4 Behavioral determinants of electricity consumption in dutch dwellings

Introductory note

Following the sensitivity analysis on heating energy consumption in Chapter 3, Chapter 4 is an analysis on the determinants of electricity consumptions in Dutch dwellings. The OTB sample was used for analysis, and it was validated with analysis of the WoON sample. The work was published as:

This Chapter deals with the Research Question II of this thesis:
(Chapter 1, Section 3, pg. 16-17)
"II. What is the influence of lighting and appliance use on the total electricity consumption in dwellings?"

The sub-questions are:
1. *What are the main direct and indirect determinants of electricity consumption? (Direct determinant: such as number of appliances and duration of appliance use ... Indirect determinant: such as household size, dwelling size, dwelling type ...)*
2. *How much of the variance in electricity consumption in dwellings can be explained by direct and indirect determinants?"*
   The research reported in this Chapter was conducted by Bedir. The data was collected by a questionnaire prepared by Guerra Santin and Bedir, using OTB's means of data collection. The analysis was done, and the paper was written by Bedir. The co-authors commented on the drafts and gave advise on the structure, and the content of the paper. The co-authors have given their permission to include the paper in the thesis.

This Chapter was published as:
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§ 4.1 Introduction

Operation of heating, ventilation and air-conditioning systems, lighting, and domestic appliances account for the electricity consumption in dwellings. This paper explores the contribution the use of lighting and domestic appliances to electricity consumption and how it is determined. Households consume electricity via domestic appliances that serve different functions such as cooking and cleaning. The type and number of appliances and the duration of use vary across households and through time, depending on the energy needs of the households and the accessibility and affordability of the appliances. Biesiot and Noorman (1999) split the electricity consumption patterns for the Netherlands into three main periods since World War II (Fig. 1). During the first period, the post- war reconstruction (1950–1965), the emphasis was on rebuilding society. During the second, the welfare state (1965–1980), households had easier access to resources and appliances and electricity consumption was 5–6 times higher than in the first period. The third period (1980–1999) started after the oil crisis, when environmental concerns increased in general, but so did dependence on electrical appliances. Indeed, the consumption of electricity in the third period was as high as in the second.

Biesiot predicted that electricity consumption would rise if people increased their use of electrical appliances. His predictions have been borne out by the results of recent research (Jeeninga et al., 2001; IEA, 2009; EnergieNed, 2009; ERC, 2008; ERC, 2009; ODYSSEE, 2008). In the 27 EU-member states, electricity efficiency has improved by almost 1.5% a year since 1990 (ODYSSEE, 2008). However, in 15 EU countries, larger homes and an increasing number of appliances are pushing up the consumption per household by about 0.4% a year (ADEME, 2007). These two factors almost completely offset the progress of the past two decades (Figure 2).

§ 4.1.1 Electrical domestic appliances

Households account for 23% of the total electricity consumption in the Netherlands (IEA, 2008). At European level, white goods and lighting are responsible for 40% of the electricity consumed by households and brown goods for 60% (13). Electronics capabilities led to the emergence of a distinction between “white goods” (the typically enameled kitchen appliances such as fridges and cookers) and “brown goods” (such as wood- or bakelite-cased record players, radios, and TVs) (Miles, 1999). Since 1996, the energy efficiency of electrical domestic appliances has been a major concern for policy, research and the market. Today, almost all such appliances consume less electricity than in 1990 (ODYSSEE, 2007).

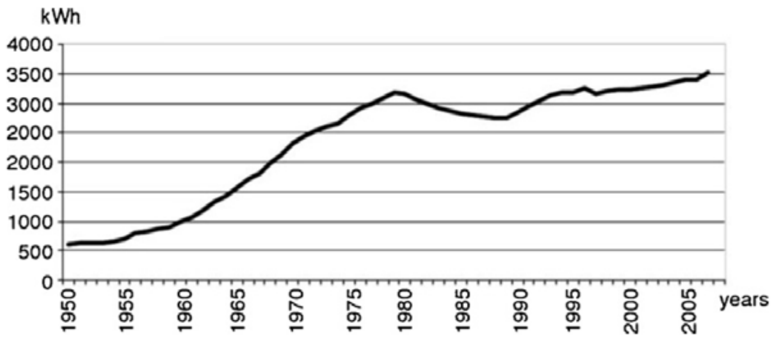

FIGURE 4.1 Average electricity consumption per household in the Netherlands (EnergieNed, 2009)

The average consumption of a washing machine has decreased by 28% since The average consumption of a washing machine has decreased by 28% since 1995, but the use of washing machines has increased by 32% (Itard et al., 2009). Dryers show less improvement in energy efficiency (12% decrease in electricity consumption between 1990 and 2007), but the use of dryers has increased considerably (38%). The same trend can be observed for dishwashers (25% decrease in specific electricity consumption between 1990 and 2007, 150% increase in use). The only appliance that has consistently been consuming more energy since 1990 is the TV – 2.5 times higher in 2007 than in 1990. This increase reflects the growing popularity of larger TVs and flat screens. Of course, when it comes to the total energy consumption per dwelling, it is not only the energy consumed by specific appliances that is important, but also the percentage of households with one or more of these appliances (ERC, 2009) (Fig. 3).

Despite the efforts to improve the energy efficiency of electrical appliances, the growing population, the increasing number of households and the wider use of electrical appliances could be instrumental factors in the rising levels of electricity consumption. To bring about a meaningful reduction in the electricity consumed by the housing stock, we need to know more about the underlying determinants. The ability to make accurate predictions of the electricity usage of households is already an important issue for energy companies and will become even more important with the emergence of smart electricity grids. It is possible to make accurate predictions of electricity consumption when the duration of use of each electrical appliance is known as well as its voltage. Unfortunately, as such data are difficult to collect by energy companies, especially at macro-level, we need to establish more easily accessible parameters with an explanatory power to determine the level and variance of electricity consumption in households. Variables of presence, household and dwelling characteristics, and technical system characteristics should be investigated. This paper reports electricity consumption of dwellings can be explained by the use of lighting and electrical appliances and to identify the underlying determinants of use.

