben op uw energiebewustzijn?

	Minst invloedrijk			Meest invloedrijk
Informatie over energiebesparing	○	○	○	○
Inzicht in het energieverbruik	○	○	○	○
Doelen stellen	○	○	○	○
Vergelijking met collega's	○	○	○	○

Kunt u in onderstaande tabel de mate van effectiviteit aangeven die de verschillende vormen van op het efficiënter gebruik van uw computer?

	Minst effectief			Meest effectief
Informatie over energiebesparing	○	○	○	○
Inzicht in het energieverbruik	○	○	○	○
Doelen stellen	○	○	○	○
Vergelijking met collega's	○	○	○	○

Rangschik de 4 vormen van feedback van "meest effectief" tot "minst effectief" op het efficiënter gebruik van licht.

	Minst effectief			Meest effectief
Informatie over energiebesparing	○	○	○	○
Inzicht in het energieverbruik	○	○	○	○
Doelen stellen	○	○	○	○
Vergelijking met collega's	○	○	○	○

« Vorige | Doorgaan »

77% voltooid

Energiebesparing voor kantoren

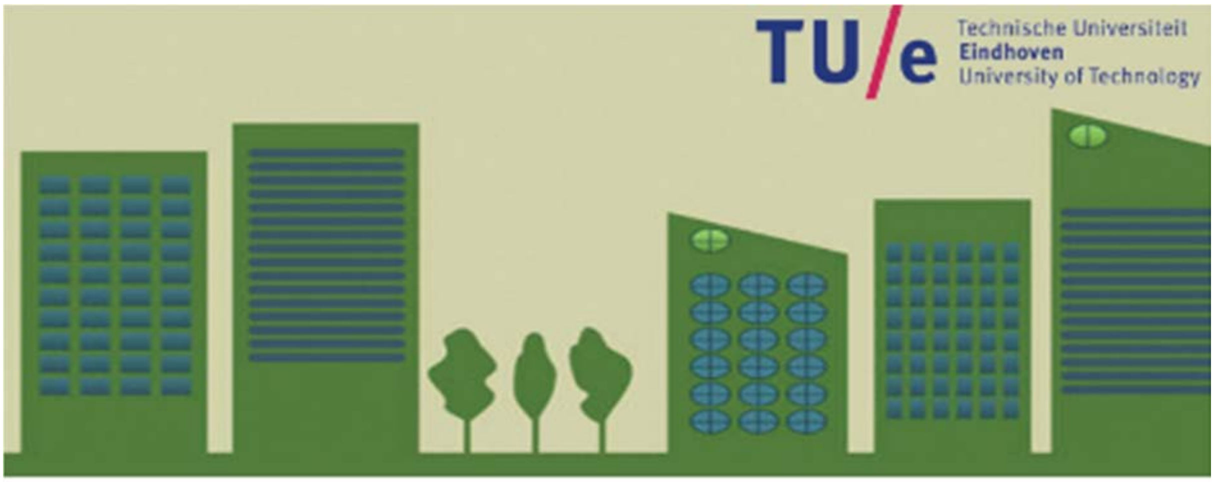
Module 3: Energie besparende maatregelen

Geef aan of u verwacht de onderstaande handelingen uit te voeren wanneer u in aanmerking komt met directe feedback.

	Nooit	Zelden	Af en toe	Vaak	Altijd	n.v.t
Uitzetten van de computer wanneer u deze langer dan 20 minuten niet meer gebruikt.	○	○	○	○	○	○
Het licht uitdoen wanneer u een ruimte verlaat.	○	○	○	○	○	○
Het licht uitdoen wanneer er voldoende daglicht binnenkomt.	○	○	○	○	○	○

« Vorige | Doorgaan »

83% voltooid



Energiebesparing voor kantoren

Module 3: Energie besparende maatregelen

Naast feedback als energie besparende maatregel is er ook nog een technische energie besparende maatregel die invloed heeft op het gedrag van de gebruiker, namelijk Power-Management

Bij de volgende vragen gaat het om of u wel of geen gebruik maakt van Power-Management en na welke tijd deze wordt ingeschakeld. Als u geen gebruik maakt van Power-Management of niet weet of u het gebruikt kies dan voor de optie n.v.t.

