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Comprehensive modelling of energy use in households.
An Agent Based case study on potential behavioural and technical measures towards an energy neutral urban environment.

by
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“Whatever you are doing, in your job or study, from now on combine it with the concepts of ‘nature’ and ‘future’. This is our task for the coming century, and where the bag of money is.”

- N.M. Groeneveld -

Voor Geert, Huib en Roelfke.

In the spirit of Daniel,
carpe diem.

PREFACE

The thesis lying before you is the closing chapter of my Construction Management and Engineering (CME) Master course, followed at the Technical University of Eindhoven. The research was conducted as part of the KENWIB initiative for the municipality of Eindhoven. And has been performed in cooperation with de Twee Snoeken in the period of January - August 2010.

Following the Masters course of CME, and especially completing my Master thesis has been an interesting journey in which I have learnt a lot. Before I begin the reporting of the actual thesis, I want to thank several people without whom I would never have succeeded.

First, I would like to thank my parents, my sister and my girlfriend for always believing in me, supporting me and correcting my numerous spelling mistakes. I want to thank all my friends, for refuelling my energy through snowboarding, wasdag, coffee breaks and all the other small moments that make life so enjoyable.

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Finally I would like to thank my current employer, Hendriks Bouw & Ontwikkeling for giving me the opportunity to fulfil my CME Master course.

Cyrille Pennavaire
Eindhoven, August 2010

SUMMARY

This research argues that everyday behaviour and lifestyle of occupants, dwelling characteristics, decentralised energy production methods and the sharing of excess produced energy have a significant influence on the energy use of households. Hence they form a serious energy saving potential to transform existing districts into an energy zero urban environment.

By making use of the Agent Based Simulation software platform of NetLogo, a computer model has been constructed that reacts to weather influences and simulates the energy use in households and the total energy use in a district on an hourly resolution scale. Through a unique approach, in which individual occupants are given a lifestyle that determines their home presence, and their day-to-day activities, a true micro-macro relationship exists that simulates the energy use of households. The dwellings in the model are complemented with technical characteristics that are based on the dwelling type and year of construction. Furthermore, the dwellings have the ability to produce energy with photovoltaics and share excess produced energy between neighbouring dwellings in their street or district.

The district of de Kruiskamp in 's-Hertogenbosch, serves as a case study to quantitatively test the effects of changes in occupant behaviour, dwelling characteristics, decentral energy production and energy sharing settings on both household and district level. Through a set of 10 simulations in which certain variables are adjusted and the outcomes are compared to a base case, the effects of the different adjustments are analysed and conclusions are drawn. The simulations contain adjustable settings for an occupant's temperature preference and its shower time length. For the U-values of a dwelling's facade, floor, roof and windows. The model also shows what the addition of 40m^2 of photovoltaics on every dwelling in the model can mean for the energy use of a household and of a district. By allowing dwellings to share excess energy with one another, the effect of a simple energy sharing network becomes clear.

Findings from the research include that changing occupant behaviour, such as setting the indoor temperature of a dwelling 1°C lower throughout a whole year can reduce the energy use of households by 6-10%, depending on the dwelling type. On a district level, the reduction on energy use can be more than 9%. Changing dwelling characteristics such as the U-value of the facade, floor or window are found to each cause a reduction between 4-22% in the energy use of households and cause a reduction of 14-15% in the energy use on a district level. Furthermore, producing energy decentralised through photovoltaics can reduce the energy use of a household by 7 - 19% or with almost 10% on a district level. Sharing excess energy between dwellings in the same street can mean an additional reduction of 1,8%, yet the sharing of excess energy on a district level only shows an additional reduction of 0,05%.

As this research is part of the KENWIB initiative, it gives insight into concrete measures that can be taken to transform existing urban districts towards energy zero urban districts. And emphasises the strengths of using an Agent Based Simulation approach as a research method for sustainable issues in which multiple fields of science are involved. Ultimately the model serves as a tool that gives insight into the effects of different adjustable variables on the energy use in households and total energy use in a district, which can serve as a good basis for future research.

CHAPTER 1 : INTRODUCTION

Within the province of Noord-Brabant, the urban environment uses some 17% of the total amount of energy. More importantly, table 1.1 shows the potential savings in energy use by the urban environment are estimated between 40% and 60%, or 25 and 59 Peta Joules (PJ) respectively. These potential savings in energy use indicate opportunities for the environmental, social and economical wellbeing of the region and should therefore be a major strategical focus area if the region is to become an energy zero urban environment by 2040. Due to the wide range of possible approaches that could effectuate these potential savings, it is important to examine the effects of these approaches. As a part of the KENWIB initiative, this research provides insights into approaches based on reducing energy demand and sustainable production of energy.

Eindgebruikers	Energie gebruik 2040 [PJ]	Extra potentiele besparing [%]	Extra potentiele besparing [PJ]
Huishoudens	63 - 98	40 - 60%	25 - 59
Diensten	73 - 108	40 - 60%	30 - 65
Landbouw	13 - 27	> 50%	6 - 14
Industrie	84 - 146	10 - 20%	8 - 29
Transport	73 - 126	20 - 65%	12 - 82
Totaal	***375 - 625***	***160 - 255%***	***83 - 249***

Table 1.1 - Primary yearly energy use according to end users and potential energy savings in Noord-Brabant (Source: SOLET report, 2008).

I argue, that a reduction in energy demand by households can be accomplished by changing the behaviour of individual occupants, improving the technical characteristics of existing dwellings, by adding decentral sustainable energy production methods or by sharing excess energy between households. Sustainable production of energy is quite possibly easier, cleaner and much cheaper on the long run then our conventional ways of energy production. Yet they cease to be adopted by the larger public although numerous products for alternative methods of energy production such as biogas, water, wind and solar are already available. One of the reasons for this expectant attitude towards sustainable energy production by both consumers and governments, is the high fluctuation rate in the amount of energy produced, which leads to a fluctuating supply of available energy. Combining this fact with a demand for energy by households that shows a great bandwidth and is influenced by human behaviour, makes this a complex problem. The forecasting of energy use by households is thus of increasing importance in order to assure a balance between energy supply and demand.

By making use of a case study, based on the district of de Kruiskamp in ‘s-Hertogenbosch, this research describes quantitatively how occupant behaviour, dwelling characteristics, photovoltaics and energy sharing affect the energy use of households and the total energy use of a district.

1.1 Area of research

Occupant behaviour has a significant impact on the energy use of households (Guerra Santin et al, 2009) and thus is an interesting field of research when considering effectuation of potential changes in energy use. When looking at preferred temperature settings and the preferred length of showering, one could argue that minimal changes in these could have a great impact on the total energy use of a district. Because an occupant’s behaviour is so difficult to simulate, there are no equations, methods, rules or models available to date that take it into account. Quite possibly,

any interpretation of human behaviour is subjected to broad discussion and maybe that is why so far no real attempts have been made. Especially models are lacking that simulate energy use on an hourly rate (Paauw et al, 2009).

Technical characteristics of dwellings, such as the U-values [W/m^{2}K] of facades, floors, roofs, and windows which describes the quality of isolation have a direct influence on the energy use for heating the dwelling. Since the energy use for heating makes up about half of the total energy use of a household (Itard et al, 2009), it is a necessary field of research when considering effectuation of potential changes in energy use. One could argue that improvements in the quality of isolation should have a great impact on the total energy use of a district. Although methods are present for calculating the statical energy use in dwellings, such as ISSO 51 and NEN 5128, dynamic models are lacking that simulate energy use in direct relation to the outside temperature.

Sustainable energy production methods such as photovoltaics or solar-heating are interesting with an energy source as abundant as the sun, which in theory produces 1000 times the total energy use of our entire planet. However in countries such as the Netherlands with a population density of 398 inhabitants/km^2, big solar power plants in the middle of districts are not necessarily the best option, or an option at all when considering high land prices. It is therefore more interesting to consider the option of photovoltaics or solar-heating on a decentral, dwelling-to-dwelling basis.

This decentralised approach uses less land area and since there are currently no straightforward methods for energy-storage, the producing dwellings could be connected into an energy sharing network to improve the amount of efficiently used energy that is produced. In such an energy sharing network they could share their excess produced electricity or heat with their neighbours on a street-level or district-level.

1.2 Relevance

It is important to know how the energy requirements of consumption patterns are established and why some households require more than others (Vringer et al, 2007). Only when we are able to predict with accuracy what the energy demand of a household or district will be at any given time, we can design our energy-network as efficiently as possible. As mentioned before, insight into effects caused by individual behaviour of occupants on total energy use is missing, and so it remains an unexplored area of research. Literature tells us that household characteristics and occupant behaviour play an important part in the spread of energy use by different households. However, it is not clear how big this part could be and there are few studies that have quantified this effect (Leidelmeijer et al, 2010; Itard et al, 2009; Haas et al, 1998).

Since households consist of different individual occupants living together, they influence one another, leading to a certain energy use behaviour. Changes in behaviour could be part of the solution for an energy zero urban environment. With better insights into the effect of this behaviour on the energy use of a household, we could determine how much behavioural changes could impact the household energy demand (Biesiot et al, 1999). These insights could also indicate sensitive parameters that are present in our current, calculation methods for energy use such as ISSO 51 and NEN 5128.

As a cause of the financial crisis of 2008, certain trends within the Dutch dwelling market have resulted. One of these trends is the approach to sell dwellings based on 'residential-charges' ('woonlasten'). The residential-charges approach aims to sell dwellings to clients, on the basis of a predetermined and transparent overview of costs. These are mortgage, energy and

maintenance. An accurate model for determining the energy use of different dwelling-household combinations could be a useful tool to predict accurately the monthly expenses of households that could be of great value for project developers and housing cooperations.

1.3 Problem statement

Although there is much knowledge about the effect of dwelling characteristics on energy use, the influence of individual occupant behaviour remains a shallow explored field of research. Efforts are being made to create an "energy pattern generator" (Paauw et al, 2009) based on different household types and many literature sources describe the need for such models due to the significant effect of individual occupant behaviour on energy use. However, my research indicates, there are currently no models available that calculate the energy use of a household based on the combination between dwelling characteristics and behaviour of individual occupants, and so the first research question is:

> **RQ1**: Is it possible to build a model that determines the energy use of a household based on the interplay between dwelling characteristics and individual occupant behaviour?

Then, by using adjustable variables in the model (concerning individual behaviour of occupants, dwelling characteristics, photovoltaics, energy sharing), the effect of changing these variables on the energy use of households will be tested through a series of simulations. By making use of a case study that is based on the existing district of de Kruiskamp in 's-Hertogenbosch, the results from these simulations become hard output data that will indicate potential measures towards an energy neutral urban environment. This results in the following additional research question:

> **RQ2**: How can we optimise the transformation of an existing district into an energy zero urban environment?

In order to find an answer to RQ2, I will answer the following subquestions:

> RQ2a: What is the effect of individual occupant behaviour, such as preferred indoor temperature and shower length, on the energy use of a household and on the total energy use within a district?
>
> RQ2b: What is the effect of dwelling characteristics such as U-values for facade, roof, floor and windows on the energy use of a household and on the total energy use within a district?
>
> RQ2c: What is the effect of adding photovoltaics to individual dwellings on the energy use of a household and on the total energy use within a district?
>
> RQ2d: What is the effect of creating an energy sharing network between individual dwellings on the energy use of a household and on the total energy use within a district?

1.4 Research method

After extensive research, I have chosen to use an Agent Based Simulation (ABS) approach to build the research model. By using an ABS approach, the influence of adjustable variable settings can be tested directly within the model (Wilensky et all, 1999). In other words, changing variables on a occupant-level will result in quantitative different outcomes for total energy use on a district-level.

The multi disciplinary nature of sustainability issues makes them highly complex. It also means they cannot and should not be solved by incorporating one single field of science. In order to find valuable solutions for these issues, there should be an interdisciplinary approach, i.e all sciences should have a say (Boulanger et al, 2005). I reason that an Agent Based Simulation (ABS) approach provides a fruitful method in which all fields of science complement each other. ABS has the potential of combining various kinds of knowledge from various scientific disciplines in different time spans and from different institutional and ontological levels, leading to solutions that show a high degree of sophistication and real life reflection.

Another reason to use ABS software, is that it enables its users to explore real connections between micro-level behaviours of individual agents and macro-level patterns that emerge from their interactions (Tisue et al, 2004). This is especially true when trying to draw conclusions on the influence of variables such as shower length, preferred indoor temperature, better isolation of floors, facades and roofs or better windows. By using the ABS model, I will be able to simulate the effect of these variables on the energy use of a household and the total energy use of an entire district in such a way that outcomes can be compared directly with one another (Wilensky, 1999).

The nature of ABS lets it bypass most mathematical jargon and instead simulates scientific hypotheses or even common knowledge directly. Without any prior mathematical translations, ABS allows for an intuitive representation of the environment and of the embedding of agents in a spatial and natural setting (Boulanger et al, 2005). Because ABS is a fundamentally stochastic approach, it can make room for and manage uncertainties. Also, due to the realism of the representation of the agents and the environment, the ABS method may promote the appropriation of the model by stakeholders and, therefore, their participation.

Conceptual model

The ABS model will be based on the conceptual model shown in figure 1.1, which shows the most important principles that influence energy use of households within this research.

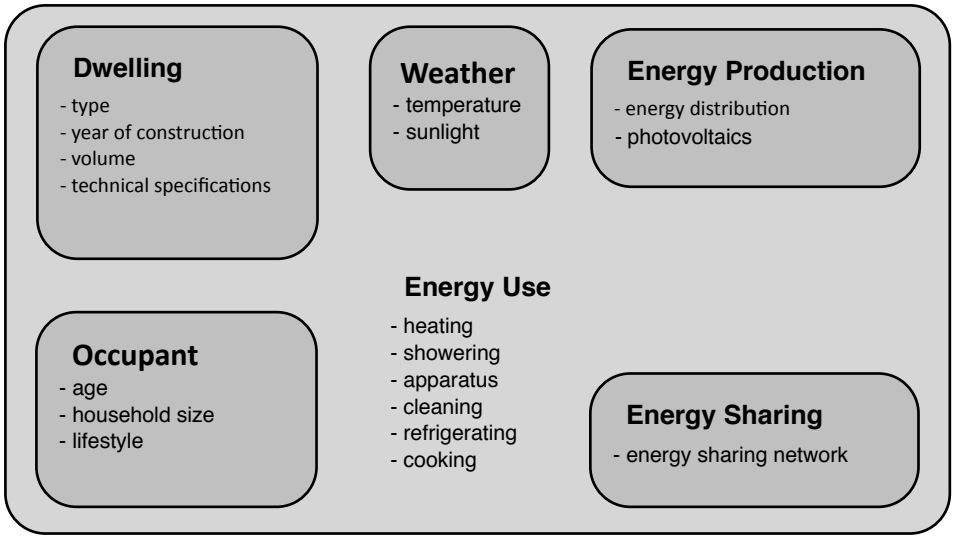


Figure 1.1 - Conceptual model of energy use and influencing factors used in this research.

The age, household size and lifestyle of an occupant determines its energy use for heating, showering, apparatus, cleaning, refrigerating and cooking and therefore are parameters in the model. Dwelling characteristics such as type, year of construction (y.o.c.), volume and technical specifications such as the U-values for the windows, facades, floor and roof determine the majority of a dwelling's energy use for heating and are therefore parameters within the model.

The model does not include installations, such as the central heating system or boilers of the dwellings. Since outside temperature plays an important role in the energy use for heating a dwelling, and sunlight is important when considering energy production by photovoltaics, these are taken into account in the model by making use of KNMI data. By connecting dwellings into an energy sharing network, they can share their excess produced energy amongst each other.

From this conceptual model, it should be clear that energy use is caused by the interplay between dwelling and occupant(s), additional energy production and energy sharing, and weather influences.

1.5 Personal motivation

While reading the book "The social atom" (Buchanan, 2007) I came across the existence of so called "power-laws". A power-law is a special kind of mathematical relation between two quantities that occurs in many different fields of science such as physics, computer science, linguistics, geophysics, sociology and economics. Much of the recent interest in power-law distributions comes from the study of probability distributions, which considers the frequency of extreme rare events like stock market crashes. These extreme events happen more often than one would assume (Mandelbrot, 1963).

A power-law is described as follows: "when something is shared among a sufficiently large set of participants, there must be a number k between 50 and 100 such that k% is taken by (100 − k)% of the participants." (wikipedia.com)

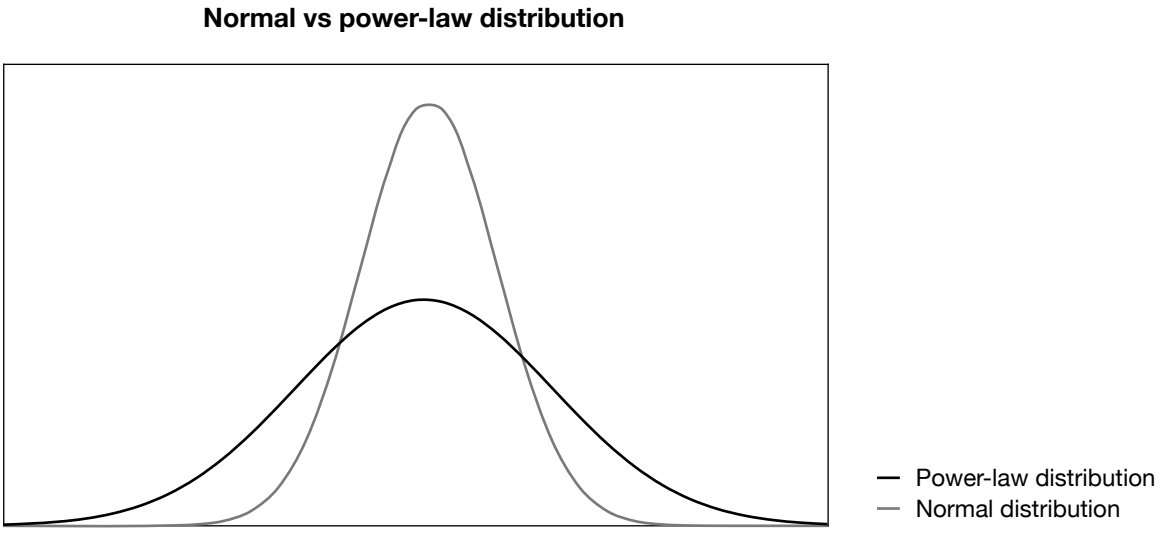


Figure 1.2 - Power-law and normal distribution (Source: Buchanon, 2007).

As can be seen in figure 1.2, in a power-law distribution, extreme values occur more often than in a normal-distribution. Also the tails in the power-law distribution play a more significant role than is the case in the normal-distribution.

The best known example of a power-law is the "Pareto-principle", also called the "80-20 rule", which was discovered in 1906, by the Italian economist Vilfredo Pareto. Pareto noticed that 80% of Italy's wealth was owned by 20% of the population. He then carried out surveys on a variety of other countries and found to his surprise that a similar distribution applied. From recent research, we know power-law distributions describe a wide variety of natural and manmade occurring phenomena such as frequencies of words in most languages, frequencies of family names, sizes of

craters on the moon, the power of earthquakes, the number of inhabitants in cities and the popularity of music and books. The Coulomb force and gravitation are also described by power-laws.

What have power-laws to do with this research? I reason, that due to the interplay between dwelling and household, the differences in individual behaviour, age and household size, energy use is more likely to be spread according to a power-law distribution than according to a normal-distribution, which is implicated by the term 'average energy use', found so often in literature. The presence of such a power-law distribution in energy use would mean individual behaviour makes extreme values of energy use occur a lot more often than one would think (Mandelbrot, 1963). And when looking at Paretos' law, this could furthermore imply a 80-20 principle, in which a minority of people are responsible for a majority of the total energy use within a district. Measures towards potential savings in energy use should therefore be aimed at the minority of the households which are responsible for causing the majority of the energy use.

1.6 Goals and product

The goals of this research are:

- Complement models of buildings and districts with human behaviour.
- Gain insight into the energy use of occupants.
- Especially gain insight into the influence an occupants individual behaviour on micro-level can have on macro-level.
- Gain insight into the effect of dwelling characteristics on total energy use.
- Gain insights into the effect of alternative energy production with photovoltaics.
- Gain insights into the effect of establishing an energy sharing network between dwellings.
- Gain insights into the bandwidth of energy use within households.

The product of this research will be a model that has the capability to simulate real micro-macro relations between dwellings, occupants and the total energy use of an entire district. The model should give clear insights into the effect certain variables can have on the energy use of households, and the effect they have on the total energy use within a district. This model could also serve as a tool for future research. It should be clear that the model can be extended with any form of decentralised energy production apparatus such as solar-heating, biomass, use of excess heat from factories, wind-power and water-power.

1.7 Expected results

By using an ABS model that combines energy use of households due to dwelling characteristics and occupant behaviour, and is extended with decentralised energy production, this research is exploratory. It aims to gain insights into the effect occupant behaviour, dwelling characteristics, energy production and energy sharing can have on energy use. It also provides insights into the way alterations of these variables affect energy use on both household and district-level. The expected results are:

1. Small changes in individual behaviour on a micro-level can have a great effect on the total energy use on a macro-level. Setting one's preference temperature 1°C lower or showering 5 minutes less, can have a significant impact on the total energy use of a district. Changes in individual behaviour can therefore be part of the solution towards an energy zero urban environment.

2. Changes in a dwelling's technical characteristics on a micro-level can have a great effect on the total energy use on a macro-level. Improving the isolation of a dwelling's floor, facade, roof, or improving the U-value of a dwelling's windows can have a great impact on the total energy use of a district. Improving these characteristics could therefore be part of the solution towards an energy zero urban environment.

3. Adding alternative decentralised energy production methods such as photovoltaics to existing dwellings will lead to a decrease in energy use by households for certain periods of the year. However not all the energy produced will be used effectively.

4. Creating an energy sharing network between dwellings in the same street or in the same district will lead to a decrease in energy use. By doing so, the energy produced will be used as efficiently as possible and the effect on the total energy use of a district should therefore be greater.

5. Furthermore, individual differences in behaviour and lifestyle will lead to a very wide bandwidth in energy use of households. When analysing the results for energy use on a dwelling-level, these might show a power law distribution, which implicates that X % of the total households are responsible for 100-X % of the total energy use. This means that only a small minority of households is responsible for the majority of the energy use.

1.8 Structure of the thesis

After this introduction chapter, the principles of the model are described, which are based on literature research in chapter 2. Then, in chapter 3, the agents and their interactions in the model are identified and UML diagrams are made. Chapter 4 explains the programming behind the model is as well as all the variables of the model. Chapter 5 describes the case study of de Kruiskamp, the data-set that was used and gives a description of the simulations done with the ABS model. Also the results from the individual simulations are presented and described in chapter 5. In chapter 6, the results are discussed and the final conclusions of this research are drawn. After this, I have made some interesting discussion points in chapter 7.

CHAPTER 2 : PRINCIPLES OF THE MODEL

In the previous chapter, the conceptual model for energy use has been presented. Before we start programming the ABS model, this chapter describes the four principles of the model; Occupant behaviour, dwelling characteristics, energy production and energy sharing into more detail.

2.1 Occupant behaviour

Occupant behaviour has a significant impact on the energy use of households (Leidelmeijer et al, 2010; Guerra Santin, 2009; Pauw et al, 2010). It could thus play an important role in reaching an energy zero urban environment. For example, preferred indoor temperature, lighting levels, use of appliances, shower length and frequency are all determined by the 'lifestyle' of occupants.

In order to determine energy use behaviour of occupants, one could create 'clusters' (Raaij and Verhallen, 1983; Leidelmeijer et al, 2010) or 'energy user profiles' (Pauw et all, 2010). Since these approaches are based on predetermined household composition, they do not incorporate individual occupant behaviour such as going to work, taking a shower, doing the dishes or watching tv. One could argue the 'true' behaviour of individual occupants is not taken into account and hence these approaches do not provide a realistic mapping of energy use within a household or districts.

In order to model the energy use behaviour of households I have looked at individual people as "social atoms". One of the primary behavioural characteristics of the social atom is acting on the basis of simple rules (Buchanan, 2007). I have therefore chosen to adopt the approach of 'activity-patterns' (Papakostas et al, 1997). By making use of activity-patterns, all occupants in the model will have a simple daily schedule that determines whether their location is "home" or "away".

If an individual occupant is "home" it can do certain activities which cause energy use. I have adopted an approach in which the behaviour of individual occupants is determined by a given 'lifestyle'. On a resolution scale of one-hour intervals, this lifestyle determines what activities individual occupants do and when they do them. Since all occupants in the model make these decisions individually and on every hour of the day, a highly complex system arises. Each activity done by the occupant has a specific energy use. Adding up the energy use of different activities done by individual occupants will result in the total energy use of a household.

2.2 Dwelling characteristics

Where occupants use energy to do activities, the characteristics of a dwelling directly influences the energy use for heating, and thus determines the greatest part of the total energy use of a household. For example, a dwelling type with a lower degree of facade isolation will lose heat more easily than a dwelling with a high degree of facade isolation. From literature we know the energy use for space heating ($Q_{prim;verw}$) is a good indicator for energy use for heating (Itard et al, 2009). To calculate the energy use for heating with $Q_{prim;verw}$ we need to know the outside temperature, and the technical characteristics of the dwelling.

The outside temperature within the model is based on the KNMI data-set from measuring station 370: Eindhoven. Since the intention is to compare the final result from simulation done with the model with results from real life data, and this data is more likely to be available for the year 2009, I have chosen to use the numerical values for outside temperature from the KNMI data-set of the year 2009.

The technical characteristics of dwellings in the model are its surface area and the ability of the surface areas to transfer heat. The ability to transfer heat is represented by a so called "U-value" [W/m^{2}K]. The higher the U-value, the more easily heat can be transferred. Transferred heat will be lost to the outside environment, which will result in a higher energy use to compensate this heat loss. Since the energy use for heating is calculated with $Q_{prim;verw}$, specific numeric values for a dwelling's facade area, roof area, floor area, window area and also their corresponding U-values are needed. However, measuring these areas by hand for single dwellings is beyond the scope of this research, and thus data from Reference Dwellings (SenterNovem, 2007) is used in the model.

The data of reference dwellings from SenterNovem consists in total of 27 different main dwelling types. I have included the sub dwelling type 'hoek-woning' in addition to the 27 main types of dwellings, since this specific type of dwelling makes up a significant part of the Dutch building stock (SenterNovem, 2007).