This paper begins with a review of previous research on electricity consumption in dwellings. This review formed the basis for the hypotheses and the research questions. Section 3 describes the methodology and the data used in the study. Variables from the literature were grouped and tested in our sample. The data were collected via a questionnaire filled in by the occupants of 323 dwellings in two neighbourhoods in the Netherlands in the autumn of 2008. Three regression models were built for the direct and the indirect determinants (see Section 3): the first was based on the total duration of use of the appliances (direct) and presence in the dwelling and in rooms (indirect); the second was based on the number of lighting and household appliances (direct) and the characteristics of the dwelling (indirect) (economics, heating and ventilation systems and household – henceforth referred to as DHES characteristics) and the third was based on the total duration of use of the appliances (direct) and DHES characteristics (indirect). The results are presented in Section 4 and the discussion in Section 5. Finally, the conclusions are presented in Section 6.

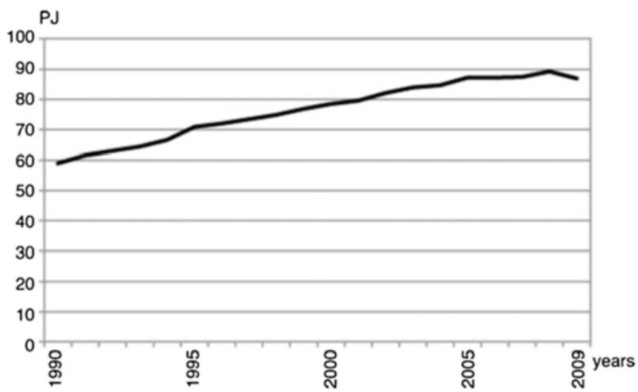

FIGURE 4.2 Total electricity consumption of households in the Netherlands (CBS, 2004; 2009; 2010)

§ 4.2 Literature, Hypotheses and Research Questions

The results of existing research on electricity consumption in dwellings vary according to the type of fuel that is used to heat space and water and the presence or absence of air conditioning (in relation to electricity consumption in summer). Only two dwellings in our sample had air conditioning (cooling). Electric radiators are not used for space heating in the Netherlands, and there was no heating by electric pumps in our sample.

Cramer et al. (1985) conducted a study on 192 dwellings in Lodi, California in 1981 with the aim of combining the engineering and social determinants of electricity consumption. The analyzed data was the summer consumption data, so air conditioning was an important determinant together with the appliance index. The appliance index included ownership, frequency of use, location in the dwelling, published average efficiencies, and estimated seasonality factors. Results of the linear regression analysis for engineering determinants, namely, the appliance index and the air conditioning index, were able to explain 51% of the variance in summer electricity consumption; the social determinants of expected electricity price, income, education, membership of a minority group, employment of spouses, if respondent is under 35, the presence of an infant (under 3), the presence of an elderly resident (over 65), number of people aged 3–18, number of people over the age of 18, thermal comfort scale (Likert-type items were used for the thermal comfort scale, conservation scale included 4, and environmentalism scale included 5 items. Energy knowledge scale was created on the basis of the level of the participant's knowledge of energy consumption. For further reading, the reader is referred to the document, itself), conservation scale, environmentalism scale, and energy knowledge scale were able to explain 34% and the combined model of engineering and social determinants was able to explain 58% of the variance in summer electricity consumption.

Appliance index and air conditioning index contributed significantly to the model in both the engineering and the combined model. In the social determinants model, income (increasing electricity usage), membership of a minority group (decreasing electricity usage), number of people aged 3–18 (increasing electricity usage), number of people of over the age of 18 (increasing influence), thermal comfort scale (increasing electricity usage), and energy knowledge scale (increasing electricity usage) were significant. In the combined model, income (increasing electricity usage), respondent age (decreasing electricity usage) and thermal comfort scale (increasing electricity usage) were significant.

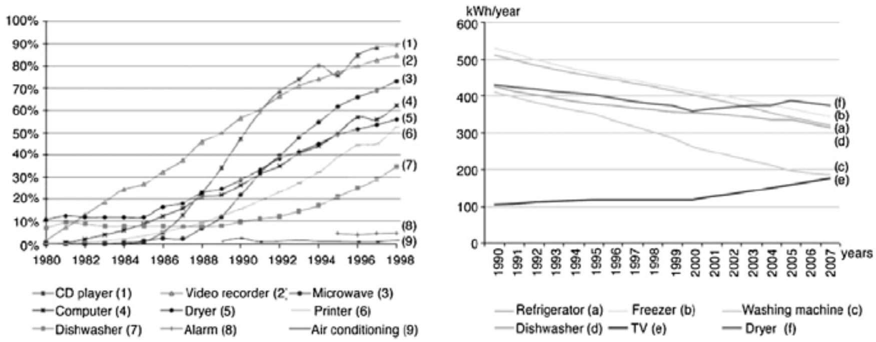

FIGURE 4.3 Ownership of appliances (left) (Jeeninga et. al., 2011); Energy consumption of specific appliances (right) (ECN, 2009) in the Netherlands.)