Als u gebruik maakt van Power-Management op uw desktop, na hoeveel tijd wordt deze ingeschakeld?

- ○ 15 minuten
- ○ 30 minuten
- ○ 45 minuten
- ○ 60 minuten
- ○ Langer dan 60 minuten
- ○ n.v.t

Als u gebruik maakt van Power-Management op uw monitor, na hoeveel tijd wordt deze ingeschakeld?

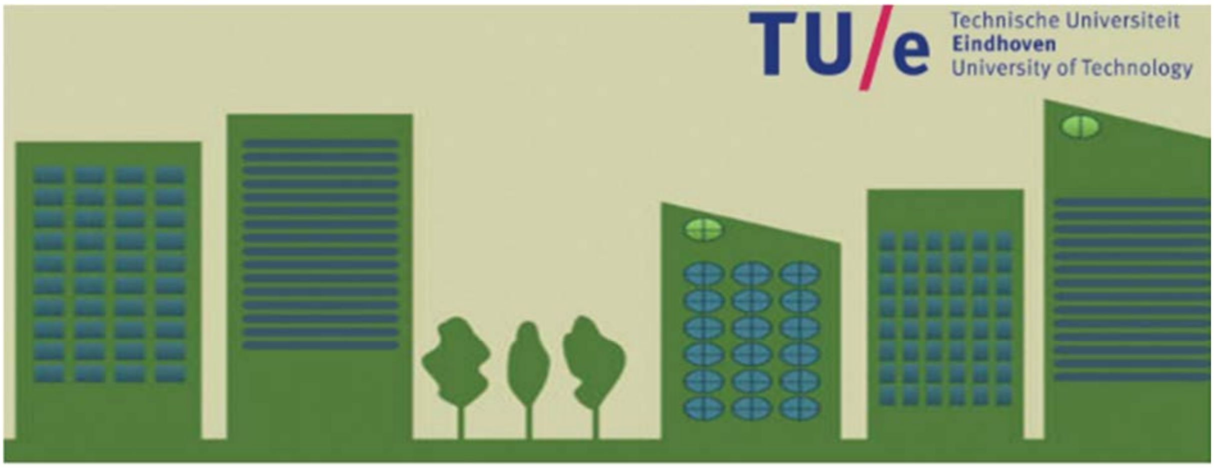
- ○ 15 minuten
- ○ 30 minuten
- ○ 45 minuten
- ○ 60 minuten
- ○ Langer dan 60 minuten
- ○ n.v.t

« Vorige | Doorgaan »

88% voltooid

Module 4: Socio-Demographic

The last module contains a set of demographic questions to form an image of the respondents who participated in this questionnaire.



Energiebesparing voor kantoren

Module 4: Persoonlijke kenmerken

Hieronder volgt een aantal korte vragen die betrekking hebben op u persoonlijke situatie. De door u ingevulde gegevens zullen vertrouwelijk worden behandeld en niet aan derden worden verstrekt.

Wat is uw geslacht?