Dwelling type	number of building periods
'vrijstaande-woning' > 150m2	3
'vrijstaande-woning' < 150m2	3
'2^1kap-woning'	3
'rij-woning'	6
'hoek-woning'	6
'maisonette'	3
'galerijf-lat'	3
'portiek-flat'	3
flat'	3
Total	***33***

Table 2.1 - The different dwelling types within the model and the number of construction periods (Source: SenterNovem, 2007).

Table 2.1 shows the total of 27 + 6 = 33 different types of dwellings. They are categorised according to dwelling type and year of construction. Of all these individual dwelling types, specific numerical values are available for ground floor, roof, facade and glass areas [m^2] and their corresponding U-values [W/m^2]. An example of these specific numerical values for a '2^1kap-woning' can be seen in table 2.2.

2^1Kap woning'	Bouwjaar < 1966		Bouwjaar 1967-1988		Bouwjaar 1989-2010	
	opp [m²]	U-waarde [W/m²K]	opp [m²]	U-waarde [W/m²K]	opp [m²]	U-waarde [W/m²K]
Begane grondvloer	52,2	2,44	54,0	1,10	54,0	0,38
Dak hellend	73,8	0,47	76,4	0,68	76,4	0,38
Dak plat	0	0	0	0	0	0
Voorgevel gesloten	15,7	1,89	16,0	0,65	16,3	0,40
Voorgevel glassoort 1	3,1	5,10	2,6	5,10	0,3	5,10
Voorgevel glassoort 2	4,7	3,10	5,6	3,10	7,7	3,10
Achtergevel gesloten	15,7	1,89	16,0	0,65	16,3	0,40
Achtergevel glassoort 1	3,1	5,10	2,6	5,10	0,3	5,10
Achtergevel glassoort 2	4,7	3,10	5,6	3,10	7,7	3,10
Zijgevel gesloten	71,6	1,89	70,8	0,65	70,8	0,40
Zijgevel glassoort 1	2,2	5,10	2,0	5,10	0,2	5,10
Zijgevel glassoort 2	3,2	3,10	4,2	3,10	5,9	3,10

Table 2.2 - Specific numerical values for area and U-values (Source: SenterNovem, 2007).

Within the model, the values for the area and U-value of all 33 types of dwellings are mapped automatically onto dwellings that appear in a given data-set. When the model generates a dwelling, it will automatically map the numeric value for the surface area and the corresponding U-value onto the correct dwelling. These variables can then be used to calculate the energy use for heating the dwelling with the following formula:

$$Q_{prim;verw} = Q_{verlies} + \eta_b \cdot Q_{winst} \qquad \textbf{(i)}$$

in which:

$Q_{wb;verw}$	heat need for space heating	[MJ]
$Q_{verlies}$	heat loss through transmission and ventilation	[MJ]
Q_{winst}	heat gain through sunshine and internal heat sources	[MJ]
η_b	utilisation factor of heat gain	[-]

<u>Note</u>

Within the SenterNovem data-set, there exist four types of states a dwelling can have: original, current, comfort and comfort +. These tell us something about the state of technical characteristics for double glazing, isolation, installations, etc. For the model I have chosen to use only the 'current state' of the 32 types of reference dwellings.

The geometry of the Reference Dwellings by SenterNovem[1] are based on an analysis of dwellings from the KWR database. From this analysis a theoretical 'average' geometry has been made, which is representative for the dwelling type and year of construction.

1 For more information see: 'Verantwoording en keuzes' (2007), Senter Novem.

There might be a big difference in theoretical and practical values, especially for U-values due to practical building faults, such as using the wrong type of isolation material or the creation of chinks (Haas et al, 1998; Vringer et al, 2007).

2.3 Energy production

Along occupant behaviour and dwelling characteristics, decentralised energy production methods and especially photovoltaics, could also play a significant role in creating energy zero urban environments. Since there already exist an electricity network, excess produced energy from photovoltaics could also be shared amongst households. In order to measure the effect of decentralised energy production, dwellings in the model will be complemented with photovoltaics that produce energy out of sunlight. In section 2.4 the possibilities will be discussed to share excess produced energy in the model between dwellings in their street or district.

Photovoltaics represent a rapidly growing, innovative industry. In August 2009, Spectrolab, a daughter company of Boeing announced the most efficient solar cell yet. They claimed to transfer 41,6% of concentrated sunlight into electricity. Although the solar cell costs USD 0,40 per watt, and this might be too expensive for now, solar energy is by far the fastest price declining energy source available (de Ridder, 2010), and sunlight is free.

With solar technology taking such a flight, and companies such as Google doing serious investments in solar farms equipped with Heliostats, it seems plausible to believe photovoltaics will accommodate a large part of the energy needs in the near future. Especially in densely populated countries such as the Netherlands, where land is scarce and expensive, decentralised energy production might be a logical, and perhaps the only choice.

Although the Netherlands, with its many cloudy days, might not sound as a profitable photovoltaic market when considering energy production, the unrealised market share of solar powered technologies in the Netherlands is huge. According to the SOLET report for the Province of Noord-Brabant by (van Kasteren et all, 2008), the solar energy potential is “enormous”. And so far only 0,06% of the technical potential has been realised. When looking at table 2.3, one should conclude that by putting solar energy-systems on all existing roofs in Noord-Brabant, 55,2 PJ of electricity or 154,5 PJ of solar heat could be produced.

Bron	Technisch potentieel [PJ/jaar]	Gerealiseerd [PJ]
Zon: Warmte [b]	154,5	0,1
Zon: Elektriciteit [b]	55,2	0,0001
Biomassa [a]	21,6	11,0
Wind	2,3	0,2
Afval	8,4	6,0
Waterkracht	0,1	0,1
Totaal	***242,1***	***17,4001***

Table 2.3 - Yearly values for technical and realised potential sustainable energy sources for the province of Noord-Brabant (2007).
[a] Taking biomass residues into account. [b] Application of solar energy-systems on existing roof area. (Source: van kasteren et al, 2008).

Solar energy production methods are a good alternative to oil dependent production methods or terrorism viable production methods such as nuclear or conventional power plants. One should

keep in mind however, that currently the biggest problem for the photovoltaic industry is the shortage of production-facilities. Perhaps this creates opportunities for the Brainport region where many production facilities of Phillips have shown an abatement of activity in recent years.

Also, the technology for producing photovoltaics is for 95% similar to that of producing computer chips (de Ridder, 2010). ASML, which originated and still remains in the Brainport area, is one of the worlds biggest producers of the complex machinery needed for producing these computer chips. Combining these two facts, one could argue the region of Noord-Brabant has a great opportunity in the near future to profit from the growing photovoltaic industry.

Solar energy is already a sector with 20 billion in revenues and has a yearly growth of 40% (De Ridder, 2010). In comparison, the top ten companies by revenue at the moment have a yearly revenue of $ 2 750 billion (wikipedia.com). Figure 2.1 shows that if it keeps growing as fast as it is (and it most likely will), that within 15 years time (around the year 2024) the solar energy market will have a higher revenue than these top 10 companies combined. However, the top 10 companies by revenue of this moment is dominated by oil companies with 7 out of 10, which could indicate a reserved attitude towards the photovoltaic technologies. It could also mean a shift in business for these top 10 companies on the longterm.

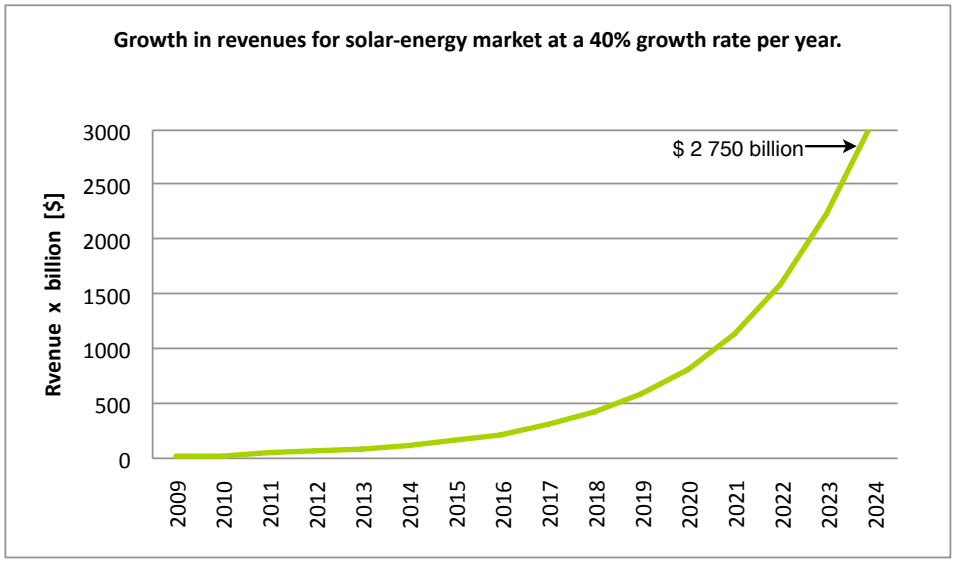


Figure 2.1 - Growth in revenues for the solar-energy market at a 40% increase rate per year (Source: de Ridder, 2010)

The development of photovoltaics follows an exponential growth that resembles Moore's law. According to this law, photovoltaics with an efficiency twice as high as todays photovoltaics will be available in 1-2 years time (de Ridder, 2010). Solar energy is thus one of the most promising technologies for sustainable energy production and it can also be easily applied on a dwelling level. Also since photovoltaics transform sunshine into electricity and there already exists an electricity network, this form of decentralised energy production seems plausible. Therefore I have chosen to complement the ABS model with photovoltaics that convert sunshine into energy on an individual dwelling level. The amount of sunshine, or solar intensity within the model is based on the KNMI data-set from measuring station 370: Eindhoven. Since the outside temperature comes from the same data-set, I have chosen to use the numerical values for Solar Intensity from the KNMI data-set of the year 2009.

2.4 Energy Sharing

From the previous section we know that energy production in the model will be accomplished through the use of photovoltaics on an individual dwelling-level. For this research I have assumed, excess produced energy cannot be stored, and would thus flow away and be wasted. A simple solution for this one's be to connect dwellings into an energy sharing network and use excess energy from other dwellings to satisfy one's energy-need. When taking into account practical limitations of the existing electricity network, this might seem unachievable. But the real problem of energy sharing between dwellings is the monopolistic structure of the distribution market for energy.

Within any given area in the Netherlands, only one company is responsible for transporting electricity. Electricity created by decentralised energy production methods, such as photovoltaics may not be transported via the network to another user directly. Instead, the produced energy must first be transported back to the electricity company. This means that currently, a dwelling with photovoltaics on its roof cannot share excess energy with its neighbour directly. Instead, the energy is delivered back to the electricity company, which could be several kilometres away, before the electricity is delivered back to the location of one's neighbour. The electricity thus travels a long distance (two times) for no apparent 'logical' reason and with all sorts of losses as a result (SenterNovem, 2007).

Also, electricity that is produced decentralised is bought by the electricity company 30% below the market price. For households, only the first 5 000 kWh of decentralised produced electricity receives this price of 30% below market value. When a household produces more than 5 000 kWh, they receive an even lower price. The reduced fee for larger amounts of decentralised produced electricity is partly explained by the unpredictability of the supply of this type of electricity. As a result, decentralised produced energy is less profitable and therefore less attractive (SenterNovem, 2007).

However, I argue the attractiveness of such energy sharing networks will increase in the future. Certain conditions must be met before such a system could work as an electricity network that provides the possibility of sharing energy with any other dwelling. Since humans are good adaptors, and one of the things we adapt to most frequently is other people (Buchanan, 2007). One could argue that within a few years time, all dwellings will have decentral energy production methods which are connected into an energy sharing network. The 'revolution' this would cause could be compared to the mobile phone revolution. Where it was no use having a mobile phone as an early adopter, since none of your friends had one, it became more attractive once more friends owned a mobile phone. The same could hold true for decentralised energy production via an energy sharing network: it is only interesting if many more people join in.

CHAPTER 3 : DESIGNING THE NETLOGO MODEL

From chapter 2 we know what the principles for the ABS model are. In this chapter I will explain why the NetLogo software platform has been chosen, how the NetLogo model is constructed, what agents exist and how these agents interact with each other.

3.1 The NetLogo platform

From literature research a number of possible ABS platforms have been identified. These are mainly based on the findings from (Railsback et al, 2009). This paper compares the MASON, objective-C Swarm, Java Swarm, NetLogo and Repast platforms with each other on more than a dozen characteristics. A simple representation of this can be seen in table 3.1. After the literature research concerning Agent Based Simulation software, NetLogo seemed to fit this profile best and will be used to program the model of for this research.

Platform	Ease of use	Execution speed	Hard coding
MASON	+	++++	++++
C-objective Swarm	++	+	+++
Java Swarm	++	+	+++
NetLogo	++++	++	+++
Repast	+	+++	++++

Table 3.1 - differences between ABS platforms (Source: Railsback et al, 2009).

NetLogo has been developed from grounds up for complex systems research and has been used for modelling and simulating complex systems such as social simulations, biological systems and file sharing networks. Also NetLogo has a strong ability to model problems based on human abstractions rather than purely technical aspects (Niazi et al, 2009) and thus makes it a useful platform for modelling occupant behaviour. The current version of NetLogo is 4.1, which demonstrates the stability of the software as well as its active development. It runs on the Mac, Windows and Linux platforms. Using the many code samples, the large models library, the documentation available[2] and the active user community[3], I was able to learn programming in NetLogo within 3 weeks.

In the NetLogo programming world there exist three different types of agents. There exist 'patches' which are places in a discrete toroidal grid space, 'turtles' that are the inhabitants of the NetLogo world and 'links' between turtles. Different 'breeds' of turtles can be defined, and different variables and behaviours can be associated with each breed. Also 'agentsets' or collections of agents exist, enabling the users to create sets of agents based on coordinates, color, size, or any other given variable. All turtles inside the world can be addressed in any conceivable way the user can think of and all agents can interact with each other to perform multiple tasks concurrently. In addition, the user can add user interface elements such as buttons, sliders, monitors and plots. In order to display an agent's variables in NetLogo, a probe is used by the 'inspect' function. It is also possible to create statistical output from the model such as histograms and line or area graphs. NetLogo provides simple primitives for opening and writing to output-

2 http://ccl.northwestern.edu/netlogo/docs/

3 http://groups.yahoo.com/group/netlogo-users/

files such as .txt and .csv file types. These file types can also be used to read a file containing input data.

NetLogo has a built in 'BehaviourSpace' tool for automating experiments. This tool enables the user to systematically test the behaviour of the model across a range of variable settings (Tisue et al, 2004; Railsback et all, 2006). However NetLogo is not open source, its capabilities can be extended with any Java written extension. For this research a csv-extension for NetLogo was written [4] and implemented successfully. When a model contains no more than 500 turtles, the execution speed of NetLogo is fast. (Railsback et al 2006) have found NetLogo to be 3-4 times slower than MASON and 1-2 times slower than Repast. Also execution speed of NetLogo depends specifically on the number of patches in the model.

3.2 UML class-diagram

Universal Modelling Language (UML) is a universal language for communicating in the programming world, and thus is very useful to explain the architecture of the NetLogo model. Figure 3.1 shows a UML class-diagram that contains the different classes (agents: patches and turtles), attributes (variables), associations (links) and aggregations (dependencies) that are present in the NetLogo model. This class-diagram is based on the conceptual diagram, but gives a higher detail level for the structure of the NetLogo model. In the model, an occupant and photovoltaics are always connected to a single dwelling. The dwelling is always connected to a single street-trafo and all street-trafos are connected to one district-trafo.

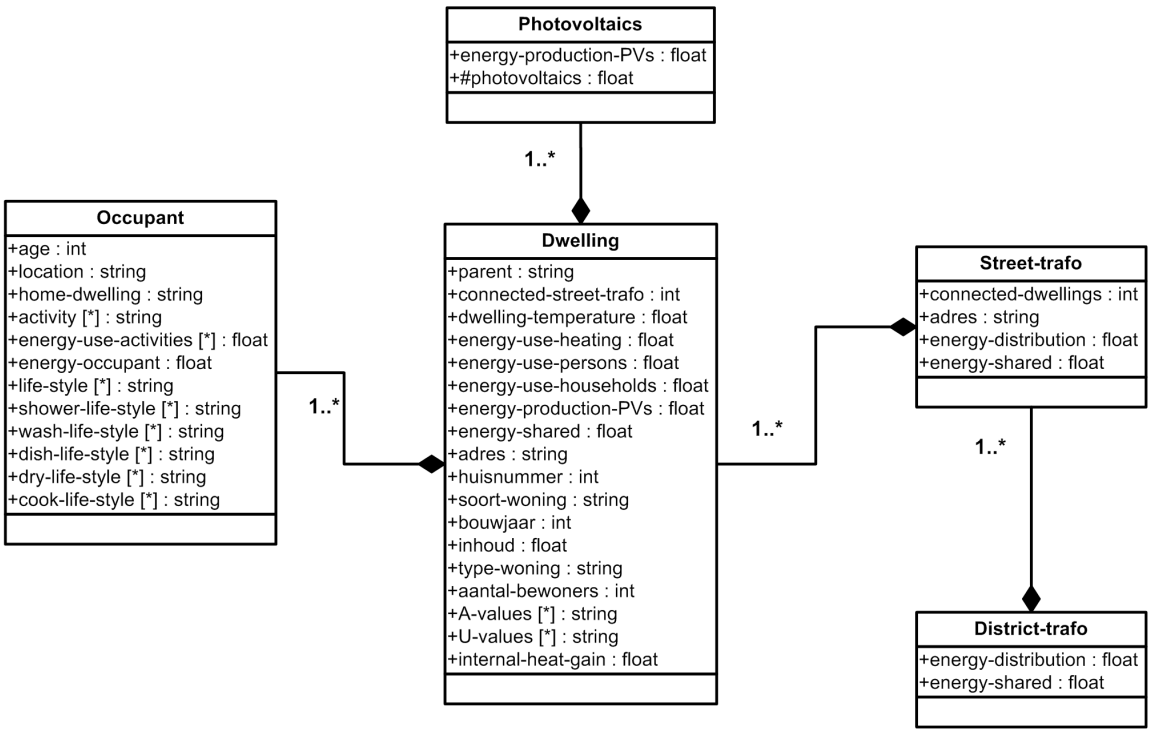


Figure 3.1 - UML class-diagram for the NetLogo model.

4 Many thanks to Ir. A.J. Jessurun of TU/e.

When combining all the agents described from the UML class-diagram, the NetLogo model will consist of: dwellings, occupants, street-trafos, district-trafos, photovoltaics and cables. Figure 3.2 shows the relations between the different agents in the model.

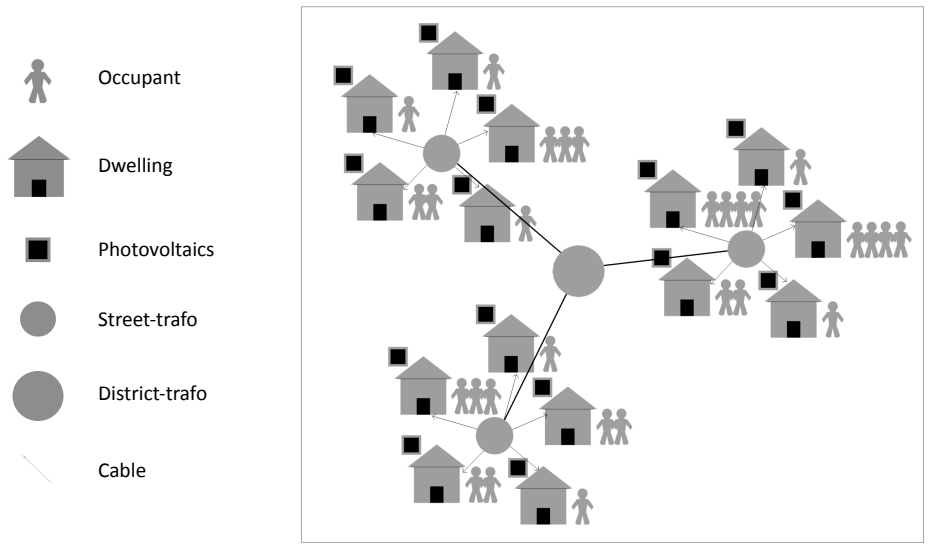


Figure 3.2 - Relation diagram showing the relations between the different agents in the NetLogo model.[5]

3.3 Agents

In order to be able to reproduce the model of this research, it is important to describe all agents, their different breeds, attributes and the working of the model. From the UML class-diagram in figure 3.1, we know the NetLogo model consists of the following agents:

5 However the figure 3.2 shows a finite number of agents (dwellings and occupants), in reality there can exist an infinite number of agents within the NetLogo model.

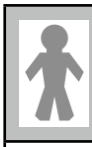
3.3.1 Dwellings

Dwellings

Dwellings form the basis of the model and have a number of occupants who live in them. A dwelling's colour can correspond to the year of construction, the household size or its type and can be preset in the model by the user.

Variable	Description
parent	The parent is the oldest occupant that lives in a dwelling. Since there are certain activities that have to be done for the entire household, it is the parent who does the activities "wash", "dishwash" and "tumbledry" for the entire household.
connected-street-trafo	This is the number of the street-trafo the dwelling is connected to.
dwelling-temperature	The current indoor temperature of the dwelling, set by an occupant that has location "home".
energy use-heating	The amount of energy [MJ] used by the dwelling for heating, dependent on the global variable for outside temperature and calculated with the formula: $Q_{wb;verw} = Q_{verlies} + \eta_b \bullet Q_{winst}$
energy use-occupants	The amount of energy [MJ] used by the occupants of the dwelling to do their activities.
energy use-household	The sum of energy use-heating and energy use-occupants of the entire household.
energy-production-pvs	The amount of energy [MJ] produced by the photovoltaics connected to the dwelling. The amount of photovoltaics [m^2] can be set by the user by altering the #photovoltaics variable setting.
energy-shared	The amount of energy [MJ] shared with other dwellings. A dwelling shares energy if its photovoltaics have an excess energy production, but only if the share-level variable setting is 'street-level' or 'district-level'.
adres	The address of the dwelling.
huisnummer	The house number of the dwelling.
bouwjaar	The year of construction of the dwelling.
inhoud	The volume of the dwelling.
type-woning	The dwelling type.
aantal-bewoners	The household size (occupants living in the same dwelling).
pers00-17, pers18-29, etc.	The number of occupants living in the dwelling from the given age range.
a-values	A list containing all facade, window and roof areas of the dwelling. These areas are mapped onto the dwelling according to its y.o.c. and dwelling type, and based on SenterNovem's Reference Dwelling (see table 2.3).
u-values	A list containing the U-values of the facade, window and roof areas of the dwelling. These u-values are mapped onto the dwelling according to its y.o.c. and dwelling type, and based on SenterNovem's Reference Dwelling(see table 2.3).

3.3.2 Occupants



Occupants

Dwellings have a number of occupants. Occupants have variables such as: age, location, activities, energy use and lifestyle.

Variable	Description
age	The occupants age, which is a randomly chosen number in one of the 5 age ranges.
location	The occupant's location which can be "home" or "away". If the set location is "home" the occupants activities will lead to energy use.
home-dwelling	The dwelling the occupant lives in.
aantal-bewoners	The household size of occupants living in the same dwelling.
#-apparatus	The number of apparatus the occupant is using on a certain hour-of-day.
activity-list	A list containing the activities the occupant is doing.
energy-use-activities	A list containing the amount of energy [MJ] the occupant uses when performing the activities from the activity list.
energy-occupant	The amount of energy [MJ] the occupant has used.
Life-style	All occupants in the model have a lifestyle. This is a list containing an occupant's values for temperature preference during day and night, the frequency of showering, the length of showering, the time of showering, the frequency and time for washing, dishswashing and tumbledrying and the time for cooking its breakfast, lunch and dinner.
shower-lifestyle	A list that holds the day-of-week numbers on which the occupant performs the activity "shower", when its location is "home".
wash-lifestyle	A list that holds the day-of-week numbers on which the occupant performs the activity "wash". Only parents perform this activity.
dishwash-lifestyle	A list that holds the day-of-week numbers on which the occupant performs the activity "dishwash". Only parents perform this activity.
tumbledry-lifestyle	A list that holds the day-of-week numbers on which the occupant performs the activity "tumbledry". Only parents perform this activity.
cook-lifestyle	A list that holds the hour-of-day numbers on which the occupant performs the activity "cook" (cooks its breakfast, lunch or dinner), when its location is "home".

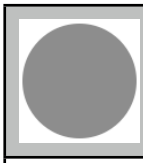
3.3.3 Street-trafos

Street-trafos

Based on their address, dwellings are connected to street-trafos. Street-trafos have variables such as: number of connected dwellings, energy distribution and energy-shared.

Variable	Description
connected-dwellings	The number of dwellings that are connected to the street-trafo.
address	The address of the street the connected dwellings belong to.
energy-distribution	The amount of energy [MJ] distributed to the street-trafo's connected dwellings. If photovoltaics exist in the model, the energy distribution will become lower, since a dwelling makes use first of the available energy production from its photovoltaics.
energy-shared	The amount of excess energy production [MJ], received from the connected dwellings and given to the district-trafo.

3.3.4 District-trafos



District-trafos

Street-trafos are connected to district-trafos. Within the energy sharing network of the model, district-trafos are the 'highest' energy producers in the district. The district-trafo distributes the energy needed within the system so that all dwellings can accomodate their energy use.

Variable	Description
energy-distribution	The amount of energy [MJ] distributed to the connected street-trafos. If photovoltaics exist in the model, the energy distribution will fall, since a dwelling makes use first of the available energy production from its photovoltaics. If energy sharing is set to the street-level, the energy distribution will fall even more, since street-trafos will make use first of the available energy-shared before 'asking' the district-trafos for energy distribution.

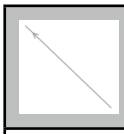
3.3.5 Photovoltaics

Photovoltaics

The agent Photovoltaic produces energy and is connected to a dwelling. The amount of energy produced is dependent upon the amount of Solar intensity received at the earth's surface.

Variable	Description
home-dwelling	The dwelling the Photovoltaic is connected to.
energy-production-Photovoltaics	The amount of energy [MJ] produced by the Photovoltaic. This amount is dependent upon the solar intensity global variable and the setting of #Photovoltaics [m^2].

3.3.6 Cables



Cables

The existence of cables allows agents to share energy between them. Cables are directed links that connect Photovoltaics to dwellings, dwellings to street-trafos and street-trafos to district-trafos.