Ndiaye and Gabriel (2010) made an analysis of 62 cases in Oshawa, Canada, with 59 predictors. The 59 predictors were reduced to nine with the latent root regression method of Hawkins. This model could predict 75% of electricity consumption; the predictors were number of occupants in the house (increasing influence), dwelling ownership status (owner-occupied dwellings consumed more), number of weeks per year on vacation (decreasing influence), type of fuel for the pool (increasing influence from 'not applicable' to 'solar energy' and 'natural gas'), type of fuel for the space heating system (increasing influence from 'natural gas' to 'oil' and 'electricity') and the domestic hot water (increasing influence from 'natural gas' to 'electricity'), presence of air-conditioning system (increasing influence), type of air-conditioning system (decreasing influence from 'not applicable' to 'heat pump', and to 'central system'), each value under 50 Pa (increasing influence from '1.5' to '13.3').

Yohannis et al. (2008) monitored 27 dwellings in detail in Northern Ireland for a year. Type of dwelling, location, ownership and size, household appliances, number of occupants, income, age, and occupancy patterns seemed to have a significant influence on electricity consumption. They found a clear correlation between electricity consumption and floor area and that electricity consumption per person decreased as the household size increased. The electricity consumption for homes that were occupied during the day by unemployed or retired people was generally lower. In homes with no daytime occupants, electricity consumption was 2.5 times higher than the average in total, and 1.5 times higher during the day than those occupied during the day. They had peak consumptions in the morning (prior to working hours) and in the evening. Houses with no presence during the day had a bigger floor area than the others and were occupied by higher income families, which could explain the higher average electricity consumption.

O'Doherty et al. (2008) carried out a survey on dwelling characteristics and problems and household members in 40 000 households in Ireland (National Survey on Housing Quality – NSHQ). The survey included data on the main electricity-consuming appliances (order in the number of dwellings that possess these appliances: refrigerator, telephone, TV, VCR, microwave oven, washing machine, freezer, dryer, electric shower, personal computer, dishwasher). The other variables were years of residence in the dwelling, dwelling value, location of the dwelling, ownership of dwelling, dwelling type, dwelling age, weekly income, electricity tariff, occupant age, occupation, and household composition. All variables were found to be significant. The regression analysis showed that the factors that increase electricity consumption were electricity tariff (low tariff households consumed more – household is on low tariff for off-peak mains electricity; this is normally used by households with electric central heating), house value (high-value dwellings consumed more), income (high-income households consumed more), dwelling age (more recent dwellings consumed more) and household type (consumption was higher in households with elderly people or children). The factors that have a negative influence on electricity consumption are years of residence in dwelling (shorter occupation in the dwelling = lower consumption), ownership of dwelling (tenants used less), occupation (groups that were present less often used less), dwelling type (apartments, semi-detached, terraced houses used less than detached houses), location (non- urban dwellings used more), age (people over 64 used less than the people below 40, and people below 40 used less than people between 40 and 64).

Genjo et al. (2005) conducted a survey on the possession of appliances in 505 Japanese households. They found that lighting and appliances account for 3 MW/h and 60% of the variance in annual electricity consumption in dwellings. They also found that owner- ship of appliances reflected the lifestyle of the residents. Income (Beta = 35, $p < 0.05$), household size (Beta = 0.23, $p < 0.05$), and number of appliances (Beta = 0.062, $p < 0.05$) were the factors behind electricity consumption.

Mansouri et al. (1996) conducted a survey among 1000 people in the South-East of England in 1994. The survey was about attitudes and beliefs, ownership of appliances, usage patterns of appliances, purchasing, and labelling schemes. They found that ownership of the dwelling had an increasing influence on electricity consumption and that people who expected an increase in electricity prices consumed less.

Bartiaux and Gram-Hanssen's (2005) paper, based on SEREC, and ODYSSEE project datasets compared electricity consumption between Danish and Belgian households. Dwelling type, floor area, and household size proved significant in both countries and explained 30–40% of the variance in electricity consumption in Denmark and 10–30% in Belgium. Growing size of dwellings, growing ownership of appliances, and the number of single-person households emerged as key factors in electricity consumption and therefore in the energy efficiency policies.

Vringer et al. (2007) researched household energy requirements (heating energy demand and electricity demand) and value pat- terns on the basis of a survey in the Netherlands with a respondent size of 1272. They defined eight social categories (caring faithful, conservatives, hedonists, balanced, materialists, professionals, broad-minded, socially-minded) and 4 consumption categories (low income-low energy, low income-high energy, high income-low energy, and high income-high energy). They found that high-energy households require between 10% (high income) and households are more likely to own a relatively older, semi-detached and 10–15% larger dwelling. Interestingly, the electricity requirement was not too different in the four energy categories, only in low energy-low income group was it fairly low. High-energy house- holds own 10% more electrical appliances; however, no differences were found between the low and high-energy households for the possession of energy-saving light bulbs and food preparation appliances.

Saidur's (2007) analysis of electricity consumption from the use of appliances in Malaysia revealed that the refrigerator/freezer is the main energy-consuming appliance, followed by the air conditioner, washing machine, fan, rice cooker and iron. Baker and Rylatt (2008) conducted a questionnaire in 190 dwellings in Leicester and Sheffield in the UK in 2005. The predictors were floor area, occupancy, age, number of rooms, number of bedrooms, home working, main heating, number of TVs, digiboxes, PCs, portable electric heaters in use, and showers per week. The regression analysis showed that all the variables had a significant influence on increasing the electricity consumption in dwellings. Number of bedrooms and home working were the most important parameters for electricity consumption.