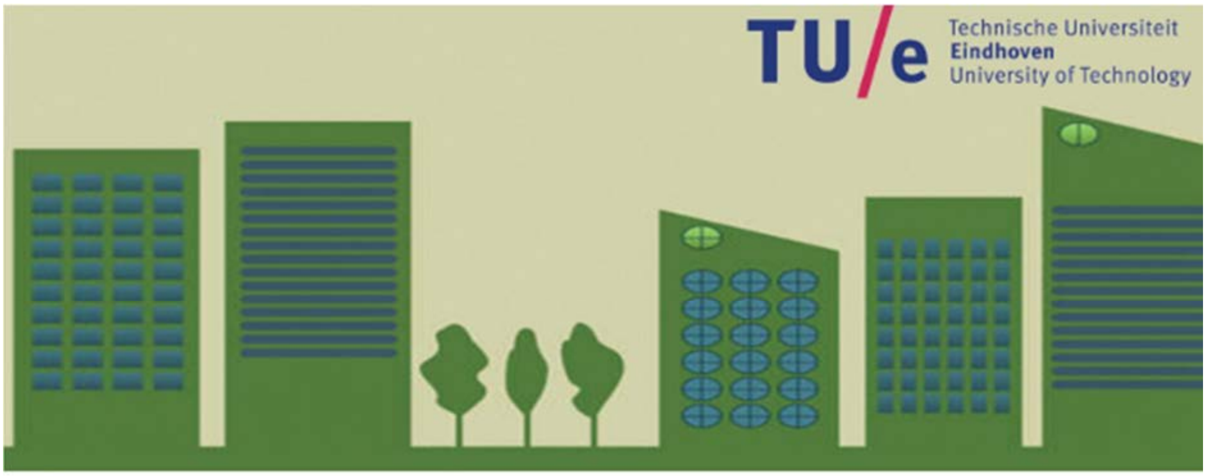
- Man
- Vrouw

Wat is uw leeftijd?

Wat is uw functie binnen de gemeente?

« Vorige | Doorgaan »

94% voltooid



Energiebesparing voor kantoren

Einde enquête!

Allereerst wil ik u nogmaals bedanken voor uw tijd en moeite om deze enquête in te vullen. Als u na het invullen van de enquête nog op en/of aanmerkingen heeft kunt u deze in onderstaande vak noteren.

Als u persoonlijk contact met mij wilt opnemen kunt u mij mailen naar het volgende adres: c.visser@student.tue.nl.

Met Vriendelijke Groet,
Christiaan Visser

Op- of aanmerkingen

« Vorige | Verzenden

Verzend nooit wachtwoorden via Google Formulieren.

100%: je bent klaar.

APPENCIX 4 – COMMENTS ON QUESTIONNAIRE

veel succes met je onderzoek.
In mijn geval heb ik zelf op mijn werkplek geen invloed op de verlichting die centraal geregeld is.
Wij werken in kantoortuinen. Dus de licht vragen zijn m.i. voor ons allemaal niet van toepassing. Maar hier zou wel bespaart kunnen worden
Licht wordt centraal geregeld (TL verlichting), deze is storend en zou echt wel uit kunnen, scheelt echt heel veel energie op jaarbasis. Ik werk op het werkplein maar ook op het stadskantoor speelt dit.
Vragen over licht (lampjes aan of uit) zijn niet van toepassing daar ik in een kantoortuin werk en geen directe invloed heb op het al dan niet aan/uitzetten.
Er is geen enkele vraag over bureaulampen of plafondverlichting. raar
Gebruik van energie wordt bijna volledig door de organisatie geregeld. Dit betekent dat er door de gebruiker weinig tot geen invloed uitgevoerd kan worden.
in een enquete vraagt men geen persoonlijke dingen waardoor me n kan weten wie de gevraagde is
makkelijk te lezen/interpreteren vind ik de vragenlijst niet.Denk dat menig een stopt met invullen.Hoop dat ik het fout heb. Succes.
Licht kan ik niet individueel aan uitzetten ivm kantoortuin. We hebben geen desktopcomputer, maar thin clients, maar dat kon ik niet invullen.
de werkplekken bevinden zich in een grote ruimte. hier is het licht niet afzonderlijk te regelen; alle lampen van de verdieping gaan tegelijkertijd aan of uit.
Waarom kan ik in een gebouw met 9 verdiepingen maar uit 4 verdiepen kiezen ????
De meeste mensen hebben geen PC meer maar een tin client (Virtuele pc). Die verbruiken niet veel stroom. Verlichting wordt voor de hele verdieping aan of uitgezet. En niet per sector. Zodoende blijft het licht altijd aan.
Ik werk op de 7e verdieping. Dit was geen keuzeoptie. De vragen mbt verlichting zijn n.v.t. De verlichting wordt per verdieping geregeld. Alleen de eerst of de laatste van de verdieping hoeft dus de verlichting aan of uit te zetten.
Naast energiebesparing is volgens mij ook waterbesparing aan de orde.
veel vragen over energiebesparing licht, terwijl dit door de kantoortuinen niet zelf beïnvloed kan worden
berichten per e-mail zijn niet effectief, we krijgen zoveel e-mail per dag. Liever 'n bericht op 't scherm als comp opstart. Na 20 min op standby is goed idee.
Ik deel mijn werkplek met 40 andere medewerkers. Het licht staat dus altijd aan. De computer uitzetten ga ik hier niet doen: het opnieuw opstarten kost 5 minuten, oftewel veel te lang en is inefficiënt.