Variable	Description
end1	The agent on end1 of the cable, this can be a dwelling, Photovoltaics, street-trafo or district-trafo.
end2	The agent on end2 of the cable, this can be a dwelling, Photovoltaics, street-trafo or district-trafo.

3.4 Variables

In the previous section we have seen what variables are 'owned' by the different agents in the NetLogo model. The numerical values of variables such as energy use are calculated by making use of other variables that are present in the model. In the model two types of other variables exist: 'global variables' and 'adjustable variables'. The global variables are necessary for the model to function. The possibility to create adjustable variables in our NetLogo model is the main reason this research is done using the ABS method. By adjusting the numerical values of these variables, their effects on energy use become quantifiable instantly. By choosing the adjustable variables carefully, we can test directly the effect on energy use caused by the four principles mentioned in chapter 2; occupant behaviour, dwelling characteristics, energy production and energy sharing.

3.4.1 Global variables

Global variables in NetLogo are variables that are necessary for the model to function and are accessible for all agents (turtles, links and patches). The following global variables exist:

<u>Temperature</u>
The temperature used in the model is from the data-set of the KNMI-2009. The values of the outside temperature are plotted on an hourly resolution scale. It is through this temperature that dwellings in the model calculate their energy use for heating.

<u>Solar Intensity</u>
The solar intensity used in the model is also from the data-set of the KNMI-2009. Also these values are plotted on an hourly resolution scale. It is through this solar intensity that Photovoltaics in the model calculate the amount of energy production which can be used by households.

<u>Hour-of-day</u>
The hour of the day which can have the numerical value of 0-23. The hour-of-day is used in the occupants activity-pattern which determines the location of the occupant.

<u>Day-of-week</u>
The day of the week, which can have the numerical value of 1-7. The day-of-week is used in the occupants lifestyles, which determine on what day of the week the occupant does certain activities.

<u>Locations</u>
There exist two locations in the NetLogo model: "home" and "away". If an occupant's location is set to "home" it will move to its home-dwelling and "do-activities". If the location is set to "away", it will move on one of the away-patches.

<u>Activities</u>
This is a list containing all the activities an occupant may perform if he performs the "do-activities" procedure. For each activity performed, there exists a corresponding energy use. These are explained into more detail in chapter 4.2.2 (shower), 4.2.4 (wash, dishwash, tumbledry), 4.2.5 (refrigeration) and 4.2.6 (cook).

Apparatus
This is a list containing all the apparatus an occupant can use if he performs the "do-apparatus" procedure. For each apparatus used, there exists a corresponding energy use. These are explained into more detail in chapter 4.2.3 (apparatus).

3.4.2 Adjustable variables

As mentioned before, the adjustable variables are related to the model's four principles from chapter 2. NetLogo enables us to program these adjustable variables in such a way that they can be altered very easily and according to the researcher's wishes. By altering the numerical values of the adjustable variables, the effect on energy use of a household or the energy use of a district can be visualised directly by graphs and data output in the NetLogo model.

Table 3.2 shows the name, units and description of the adjustable variables present in this research's NetLogo model. In chapter 5, the adjustable variables from table 3.2 are used to run different simulations of which the outcomes make it possible to quantify the effect on energy use of households and energy use of a district. And thus conclusions can be drawn on the effect of potential measures towards an energy zero urban environment.

Principle	Adjustable Variable	Units	Description
Occupant behaviour	thermostat	°C	The 'thermostat' variable decreases or increases the preferred indoor temperature setting from an occupant's lifestyle by X °C.
	shower	min.	The 'minutes' variable decreases or increases the preferred shower-length from an occupant's lifestyle with X minutes.
	#apparatus	-	The '#apparatus' variable decreases or increases the occupant's number of apparatus used per hour from the occupant's lifestyle with X.
Dwelling characteristics	U-facade	%	The 'U-facade' variable increases the performance of the U-value for the facade of dwellings by X%.
	U-glass	%	The 'U-glass' variable increases the performance of the U-value for the facade of dwellings by X%.
	U-roof	%	The 'U-roof' variable increases the performance of the U-value for the facade of dwellings by X%.
	U-floor	%	The 'U-floor' variable increases the performance of the U-value for the facade of dwellings by X%.
Energy production	#photovoltaics	m^2	The '#photovoltaics' variable increases the amount of photovoltaics on the roof of the dwellings, which produce energy with X m^2.
Energy sharing	share-level	-	The 'share-level' variable determines if excess produced energy is shared between dwellings on 'street-level' or 'district-level'.

Table 3.2 - Adjustable variables in the NetLogo model.

CHAPTER 4 : PROGRAMMING THE NETLOGO MODEL

In chapter 3 the agents and their relations have been identified and thus we can start programming the model in NetLogo. This chapter firstly describes the global approach for programming the agents in the model and the activities occupants can perform are identified. After this, the individual activities are explained more profoundly in text and NetLogo code. As a result, the final NetLogo model is finished and shown at the end of the chapter. We can then move on to doing simulations by making use of a case study for de Kruiskamp in 's-Hertogenbosch in chapter 5.

4.1 Programming approach

Since occupant behaviour is a unique and very important part of this research, it plays an important role in the model we are about to program. From chapter 2.1 we know the "social atom" acts on the basis of simple rules, and thus by modelling the most important factors correctly (Buchanan, 2007) the model should give a plausible representation of human behaviour concerning energy use.

In order to model the occupants behaviour in the NetLogo model, I have identified five important factors from literature. These factors are based on the 'activity-patterns' approach from (Papakostas et al, 1997), the 'use-patterns' approach from (Widen et al, 2009), 'age', 'household-size' and 'dwelling-size' which I have based on information from (Leidelmeijer et al, 2010; Itard et al, 2009). By combining these factors, nine occupant activities have been identified that cause energy use in the NetLogo model of this research.

An occupant's 'activity-pattern' determines when its location is "home" and when its location is "away". This is important since the occupant will only use energy if its location is "home" for activities such as using apparatus or cooking. The 'use-patterns' determine on what hour-of-day an occupant will do activities. This is important since there are certain 'trends' in the hour-of-day for taking one's shower and cooking dinner. The 'age' of an occupant determines certain preferences, such as indoor temperature setting, the frequency of showering, the length of showering and the number of apparatus present in a dwelling. The 'household-size', which is the total number of occupants living in the same dwelling, determines the frequency of certain activities occurring per week, such as washing, dishwashing and tumble drying. The 'dwelling-size' determines the volume that has to be heated and the number of apparatus present in a dwelling.

Table 4.1 shows how activities of occupants in the NetLogo model are programmed by making combinations between the identified factors: activity-patterns, use-patterns, age, household-size, and dwelling-size.

Activity	Activity-pattern [location]	Use-pattern [hour-of-day]	Occupant age [preference]	Household size [frequency]	Dwelling-size [volume]
"Sleep"	X	X			
"Heating"	X	X	X		X
"Shower"	X	X	X		
"Apparatus"	X	X		X	X
"Wash"		X		X	
"Dishwash"		X		X	
"Tumbledry"		X		X	
"Refrigeration"		X		X	
"Cook"	X	X			

Table 4.1 - Activities and their programming approaches.

Note

Since the use activity-patterns and use-patterns found in literature are based on Greek and Swedish households respectively. I have used information found in literature from (Leidelmeijer et al, 2010; Itard et al, 2009) to adjust these patterns for Dutch households. Although the used activity-patterns are based on Greek and Swedish households, I argue the major features of the data still reflects a plausible 'average-behaviour' for Dutch families. For better and yet more specific activity-patterns of age-groups or households, research should be done by making use of questionnaires or other methods. This is however, beyond the scope of this research.

4.1.1 Activity-patterns

The activity-patterns from (Papakostas et al, 1997) provide insight in the percentage (%) of occupants from a certain age group that are at home during a certain hour-of-day. These patterns are used in the NetLogo model to set an occupant's location to "home" or "away". The reasoning behind these activity patterns is the fact that in dwellings where there is always somebody present during the day, more energy will be used than in dwellings where there is nobody home during the day or where the presence of people during the day varies considerably (Guerra Santin et al, 2009). Table 4.2 shows how different activity-patterns are correlated to the age of the occupants in the NetLogo model.

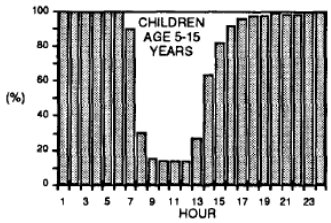
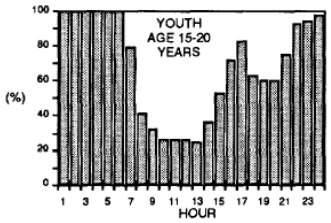
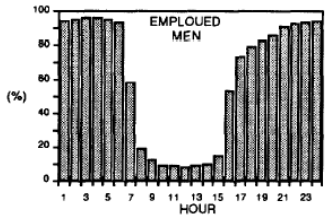
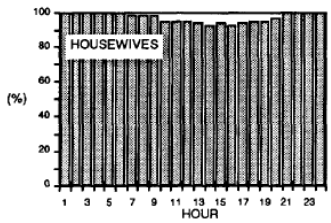
Age group	Age [years]	Activity-pattern	Description
Children	00-17		Children start to leave the dwelling at 07.00 in the morning to go to school. At 08.00, only 30% is still at home. By 14.00 65% have returned to their home-dwelling. During the evening around 19.00 and 21.00 some 2-3% leave their homes to do some leisure activities, but from 22.00 100% of the children are back home.
Youth	18-29		The youth group also start leaving their dwelling at 07.00 to go to school and at 8.00 only 40% is still at home. By 15.00 50% has returned home. At 17.00 80% of the youth is home to have dinner. In the evening they prefrom some leisure activities and until 22.00 only 90% is at home. By 01.00 all youth is back home.
Adults [1]	30-64		Adults start to leave their dwelling at 06.00 to go to work. By 08.00 only 20% is still at home. They stay away throughout the majority of the day and at 16.00 some 55% has returned to their dwellings to prepare for dinner. During the evening more adults return home each hour up to 95% at 03.00. This indicates some of the adults work or do leisure during the night.
Elderly [2]	> 65		Elderly remain at home throughout the major part of the day. Around the mid-day still 95% of elderly remain at home, but it indicates some of them go to the supermarket or do some leisure activities.

Table 4.2- activity-patterns for different age-groups (Papakostas et al, 1997). [1]Adults are modeled according to employed men. [2]Elderly are modeled according to housewives.

All occupants in the model are programmed to “sleep” between midnight and 6 o’clock in the morning, hence they do not use energy during this time and no further description of this activity will be presented. If an occupant’s location is “home” it will do certain activities that will cause energy use, but there is one exception to this. Occupant’s that are ‘parents’ (which means they are the oldest member of the household) can do certain activities which cause energy use if their location is “away”, such as washing, dishwashing and tumble drying. The reason for this is that these machines can be programmed, meaning it is nog necessary for the occupant to be home for the activities to be performed.

On every hour-of-day the corresponding percentage of occupants is asked to determine its location. This will lead to n-random occupants being asked to go “home” or go “away”. The coding for this is shown on the next page.

Code:

```
ask n-of (int ((item hour-of-day Children) / 100 * count occupants with [age <=
17])) occupants with [age <= 17] [
  move-to home-patch
  set location "home"
  ifelse hour-of-day >= 0 and hour-of-day <= 6 [
   go-to-sleep
   ] [
   set #-apparatus (random 2) + 1
   do-activities
   ]
 ]
```

4.1.2 Use-patterns

The use-patterns from (Widen et al, 2009) give the amount of Watts that are used for doing a certain activity at a certain hour-of-day. By comparing the use-pattern with the activity-pattern for a certain activity, a 'mean' hour-of day of a certain activity can be concluded. Occupants in the model are then asked to choose a normally-distributed number around this mean value and use this number as the hour-of-day to perform the activity. The use-patterns are explained more profoundly per activity in the following sections.

4.1.3 Age, household-size and dwelling-size

In literature, correlations between energy use, age, household-size and dwelling-size have been found (Leidelmeijer et al, 2010; Itard et al, 2009) which will be used to give occupants certain preference setting for indoor temperature, shower frequency, frequency for washing, dishwashing, tumble drying, and number of apparatus present in a household. These correlations are explained more profoundly per activity in the following sections.

4.2 Energy use by households

Since energy use is caused by the combination between occupant and dwelling, the following sections describe per activity how the agents in the NetLogo are programmed to perform these activities. The coding of the agents, used in the NetLogo model is also presented.

4.2.1 Heating

Heating our dwellings is by far the most energy consuming activity. Numbers as high as 47% of total energy use have been estimated (Itard et al, 2010). The combination of different dwelling types and different household-types lead to different heating patterns. The amount of energy use for heating in the model is dependent upon the difference between the preferred temperature setting of the occupant and the outside temperature. In the NetLogo model, energy use for heating is the most complicated variable to calculate, especially when dealing with an hourly resolution scale.

We know older people have a higher inside temperature setting (Leidelmeijer et al, 2010) and a linear relationship has been found between energy demand and indoor temperature (Haas et al, 1998). In general older households tend to use more energy than younger households, especially for space heating (Guerra Santin et al, 2009). Thus age is an important characteristic determining energy use for heating.

From figure 4.1 we can conclude that indoor temperature setting rises as the age of an occupant rises.

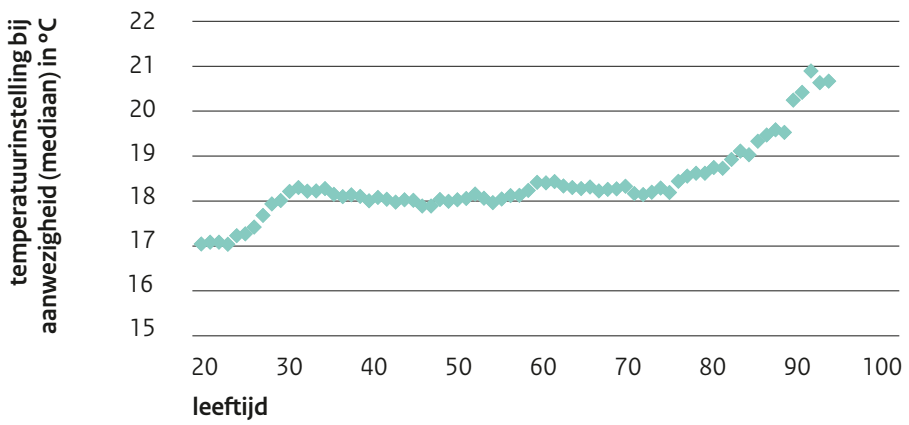


Figure 4.1 - Set temperature during the week, at day time for age groups (Source: Leijdelmeijer et al, 2010).

In the model the set temperature of an occupant's dwelling is related to its age since this set temperature has to do with the comfort level of the individual occupant (Leidelmeijer et al, 2010).

Interpretation of figure 4.1 has resulted in programming the individual occupant's preferred temperature setting according to table 4.3. Both day and night temperature are added to the lifestyle of individual occupants and are correlated to their age. When an occupant's location is "home" it will set the indoor temperature to it's preferred setting (see the flowchart in appendix 2). Also it is important to note that there can be more than one occupants present at home during the same time. If this is the case, then all the occupant-temperatures are put into a list of which the dwelling-temperature is set to the highest value from that list. By doing so, none of the occupants will ever be 'cold'.

Set indoor temperature		
Age [years]	Day setting [°C]	Night setting [°C]
0-17	17	10
18-29	18	10
30-54	18,4	15
55-64	18,8	19
65-74	19	19
75-95	20.5	19

Table 4.3 - Preferred temperature settings for occupants of a certain age group.

Since we know Q_{verw} is a good predictor for the energy use for heating (Itard et al, 2009) the formula for the heat-demand from NEN 5128 (Nieman et al, 2007; Bakker et al, 2006) is used to calculate the energy use for heating

4.2.1.1 Formula for calculating energy use for heating

The formula to calculate the energy-us for heating a dwelling in the model is:

$$\textbf{Energy Use for heating} = Q_{wb;verw} = Q_{verlies} + \eta_b \cdot Q_{winst} \qquad \textbf{(i)}$$

in which:

$Q_{wb;verw}$	heat need for space heating	[MJ]
$Q_{verlies}$	heat loss through transmission and ventilation	[MJ]
Q_{winst}	heat gain through sunshine and internal heat sources	[MJ]
η_b	utilisation factor of heat gain	[-]

In which the heat-loss is:

$Q_{verlies} = (H_{tr} + H_{vent}) \bullet (\theta_i - \theta_j) \bullet t \bullet 10^{-6}$

In which:

$Q_{verlies}$	heat need for space heating	[MJ]
H_{tr}	specific heat loss through transmission	[W/K]
H_{vent}	specific heat loss through ventilation	[W/K]
θ_i	average outside temperature	[°C]
θ_j	average inside temperature	[°C]
t	time frame of calculation	[s]

And in which the heat-gain is:

$\eta_b \bullet Q_{winst} = Q_{int} + Q_{zon}$

In which:

η_b	utilisation factor of heat gain	[-]
Q_{winst}	heat gain through sunshine and internal heat sources	[MJ]
Q_{int}	heat gain through internal heat sources	[MJ]
Q_{zon}	heat gain through sunshine	[MJ]

After substituting all relevant information in the original formula:

$$\mathbf{Q_{wb;verw} = Q_{verlies} + \eta_b \cdot Q_{winst}}$$

We end up with:

$Q_{wb;verw} = (\sum a_k \bullet U_k \bullet A_k + \rho \bullet C_p \bullet V) \bullet (\theta_i - \theta_j) \bullet t \bullet 10^{-6} - \eta_b \bullet (q_{int} \bullet A_g \bullet t \bullet 10^{-6} + Z_r \bullet A_r \bullet ZTA \bullet E_{zon})$

And after substituting all assumptions from the sections that will follow we end up with:

$Q_{wb;verw} = ((\sum U_k \bullet A_k + 1{,}275 \bullet 1.0035 \bullet V / 3.29) \bullet (\theta_i - \theta_j) - \eta_b \bullet (q_{int} \bullet A_g + Z_r \bullet A_r \bullet ZTA \bullet 0.885 \bullet I_{zon})) \bullet t \bullet 10^{-6}$

This is the formula used in the model to calculate the energy needed by the dwellings to maintain a set thermostat temperature while the outside temperature is fluctuating.

Code

```
ask dwellings [
 let Q-verlies (((A*U + (1.2 * 1.0035 * inhoud * 3.29 / (3600))) * abs
(temperature - dwelling-temperature) * 10 ^ -6 * (3600)))
 let Q-winst (((0.378 * (count [in-pcable-neighbors with [location ="home"]] of
self) + internal-heat-gain) + (0.615 * A*ZTA-window * 0.885 * SolarIntensity) *
10 ^ -6 * (3600)))
 let gamma (Q-winst / Q-verlies)
 if gamma >= 0 and gamma < 0.5 [set y-wv 1]
 if gamma >= 0.5 and gamma < 1 [set y-wv 0.9]
 if gamma >= 1 and gamma < 1.5 [set y-wv 0.75]
 if gamma >= 1.5 and gamma < 2 [set y-wv 0.55]
 if gamma >= 2 and gamma < 2.5 [set y-wv 0.45]
 if gamma >= 2.5 [set y-wv 0.35]

 set energy use-heating (Q-verlies - (y-wv * Q-winst))
```

In the following sections I will explain how I have approached the factors for heat loss through transmission heat loss through ventilation, heat gain through internal heat-production and heat gain through sunshine.

Note

I have assumed the whole volume of a dwelling is to be heated according to the preferred temperature setting of the occupants. In real life this will be more subtle, since there exist different spaces or rooms inside a dwelling that all can have a different temperature.

4.2.1.2 Specific heat loss through transmission

$$H_{tr} = \sum a_k \cdot U_k \qquad \text{(ii)}$$

In which:

H_{tr}	specific heat loss through transmission	[W/K]
U_k	heat transfer coefficient	[W/m^{2}K]
A_k	surface area separating construction	[m^2]

Since we use formula (i) to calculate the energy use for heating a dwelling, we need numerical values for A_k, the surface area [m^2] of the facade, the floor, the roof and the windows as well as information about the corresponding value of U_k, or U-value [W/m^2] of these areas.

As mentioned in chapter 2.2, I will use information from the reference dwelling of SenterNovem. Table 2.2 shows an example of the given data on the surface area (A_k) of the facade, floor, windows and floorspace as the corresponding U-values (U_k). These numerical values can then be used in formula (ii) in order to calculate the total specific heat loss through transmission.

4.2.1.3 Specific heat loss through ventilation

$$H_{vent} = \rho \cdot C_p \cdot V \qquad \text{(iii)}$$

In which:

H_{vent}	specific heat loss through ventilation	[W/K]
ρ	density of air	[kg/m^{3}K]
C_p	specific heat capacity of air	[J/kgK]
V	volume flow	[m^3/s]

The density of air, (ρ) is the mass per unit volume of Earth's atmosphere, and decreases with increasing altitude, as does air pressure. It also changes with variances in temperature or humidity. At sea level and at 20 °C, air has a density of approximately 1.2 kg/m3. Also, at sea level, air has a specific heat capacity (Cp) of approximately 1.0035 J/(g·K) (wikipedia.com).

The value for the volume flow (V), or flow rate can also be expressed as the ventilation rate (n) in 1/hr. and is based on the the guidelines for ventilation of Dutch residences NEN 1087 and is shown in table 4.4. The value for n in the model is calculated as the mean minimum value and n = 3,29 times/hour. This means that per hour, the entire volume of the dwelling is replaced 3,29 times with fresh air.

Richtlijn tabel ventilatievoud voor woningen		
Omschrijving	**Minimaal [1/uur]**	**Maximaal [1/uur]**
Woonkamer	3	5
Slaapkamers	2	3
Kelderruimten	3	5
Hobbyruimten	5	7
Andere kamers	2	3
Keuken	10	15
Bijkeukens	8	10
Bad- en wasruimten	3	4
Trappenhuis	1	2
Hal	1	2
Gang	1	2
Toilet	3	4
Zolder	2	3
Bergruimte	2	3

Table 4.4 - Guidelines for ventilation rate of different spaces in a dwelling (source: NEN 1087)

4.2.1.4 Specific heat gain through internal source

$$Q_{int} = q_{int} \cdot A_g \cdot t \cdot 10^{-6} \qquad \text{(iv)}$$

In which:

Q_{int}	heat gain through internal heat sources	[MJ]
q_{int}	heat flow by internal production per m^2 floor area	[W/m^2]
A_g	floor area of considered space	[m^2]
t	time frame of calculation	[s]

In literature, two different approaches for calculating the internal heat gain by internal sources were found. Both approaches will therefore be explained. After this, there will follow an explanation on how the model calculates the heat a dwelling gains through internal sources.

Approach 1

According to table 4.5 from the NEN 5128 an internal heat production of 6W/m^2 floor area can be used to calculate heat-production by internal sources. Also the calculation period for a heating-season is 212 days long. (Nieman et al, 2007).

Tijd [uren]	'Woonzone' [W/m²]	'Slaapzone' [W/m²]		Verwarmde zone gemiddeld [W/m²]
		2 dagen per week	5 dagen per week	
van 7 tot 17	8,0	2,0	1,0	4,64
van 17 tot 23	20,0	4,0	1,0	10,93
van 23 tot 7	2,0	6,0	6,0	4,0
etmaal gemiddelde	9,0	3,83	2,67	6,0

Table 4.5 - Heat-production by internal sources (source: NEN 5128).

From the NEN 5128 it is not clear how big an 'average' Dutch household is, therefore I have assumed it consists of 2,3 occupants (cbs.nl). And so, the total yearly internal heat-production for a 212 day period for a dwelling of 100m2 can then be calculated as follows:

6 Watt/m2 * 100m2 * 212 days

We know:
1 Watt = 3.600 J/hr

And thus:
6 * 3 600 * 100 * 212 * 24
= 10.990 MJ/year

Approach 2

Internal heat-production for an 'average' Dutch household can be divided between: occupants, apparatus and tap water + cooking heat (Bakker et al, 2007). Also in this approach it is not clear how big an average Dutch household is and I have assumed it consists of 2,3 occupants. A conclusion from table 4.6 is that per 24 hours:

- 15,6 MJ of internal heat is produced by occupants
- 17,9 MJ of internal heat is produced by electrical apparatus
- 10,6 MJ of internal heat is produced through heating water and cooking

in Watt	Tijd [uren]	woonkamer	keuken	slaapkamer	totaal [MJ/etmaal]
Personen	07-17				
Personen	17-19	1x120			
	19-23	2x80	1x80		15,6
	23-07	3x80		3x70	
Elektriciteit	07-17	45	80		
	17-23	435	80		17,9
	23-07		80		
Warmte + tapwater	07-17		140		
	17-19		500		10,6
	19-23		140		
	23-07				
Totaal [MJ/etmaal]		19,9	18,1	6,1	44,1

Table 4.6 - Global estimation of heat-production in spaces by internal heat sources for an average one family dwelling (source: Bakker et al, 2006).

In total 44,1 MJ of internal heat is produced per day. The total yearly internal heat-production for a 212 day period of a dwelling with floor area X m^2 can then be written as:

212 days * 44,1 MJ/day
= 212 * 44,1
= 9.349 MJ/year

Comparing approach 1 and 2
Note that the difference between approach 1 and 2 = 10.990 - 9.349 = 1.641 MJ or 14,9%. Meaning that for the entire dataset of 3389 dwellings in de Kruiskamp this would be equivalent to:

3389 dwellings * 1.641 MJ
= 5.561.349 MJ or 5.61 GJ or 1.544.819 kWh or 158.896 m3 gas per year.

I have therefore decided to use an approach that makes use of known numbers of occupants and apparatus used in the model.

Own approach
According to (NEN 5128; Nieman, 2007; Bakker et al,2006) the heat of tap water plays a significant role in the heat gain by internal sources calculation. One could argue that the larger part of the heat in tap water is however wasted directly, since it runs straight through the sink, and thus only plays a negligible role in the total heat-gain calculation. I have therefore excluded the heat from tap water from formula (iii).

As we have seen from approach 2, and after taking into account that the role of heated tap water is negligible, there remain two significant factors that produce internal heat; occupants and electrical apparatus.

Occupants

The presence of occupants at home and behaviour such as household work, in-home entertainement, hobbies, sleeping, resting and eating generate heat gains in a residence (Biesot et al, 1999). Since we know how many occupants are present in a dwelling at every hour-of-day, we can use this information to calculate the internal heat-production by occupants. This would give a more accurate estimate than approach 1 or 2 which both use a "static" numerical value. I argue that the size of the household can vary considerably between households and should thus individually be taken into account when calculating the internal heat-production.