Tiwari's (2000) regression model on the 1987–1988 household survey of the Bombay Metropolitan Regional Development Authority (BMRDA), which included a total of 6358 dwellings, analyzed the impact of the structure of the dwelling, age of the dwelling, location of the dwelling, number of rooms, household size, age of respondent, appliance index (ownership of an appliance and the voltage), income and electricity tariff on electricity consumption. The electricity consumption increased with the income of the family, household size, age of the dwelling, number of rooms, age of respondent, and appliance index and decreased as the electricity tariff increased. Chawl, flat, and bungalow dwellings consumed more electricity than huts.

ODYSSEE research (2008) measured the impact of lifestyle factors on the average electricity consumption per dwelling. Three main influences were found in this research: increase in the average size of dwelling, the diffusion of electrical appliances and central heating, i.e. the influence of increased appliance ownership and the comfort-related behavior (mainly increasing use of hot water). Parti and Parti (1980) created an economic model with data on 5286 dwellings in San Diego County in 1975. The dataset included data on demographics, appliance ownership, electricity consumption, electricity price and weather characteristics. The regression model with air conditioning and space heating, water heating and appliances explained around 60% of the electricity consumption.

A similar economic model by Fuks and Salazar (2008) introduced a bottom-up approach to electricity consumption modelling by using the proportional odds, partial proportional odds methods, and the generalized ordered logit. The data were collected from dwellings in Rio de Janeiro, in 2004. Income, appliance index, floor area of the house, and if the household is new in the dwelling (more than one year, less than one year) were used to set up both models. The proportional odds model was able to estimate the consumption correctly in 53% of the cases, the partial proportional odds model in 55%.

Rooijers et al.'s (2003) research about energy consumption and behavior at home in Dutch context, revealed that household size and floor area are the crucial determinants and household income is equally significant. Similarly, ERC (2009) conducted a research named MONITWeb in Dutch dwellings, where they applied linear regression analysis and found that the household size, and the floor area of the dwelling are the important factors of electricity an analysis on a sample of more than 300,000 Dutch homes and their occupants (Central Office for Statistics, Netherlands dataset). The results indicated that residential electricity consumption varied directly with household composition, in particular income and family composition. Dwelling size is strongly related to total energy consumption; electricity consumption is substantially larger in detached and semi-detached houses than in row houses or apartments. Besides, an additional room decreases electricity consumption by 0.5 percent. Age is not monotonically related to electricity consumption. Households with children – particularly teenagers – consume much more electricity than other household units. They found that a one-percent increase in disposable income is associated with an eleven percent increase in household electricity usage.

On the basis of the literature review, the determinants of electricity consumption in dwellings were classified under appliance ownership and use, dwelling characteristics, household characteristics, economic characteristics, and heating, ventilation and air-conditioning (HVAC) system characteristics.

Appliance ownership and size are proved to be significant predictors of electricity consumption. The appliance index of Cramer et al. (1985), included number, frequency of use, location in dwelling, published efficiency, and estimated seasonality factor. The appliance index of Tiwari (2000), on the other hand, was based on ownership of an appliance and the power data. Dwelling type and floor area were identified as significant predictors of electricity consumption in much of the previous research. The location of the dwelling is another important parameter and the age of the dwelling also appears to have a significant impact on electricity consumption. Lastly, the number of rooms and bedrooms also emerged as significant predictors of electricity consumption.

Household size is the main and most common predictor of electricity consumption, common to all existing research. Age, thermal comfort, employment/working at home and occupancy patterns are also important. People who expect electricity prices to rise were shown to consume less electricity. Households with several weeks' holiday in a year and households that are new to the dwelling consume more electricity. Lastly, education, and belonging to a minority group have also proven important factors in electricity consumption.

Income was identified as a significant predictor of electricity consumption as well as home ownership, the electricity tariff and the value of the house. An air-conditioning index, space and the type of water heating system, the type of fuel for heating the pool water and the domestic hot water were confirmed as important factors.

Electricity consumption in dwellings can be explained by direct and indirect determinants. The direct determinants are the number, the voltage, and the total duration of use of lamps and domestic appliances. In this research, we did not use any data on the voltage and the total duration of use of the lamps and the voltage of appliances, as these are generally impossible to collect without inspecting the dwelling. Also, most occupants skip the questions on the voltage of appliances in a survey, probably because they do not know this information by heart (in our survey, the questions on label and size of appliances were left empty). Accordingly, we used only the number of lamps and appliances and the total duration of use of appliances. In addition, we related the use of appliances to the indirect determinants of presence in the dwelling and rooms and to the DHES characteristics.

The determinants of electricity consumption mentioned in the literature were tested in our survey dataset. Section 3 contains a detailed description of the survey data, as used in the regression analysis. Having reviewed the literature, the main research questions addressed in this paper are:

- How much of the variance in electricity consumption in dwellings can be explained by direct and indirect determinants?

- What are the main direct and indirect determinants of electricity consumption?
- Do our results correspond with the results obtained in the Netherlands by Biesiot and Noorman (1999), Rooijer et al. (2003), Vringer et al. (2007), ODYSSEE (2008), and Brounen et al. (2011)?

§ 4.3 Methodology

The study data were collected via a survey in two districts (Wateringse Veld and Leidsche Rijn) in the Netherlands in the autumn of 2008. The dataset of 323 cases covered a range of topics in the questionnaire with regard to household characteristics (size, composition, years of residence in the dwelling, change in household composition in the previous year), individual characteristics (age, education, occupation, hours spent outside home), economic characteristics (income, ownership, electricity tariff), presence (number of people and duration of occupation in each room), dwelling characteristics (type, number of rooms, function of rooms), appliance use (number of domestic appliances, number of appliances in the living room, standby appliances, chargers, duration of use, appliance labels, sizes), and lighting devices (number, type).

Correlation and multiple regression were used to set up a model to explain electricity consumption via (1) direct use: lighting and appliances, and (2) indirect use: factors that influence the use of lighting and appliances. First, by correlation analysis, the variables in each category in Table 1 were investigated to find if and how strong a correlation occurred with electricity consumption. Afterwards, using a stepwise (backward) technique, the variables that were found to be correlated were placed in the regression analysis. The variables that emerged as significant were then combined in the final regression models. Three regression models were constructed for the use of appliances and electricity consumption (Table 1 and Figure 4). Model I (technical/engineering approach) uses the duration of use of each appliance (direct use) and hours of presence in dwellings and in rooms (indirect use). Model II (social approach) uses the number of lamps and appliances (direct use) and the DHES characteristics (indirect use). Model III (combining engineering and social) uses the total duration of use of each appliance and DHES characteristics.

As we explained in Section 1, it is possible to make accurate predictions of electricity consumption when we know the duration of use, and voltage of each electrical appliance. However, this data is difficult to gather by energy companies, so we are looking for more 'easy to gather determinants' with good explanatory power.

The reasons for building three separate models were: (1) to evaluate and compare the social and the engineering approaches, many examples of which are mentioned in the literature review, and combine them to see if it is possible to achieve a stronger and more explanatory model, (2) to determine how much of the variance could be explained with the number and duration of use of the appliances separately, and in combination, and (3) the indirect use variable of presence created collinearity with the indirect use variables of DHES characteristics.

§ 4.3.1 Description of the Data

The survey data were examined with a view to the multiple regression analysis. Outliers were analyzed, variable frequencies were checked to see how many of the variables could be used for statistical analysis and the categorical variables were transformed into dummy variables.

§ 4.3.1.1 Outliers

Out of the 323 cases in the dataset, the electricity consumption data for seven were exceptionally high, probably because the occupants did not actually record the electricity consumption in the past year, but took the meter reading. Twelve questionnaires were returned blank. These 19 cases were therefore excluded from the dataset, leaving a final sample size of 304.

§ 4.3.1.2 Missing data

Some of the data in the dataset were insufficient to be included in the statistical analysis, namely:

- The number of weeks when nobody is at home;
- The volume and label data for the appliances (fridge, freezer, washing machine, dishwasher, dryer);
- Whether the electricity and gas meters were checked regularly;
- Whether there was a PV/solar collector in the dwelling.

§ 4.3.1.3 Variables

Transformed variables:

'Electricity tariff' can take two values in the Netherlands: (1) single tariff consumption – one daytime and evening rate on weekdays and weekends, (2) double tariff consumption – two different rates, one for during the day and another for evenings, nights and weekends. The electricity consumption data obtained from the survey were based on kWh values. Some cases had single tariff consumption records (9%), and some had double records (91%). In order to obtain a final variable for electricity consumption, a check was performed to determine whether a single or double electricity tariff made a difference. No significant correlation was found, so the single and the double tariff recordings were computed to one electricity consumption category.

Variables for 'Use of appliance' were computed into different continuous variables according to the number and function of the appliances (see Table 1):

- General appliances: according to their frequencies, the appliances that were found in most of the dwellings: TV, computer (desk- top, laptop), stereo, wireless telephone, dishwasher, and fridge. Since a fridge and washing machine were present in most of the dwellings, they were categorized as general appliances, and not as food preparation or cleaning appliances.
- Food preparation appliances: coffee machine, electric kettle, electric grill, microwave oven, toaster, induction cooker, electric hot plate, freezer;
- Cleaning appliances: dryer, dishwasher, iron, vacuum cleaner;
- Hobby appliances: video games console, home cinema system, hard disc recorder, video camera, video recorder, wireless inter- net, solarium, jacuzzi, sauna, waterbed, aquarium, terrarium;
- Extra ventilation appliances: air conditioner, fan.

Variables for 'Presence in dwelling' and 'Presence in rooms' that were originally obtained on an hourly basis were computed into different continuous variables according to times of the day, week- day/weekend. Our point in investigating the parameter 'presence' in detail is that 'presence in a room' could give more information than 'presence in dwelling' because activities that lead to electricity consumption may be related to the rooms with certain functions. Presence in room 1, 2, or 3 represents presence in rooms with a function other than living room. These rooms have a function of bedroom, study, hobby, etc. (see Table 1).

- Total hours of presence in living room and in other rooms;
- Weekdays and weekend patterns of presence; presence patterns in certain parts of the day: morning (05.00–08.00), day (08.00–17.00), evening (17.00–23.00), night (23.00–05.00).

Dummy variable for 'Dwelling type': flats and maisonettes on top floors, flats and maisonettes on ground floors, corner, semi- detached and detached dwellings and terraced houses. Terraced houses were taken as the reference case, so they do not appear in the final model.