In order to calculate how much internal heat-production is caused by a dwelling's occupants, wI have assumed the metabolism of an occupant is expressed with the [met] unit, in which 1 met = 58,2 Watt. The met is defined as the heat-production per m^2 average occupant in rest. An average occupant has a surface area of $1{,}8m^2$ and thus the average heat-production of a single occupant is 105 Watt (wikipedia.com). We can then calculate:

since 1 Watt = 1J/s
105 Watt = 378.000 J/hour per occupant = 0,378 MJ/hour per occupant

In order to see if this assumption is within a acceptable bandwidth of approach 2 we can assume an occupant is home 16 hours per day. So 1 occupant produces:
16 * 0.378
= 6,048 MJ per day

The average Dutch household used in approach 1 and 2 is presumably 2,3 occupants, so:
2,3 * 6,048
= 13,9 MJ/day

Note that the difference with approach 2 for the energy production per occupant is 15,6 - 13,9 = 1,7 MJ or 10,8 %, and thus seems within a reasonable bandwidth. The internal heat gain by persons will therefore be calculated by simply counting the number of occupants present in the dwelling and multiplying this number with 0,378 MJ.

Code

```
ask dwellings [
 set Q-winst-persons (0.378 * count in-pcable-neighbors with [
 location = "home"] of self)
```

Electrical apparatus

As the family size increases, the possession of appliances increases (de Groot et al, 2008). The amount of heat that is generated from each appliance is dependent upon its type and its nominal power (Biesot et al, 1999).

Since we know at every hour-of-day what household uses which apparatus, and we know how much energy use [MJ] each particular apparatus uses (see chapter 4.2.3), we could easily calculate the internal heat gain produced by these apparatus if we know what percentage of initial energy use they convert to internal heat gain. However after doing literature research on

finding sources that specify such percentages, I must conclude that they are not available in ISSO 51, NEN 5128 nor in installation textbooks. And thus I have adopted an alternative approach.

After doing some testing, I found out that the amount of heat gain caused by using apparatus is a very sensitive variable when using formula (i) to calculate energy use and trying to find a value for Q_{int}. This seems logical since the energy use of a household will increase when apparatus are used, but the energy use will decrease proportionally since the used apparatus cause internal heat gain. After running several tests that were aimed at producing an average heat gain per occupant of 17,9 MJ per day (based on approach 2), I found this average heat gain per occupant, per day could be reached when 40% of the energy use of apparatus was converted into internal heat gain.

I have therefore programmed the NetLogo model in such a way that all apparatus used by occupants produce an internal heat gain that is 40% of their initial energy use in MJ.

<u>code</u>

```
ask dwellings [let x [] let y [] let z []
 ask [in-pcable-neighbors] of self [
  foreach activity-list [
   set y lput ? y
  ]
  foreach y [if member? ? heat-gain-activities-apparatus [
   set x lput (position ? heat-gain-activities-apparatus) x]
  ]
  foreach x [
   set z lput (item ? energy use-heat-gain-activities-apparatus) z
  ]
 ]
 set Q-winst-apparatus ((sum z) * 0.4)
]
```

4.2.1.5 Specific heat gain through sunshine

$$Q_{zon} = Z_r \cdot A_r \cdot ZTA \cdot E_{zon} \qquad \text{(v)}$$

In which:

Q_{zon}	heat gain through sunshine	[MJ]
Z_r	orientation number of window	[-]
A_r	area of window	[m^2]
ZTA	sun accessionfactor	[-]
E_{zon}	accumulated solar intensity	[MJ/m^2]

In formula (v) the orientation number of the window (Z_r) can be determined using table 4.7, since the slope of all windows in the reference dwelling of SenterNovem is 90° to the horizontal and use a symmetrical division of glass present in the front and back facades (SenterNovem, 2007). In other words, the front facade contains the same area of glass as the back facade does.

Orientation	Slope = 90°
S	1,00
SE, SW	0,85
E,W	0,56
NE, NW	0,38
N	0,33

Table 4.7 - Orientation-number, dependent on orientation and inclination angle to the horizontal (Source: Bakker et al, 2006).

Since the dwellings in the model have a symmetrical division of glass:

- all dwellings having a N-S orientation have an average orientation number of:
  Z_r = (1,00 + 0,33) / 2
  Z_r = 0,665

- all dwellings having a E-W orientation have an average orientation number of:
  Z_r = (0,56 + 0,56) / 2
  Z_r = 0,56

- all dwellings having a NE-SW orientation have an average orientation number of:
  Z_r = (0,85 + 0,38) / 2
  Z_r = 0,615

- all dwellings having a NW-SE orientation have an average orientation number of:
  Z_r = (0,38 + 0,85) / 2
  Z_r = 0,615

For white single glazing the sun accession factor (ZTA) is 0,8. For white double glazing, the ZTA is 0,7 (SenterNovem, 2007; Bakker et al, 2006). By using the SenterNovem reference dwelling in the model, any dwelling can have two types of glazing:

- type 1 (ZTA = 0,8)
- type 2 (ZTA = 0,7)

For the calculation of internal heat-gain by sunshine, the model will therefore map the ZTA value onto the area for different types of glazing and use this value in formula (v).

The accumulated solar intensity (E_{zon}) has a value of 1.200 • 0.75 • 0.95 = 850 MJ in NEN 5128.

In which:
1.200 is the amount of MJ that falls on a vertical area of 1 m^2 per year (Bakker et al, 2006). Since a horizontal area of 1 m^2 receives 1.000 MJ per year, I assume, there is a factor between a vertical and horizontal area receiving sunlight. This factor = 1.200/1.000 = 1.2 and is useful since we know the hourly Solar Intensity falling onto a horizontal area from our KNMI data-set. For an accurate calculation on the hourly rate, we can thus use the value for Solar Intensity from the KNMI (2009) in formula (v) to calculate the total heat-gain by sunshine (Q_{zon}).

In order to do so, we must add t, the time frame of calculation and we let I_{zon} be the total amount of solar intensity received in MJ on an area of 1 m^2.

We use a reduction factor of 0,75 for the fact that within the given area per $1m^2$ for a window, some 25% of the area consist of the framework holding the window (Bakker et al, 2006).
And add another reduction factor of 0,95 since a window can be dirty or has some sort of curtaining that reduces the total amount of sunlight falling into the dwelling (Bakker et al, 2006).

From the explanation above, we can thus write:
$E_{zon} = 1.2 \bullet I_{zon} \bullet 0.75 \bullet 0.95 \bullet t \bullet 10^{-6}$

Simplifying gives:
$E_{zon} = 0.885 \bullet I_{zon} \bullet t \bullet 10^{-6}$
In which:

E_{zon}	accumulated solar intensity	[MJ/m^2]
I_{zon}	solar intensity	[MJ/m^2]
t	time frame of calculation	[s]

The coding used in the NetLogo model that calculates the internal heat gain by sunshine (Q_{zon}) is shown below.

Code
```
ask dwellings [
 set Q-winst-sunshine ((0.615 * A*ZTA-window * 0.885 * SolarIntensity)
* 10 ^ -6 * (3600))
]
```

4.2.1.6 The heat-gain / heat-loss ratio

$\gamma = Q_{winst} / Q_{verlies}$ (vi)

In which:

γ	heat-gain / heat-loss ratio	[-]
Q_{winst}	heat gain through sunshine and internal heat sources	[MJ]
$Q_{verlies}$	heat loss through transmission and ventilation	[MJ]

From formula (i) we know the utilisation factor of heat gain (ηb) is dependent on the gain-loss relation (γ) and is determined by making use of table 4.8. The relation between ηb and γ is given in figure 4.2. The dependency of ηb on the gain-loss relation is logical. If the heat-loss of a building is high, and the heat-gain is, relatively low, than most heat produced by internal sources and sunshine will be used profitable. However, the bigger the heat-gain in relation to the heat-loss, the more likely it is that heat-gain from internal sources and sunshine will lead to over-heating, especially at the beginning and end of the heating season, and thus heat-gain will not be used profitable (Bakker et al, 2006).

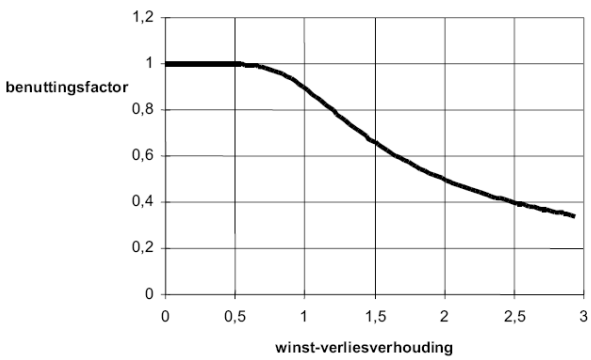


Figure 4.2 - Utilization factor for heat-gain as function of gain-loss relation (source: NEN 5128).

Within the model the procedure 'determine-y' calculates the value for γ and determines the value for ηb according tot table 4.8.

γ	ηb
≥ 0 < 0,5	1,00
≥ 0,5 < 1,0	0,90
≥ 1,0 < 1,5	0,75
≥ 1,5 < 2,0	0,55
> 2,5	0,45

Table 4.8 - Values for ηb, used in the model (Source: Bakker et al, 2006).

4.2.2 Showering

Heating tap water is the second biggest consumption factor in the total energy use of a household with some 15% of the total energy use (Itard et al, 2010) and the hot water demand is influenced the most significantly by shower and bath frequencies (de Groot et al, 2008). Therefore only the hot water use for showering is modelled exclusively in the NetLogo model. The hot water demand for cooking is covered in the "cook" activity described in chapter 4.2.6.

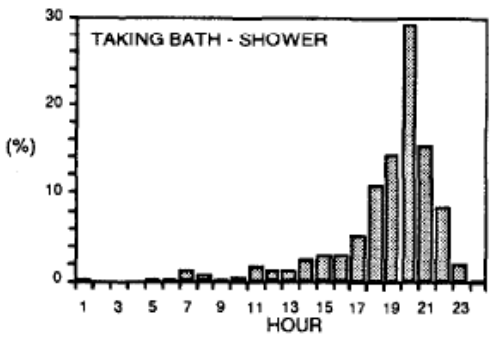
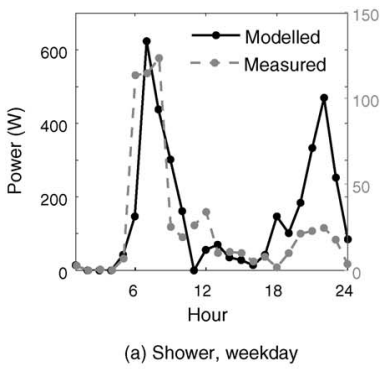
Activity-pattern	Use-pattern
	

Figure 4.3 - Activity-pattern for showering in Greek households (Source: Papakostas et al, 1997)
Figure 4.4 - Use-pattern for showering in Swedish households (Source: Widen et al, 2009)

When comparing the activity-pattern from figure 4.3 with the use-pattern from figure 4.4, we can clearly see both patterns showing a trend towards certain hour-of-day values for showering. For the Greek occupants this trend is toward the evening. The Swedish trend is more towards the morning. I reason that the Dutch shower-time will either be:

- in the morning between 5 and 11 o'clock
- in the evening between 18 and 24 o'clock

In order to determine when occupants take a shower, I let occupants choose a number at random from a list containing 3 normal-distributed values with a density and standard deviation according to the table 4.9. The chosen is the hour-of-day value on which an occupant will take a shower. This value is added to the occupant's lifestyle. The density enables the activity of showering to occur with a slightly higher chance in the mornings.

Density [-]	Mean [hour-of-day]	SD [hours]
2	7	1.5
1	20	1.5

Table 4.9 - Density, mean and SD to determine the hour-of-day for the shower activity of occupants.

Code:

```
ask occupants [
 let y []
 set y lput (random-normal 7 1.5) y
 set y lput (random-normal 7 1.5) y
 set y lput (random-normal 20 1.5) y
 let shower-time one-of y
 set lifestyle lput shower-time lifestyle
]
```

Figure 4.5 and figure 4.6 show clearly that shower behaviour is determined by age. By combining both figures table 4.10 results and is used in the NetLogo model to create shower preferences. Both values for frequency and shower length from table 4.10 are added to the occupant's lifestyle list according to its age. With the frequency value, a shower-lifestyle is created, which is a list containing the day-of-week values the occupant will take its showers.

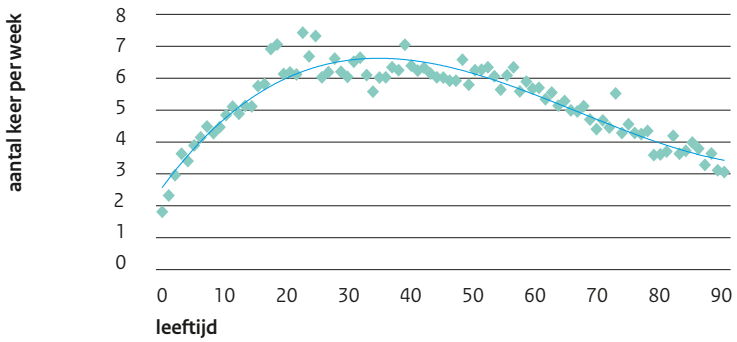


Figure 4.5 - Shower frequency per age group (Source: Leijdelmeijer et al, 2010).

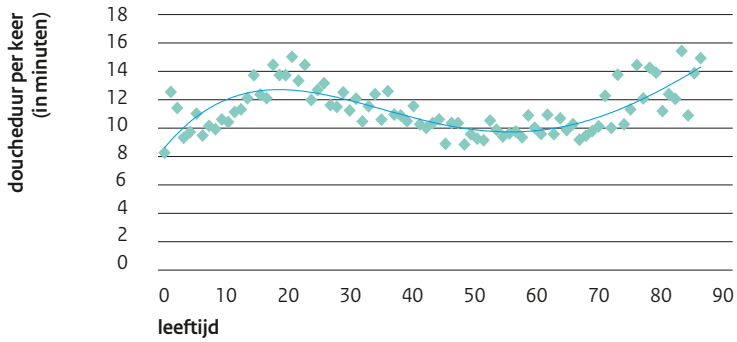


Figure 4.6 - Average shower duration per age group (Source: Leijdelmeijer et al, 2010).

Showering		
Age [years]	Frequency [times/wk]	Length [min]
0-17	4	10
18-29	7	12
30-54	7	11
55-64	6	10
65-74	5	11
75-95	4	13

Table 4.10 - Showering frequency and length per age group (Source: Leidelmeijer et al, 2010)

In order to calculate the amount of energy use [MJ] of showering, we assume the following:

- water has to be heated from 10 °C to 37 °C
- the rate of water flow, depending on the shower head and the installations, is between 4,5 and 22 ltrs./min. The average is 10 ltrs./min. (milieucentraal.nl).
- the amount of energy use = $\Delta\theta = m * C_p * \Delta T$

in which:

$\Delta\theta$	amount of heat transferred	[J]
m	mass	[kg]
C_p	specific heat capacity of water	[J/kgK]
ΔT	temperature rise	[°C]

Thus the total amount of energy for taking a shower can be calculated as follows:

Heating water from 10 °C to 37 °C gives ΔT = 27 °C, for water C_p = 4.181 [J/kgK] and the mass of 1 litre water = 1 kg. The average shower head uses 10 ltrs./min.

And so:
$\Delta\theta$ / min = 10 * 4.181 * 27
= 1,129 MJ/min

So for every minute of showering length, an occupant in the model will use 1,129 MJ.

When the day-of-week corresponds to the occupant's set shower-lifestyle and the hour-of-day corresponds to the occupants shower-time, then the occupant will add the activity "shower" to its activity-list (see the flowchart in appendix 2). It will also add the corresponding energy use for this activity to its energy use activities-list.

<u>code</u>

```
ask occupants [
 if member? day-of-week shower-lifestyle and hour-of-day = item 5 lifestyle
 [do-shower]
]
```

4.2.3 Apparatus

Energy Use due to apparatus is the third biggest consumption factor in households with some 11% of the total energy use (Itard et al, 2010). Apparatus in this research is the collective noun for TV's, Lighting, DVD-players, water cookers, stereo's, etc. Although, the energy efficiency of apparatus has risen in the past decades, the energy use of European households has not shown any decline for a period of ten years, but keeps increasing with some 2% per year. For example, the energy use of TV's has risen by a factor of 2.5 between 1995 and 2002 from 157 to 343 kWh per year (Itard et al, 2009).

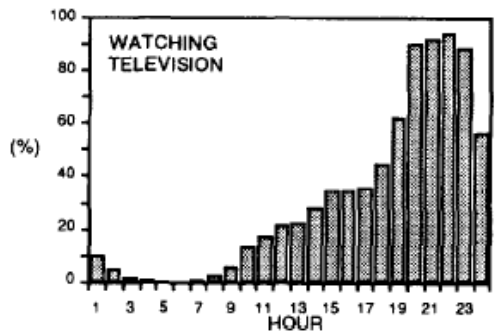
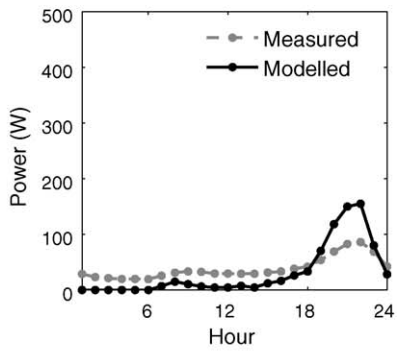
Activity-pattern	Use-pattern
	 (f) TV, VCR, DVD

Figure 4.7 - Activity-pattern for watching television in Greek households (Source: Papakostas et al, 1997)

Figure 4.8 - Use-pattern for TV, VCR and DVD use in Swedish households (Source: Widen et al, 2009)

When looking at figures 4.7 and 4.8, a trend can clearly be seen in both patterns for using apparatus. Especially during the evening, when occupants are at home, they watch TV or use other apparatus. I have assumed this trend can also be used for using other apparatus. An occupant will thus only use its apparatus when its location is "home" (see the flowchart in appendix 2). I have also assumed there is no need to determine specifically when an occupant will use a particular type of apparatus. Instead, I assume that if there is apparatus present, the occupant will use it.

Firstly, for using apparatus in our homes, I have adopted the idea of dealing with a 'bank of ideas' (Arthur, 1994). When we own more apparatus, there will be a higher chance we use those apparatus.

Secondly, the number of different apparatus is proportional to our income. And income is proportional to the size of the dwelling we live in, since income determines the type of dwelling we can afford (Itard et al, 2009; Guerra Santin et al, 2009), meaning that people who live in larger dwellings will also own more apparatus. Also larger households will live in larger dwellings and have more apparatus (Leidelmeijer et al, 2010). I reason that the number of apparatus in any house will be higher than ten different pieces of apparatus. Also a correlation between age and use of apparatus exists, which shows a 'peak' around the age range of 30-54.

used apparatus [times/hour]	Age range [years]	Dwelling-size 300-500 m^3	Dwelling-size 500-1000 [m^3]
1	0-17	+ 1	+ 2
2	18-29	+ 1	+ 2
3	30-54	+ 1	+ 2
2	55-64	+ 1	+ 2
1	65-99	+ 1	+ 2

Table 4.11 - Apparatus used by occupants per hour, based on age and dwelling-size.

Table 4.11 shows the number of apparatus used per hour by the occupants in the NetLogo model. Initially the number of apparatus used is based on the age of the occupant. According to the occupant's dwelling-size, this number can be increased with 1 or 2 additional apparatus. The value of the total number (n) of apparatus is added to the occupant's lifestyle. If the occupants location is "home", the number of apparatus used by the occupant is determined by a randomiser function.

In the model I let occupants with location "home" answer two simple questions on every hour-of-day:

1) How many apparatus do you use?
2) What apparatus do you use?

The answer to question 1 is the value of n from the occupant's lifestyle. The NetLogo randomiser function takes the value n from the occupant's lifestyle and draws a random number between 1 and n. For example, an occupant of 35 years old living in a dwelling of 600 m^3 could use a maximum of 3 + 2 = 5 apparatus per hour. The randomiser function then determines if the occupant will use 1, 2, 3, 4 or 5 of the available apparatus.

In order to answer question 2, the occupant chooses n random apparatus from the long list shown in table 4.12. The number of apparatus chosen from this list is equal to the answer on question 1. Since the different apparatus own a specific energy use, the total amount of energy use per hour of an occupant can easily be calculated by adding the individual energy the apparatus use.

Apparatus	Power [Watts]	Length of use [min]	Energy Use [MJ/use]
Coffee machine	900	5	0,270
Fryer	850	10	0,510
Water cooker	1725	3	0,311
Blender	150	4	0,036
Read book	0	45	0,000
Electric guitar	100	30	0,180
TV	120	40	0,288
DVD	130	40	0,312
Computer	80	40	0,192
Light	180	60	0,648
Iron	600	15	0,540
Vacuum cleaner	900	15	0,810
TV 2	80	20	0,096
Play	0	30	0,000
Amplifier	53	45	0,143

Table 4.12 - Energy Use for different apparatus (Source: SenterNovem, 2007)

Code:

```
ask occupants with [age >= 30 and age <= 54 and dwelling-size > 600] [
 set #-apparatus (random 3 + 2) + 1
 let apparatus-chosen []
  repeat #-apparatus [
   set apparatus-chosen lput (random length apparatus) apparatus-chosen
  ]
 foreach apparatus-chosen [
  set activity lput (item ? apparatus) activity
  set energy use-activities lput (item ? energy use-apparatus)
  energy use-activities
 ]
]
```

4.2.4 Cleaning

Washing, dishwashing and tumbledrying together form the energy use activities for cleaning. Together these make up some 8% of our total energy use (Itard et al, 2010). All families of two or more occupants posses a washing machine and the frequency of use increases as the number of occupants in the household increases (de Groot et al, 2008). The apparatus used for the activities of washing, dishwashing and tumbledrying also use the most energy in any household (Leidelmeijer et al, 2010). And although the average energy use of a washing machine has

declined with 28% between 1995 and 2002, the use of the washing machine has risen with 32% (de Groot et al, 2008).

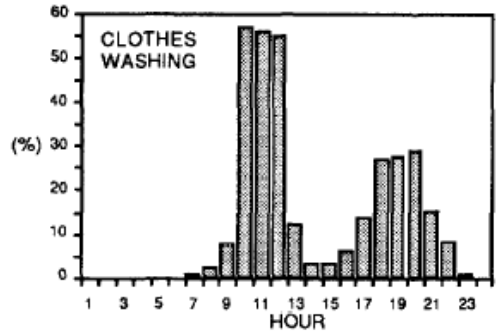
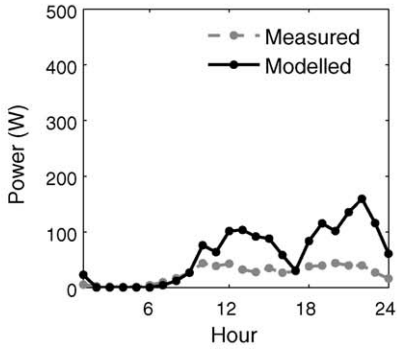
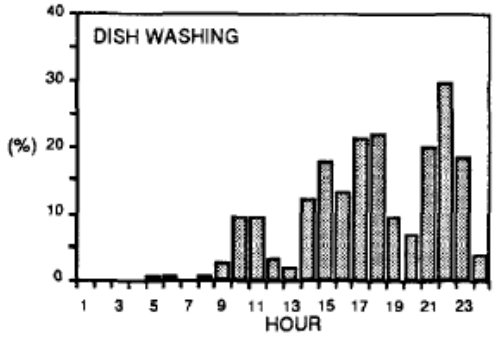
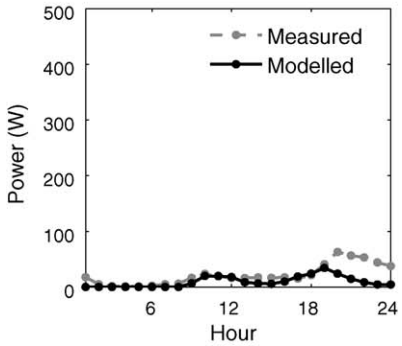
Activity-pattern	Use-pattern
	 (e) Washing and drying
	 (d) Dishwashing

Figure 4.9 - Activity-pattern for clothes washing and dishwashing in Greek households (Source: Papakostas et al, 1997)
Figure 4.10 - Use-pattern for washing and drying and dishwashing in Swedish households (Source: Widen et al, 2009)

When looking at the activity and use-patterns for washing in figure 4.9 and 4.10, we can see a trend towards two hour-of-day values. Washing occurs more often during set hours in the morning in Greece and in the evening, but almost never after midnight. The Swedish pattern shows a similar trend, but there does also occur washing after midnight sometimes. From this I reason that the Dutch washing time will be:

- in the morning between 9 and 17 o'clock
- in the evening between 17 and 24 o'clock

Since washing is usually followed by drying, I assume the hour-of-day time to perform this activity will be the same as for washing. For dish washing a similar trend can be seen in the activity- and use-patterns from figures 4.9 and 4.10,as this activity also occurs around noon or later in the evening. Therefore I assume, the hour-of-day for washing, dishwashing and tumbledrying will be the same.

Since all three cleaning activities can occur when occupants are not at home, due to the ability to program one's machine, I have introduced 'parents' in the NetLogo model. A parent is the occupant with the highest age in a certain household. Since cleaning activities are for the entire household, it is the parent who will perform them and only the energy use of the parent will be influenced by these activities.

In order to determine on what hour-of-day the parents will wash, dishwash or tumbledry, I let them choose a random-number from a list containing four normal-distributed values with corresponding density and standard deviations as shown in table 4.11. The density should prevent all cleaning activities to occur around the same time. The number chosen is the hour-of-day value on which the parent of the household will perform the wash, dishwash or tumbledry activity and is put in the occupants lifestyle (see the flowchart in appendix 2).

Density [-]	Mean [hour-of-day]	SD [hours]
2	12	3
2	20	3

Table 4.11 - Density, mean and SD to determine the hour-of-day for the wash, dishwash and tumbledry activity of parents.