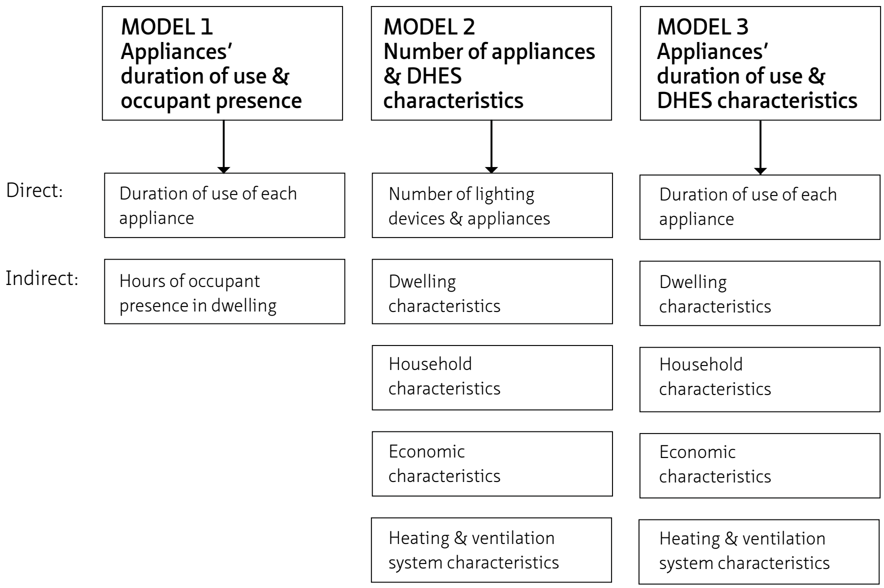

FIGURE 4.4 Model I (duration of appliance use and hours of presence in the dwelling), Model II (number of lamps and appliances and DHES characteristics), and Model III (duration of appliance use and DHES characteristics).

§ 4.4 Results

This section explains the correlations and the three regression models. In all the models the influence of 'direct use' variables on the electricity consumption is explained first, followed by the 'indirect use' variables and finally the combination of direct and indirect use variables.

§ 4.4.1 Correlations

First step was to find the correlations between the variables listed in Table 1 and electricity consumption. In Annex 1.1, a correlation table for all the p and r values of all the variables are displayed. Later, the correlated variables are used to set up the regression models.

The duration of use of general appliances ($r = 0.47$, $p < 0.00$), cleaning appliances ($r = 0.33$, $p = 0.00$), food preparation appliances ($r = 0.20$, $p < 0.01$), and hobby appliances ($r = 0.33$, $p < 0.00$; and the number of general appliances ($r = 0.41$, $p < 0.00$), cleaning appliances ($r = 0.25$, $p < 0.00$), food preparation appliances ($r = 0.23$, $p < 0.00$), hobby appliances ($r = 0.35$, $p < 0.00$), standby appliances ($r = 0.14$, $p < 0.04$), battery chargers ($r = 0.16$, $p < 0.03$), light bulbs ($r = 0.20$, $p < 0.04$), energy-saving light bulbs ($r = -0.18$, $p < 0.05$) are found to be significantly correlated to electricity consumption.

List of variables used

Group	Variable	Variable type	Unit
Appliances	Duration of use, general appliances	Continuous	Minutes a day
	Duration of use, cleaning appliances		
	Duration of use, food preparation appliances		
	Duration of use, hobby appliances		
	Number of general appliances/ number of general appliances in living room		
	Number of cleaning appliances/ number of cleaning appliances in living room		
	Number of food preparation appliances/ number of food preparation appliances in living room		
	Number of hobby appliances/ number of hobby appliances in living room		
	Number of extra ventilation appliances/ number of extra ventilation appliances in living room		
	Number of standby appliances/ number of standby appliances in living room		
	Number of battery chargers/ number of battery chargers in living room		
	Number of light bulbs/number of light bulbs in living room		
	Number of energy-saving lights/ number of energy-saving lights in living room		
Presence in dwelling	Presence in living room and kitchen	Ordinal	Hours: all day/morning/day/evening/night in w.days & w.ends
	Presence in room 1		
	Presence in room 2		
	Presence in room 3		
	Presence in bathroom		
	Presence in attic		
Dwelling characteristics	Dwelling type (1) Terraced, (2) top floor apartment/ maisonette, (3) ground floor apartment/maisonette, (4) semi detached/corner/detached	Categorical	
	Number of rooms	Continuous	
	Number of bedrooms		
	Number of study/hobby rooms		
	Floor area of the house		m2
	Rented/owner occupied	Dichotomous	

TABLE 4.1 Variables tested with regression analysis

List of variables used			
Group	**Variable**	**Variable type**	**Unit**
Economic characteristics	Rent/mortgage	Continuous	Euros
	Electricity included in rent	Dichotomous	
	Electricity tariff		
	Income	Continuous	Euros
	Gas consumption, yearly		kWh
Household characteristics	Household size	Continuous	
	Years of residence in the same house		Years
	If the household composition has changed in recent years	Dichotomous	
	Occupation (1) At home, (2) work outside, (3) work at home, (4) other	Categorical	
	Working outside hours	Continuous	h/week
	Education	Ordinal	
	If there are elderly people in the household	Dichotomous	
	If there are infants in the household		
	Age groups (1) 0–6 years, (2) 6–18 years, (3) 18–65 years, (4) over 65	Categorical	
	Any hobby including use of electricity	Dichotomous	
	Dishwasher use	Continuous	Cycles a week
	Washing machine use		
	Number of hot washes (90 oC)		
	Number of cold washes (30 oC)		
	Dryer use		
	Number of baths	Continuous	Times a week
	Number of showers		
	Duration of shower		Min.s per shower
Heating & ventilation system characteristics	Mechanical ventilation set point adjustment for flow rate (hour/day during w.day/w.end & winter/summer)	Ordinal	
	Ventilation system off	Continuous	Weeks/ year
	Heating system type (District heating or individual boiler)	Dichotomous	

TABLE 4.1 Variables tested with regression analysis

Presence in room 1 (week – all day) ($r = 0.20$, $p < 0.00$), room 2 (week – all day) ($r = 0.23$, $p < 0.00$), bathroom (week – morning) ($r = 0.23$, $p < 0.00$), room 3 (week – during day) ($r = 0.01$, $p < 0.04$) are significantly correlated to electricity consumption.

In terms of household and dwelling characteristics, dwelling type ($r = 0.14$, $p < 0.03$), number of study/hobby rooms ($r = 0.00$, $p < 0.01$), income of the household ($r = 0.17$, $p < 0.01$), yearly gas consumption ($r = 0.12$, $p < 0.03$), household size ($r = 0.38$, $p < 0.00$), years of residence in the current house ($r = 0.11$, $p < 0.04$), hours of working outside ($r = 0.16$, $p < 0.01$), age groups ($r = 0.14$, $p < 0.04$), dishwasher use ($r = 0.31$, $p < 0.00$), washing machine use ($r = 0.37$, $p < 0.00$), number of hot (90 C degrees) ($r = 0.18$, $p < 0.01$) and cold washes (30 C degrees) ($r = 0.33$, $p < 0.00$), dryer use ($r = 0.39$, $p < 0.00$), number of baths ($r = 0.16$, $p < 0.01$) and showers ($r = 0.30$, $p < 0.00$), duration of shower ($r = 0.23$, $p < 0.00$); and lastly the heating system type ($r = -0.15$, $p < 0.02$) appeared to be significantly correlated to the electricity consumption.

We found no correlation between the location of appliances, the existence and duration of use of mechanical ventilation, the duration of use of ventilation appliances, the number of energy- saving light bulbs in the living room, or in the rest of the house and electricity consumption. In addition, home ownership and electricity-inclusive rent did not emerge as significant predictors of electricity consumption. Gender, education, existence of elderly people and infants in the household, change in household composition in the previous year did not appear to influence electricity consumption either.

§ 4.4.2 Regression Model I: duration of appliance use and presence

The model for the use of the appliance and presence was constructed from the duration of use (minutes/day) of the appliances in the five groups (general, food preparation, cleaning, hobbies, and extra ventilation) and presence at home and in rooms (hours per day).

The descriptive statistical analysis on the significant variables is shown in Table 2, and Table 3 displays the regression model set up with the same variables. Although cleaning appliances are used for only a short time every day, they exert the greatest influence on the variance in electricity consumption (mean = 107.37, $B = 4.24$, $Beta = 0.30$, $p < 0.001$) together with hobby appliances ($B = 0.39$, $Beta = 0.31$, $p < 0.001$). The use of general appliances has an important impact on the model ($p < 0.01$), but the influence on electricity consumption is not as high as the use of cleaning appliances

(B = 0.43). The last group is the duration of the use of food preparation appliances, which makes no significant contribution to the model (Beta = 0.01). Duration of appliance use explains 37% of the variance in electricity consumption

Predictor	Mean	SD
Total electricity consumption	3058.57	1585.26
Daily use/general appliances (min)	3272.28	1279.81
Daily use/cleaning appliances (min)	107.37	105.52
Daily use/food preparation appliances (min)	1270.58	690.26
Daily use/hobby appliances (min)	1440.21	847.59
Presence in room 1 all day (h)	13.60	5.34
Presence in room 2 all day (h)	5.18	6.08
Presence in bathroom in the morning (h)	1.18	1.17
Presence in room 3 during the day (h)	0.15	1.02

TABLE 4.2 Mean and standard deviations of predictors in the regression model for the duration of appliance use and presence (Model I)

Model	B	Std. error	Beta
(Constant)	587.59	368.88	
Daily use/cleaning appliances (min)	4.24	1.02	0.30***
Daily use/hobby appliances (min)	0.39	0.10	0.31***
Daily use/general appliances (min)	0.43	0.14	0.23**
Daily use/food preparation appliances (min)	0.02	0.11	0.01

Note: R2 = 0.370.
** $p < 0.01$.
*** $p < 0.001$.

TABLE 4.3 B, standard error of B, and beta values of predictors in the regression model for the duration of appliance use

If variable ‘presence’ is considered, presence in rooms 1–3 and bathroom appears to be significant. (Note that room 1 is the first room after the living room in the dwelling.) Presence in the living room and kitchen does not appear to explain any variance in electricity consumption. Presence in room 3 during the day and in the bathroom in the morning have the greatest influence on electricity consumption, followed by room 1 and room 2 all day long. This model explains 14% of the variance in electricity consumption (Table 4).

When the predictors of duration of appliance use and presence are combined (see Table 5), the model still explains 37% of the variance in electricity consumption. The significance of the use of general appliances increases in this model and the significance of the use of hobby appliances and presence at home and in rooms decreases. Therefore, presence data does not add valuable information to the model in terms of the duration of appliance use (hobby, cleaning and general). This is probably because the duration of appliance use (a) does not relate to presence at home or in rooms for a number of appliances (e.g. fridge) or (b) it already includes presence at home.

Model	B	Std. error	Beta
(Constant)	1996.61	305.29	
Presence in room 1 all day (h)	52.95	20.53	0.17**
Presence in room 2 all day (h)	29.66	18.12	0.11**
Presence in bathroom in the morning (h)	234.72	94.98	0.17**
Presence in room 3 during the day (h)	401.68	127.55	0.20**

Note: $R2 = 0.141$.
** $p < 0.01$.

TABLE 4.4 B, standard error of B, and beta values of predictors in the regression model for presence.

Model	B	Std. error	Beta
(Constant)	569.51	409.74	
Daily use/general appliances (min)	0.37	0.10	0.30***
Daily use/cleaning appliances (min)	3.97	1.10	0.29***
Daily use/food preparation appliances (min)	0.01	0.12	0.01
Daily use/hobby appliances (min)	0.41	0.14	0.22**
Presence in room 1 all day	34.65	23.26	0.11*
Presence in room 2 all day	15.00	20.20	0.06*
Presence in bathroom in the morning	11.33	101.05	0.01*
Presence in room 3 during the day	73.54	131.02	0.04*

Note: $R2 = 0.370$.
* $p < 0.05$.
** $p < 0.01$.
*** $p < 0.001$.