Code:

```
ask parents [
 let z []
 set z lput (random-normal 12 3) z
 set z lput (random-normal 12 3) z
 set z lput (random-normal 20 3) z
 set z lput (random-normal 20 3) z

 let wash-time one-of z
 set lifestyle lput wash-time lifestyle

 let dish-time one-of z
 set lifestyle lput dish-time lifestyle

 let dry-time one-of z
 set lifestyle lput dry-time lifestyle
]
```

When the hour-of-day corresponds to the parent's set wash-time, dishwash-time or tumbledry-time, the parent will respectively add the activity "wash", "dishwash" or "tumbledry" to its activity-list. It will also add the corresponding energy use for the activity to its energy use activities-list.

Next to knowing at what hour-of-day washing, dishwashing or tumbledrying occurs, it is important to know how often or in other words, on what day of the week these activities occur. The frequency of all three activities can be correlated to the household size (Itard et al, 2009). And thus, the corresponding frequencies for washing, dishes and drying are correlated to the size of the household. These frequencies are placed in the parent's lifestyle.

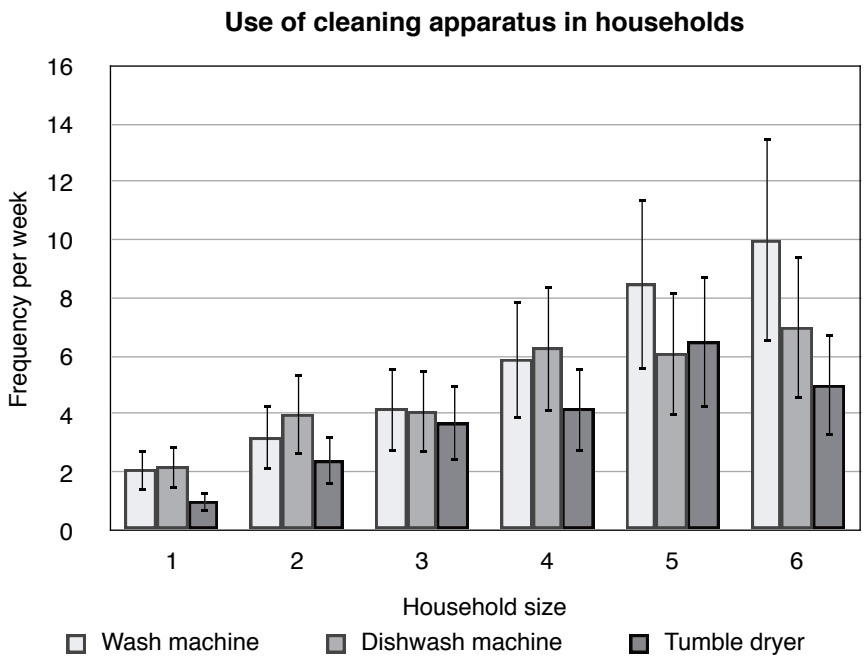


Figure 4.12 - Frequency of using wash machine, dishwasher and drying machine according to household size (Source: Itard et al, 2009).

By interpreting figure 4.12 I have created table 4.13. The values from table 4.13 are used to determine the frequencies of washing, dishwashing and tumbledrying of households in the model and placed in the lifestyle of parents. In the model all parents are asked to determine their wash-lifestyle, dish-lifestyle and dry-lifestyle, which are lists that contain the day-of-week values on which the parent will perform the cleaning activities.

Size of household [# occupants]	Wash frequency [times/wk]	Dishwash frequency [times/wk]	Tumbledry frequency [times/wk]
1	2	2	1
2	3	4	2
3	4	4	3
4	6	6	4
5	8	6	6
6 or more	10	7	5

Table 4.13 - Frequency of using washing machine, dishwasher and drying machine according to household size.

All three different apparatus for cleaning own a specific energy use that are shown in table 4.14. The amount of energy use [MJ] is used in the model when an occupant does the corresponding activity. Note that tumble drying cost twice the amount of energy compared to using a dishwasher or a washing machine.

Apparatus	Power [Watts]	length of use [min]	Energy Use [MJ/cycle]
Washing machine	490	130	3,822
Dishwasher	430	160	4,128
Tumbledryer	1650	90	8,910

Table 4.14 - Power, length of use and energy use for cleaning apparatus (Source: Widen et al, 2009; SenterNovem, 2007)

For example, the following code shows how parents determine their 'wash-lifestyle', which is a simple list that contains the values of the day-of-week values on which the "wash" activity will be performed. Item 5 from a parent's lifestyle is the frequency for washing. The result is parent 110 will do its washing on day-of-week 4, 5 and 6 of the week or on Thursday, Friday and Saturdays. Every parent also owns a 'dishwash-lifestyle' and a 'tumbledry-lifestyle'.

Code:

```
ask parents [
 let week-schedule [1 2 3 4 5 6 7]
 set wash-lifestyle n-of (item 5 lifestyle) week-schedule
]
ask parent 110 [
 show wash-lifestyle
]
(parent 110): [4 5 6]
```

4.2.5 Refrigeration

The energy use for cooling food in a refrigerator or a freezer is periodic (24 hours a day, 7 days a week), and they use some 6% of our total energy use (Itard et al, 2010).

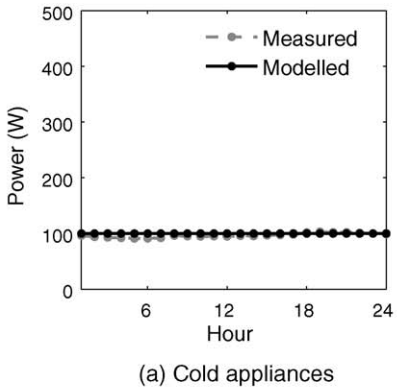
Activity-pattern	Use-pattern
No activity-pattern available on cooling.	

Figure 4.13 - Use-pattern for refrigeration in Swedish households (Source: Widen et al, 2009)

I argue that the energy use for cooling is correlated with the household-size, since a larger family will need more freezer space. Since our fridges and freezer run a twenty four hour cycle each day, the energy use for cooling is a constant depending on the household size according to the table 4.15.

Household size [# occupants]	Fridge type [-]	Power [Watts]	Energy Use [MJ/hr]
≤ 2	Fridge small	50	0,180
≥ 3	Fridge big	80	0,288

Table 4.15 - Energy Use for cooling (Source: Widen et al, 2009).

Within the model the corresponding amount of energy is added to the total energy of the household on each hour-of-day (see the flowchart in appendix 2).

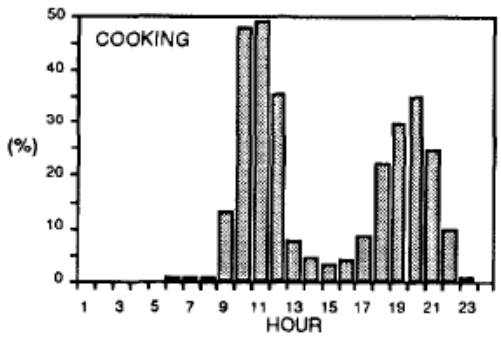
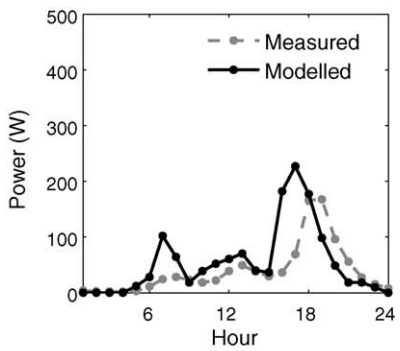
Code

```
if aantal-bewoners <= 2 [ask dwellings [
 set energy use-household energy use-household + (item 8 energy use-activity)
]

if aantal-bewoners >= 3 [ask dwellings [
 set energy use-household energy use-household + (item 9 energy use-activity)
]
```

4.2.6 Cooking

The activity of cooking only uses some 2% of the total energy use in a household (Itard et al, 2009).

Activity-pattern	Use-pattern
	

(c) Cooking

Figure 4.14 - Activity-pattern for cooking in Greek households (Source: Papakostas et al, 1997)
Figure 4.15 - Use-pattern for cooking in Swedish households (Source: Widen et al, 2009)

From figures 4.14 and 4.15 we can see trends towards certain hour-of-day values in both patterns for the cooking activity. They occur around lunch and supper time in the Greek activity-pattern. From the activity-pattern we can conclude Swedish cooking takes place around breakfast, lunch and dinner time. I argue the latter, is more likely to be occurring in Dutch households.

From this I reason that the Dutch cooking-time will be:

- in the morning between 6 and 9 o'clock
- in the afternoon between 11 and 14 o'clock
- in the evening between 17 and 19 o'clock

I reason all occupants have breakfast, lunch and dinner on every day. In order to determine during what hour-of-day an occupant will perform the activity “cook”, I let them choose a number for breakfast, lunch and dinner time that are normal-distributed with corresponding density and standard deviations as shown in table 4.16. The number is the hour-of-day value on which an occupant will cook and is put in the occupants lifestyle.

Density [-]	Mean [hour-of-day]	SD [hours]
1	8	1
1	12	2
1	18	3

Table 4.16 - Density, mean and SD to determine the hour-of-day for the cooking activity of occupants.

When the hour-of-day corresponds to an occupants set ‘breakfast-time’, ‘lunch-time’ or ‘dinner-time’ and the occupants location is “home”, then the occupant will add the activity “cook” to its activity-list (see the flowchart in appendix 2). It will also add the corresponding energy use for this activity to its energy use-activities list. The model is programmed in such a way that there’s always a maximum of one occupant in a dwelling that can cook at the same time, because it is very likely that occupants from the same household will cook and eat together.

In the Netherlands we use an average of 55 kWh for cooking devices (milieucentraal.nl). If I assume I cook every day, then I use:
55 * 3.6 MJ = 198 MJ per year
198 / 365 = 0,542 MJ/day

I reason cooking breakfast, lunch or dinner consumes 0,542 MJ.

Code:

```
ask occupants [
 let breakfast-time []
 set breakfast-time lput (random-normal 8 1) breakfast-time
 set lifestyle lput one-of breakfast-time lifestyle

 let lunch-time []
 set lunch-time lput (random-normal 12 2) lunch-time
 set lifestyle lput one-of lunch-time lifestyle

 let dinner-time []
 set dinner-time lput (random-normal 18 3) dinner-time
 set lifestyle lput one-of dinner-time lifestyle
]
```

4.3 Decentral energy production

From chapter 2 we know decentral energy production is a good alternative to conventional methods of central energy production, especially in a highly populated country as the Netherlands. The decentral energy production in the NetLogo model is effectuated by adding a

number of photovoltaics on a dwelling. A photovoltaic installation converts sunlight into direct current (DC). An inventor then transforms the DC into alternating current (AC), which can be used as electricity (wikipedia.nl).

Since the NetLogo model is programmed with weather data from the KNMI, we know for every hour-of-day throughout a whole year how much the solar intensity [J/cm^2] is. The value for solar intensity is plotted per hour in a Solar Intensity graph in the model and can be used by the photovoltaics agents in the NetLogo model to calculate their energy production.

From the KNMI data set for solar intensity, we know that in 2009, a total of 387.676 J/cm^2 fell onto the earths surface near the measuring station 370: Eindhoven.

Converting:
387.676 J/cm^2 = 3.876,76 MJ/m^2 = 1.076 kWh/m^2, which is within a 7% bandwidth of the average 1000 kWh/m^2 for the Netherlands (van Kasteren et al, 2008). We can therefore assume the KNMI data-set is correct.

Then, if we assume photovoltaics have an efficiency of 15%. We can calculate the total amount of energy from solar radiation as:
1.076 kWh/m^2 * 0.15 = 161 kWh/m^2, in the year 2009.

But a photovoltaic panel of 1 m^2 consists not only of pure solar-cells, which convert light into electricity. The photovoltaic installation also has a frame. Let's assume the frame is 15% of the total area of 1 m^2. This leaves 0,85 m^2 of surface area for the actual cells that produce energy from sunlight.

161 kWh/m^2 * 0.85 = 137 kWh or 493,2 MJ per m^2 photovoltaic panel, in the year 2009.

Since the KNMI data-set gives us the hourly global radiation, we know for each hour-of-day how much energy [MJ] falls on a surface of 1 m^2. And thus we can calculate per hour, how much energy can be produced by 1 m^2 photovoltaic panel that is placed on a dwelling.

Code

```
ask photovoltaics [
 set energy-production-photovoltaics (SolarIntensity * 0.15 * 0.85 *
 #photovoltaics)
]
```

If there is energy production by the photovoltaics, this energy will be used by the household of the dwelling. As a result, the energy use of the household will decrease. However, all energy production by photovoltaics that is not used by the household, because the supply is higher than the demand, can be seen as 'excess energy'. This energy will be 'wasted' since there is no possibility within the model to save this produced energy. In the following section I will discuss the functioning of the energy sharing network, which enables dwellings to share their excess energy between them.

4.4 Energy Sharing network

In the NetLogo model, excess energy production from photovoltaics can be shared between dwellings. By doing so, there should be less energy 'wasted'. For this research I have chosen to adopt three different 'levels' of energy sharing.

1. no-sharing : no energy is shared between dwellings.
2. street-level sharing : excess energy is shared between dwelling in the same street.
3. district-level sharing : excess energy is shared between dwellings in the same district.

<u>Code</u>

```
if share-level = "street-level" or share-level = "district-level" [
 let energy distribution-need-dwellings (sum [energy use-household] of
 out-cable-neighbors)
 let energy-shared-dwellings sum [energy-shared] of out-cable-neighbors

ifelse energy-shared-dwellings > energy distribution-need-dwellings [
 set energy-shared
 (energy-shared-dwellings - energy distribution-need-dwellings)
 set total-energy-shared (total-energy-shared + energy-shared)
 set energy distribution (energy distribution-need-dwellings -
 (energy-shared-dwellings - energy-shared))
 set total-energy distribution
 (energy distribution + total-energy distribution)
 ] [
 set energy-shared 0
 set energy distribution
 (energy distribution-need-dwellings -
 (energy-shared-dwellings - energy-shared))
 set total-energy distribution
 (energy distribution + total-energy distribution)
 ]
]
```

4.5 Final model

After programming all the information from the previous sections into NetLogo, the final result is an ABS model that gives insight into the energy use of households. The final NetLogo model, shown in figure 4.16 consists of 5 parts that are explained in table 4.17. This model will be used to perform a set of simulations based on a case study of de Kruiskamp in chapter 5. By doing these simulations, the model will give insight into the effect of occupant behaviour, dwelling characteristics and energy production on energy use of households and on energy use in a district.

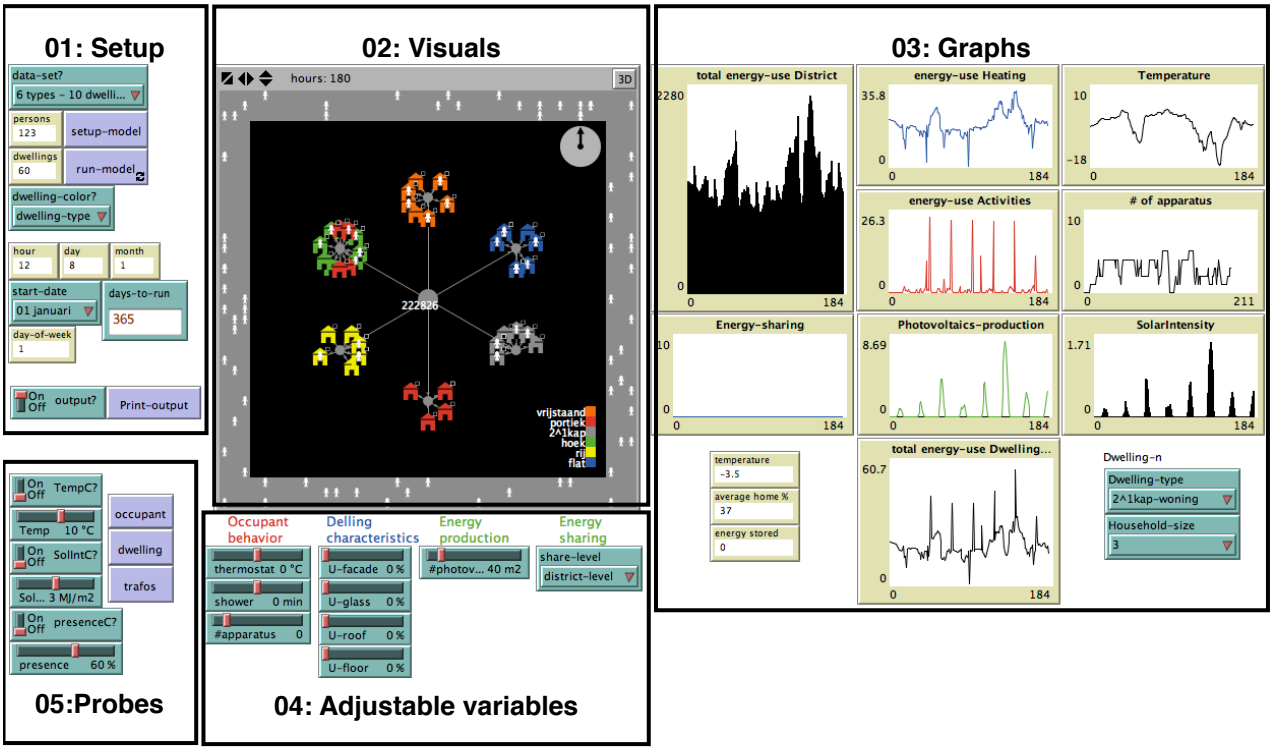


Figure 4.16 - Screenshot of the final NetLogo model.

Section	Description
01: Setup	The user can setup the model by pressing the 'setup-model' button and run the model by pressing the 'run-model' button. The user can specify a 'data-set?', a 'start-date' for the simulation and the number of 'days-to-run' the simulation should cover. Additionally the user can chose if there has to be any 'output' for the results of the simulation in the form of a CSV file.
02: Visuals	The visuals part, shows the setup of dwellings and occupants specified in the ' data-set? When the modelruns, this part of the model shows the dynamics between dwellings and occupants.
03: Graphs	The graphs part plots a variety of graphs, these include: outside temperature, energy use for heating, energy use of activities, photovoltaics-production, energy sharing, total energy use-household and total energy use of the district.
04: Adjustable variables	The adjustable variables are ordered according to the four principles of the model and consist of: occupant behaviour (thermostat, shower, #apparatus), dwelling characteristics (U-facade, U-glass, U-roof, U-floor), energy production (#photovoltaics) and energy sharing (no-sharing, street-level, district-level). The effect of adjusting one or multiple of these variables can be seen directly in the graphs part of the model.
05: Probes	The probe section of the model are some extra settings that help to understand the effects of the adjustable variables more easily. A good example of this is the 'TempC?' switch. If this switch is turned on, the outside temperature will remain at a constant value, so the effect of adjustable variables becomes more obvious in the graphs section of the model. There are also buttons to 'inspect' dwellings, occupants and street-trafos.

Table 4.17 - Explanation of the different part of the final NetLogo model.

4.6 UML Instance-diagrams

In order to give the reader some insight and 'feeling' for the agents in the NetLogo model and the attributes or variables they posses, an UML instance-diagram of an occupant is shown in figure 4.17 and of a dwelling in figure 4.18. Keep in mind that some of the agent's attributes can have alternating values during a model run.

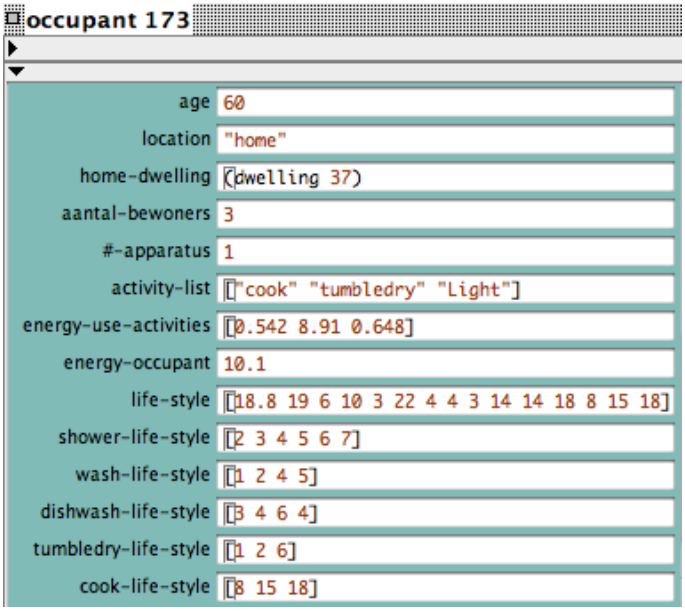


Figure 4.17 - Instance-diagram of an occupant agent in the NetLogo model.

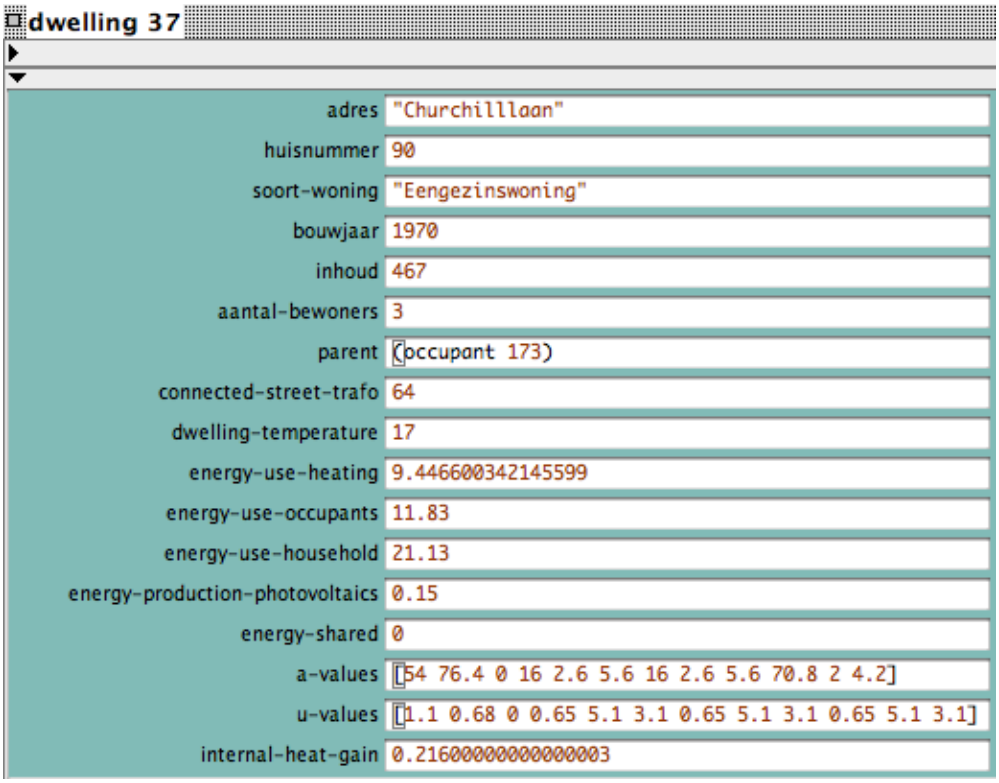


Figure 4.18 - Instance diagram of a dwelling agent in the NetLogo model.

CHAPTER 5 : CASE STUDY

In the previous chapters the workings and programming of the NetLogo model have been discussed. Now that the final NetLogo model is constructed, this chapter describes the simulations that are done using the NetLogo model. By making use of the adjustable variables described in section 3.4.2 and by running a simulation of 365 days, we can quantify the effects of the adjustments made to these variables on energy use of households and on the total energy use in a district. Trough a case study, based on the district of de Kruiskamp in 's-Hertogenbosch we will have a good data-set to construct the dwellings and their occupants with in the NetLogo model. After running different simulations, the results will be analysed and presented graphically in order to draw conclusions.

First I will describe some general features concerning the district of de Kruiskamp, then I will describe into detail the content and characteristics of the data-set. Then a description of the simulations is given and finally the results from the simulations are presented graphically and will be discussed. The results form the simulations are used in the chapter 6 to draw conclusions.

5.1 De Kruiskamp in 's-Hertogenbosch

The district of de Kruiskamp in 's-Hertogenbosch consists of 3389 dwellings and 8161 occupants. Through our connections with de Twee Snoeken in 's-Hertogenbosch, we have been able to get a very specific data-set for the district of de Kruiskamp. By making use of this data-set, we hopefully gain insight into the effect of occupant behaviour, dwelling characteristics, energy production and energy sharing on energy use.

Figure 5.1 - De Kruiskamp (Source: Google Maps, 2010).

Trough the department of Research & Statistics department of the municipality of 's-Hertogenbosch I was able to collect a real-life data-set on postal code level for the district of de Kruiskamp. This means data is available on how dwelling type, household-type and household-size relate to one another. Since the combination of dwelling type and household-type is an important factor for determining energy use, this data-set is very useful for this research.

In the model, the total energy use of a dwelling is equal to the sum of the energy needed for heating the dwelling + the sum of the activities of all the occupants in the household. Since the model is built on a resolution scale of one hour, it will perform this calculation every hour, for every dwelling, and for every occupant in the model.

Note

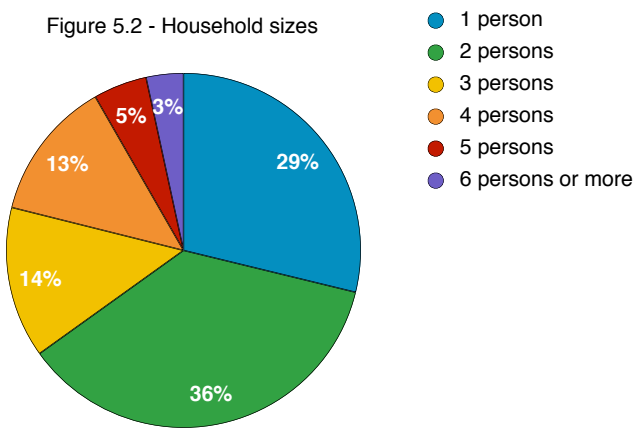
An important note before I further explain the working and thoughts behind the NetLogo model is the fact that the model calculates the energy use, and that this is not the same as the actual energy-consumption. Installations are not part of the model, but typically have an efficiency of 80% to 95%. Neither are district power-plants part of the model, typically they have an efficiency of 39% (wikipedia.nl).

This means that for 1 MJ of energy use in the model, a dwelling owning installations that have an efficiency of 80%, the actual energy-consumption will be:
1 / 80% * 1 = 1,25 MJ.

5.2 Data-set for simulations

The complete data-set of de kruiskamp contains 3389 dwellings and 8161 occupants. Detailed information on dwelling types, their year of construction and household size are given in table 5.2 and figures 5.2, 5.3 and 5.4. Due to the large number of dwellings and occupants in the NetLogo model, a single simulation took over 35 hours to complete.

Figure 5.2 - Household sizes



dwelling type	Average household size
'portiek-flat'	2,11
'flat'	1,49
'2^1kap-woning'	2,79
'rij-woning'	2,74
'hoek-woning'	2,65
'vrijstaande-woning'	2,09

Table 5.2 - Average household size.

Figure 5.3 - Dwelling-types

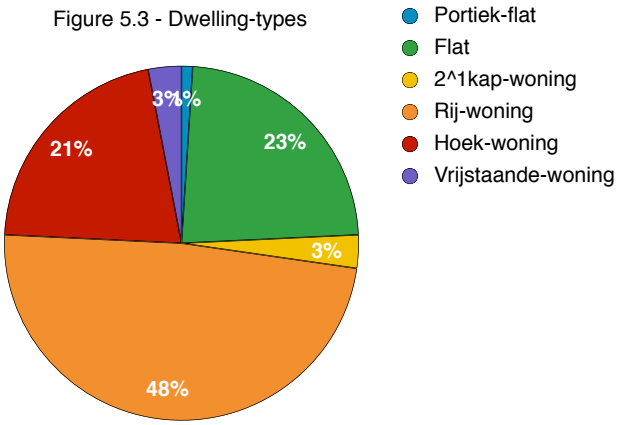
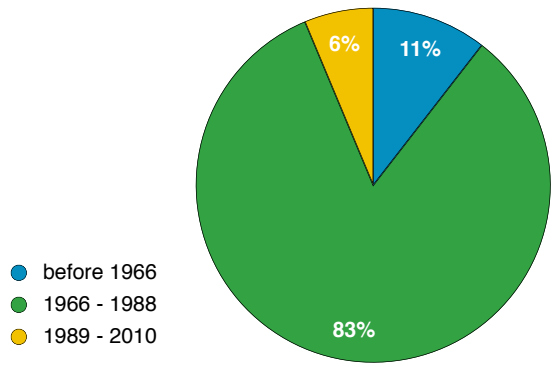


Figure 5.4 - Year of construction



In order to assure the data-set of de Kruiskamp can be used with the Reference Dwellings (SenterNovem, 2007) that are part of the NetLogo model, some dwelling types from the data-set of de Kruiskamp have been replaced, since they are not present in the Reference Dwellings data. The alteration I have made to the data-set of de Kruiskamp are shown in table 5.3.

Original type	# of dwellings	Replaced with
vrijstaande woning (Bungalow)	2	'vrijstaande-woning'
woning-benedenwoning	14	'flat'
woning-bovenwoning	14	'flat'
praktijkrijwoning	8	'rij-woning'
woning-vrijstaand (bungalow)	4	'vrijstaande-woning'
woning-geschakeld	10	'2^1kap-woning'
woning-geschakeld (bungalow)	8	'2^1kap-woning'
hoekwoning (bungalow)	12	'hoek-woning'
vrijstaande bedrijfswoning	5	'vrijstaande-woning'

Table 5.3 - Replaced dwelling types in the data-set of de Kruiskamp.

As we have seen in section 4.2.1.5, an orientation number for the dwellings in the data-set are needed to calculate the energy use for heating with formula (i). Because determining the exact orientation of every single dwelling and every single window within the dwelling in the data-set of de Kruiskamp goes beyond the scope of this research, I assume all windows in all dwellings are vertical and all dwellings in de Kruiskamp either have a NW and SE or NE and SW orientation (see figure 5.1).

In other words, some dwellings within de Kruiskamp have windows facing NW and a facade facing SE, while other dwellings have windows facing NE and a facade facing SW. From chapter 4 we know:

- all dwellings having a NE-SW orientation have an average orientation number of:
  $Z_r = (0,85 + 0,38) / 2$
  $Z_r = 0,615$

- all dwellings having a NW-SE orientation have an average orientation number of:
  $Z_r = (0,38 + 0,85) / 2$
  $Z_r = 0,615$

The orientation number for all dwelling in the data-set of de Kruiskamp are thus the same and the value $Z_r = 0,615$ will be used in formula (i) to calculate the energy use for heating in the NetLogo model.

5.3 Description of simulations

In order to gain insight into possible measures that can be taken to transform the district of de Kruiskamp into an energy zero urban environment, there are multiple interesting settings for the adjustable variables we can test with the NetLogo model. The settings of these variables lead to different simulations. For this research, ten different simulations have been run in the NetLogo model. The outcomes of these simulations can then be used to draw conclusions on the effect of

occupant behaviour, dwelling characteristics, energy production and energy sharing on energy use. The simulations and corresponding settings of the adjustable variables are briefly explanation in table 5.4.

Note:
The variable settings have theoretical values. I have at this point not checked whether an improvement of 50% in the U-value for the facades is practically possible and what it will cost in time, effort and money to realise.

Principle	Simulation	Adjustable variable setting	Description
	s1	Base case	Since no adjustable variables are used in this simulation, the base case serves as the reference point for all the other simulations.
Occupant behaviour	s2	Shower-length: - 5 minutes	What happens if we tell all occupants in the model to set their shower time 5 minutes shorter?
	s3	Thermostat: - 1°C	What happens if we tell all occupants in the model to set their thermostat (inside temperature of dwelling) 1 °C lower?
Dwelling characteristics	s4	U-roof: 50%	What happens if we improve the U-value for the roof with 50% in all dwellings in the model?
	s5	U-facade: 50%	What happens if we improve the U-value for the facade with 50% in all the dwellings in the model?
	s6	U-floor: 50%	What happens if we improve the U-value for the floor with 50% in all dwellings in the model?
	s7	U-glass: 50%	What happens if we improve the U-value for the glass with 50% in all dwellings in the model?
Energy production	s8	photovoltaics: 40m^2, sharing: house-only	What happens if we give all the dwellings in the model 40m^2 of photovoltaics of which they use the produced energy directly for their own energy-need?
Energy sharing	s9	photovoltaics: 40m^2, sharing: street-street-level	What happens if we give all the dwellings in the model 40m^2 of photovoltaics of which they can use the produced energy directly for their own energy-need, and share the excess energy with dwellings in their street?
	s10	photovoltaics: 40m^2, sharing: district-level	What happens if we give all the dwellings in the model 40m^2 of photovoltaics of which they can use the produced energy directly for their own energy-need, and share the excess energy with dwellings in their district?

Table 5.4 - Description of simulations, their adjustable variable settings and a brief explanation.

5.4 Results of simulations

After running the model for several days and doing all simulations mentioned in table 5.4, this section describes and analyses the results of those simulations. The absolute and relative effects of the simulations on the energy use of households are presented in section 5.4.1. The total energy use in the district of de Kruiskamp is presented in section 5.4.2. Then the effects of the individual simulations are described into more detail. After this, correlations between energy use and household size, volume, y.o.c. and dwelling type are discussed. Also the possible presence of a power-law distribution in the simulation outcomes is discussed. For good interpretation of the results, variance in the outcomes of the NetLogo model is discussed. To indicate the plausibility of the model, I will compare the outcomes of energy use for heating and energy use for activities from the base case (s1) with values found in literature.

5.4.1 Energy Use of Households

Figure 5.5 shows the absolute reduction in the mean energy use of households over a period of 365 days. It should be clear that the used colours of the bars in the graphs indicate whether the effect is caused by occupant behaviour (red), dwelling characteristics (blue), energy production (yellow) or energy sharing (green).

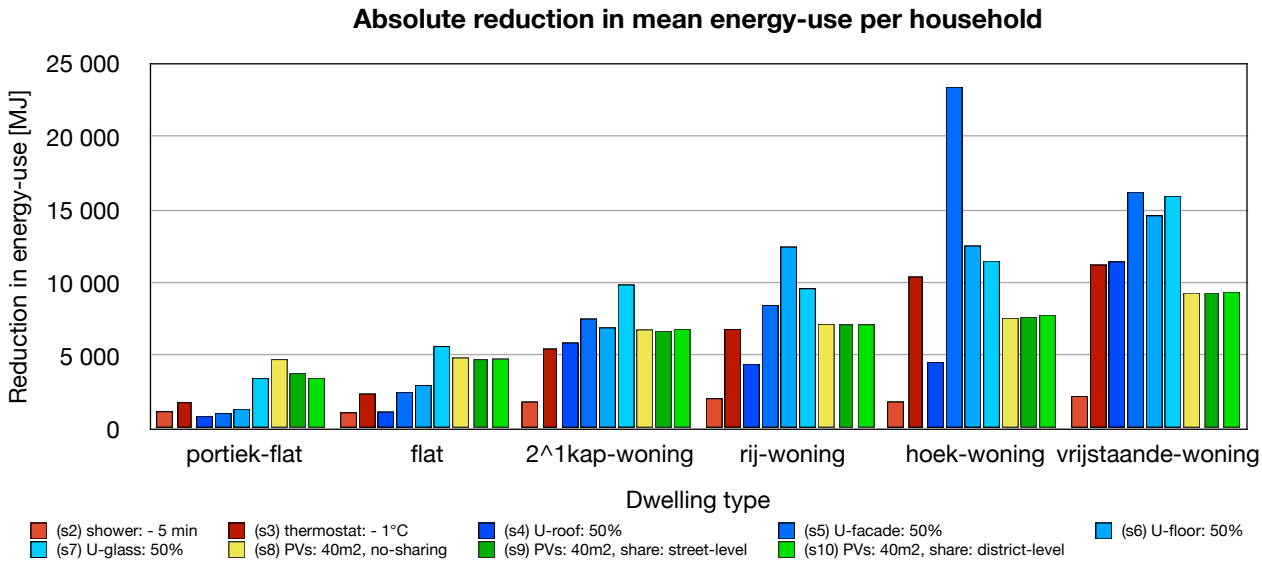


Figure 5.5 - Absolute reduction on the mean energy use of households living in certain dwelling types in de Kruiskamp.

Figure 5.6 shows the % reduction in the mean energy use of households over a period of 365 days. Also in this graph, colours indicate by what type of adjustable variable the effect is caused.

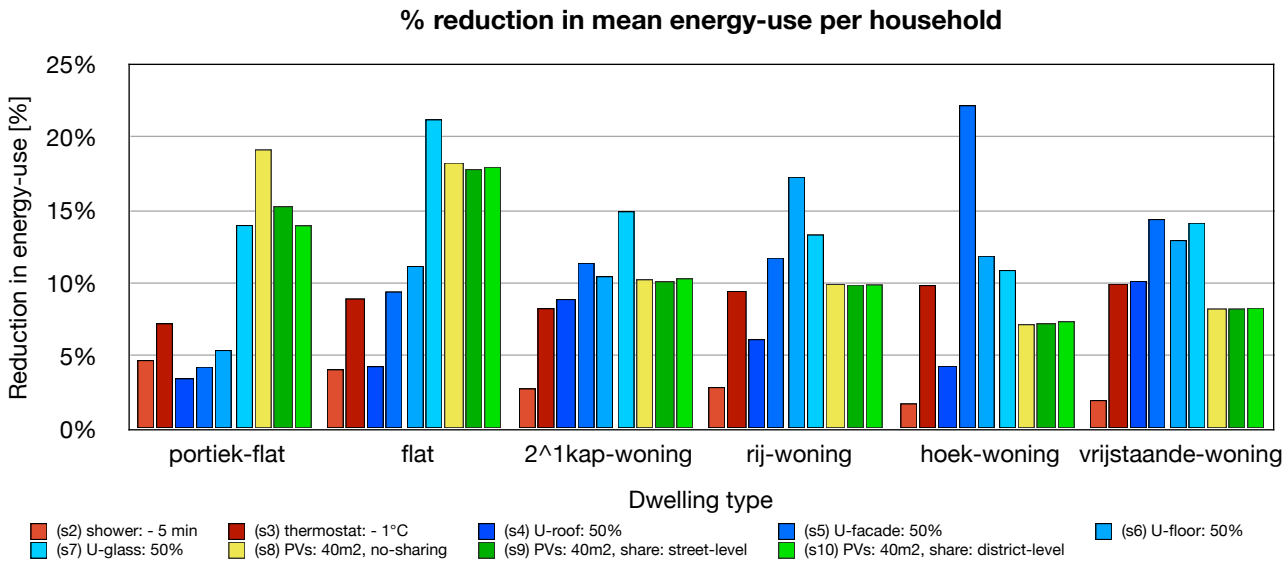


Figure 5.6 - % reduction on the mean energy use of households living in certain dwelling types in de Kruiskamp.

From figure 5.5 and 5.6 we can draw conclusions on the effectiveness of the settings for the adjustable variables. I will discuss the effect of all the adjustable variable settings separately in section 5.5.

5.4.2 Total energy use of District

Since the district-trafo distributes all the energy within the district, it is therefore important to see how the adjustable variable settings influence the total energy use in the district. Doing so will enable me to draw conclusion of their effect on the entire district.

Figure 5.7 shows the absolute reduction in the mean energy use of the district trafo over a period of 365 days. Again, it should be clear that the used colours of the bars in the graphs indicate whether the effect is caused by occupant behaviour (red), dwelling characteristics (blue), energy production (yellow) or energy sharing (green).

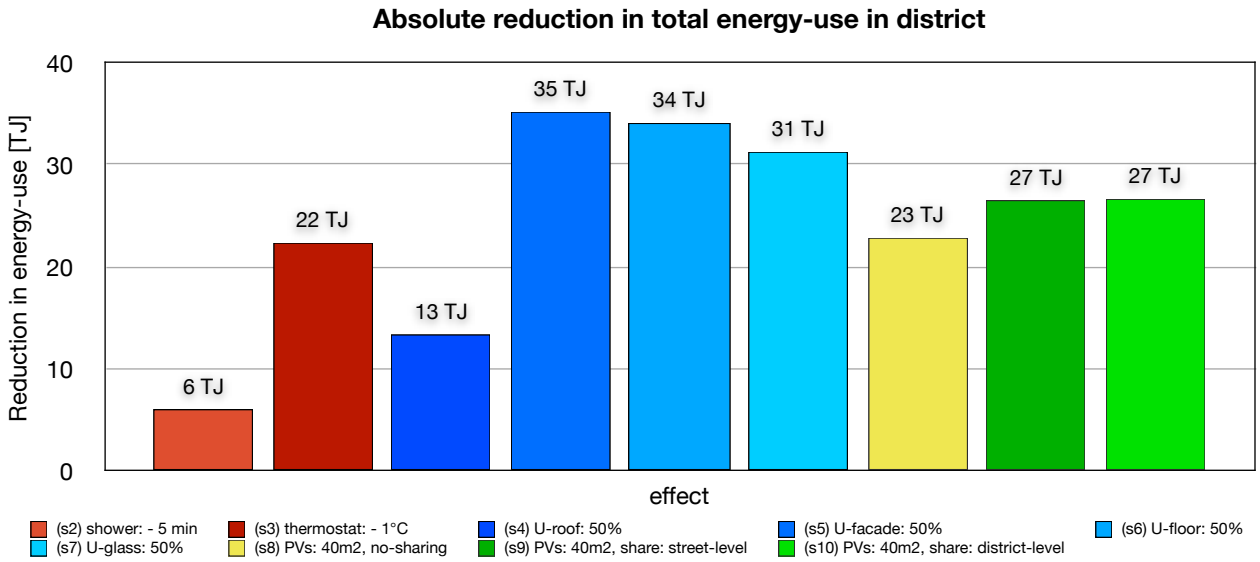


Figure 5.7 - Absolute reduction on the mean total energy use in the district of de Kruiskamp.

Figure 5.8 shows the % reduction in the total energy use in the district over a period of 365 days. Also in this graph, colours indicate by what type of adjustable variable the effect is caused.

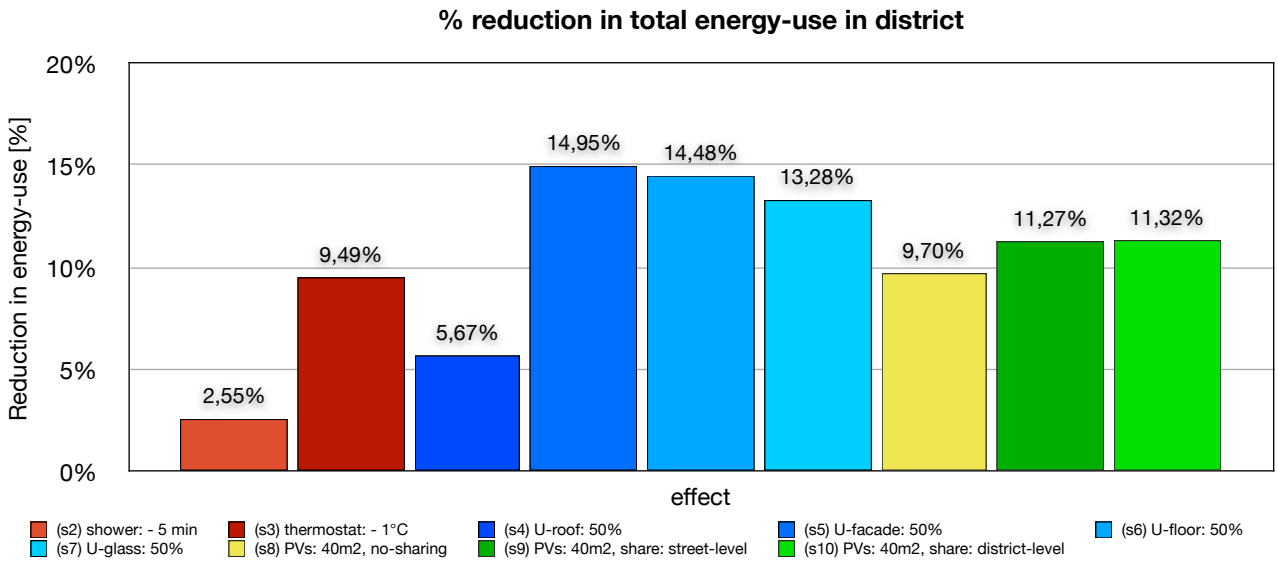


Figure 5.8 - % reduction on the total energy use in the district of de Kruiskamp.

From figure 5.7 and 5.8 we can draw conclusions on the effectiveness of the settings for the adjustable variables, which will be discussed separately in the next section.

5.5 Discussion of variable settings

In this section I will discuss the effects of the adjustable variable settings on energy use of households and on the total energy use of the entire district. Since the graphics in the previous chapter 'explain more than a thousand words' I encourage the reader to study them and draw his own conclusions as well as read mine.

Overall we can conclude that all settings of the adjustable variables have had a positive effect on the energy use of households and the total energy use of the district, meaning both show decrease. This is within our expectations, since all settings to the adjustable variables were aimed at decreasing energy use.

5.5.1 The effect of s2 - shower: - 5 minutes

s2 has, by far the smallest effect of all variable settings and this is true for all dwelling types. A reason for this could be an erroneous assumption of the energy use involved in taking a shower and should therefore be revised in future research. Also on a district level, the effect of s2 could be considered minimal with 2,55% in comparison to the effect of the other adjustable variable settings. Although on a district level, it would still give a reduction of 6 TJ a year.

5.5.2 The effect of s3 - thermostat: -1°C

s3 has a bigger influence on larger dwelling types with 9,83% and 9,92% for 'hoek-woning' and 'vrijstaande-woning' respectively. There seems to be a linear relation between dwelling size and the effect of s3. This seems logical, since larger dwellings use more energy for heating due to their dimensions and volume. Unlike the effect of s2, the effect of s3 is considerable with a 9,49% reduction on the district level, or 22,33 TJ a year.

5.5.3 The effect of s4 - U-roof: 50%

s4 has the most effect on the 'vrijstaande-woning' (10,12%), which could be explained through its roof area, being the largest of all dwelling types. The effect on the '2^1kap-woning' is considerable (8,87%), but the effect on the other types is much smaller. This seems logical since the other dwelling types are more compact or have no roof at all, such as flats. The moderate reduction, could indicate that the isolation of the roofs in all dwellings are already up to standard,. THis could be explained from the fact that isolating a dwelling's roof is practically easier to accomplish than isolating a facade or floor. The effect of s4 on a district level is only small with 5,67%.

5.5.4 The effect of s5 - U-facade: 50%

s5 has by far the biggest effect on the 'hoek-woning' with 22,13% or 23.366 MJ per year, which is almost the same amount of total energy use in a 'portiek-flat'. This could mean that dwellings of this type have extreme badly isolated walls. It might also indicate the 'hoek-woning' in the data-set are mostly from a certain building period in which facade isolation was not considered necessary yet. The absolute effect of s5 on the 'vrijstaande-woning' is big as well (14,34%), and could be explained by the dwelling type's large facade areas. On a district level, the effect of s5 is the largest of all with 14,95%. On a yearly basis a theoretical reduction on energy use as high as 35,17 TJ could be effectuated.

5.5.5 The effect of s6 - U-floor: 50%

s6 has the biggest effect on the 'rij-woning' with 17,24%. This could indicates poor floor isolation for this type of dwelling and might be due to a certain building period in which isolation was not considered necessary yet. This is more or less confirmed by the effect of s6 on the 'hoek-woning' (11,83%). Since both dwelling types are always built together, Isolating existing floors in dwellings will most likely pose even larger practical and technical difficulties than isolating facades, since many old floors are built directly onto the Earth's surface. The effect of s6 on a district level is 14,48% and has the potential of reducing energy use with 34 TJ on a yearly basis.

5.5.6 The effect of s7 - U-glass: 50%

s7 has the most influence on the 'vrijstaande-woning' in an absolute sense (15.902 MJ). Again, this can be explained by the large window areas this type of dwelling has. For all the other types of dwellings s7 also has a big influence in absolute sense. Percentage wise, s7 has a particularly big influence on the smaller dwelling types 'portiek-flat' (13,94%) and 'flat' (21,16%). In both types of smaller dwellings, the effect of s7 is easily twice as high as for all other dwelling characteristic related adjustable variables. On a district level, s7 has the third biggest effect with 13,28%, which indicates a reduction potential of more than 31,24 TJ a year.

5.5.7 The effect of s8 - photovoltaics: 40m2, sharing: no-sharing

s8 has an increasing effect, as dwelling size increases in an absolute sense. This seems logical since larger dwellings have a higher energy need. Percentage wise however, the effect of s8 on the smaller dwelling types is much bigger, which is also logical since the total energy use of these smaller dwelling types is lower. For dwelling types 'flat' and 'portiek-flat' the effect of having 40m^2 of photovoltaics can mean a reduction of 18,20% and 19,11% in the yearly energy use respectively. This is twice as big as for the larger dwelling types. On a district level, s8 has an effect of 9,70% or 22,82 TJ.

5.5.8 The effect of s9 - photovoltaics: 40m2, sharing: street-level

s9 has the same effect as s8 on the energy use of households. The similar effect in an absolute sense between s8 and s9 can be explained by the way the sharing-network in the model is programmed. It distributes the excess produced energy to the street-trafo, and the street-trafo uses the excess energy in such a way that it needs less distributed energy from the district trafo. The unbalanced reduction for the 'portiek-flat' between s8 and s9 is unexplainable and must be a matter of variance. On a district level however, sharing excess energy between dwellings on a street-level has 1,57% more effect than s8 with 11,27% or 26,5 TJ absolutely.

5.5.9 The effect of s10 - photovoltaics: 40m2, sharing: district-level

s10 has the same effect as s8 and s9 on the energy use of households due to the functioning of the sharing-network. On a district level, the effect of s10 is only 0,05% larger than the effect of s9, which indicates that a large energy sharing network on district level, basically is no better than an energy sharing network on street-level. Also I conclude that the unbalanced variance for the 'portiek-flat' shows a decreasing trend, which might be due to the fact that this type of dwelling is very sensitive to small changes in energy use.

5.6 Correlations

The NetLogo model is programmed in such a way that it can also give data output for the energy use of all the individual dwellings present in the data-set of de Kruiskamp. Using the 'correlations function' in Microsoft Excel I have determined correlations between certain variables and the energy use of households. The correlations between energy use and year of construction, volume, household-size, age of parent, dwelling type and energy-label are shown in figure 5.9

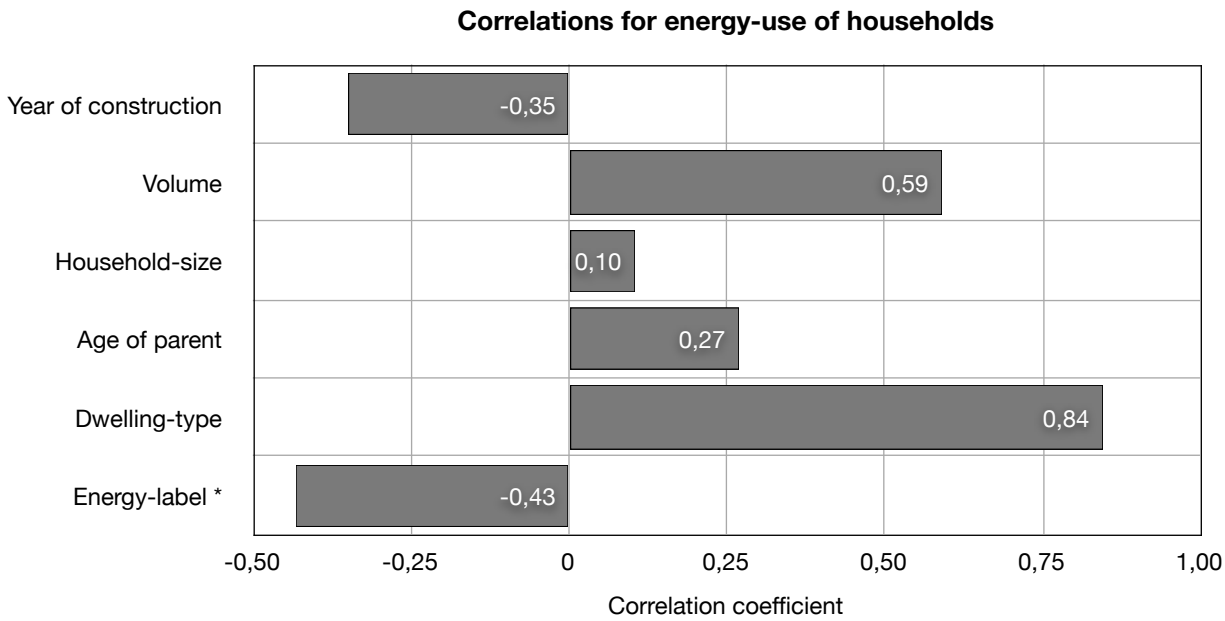


Figure 5.9 - Correlations for different types of energy use (*Energy-label coefficient is based on data present for 50% of data-set).

When looking at figure 5.9, I conclude that dwelling type (0,84) and volume (0,59) show the strongest correlation with the energy use of households. This seems due to the fact that heating the dwelling determines the majority of energy use in households. The year of construction (-0,35) shows a negative correlation with the energy use of households, which means that as the year of construction increases, the energy use decreases. This is logical since newer dwelling have a better isolation of facade, floor, roof and windows. The age of the parent (0,27) shows a moderate correlation with the energy use of households. Which is most likely due to the fact that age determines an occupant's preference indoor temperature setting, and is thus directly related to the energy use for heating the dwelling. Furthermore, the household size (0,10) is not very strongly correlated with the energy use.

5.7 Distributions

Figure 5.10 shows the distribution of the energy use in de Kruiskamp. The graph shows the frequency a certain energy use range occurs in the outcomes from the base case simulation of de Kruiskamp. By making use of the 'frequency function' in Excel and setting the ranges at 5.000 MJ per step the line for energy use de Kruiskamp in figure 5.10 resulted. For comparison, I have also graphed the normal distributed curve with the mean (μ = 69.413) and standard deviation (σ = 32.555) from the outcomes of the base case in the same figure.

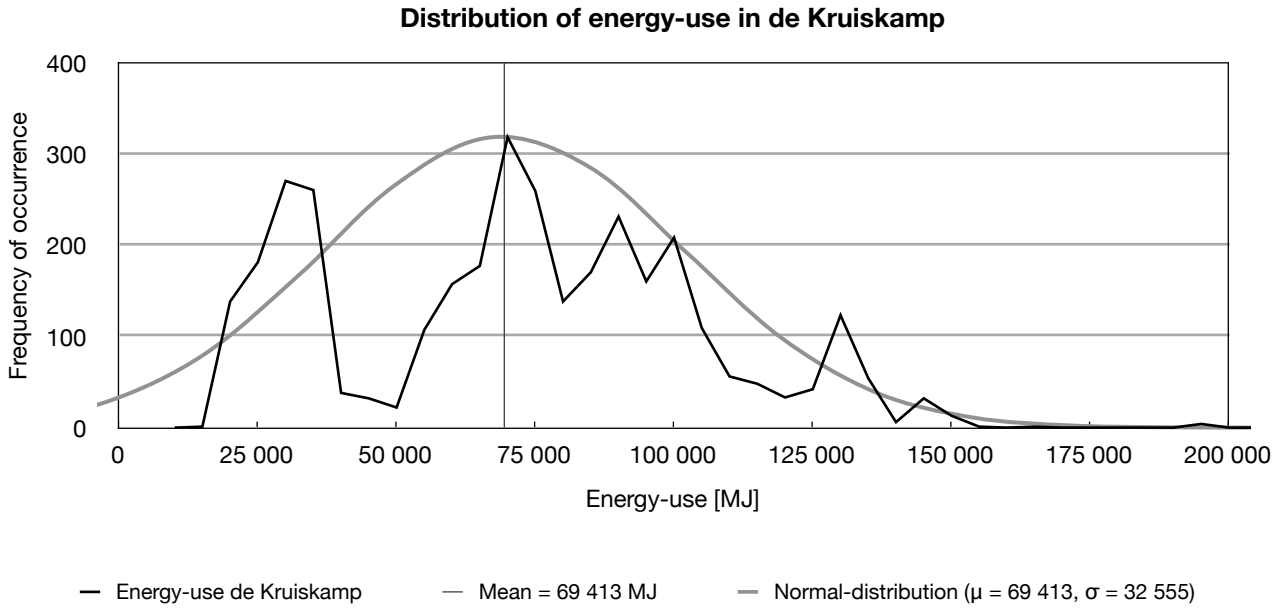


Figure 5.10 - Distribution of energy use in de Kruiskamp

When looking at figure 5.10, I conclude, the shape of the distribution is 'wide' and there exists a broad bandwidth in energy use for households. The energy use stretches from 20.000 MJ to 150.000 MJ a year. A 'gap' exists for households that have an energy use of around 50.000 MJ. Furthermore I conclude the energy use distribution of de Kruiskamp does not follow the normal-distribution fluently. Although the highest frequency of occurring energy use is close to the mean value, around 70.000 MJ, the energy distribution seems skewed towards approximately 90.000 MJ.

It is also worth noting that the frequencies of energy use around 30.000 MJ and 130.000 MJ occur quite more often than the normal-distribution curve predicts. Referring to chapter 1.6, one could argue this indicates the presence of a power-law distribution, as extreme values occur more often and the tails in the distribution play a more significant role. This is strengthened by the fact that there exist some households that use more than 200.000 MJ of energy a year. The presence of a power law distributions in energy use might be an interesting topic for future research.

5.8 Power-laws

Figure 5.11 shows the rankings of energy use in de Kruiskamp. The graph shows the ranking of the values for energy use per household from the outcomes of the base case simulation. I have used the 'ranking principle' from (Laherre et al, 1998) to sort all values for energy use from large to small, and apply a ranking to them, in such a way that the largest value for energy use has rank 1, the second largest value has rank 2, etc. When these values are plotted, the result is the graph in figure 5.11.

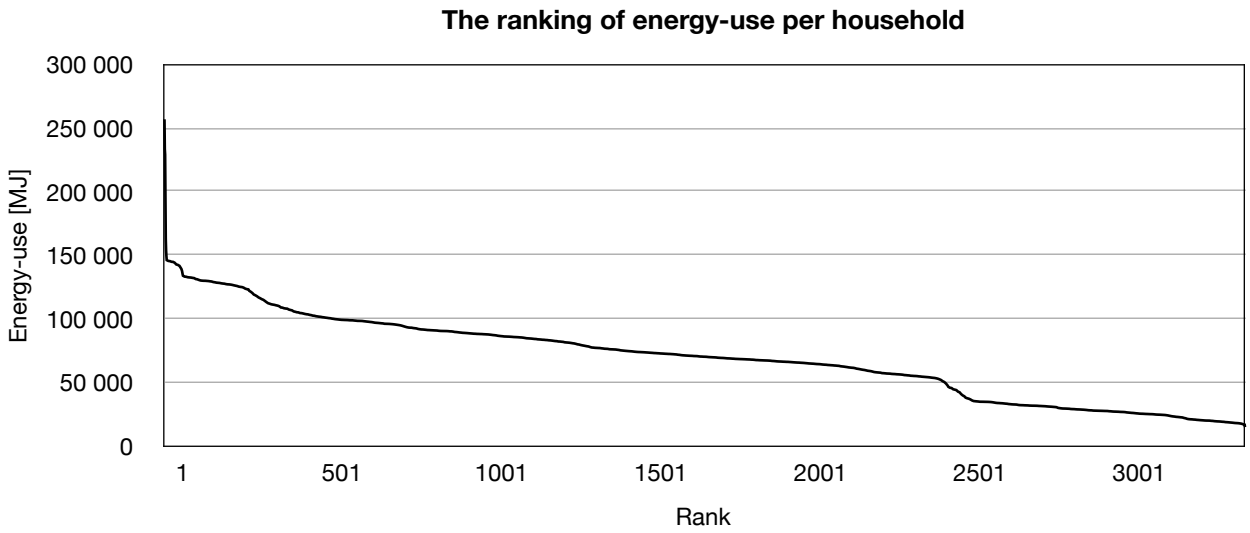


Figure 5.11 - Rank vs total energy use plot.

When analysing figure 5.11, some interesting observations can be made. While the mathematical average of all values is 69.413 MJ per year, one should observe there are many dwellings that use less than this, and there are also many dwellings that use more energy than this average value.

Analysing the graph into more detail, I have concluded the following:

- 25% of the households consume 40% of the total energy use in the district.
- 33% of the households consume 50% of the total energy use in the district.
- 41,5% of the households consume 60% of the total energy use in the district.
- The dwelling-household combination that had rank 1 is a 'vrijstaande-woning' built in 1965 with a volume of 527 m^2 and a household consisting of 2 elderly people of 75 years or older.
- The top 5 are all of dwelling type 'vrijstaande-woning' with a volume larger than 380 m^3 and built before 1966.
- The top 500 consists only of dwelling types 'vrijstaande-woning' and 'hoek-woning' which are built before 1975.

The fact that 33% of the households consume 50% of the total energy use in the district could be another indicator for the presence of a power-law distribution in the energy use.

5.9 Variance in simulation outcomes

For a good interpretation of the results from the simulations, we should consider the presence of variance. There is a high chance, there will be variance in these output values, since the model makes use of random-values, which are given to occupants to do operations. An example of this is the fact occupants have an activity-pattern in the model. Through this activity-pattern, n-random occupants are asked to move (go “home” or go “away”) on an hourly resolution scale. Since the model choses random occupants to do this, this means that for different simulation runs its not always the same occupants that are asked to move, which leads to different occupants being “home” and thus a different amount of energy use for the household the occupant is part of when doing simulations multiple times.

It is clear that for the model to work flawless, this should be improved in such a way the model will always ask exactly the same occupants in every simulation run to move. This however is beyond the scope of this research for now and thus should be done in future research.

The setup of the variance simulations was for a series of 10 simulations.There were no adjustable variable settings applied and the simulation period was set to 365 days. The data-set for the variance simulations consist of 10 dwellings from all 6 types of dwellings, making 60 dwellings in total. The outcomes of v1-v10 are used to calculate the average values for energy use for heating, energy use for households and total energy distribution in the district. Then the individual outcomes of v1-v10 are compared to the average calculated values and the % difference between them is plotted in the graphs. The same method is applied using standard deviations. These outcomes are not shown in graphs, but mentioned in the text.

<u>Variance in energy use for heating</u>
From figure 5.12 we can conclude that for all 10 simulations, the % variance compared to the average energy use for heating is smaller than 0,07% in all cases. Also all 10 simulations give output values that are within 2 standard deviations from the average value in 97% of the cases. And thus I conclude, that however there is a variance in the output values from the model, this variance is acceptable, but should be taken into account when drawing conclusions from output values from the model.

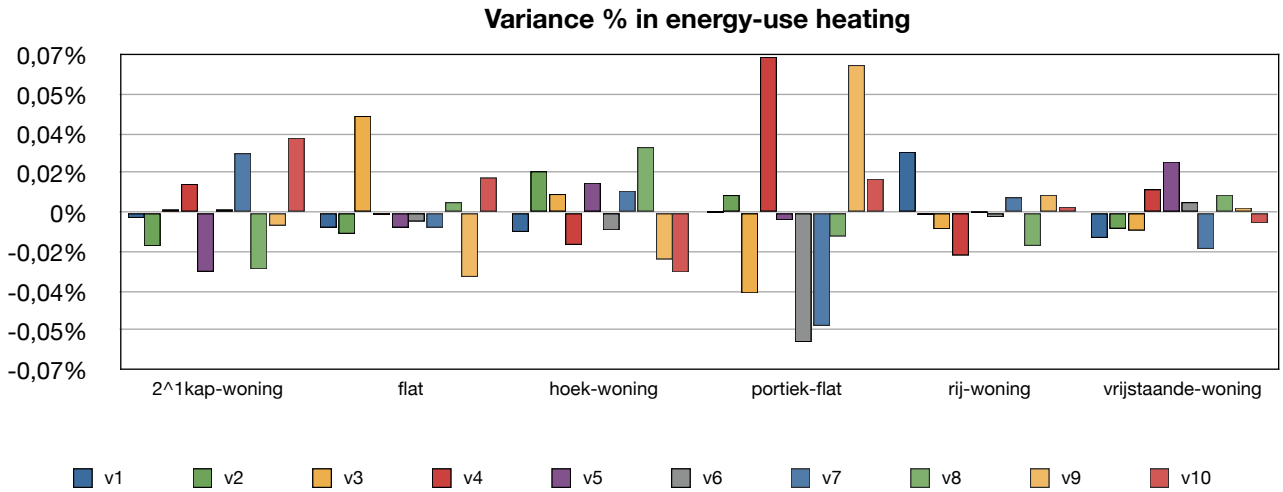


Figure 5.12 - Calculated variance % for energy use for heating of households.

<u>Variance in energy use of households</u>
From figure 5.13 we can conclude that for all 10 simulations, the % variance compared to the average energy use of households is smaller than 2,25% in 99% of the cases. Also all 10

simulations give output values that are within 2 standard deviations from the average value in 97% of the cases. And thus I conclude, that however there is a variance in the output values from the model, this variance is acceptable, but should be taken into account when drawing conclusions from output values from the model.

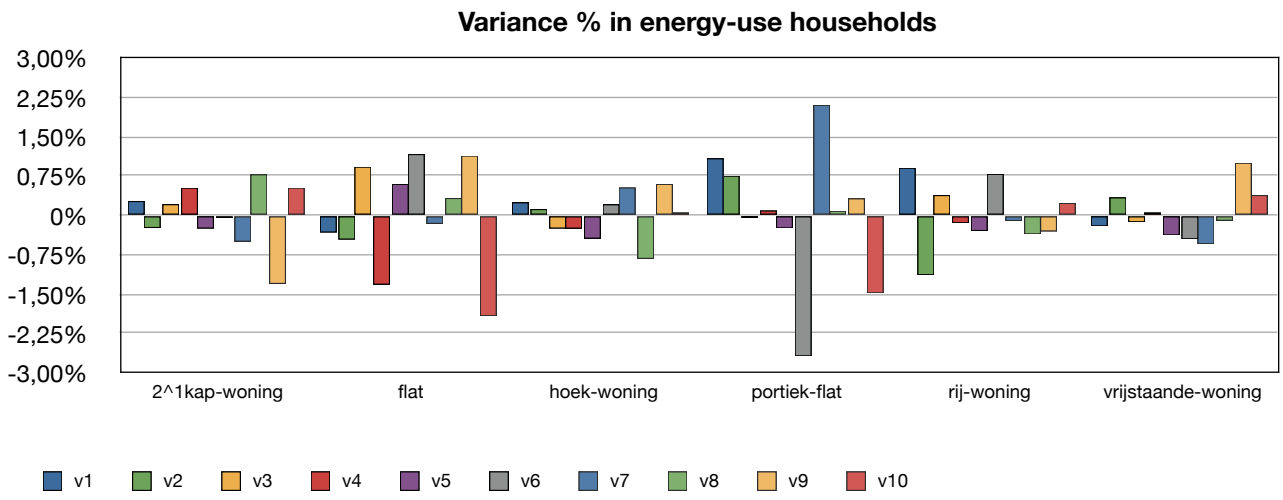


Figure 5.13 - Calculated variance % for energy use of households.

From figure 5.13 one could argue that a variance % should be applied to the outcomes of the simulations. I conclude a variance of ±3% could be applied, if it were desirable, since all calculated variance % from the series of 10 simulations are under 3%.

<u>Variance in energy distribution by district-trafo</u>

From figure 5.14 we can conclude that for all 10 simulations, the % variance compared to the average energy distribution of the district-trafo is smaller than 0,25% in all cases. Also all 10 simulations give output values that are within 1,6 standard deviations from the average value in all cases. And thus I conclude, that however there is a variance in the output values from the model, this variance is acceptable, but should be taken into account when drawing conclusions from output values from the model.

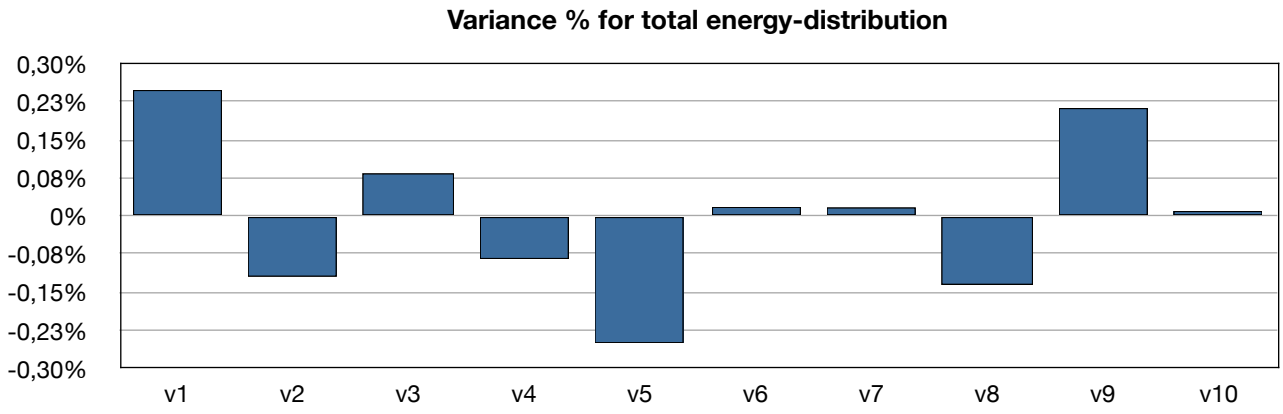


Figure 5.14 - Calculated variance % for total energy distribution of the district trafo.

Concluding from figures 5.12, 5.13 and 5.14, I feel there is no reason to believe that there is a high variance in the outcomes of the NetLogo model. Although some variance is present in the simulation results, the results from the mentioned figures show a variance that is never higher than 3%. Since this is very negligible, I have chosen for clarity's sake, not to make use of variance in my outcomes.

5.10 Simulation results and Literature

In chapter 2 I have specified that a comparison between outcomes from the NetLogo model and real life date on energy use in de Kruiskamp would be most preferable. However, after having communicated with the local energy company that supplies gas and electricity to the district of de Kruiskamp, I must conclude that due to 'legislation' this market party was unable to deliver a data-set with real life energy use data. To get a feeling for the accuracy, and the plausibility of the NetLogo model constructed for this research, I will compare the outcomes of the simulations to outcomes found in literature.

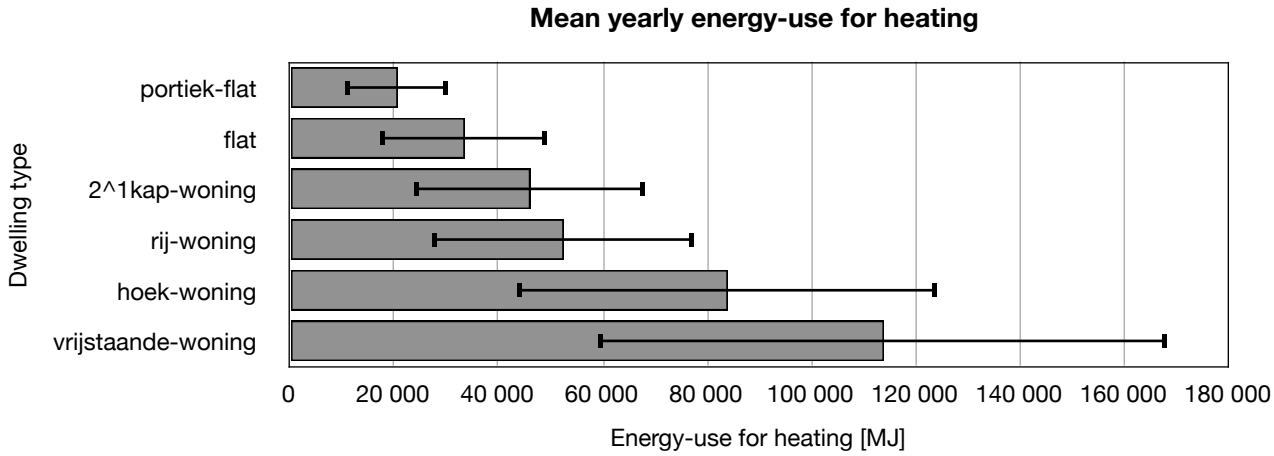


Figure 5.15 - Mean total energy use for heating form NetLogo model simulations.

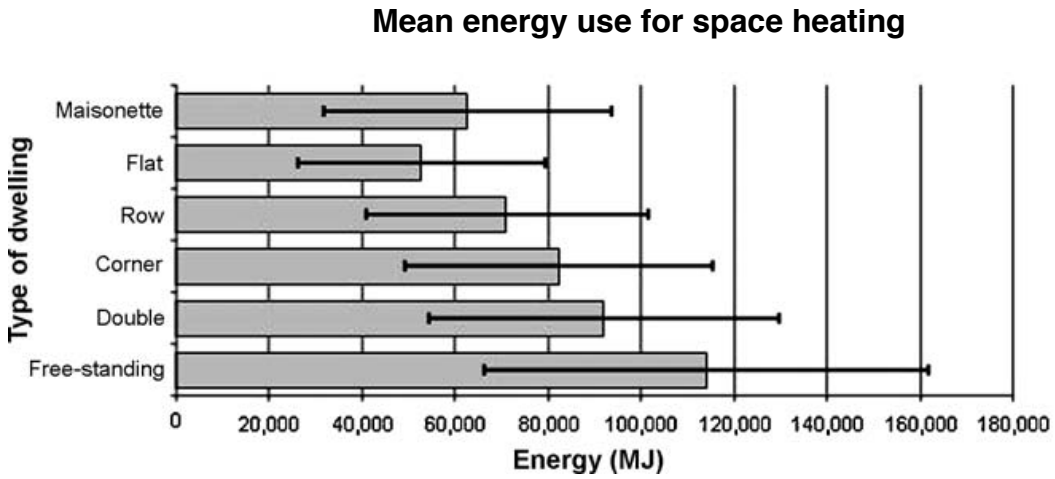


Figure 5.16 - Mean energy use for space heating from Guerra Santin et al, 2008.

Figure5.15 shows the results for the mean energy use for heating from the base case or simulations s1 that was done with the NetLogo model. Since a similar graph found in literature (figure 5.16) shows values for the mean energy use for space heating for 'an average Dutch household' per dwelling type, I have corrected the outcomes from the NetLogo model for an average Dutch household size of 2,3 occupants per dwelling (cbs.nl). When comparing figure 5.15 and figure 5.16 with one another, we can see that however there are some differences between both outcomes, the graphs resemble one another quite strongly. This indicates the NetLogo model gives a good representation, or at least a plausible representation for the mean energy use for heating.

We can observe that the values from the NetLogo model are almost identical for the dwelling types 'vrijstaande-woning' and 'hoek-woning', but lower for the dwelling types 'rij-woning' and

‘flat’, which are both 10.000 MJ lower than the values from literature. This might amongst other things be due to the following reasons:

- a different data-set for reference dwellings (SenterNovem vs KWR)
- a different data-set for the reference year temperature (2009 vs 1964)
- the method of calculating the energy use for heating (ABS vs NEN 5128)

Figure 5.17 shows a graph, produced with the NetLogo model, of the energy use for heating as identified in chapter 3. The graph is based on a 3 person household living in a ‘rij-woning’ and shows the energy use for activities in the first week of March. Figure 5.18 shows a similar graph found in literature that is produced with an ‘energy pattern generator’ for the gas demand in the first week of March.

Although the shapes of the graphs are different it can be observed that the patterns show a similar trend. This indicates the NetLogo model gives a plausible representation for the energy use for activities. The difference in shape could be explained by the fact that a heating installation does not run continuously. It will only run, and hence demand gas when a critical lower limit for the indoor temperature will have been reached. When it turns on, it will heat the dwelling and when the dwelling has reached the upper critical limit for the indoor temperature, it will shut down again. This pattern would be repeated throughout the day.

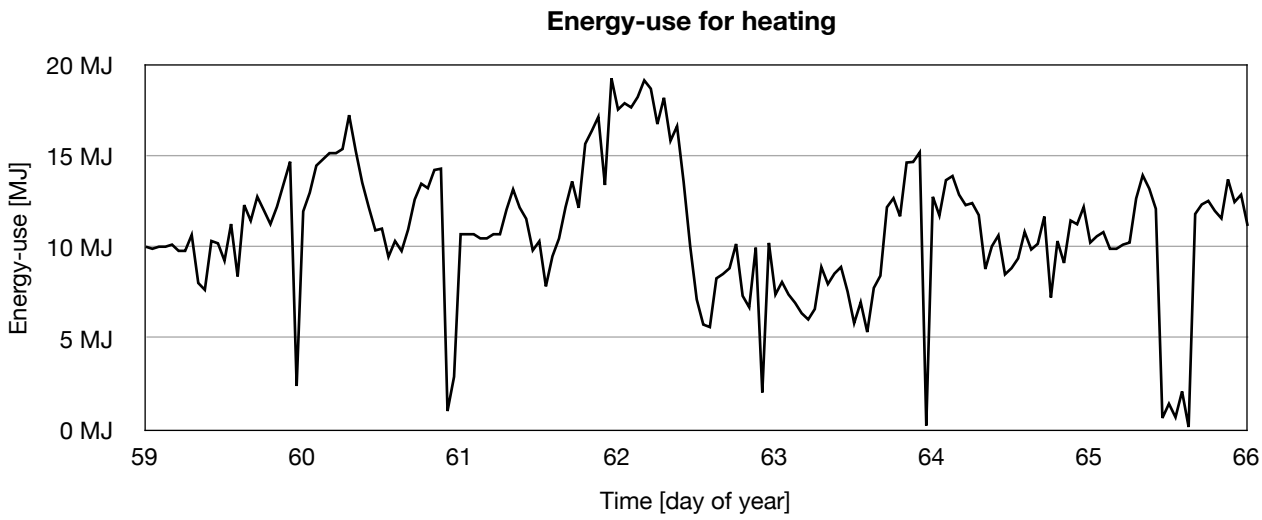


Figure 5.17 - Energy Use for heating for the first week of March 2009.

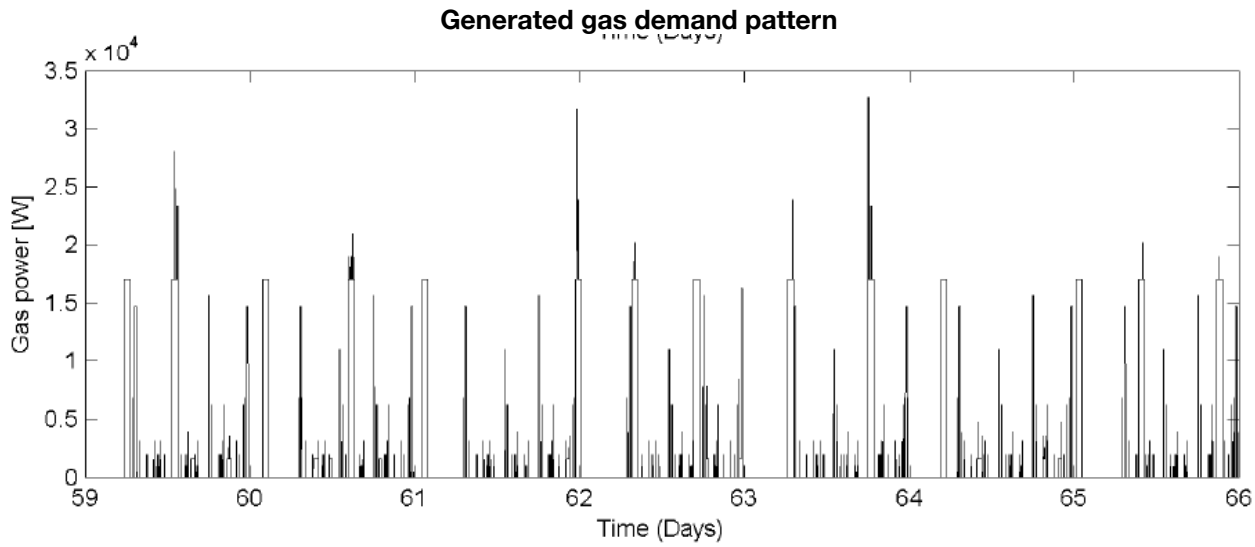


Figure 5.18 - Generated gas demand pattern for the first week of March from the ‘pattern generator’ (Source: Paauw et al, 2009)

Figure 5.19 shows a graph, produced with the NetLogo model, of the energy use for activities as identified in chapter 3. The graph is based on the same 3 person household living in a 'rij-woning' used in figure 5.17 and shows the energy use for activities in the first week of March. Figure 5.20 shows a similar graph found in literature that is produced with an 'energy pattern generator' for the electrical demand in the first week of March.

Although one could argue that energy use and electricity demand are not necessarily the same thing, it can be observed that the patterns show a similar shape. This indicates the NetLogo model gives a plausible representation for the energy use for activities.

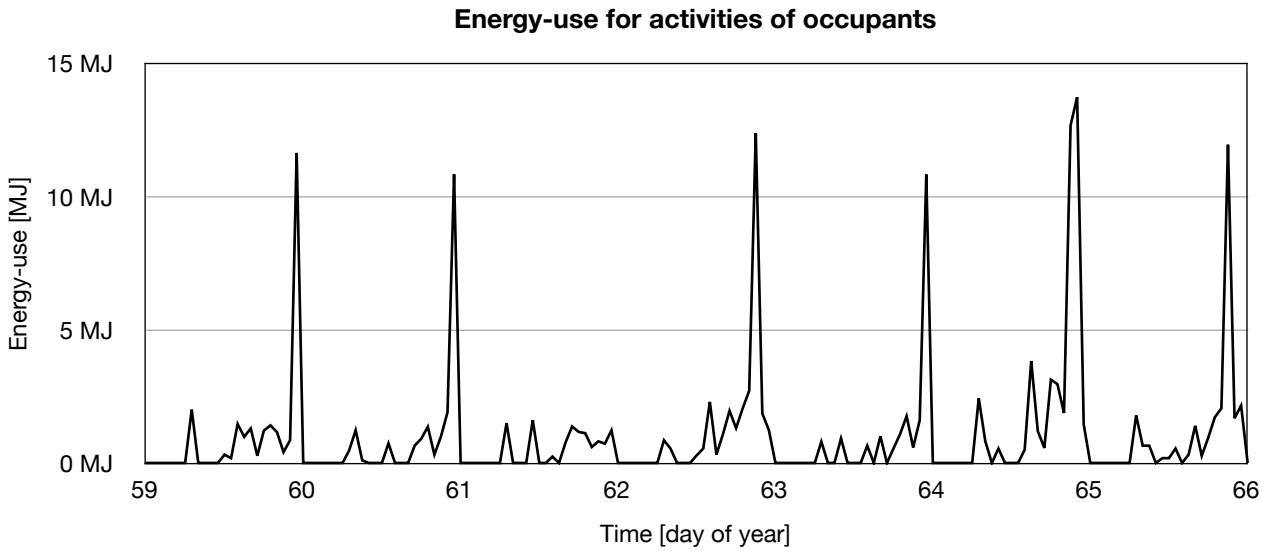


Figure 5.19 - Energy Use for activities of occupants for the first week of March 2009.

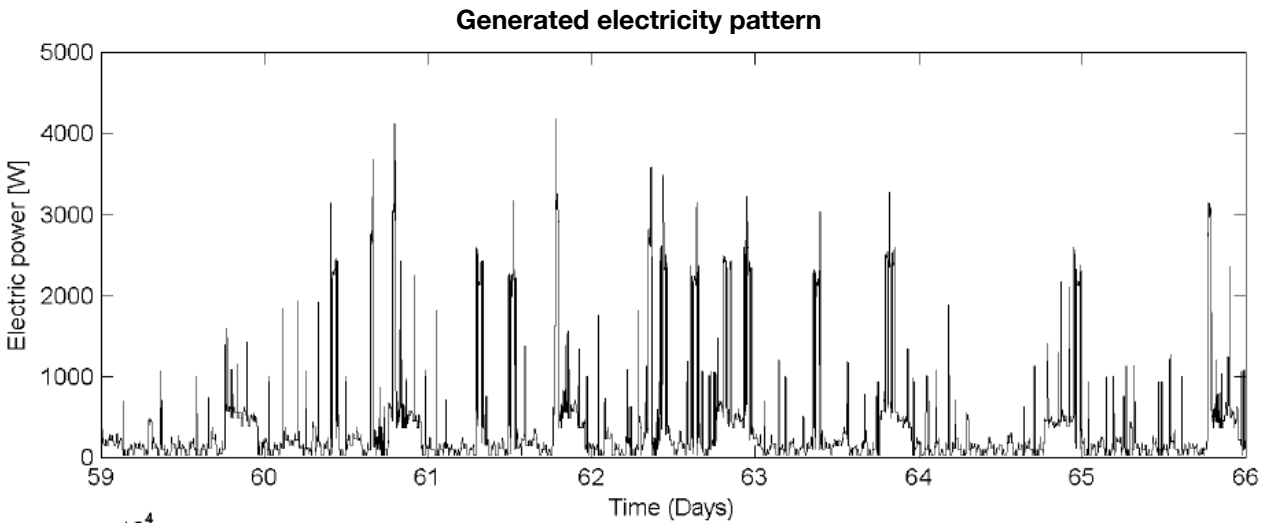


Figure 5.20 - Generated electricity demand pattern for the first week of March from the 'pattern generator' (Paauw et al, 2009)

CHAPTER 6 : CONCLUSIONS

In this chapter I will reflect on the findings of my research and to the problem statement and research questions from chapter 1. First I will draw conclusions on the ABS model to answer RQ1. After this, I will draw conclusions on the effects of occupant behaviour, dwelling characteristics, decentral energy production and energy sharing in order to answer RQ2. In the next and final chapter, I will discuss the interesting findings from this research and propose topics for future research.

6.1 The ABS model

As we have seen in chapter 1, the first research question was:

> **RQ1**: Is it possible to build a model that determines the energy use of a household based on the interplay between dwelling characteristics and individual occupant behaviour?

In answering RQ1, I must conclude that it is indeed possible to build a model that reflects the energy use of households within a district in which dwellings are complemented with the behaviour of their occupants. Using the ABS approach, a successful NetLogo model has been built. The model provides insights into the effect of micro-level behaviour by occupants that becomes directly visible in macro-level outcomes for energy use on a household level and district level. The NetLogo model can serve as a communication and research tool, giving dynamic insights into the effect of an occupants lifestyle, dwelling characteristics, decentralised energy production and energy sharing.

Although I have built a model with photovoltaics for this research, the model could easily be extended by adding Wind, water or Biogas as energy producers. From nature we have learned that diversity is key to survival, and some diversity should therefore be applied in our energy sources.

6.2 Transforming districts

In order to answer the second research question from chapter 1:

> **RQ2**: How can we optimise the transformation of an existing district into an energy zero urban environment?

I will answer the subquestions on 2a: Occupant behaviour, 2b: dwelling characteristics, 2c: decentral energy production and 2d: energy sharing in the following sections. Per specific section I will indicate how potential measures can transform an existing district towards an energy zero urban environment.

6.2.1 Occupant behaviour

Occupant behaviour such as indoor temperature settings and shower length influence energy use of households directly. Since the activity-pattern of an occupant determines how often and when an occupant is home, this also influences the energy use of the household. Age is an important variable for energy use, especially for indoor temperature setting, which causes the major part of a household's energy use. The setting of indoor temperature increases as age increases. Also one's frequency and length of showering is dependent upon age. Furthermore an occupant's

household size influences the frequency of washing, dishwashing and drying directly, which account for a considerate amount of the energy use.

The lowering of indoor temperature setting causes a linear reduction in energy use for heating. Setting the indoor temperature - 1°C lower for an entire year can result in an average reduction of almost 9% per year on the total energy use for a single household, but has the most significant effect on the larger dwelling types 'rij-woning', 'hoek-woning' and 'vrijstaande-woning'. For a typical 'rij-woning', this can mean an absolute reduction of almost 6.800 MJ or 194 m^3 of gas per year. In the district of de Kruiskamp, the absolute reduction could be as high as 22,33 TJ or over 638.000 m^3 of gas per year. Although decreasing one's shower length does not have an effect that is as significant as lowering the indoor temperature setting, it can still cause a considerable amount of reduction in the total energy use of a household on a yearly basis. The absolute effect in de Kruiskamp is equivalent to 171.500 m^3 of gas on a district level annually. Combined, setting the indoor temperature -1°C and reducing one's shower length with 5 minutes could mean a reduction between 11-12% on the total energy use of households. Simply put, setting the indoor temperature lower would save us money and could be an important finding for housing corporations that aim towards a 'residential-charges' approach.

6.2.2 Dwelling characteristics

From the results, we can conclude that any improvement of U-values for the dwelling characteristics will mean a reduction in the total energy use of households and should therefore always be considered. However, most of these adjustments will show practical, technical, financial and legislative difficulties. Yet, they also indicate opportunities for the (local) innovation sciences and production industry. Conclusions on all four separate dwelling characteristics are presented in the sections below.

<u>Windows and glass</u>
Improving U-values for glass should be especially aimed at the smaller dwelling types such as 'flat' and 'portiek-flat'. Theoretically increasing the U-value of glass with 50% in general would give the third highest reduction on the total energy use in the district of de Kruiskamp. An increase of 50% in the U-value for glass would result in:

- transform all existing single glazing into double HR glass (U = 2,0-2,5 [W/m^2K])
- transform all existing double glazing into triple HR+++ glass (U = 1,2 - 1,5 [W/m^2K])

These measures indicate both practical and technical challenges, but seem feasible, although there might be some legislative problems due to commissions for monuments and aesthetics (welstand commissie). Most of these adjustments involve investments and risk, but also may provide employment opportunities, i.e. installing windows and new jobs in the window production industry.

<u>Facade isolation</u>
Improving isolation in facades would have the most significant effect on total energy use reduction for households and for the district of de Kruiskamp. It should especially be implemented for the 'hoek-woning' dwelling type and older houses that were constructed before 1988. Improving facades of dwellings built after 1989 does not have as significantly an effect as improving the U-value of the facades for these older dwellings. The latter seems technically possible and there already are a wide variety of products available. However, some older dwellings, especially those built before 1966, might not have a sufficient cavity depth (spouw diepte) to use these existing methods. This indicates opportunities for the innovation sciences and the production industry to come up with better isolation materials and alternative application methods. It could however lead to legislative conflicts with commissions for monuments and

aesthetics. Improving isolation in existing dwellings is technically challenging, time consuming and could be unpleasant for the occupants. In addition, it will need financial investments from house owners, dwelling cooperations or municipalities, but it will provide employment opportunities in the innovation sciences and production industry in return.

Floor isolation

Floor isolation should be realised especially in the 'rij-woning' and the 'hoek-woning' dwelling types, which are by far, the most common dwelling types in the building stock of the Netherlands. In the district of de Kruiskamp alone these two types make up 69% of the total stock. Isolating floors of existing dwellings will most likely pose a practical problem since older dwellings do not have crawl space underneath their foundations. Yet they are usually directly built upon the underlying soil. Isolating floors in existing dwellings will be extremely inconvenient for occupants. It could therefore serve as an important incentive for the innovation sciences and the production industry to come up with a cost effective and more convenient solution for this problem. In addition, to realising the isolation of existing floors, investments from house owners, dwelling cooperations or municipalities are necessary, but will provide employment opportunities in the innovation sciences and production industry in return.

Roof isolation

Roof isolation should be realised only for the 'vrijstaande-woning' dwelling type. It has by far the smallest effect of all dwelling characteristic adjustments, but is also the easiest dwelling characteristic to adjust.

6.2.3 Energy production by photovoltaics

From the results of simulations s8, I conclude that placing photovoltaics on a dwellings roof has especially a significant effect on the smaller dwelling types 'portiek-flat', 'flat' and '2^1kap-woning'. The use of decentralised photovoltaics means an average reduction of some 6.700 MJ or 1.800 kWh on a yearly basis. This indicates that 40m^2 of photovoltaics on existing dwelling could produce 100% of a household's annual electricity demand and this measure should therefore be taken for all dwelling is de Kruiskamp.

However, the simulations run with the NetLogo model indicate that the production of energy by making use of photovoltaics is especially lucrative in the summer period. During a period of some 167 days, the photovoltaics can produce the amount of energy-required by the household for activities. For the colder winter period, in which most of the energy is used by households, the sun does not shine as intense or as long as during the summer period. This obviously leads to an imbalance between energy-demand and energy production and thus additional power sources such as conventional power plants remain important.

Also, placing photovoltaics on a roof is technically easy compared to isolating an existing dwelling floor. This is especially true for flats, since this dwelling type is already built compactly close to its neighbours, and the implementation of photovoltaics should therefore start with this dwelling type. Furthermore, the market potentials for photovoltaics in the Brainport region are huge, production wise as well as innovation wise. The technological knowledge about computer chips production in combination with the unrealised Dutch solar market potential should make future developments in solar technologies interesting for the Brainport region. Moreover, the under-production capacity for photovoltaics in the world could mean an opportunity for the municipality of Eindhoven and the Brabant region as a whole for employment in the production industry of photovoltaics.

6.2.4 Energy Sharing network

From the results of NetLogo model we can conclude that sharing excess energy between dwellings on a street-level is about 1,5% more efficient than having photovoltaics on a dwellings roof and not sharing energy. An energy sharing network on street-level should therefore be implemented in de Kruiskamp. According to the outcomes of simulation s10, energy sharing between dwellings on a district-level is 0,05% more efficient than sharing energy on a street-level. Keeping in mind the financial investments, technical and practical difficulties of constructing such an energy sharing network, I reason that the necessary investments would not outweigh the effect and an energy sharing network on district level should not be implemented. For the street-level sharing of energy, I think this could be realised more easily, i.e. by connecting different photovoltaics on 'rij-woning' by simply connecting them through the gutter.

CHAPTER 7 : DISCUSSION & FUTURE RESEARCH

From my research I have collected interesting findings, which I would like to discuss. They are not presented in any order of importance and should be helpful t indicate future research. .

The NetLogo model

The NetLogo model constructed for this research makes use of an hourly resolution scale for energy use, but almost no information is available on such hourly, small-scale intervals. When talking about, or discussing energy use, we tend to always talk in terms of years. However, some useful information was found in literature about Finland and Greece. And although attempts are being made, information on an hourly resolution scale is especially lacking for the Netherlands at the moment. Literature only mentions 'average' energy use, but the same sources hardly ever specify what 'average' means. For example, these sources never mention what dwelling type, household size, y.o.c., etc. were used to calculate the energy use. The only way to improve both the quality and quantity of information that is based on an hourly resolution scale, is to start measuring our exact energy use. Applications such as SMART meters, or initiatives such as Google-meter could provide such information in the near future.

For future research, the existing NetLogo model could be extended in the following ways:

- create data-set in the lines of de Kruiskamp for districts in Eindhoven
- simulate week days and weekend days and holiday (= long period of absence)
- include office buildings (now the model is only based on dwellings)
- incorporate stand-by energy use of apparatus (section 4.2.3)
- include installations for heating
- find if there exists an optimal number of connected dwellings in an energy sharing network
- program ventilation as part of lifestyle (section 4.2.1.3)
- use BIM as input of A-values and U-values
- extend model with energy-costs or energy revenues
- revise the internal heat production of apparatus (section)
- revise showering of occupants (section 4.2.2)
- power-law distributions in energy use (section 5.7 and 5.8)

Use an ABS approach for sustainability related issues

The first point of discussion from this research is that I have found the nature of an Agent Based Simulation approach makes it quite possible the best research method currently available to answer energy related questions or issues. It clearly is a research method in which all sciences can have their say. This is important since all sciences are concerned with sustainability related issues. My research has shown that by combining simple technical data of dwellings, social data of occupants and meteorological data of weather, a realistic representation of the real world functioning of energy use can be created. ABS programming should therefore be promoted at institutions such as the TU/e to research energy or sustainability related issues.

Redesign thermostats

On the one hand, the design of thermostats might be too complicated for occupants to understand and use. This indicates a necessity for innovation on the design of them and therefore indicates opportunities for production industries. On the other hand, our instinctual mind will not agree, but judges that money is worth more in one case than in the other. Costs for energy use seem to be a typical example of this and thus convincing people to perform such simple and small changes to their lifestyle remains one of the greatest challenges for sustainability in general and in particular towards an energy zero urban environment. One could argue that there are no high risks or significant investments involved in communicating towards people that they should put on an extra jumper, or turn down their thermostat when they leave their home. Yet changing the habits of people can be a very cost and time intensive business, since there is nothing harder to

change than human behaviour. However, changing this behaviour could play a significant role in reaching an energy zero urban environment. Measures should be aimed specifically at the top 40% of energy users and it indicates opportunities in the education of children about energy use, since parents might be influenced more easily by their children than by their municipalities.

There is an information overload on energy related topics

Another point of discussion is that the topic of sustainability and energy have been so fast evolving in the past years, that one of the biggest challenges of this research was sifting through the information load in order to find useful information and data. Since the topic of sustainability and energy zero are 'hot' at the moment, one has the impression there exists an overload on information and this is complicated by the fact that insights are subjected to constant changes, which lead to even more additional information and data.

We need real life data to validate our research models!

From my own experience, I can conclude that it is almost impossible to obtain real life data from market players on the energy use of households or districts. Even on a district level it was not possible to obtain data on energy use due to legal issues. This type of data is however of key importance when it comes to comparing and validating research models and simulation outcomes. Since the availability of this type of information could serve to calibrate models such as the NetLogo model used in this research, the outcomes of simulations would give a better real life representation.

Revise energy calculation methods

During the research, I found that the approaches of ISSO 51 and NEN 5128; 2004 take into account there is an internal heat gain due to heating tap water. However, this heated tab water is mostly wasted directly through the sink and should in my opinion thus not be taken into account as an internal heating source. Furthermore I have found that the % of heat gain produced by the actual apparatus in a dwelling is a very sensitive variable when using $Q_{prim;verw}$ to calculate energy use, but information is lacking on the exact % of heat gain produced by different sorts of apparatus. Also, we should structurally incorporate occupant behaviour when developing building concepts. Old people, should live in new dwellings, since they use a higher thermostat setting and thus better isolation has a bigger effect for this specific combination between dwelling and occupant. Since building code, NEN and ISSO do not take into account the specific occupant that will live in a dwelling, the design of a dwelling's isolation is therefore never optimised. Perhaps we should stop mass-production, and start a 'mass-of-niches' within the building code, NEN and ISSO. In other words, make building code regulations specific for occupant-dwelling combinations. This would mean a dwelling for elderly people would need far more isolation than a dwelling for two working people.

Municipalities should inventory their assets on the energy market

Although personally I strongly have the feeling that market players such as energy companies do not have the slightest interest in sharing information on energy use since this could be decremental to their business, I endorse the importance of privacy. However, there might be a growing conflict between market parties and municipalities, since the first is only interested in a higher demand for energy and the latter wants to decrease this demand. Our world is still led by oil companies, who will do about anything to keep countries dependent on their fossil fuels for some time to come and avert alternative energy production methods in their mission. Examples from Denmark however show that it is already possible to create independent local energy companies that are led and managed by the inhabitants of a district, which produce energy with alternative, sustainable production methods. Another advantage of such local energy companies

is that the energy costs in the 'residential-charges' can be controlled by the occupants themselves.

Aim concrete measures towards the top 40% of energy users

As we have seen in this research, 40% of the households use 60% of the total energy in a district. Therefore, if we want to effectively transform our existing urban environment towards energy zero, measures should be directed towards the top 40% of the energy users. But in order to do so, it is of key importance to know who these top 40% energy users are. Since energy companies in the Netherlands often have a local history municipalities often posses shares in these companies. This means municipalities have something to say and could compel the energy companies into sharing their information on energy use. In this way the top 40% of energy users could be identified and efficient measures could be directed towards them in order to transform existing districts towards energy zero urban districts. Since some of the municipalities have not been actively involved in the day-to-day business of the energy companies even though they are shareholders, it is extremely important that municipalities inventory their assets and make better use of their position in the years to come.

'Average energy use'

Although many different values for the 'average' energy use of a Dutch household can be found in literature and on the internet, I reason that the 'average' energy use of a household does not exist, as there does not exist an average 'human' in ergonomics. From a mathematical point of view, when considering 5 dwelling types, 6 periods of construction, 5 volume ranges and 6 household sizes, there already exist: 5 x 6 x 5 x 6 = 900 possible combinations between occupants and dwellings. The term 'average' might hence better be abandoned, since it could lead to the misunderstanding that energy use is some 'average' value which is the same for every household, which I believe it is not.

The most important thing to keep in mind is that the constructed ABS model of this research can be extended with the proposed, or any other additions. If the municipality of Eindhoven or initiatives such as KENWIB could deliver a data-set describing occupant-dwelling organisation and real life data on energy use of the past years from these districts to calibrate the model, it could serve as a great tool to help transform Eindhoven into an energy zero urban environment before 2040.

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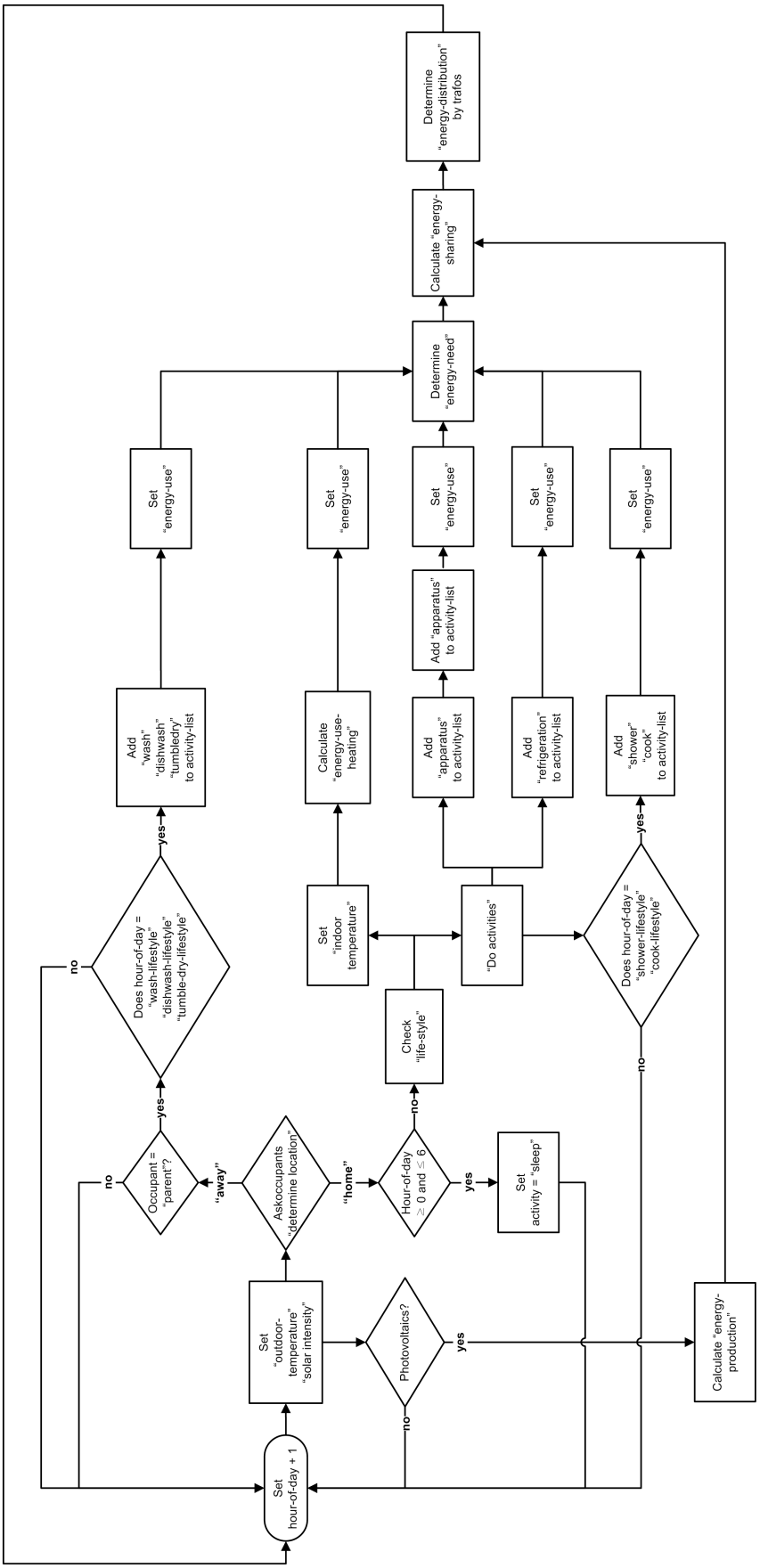
APPENDIX 1 : DEFINITIONS

Below the English translations of Dutch terminologies used for dwelling types is shown.

- ‘vrijstaande-woning’ : detached dwelling
- ‘hoek-woning’ : corner dwelling
- ‘rij-woning‘ : row dwelling
- ‘2^1kap-woning’ : semi-detached dwelling
- ‘flat‘ : flat
- ‘portiek-flat‘ : portico flat

APPENDIX 2 : FLOWCHART

Below the workings of the NetLogo model are shown. The flowchart describes the steps, the model takes and calculates on every hour-of-day.