TABLE 4.5 B, standard error of B, and beta values of predictors in the combined regression model for duration of appliance use and presence (Model I)

§ 4.4.3 Regression Model II: number of lighting devices and appliances and DHES characteristics

Regression Model II was set up with the number of lamps and appliances in the dwellings and the DHES characteristics. This model explains 52% of the variance in electricity consumption.

Although significantly correlated with the electricity consumption, the number of halogen and energy saving light bulbs did not appear in the regression model. Similarly, income, hours that the inhabitants work outside the house, age groups, dishwasher use, cold and hot washing machine load number, and the number of baths taken per week and its duration did not appear in the regression model, either (Table 6).

In the first step the number of general appliances explains the largest part of the electricity consumption ($B = 149.07$, $p < 0.001$). Hobby appliances come next ($B = 139.75$, $p < 0.01$). In this model the number of food preparation and cleaning appliances do not appear to be significant. The number of appliances explains 21% of variance in electricity consumption (Table 7).

Predictor	Mean	SD
Number of general appliances	8.66	2.84
Number of food preparation appliances	5.56	1.59
Number of cleaning appliances	3.56	0.91
Number of hobby appliances	3.10	2.10
Household size	2.56	1.20
Years of residence in current house	5.49	3.03
Number of washing machine loads per week	4.62	2.95
Number of dryer loads per week	1.96	2.42
Number of study/hobby rooms	0.67	0.81
Outside working hours / weekly (household)	24.63	13.30

TABLE 4.6 Mean and standard deviations of predictors in the regression model for number of appliances and DHES characteristics (Model I).

Model	B	Std. error	Beta
(Constant)	630.11	499.65	
Number of general appliances	149.07	38.20	0.26***
Number of hobby appliances	139.75	51.67	0.18**
Number of food preparation appliances	90.16	64.71	0.10
Number of cleaning appliances	107.24	109.69	0.07

Note: R2 = 0.206.
** p < 0.01.
*** p < 0.001.

TABLE 4.7 B, standard error of B, and beta values of predictors in the regression model for number of appliances used

Model	B	Std. error	Beta
(Constant)	948.14	511.70	
Household size	589.46	165.20	0.47***
Gas consumption	0.74	0.15	0.31***
Number of bedrooms	-526.07	198.65	-0.33**
Number of dryer loads per week	127.74	41.38	0.21**
Dummy (house type: flat & maisonettes on ground floor)	719.24	336.02	0.15*
Dummy (house type: corner & semi-detached)	193.59	220.90	0.06*
Dummy (house type: flats & maisonettes on top floor)	83.07	306.74	0.02
Number of study/hobby rooms	90.43	126.72	0.04*
Heating system type (individual/district)	-178.85	194.97	-0.06*
Number of washing machine loads per week	69.43	43.49	0.13*
Number of showers taken per week	28.48	16.40	0.14*
Years of residence in current house	11.38	32.87	0.02
Outside working hours/weekly (household)	-0.03	6.99	0.01

Note: R2 = 0.421.
* p < 0.05.
** p < 0.01.
*** p < 0.001.

TABLE 4.8 B, standard error of B, and beta values of predictors in the model for DHES characteristics.

Model	B	Std. error	Beta
(Constant)	791.24	658.54	
Number of appliances (general appliances)	115.99	35.09	0.21**
Number of appliances (food preparation appliances)	101.78	56.21	0.12*
Number of appliances (cleaning appliances)	14.40	105.11	0.01
Number of appliances (hobby appliances)	59.54	46.60	0.08
Gas consumption	0.68	0.15	0.28***
Household size	447.124	156.38	0.36**
Number of dryer loads per week	109.12	40.28	0.17**
Years of residence in current house	31.10	30.85	0.06*
Number of bedrooms	-404.54	187.23	-0.26*
Number of study/hobby rooms	102.29	118.57	0.05*
Number of washing machine loads per week	87.30	40.86	0.16*
Number of showers per week	15.51	15.50	0.07*
Dummy (house type: flat & maisonettes on ground floor)	712.19	314.26	0.15*
Dummy (house type: corner and semi-detached)	235.70	206.66	0.07*
Dummy (house type: flats and maisonettes on top floor)	297.37	288.65	0.07
Heating system type (unit/district)	-59.28	193.39	-0.02
Outside working hours/weekly (household)	1.78	6.55	0.02

Note: R2 = 0.517.
* p < 0.05.
** p < 0.01.
*** p < 0.001.

TABLE 4.9 B, standard error of B, and beta values of predictors in the combined regression model for number of appliances and DHES characteristics (Model II)

Household size and gas consumption appear to be the most important predictors of electricity consumption in household and dwelling characteristics ($p < 0.001$), followed by number of bedrooms and number of dryer loads per week. The third group with $p < 0.05$ consists of flats and maisonettes on the ground floor and semi-detached/corner/detached dwellings, number of hobby rooms, heating system type, number of washing machine loads and number of showers per week. Flats and maisonettes on the top floor, years of residence in current house and outside working hours do not appear to be significant in this model. This model can explain 42% of the variance in electricity consumption (Table 8).

When the number of appliances and the household and dwelling characteristics are combined, general appliances, gas consumption, household size and number of dryer loads per week emerge as the most important predictors. Food preparation appliances, years of residence in current house, flats on ground floor, semi-detached/corner/detached dwellings, number of bedrooms, number of study/hobby rooms, number of washing machine loads and number of showers per week are secondarily significant. In this combined model cleaning and hobby appliances, outside working hours, flats and maisonettes on top floors, and heating system type do not appear significant. This model explains 52% of the variance in electricity consumption (Table 9).

§ 4.4.4 Regression Model III: duration of appliance use and DHES characteristics

Lastly, we combined the total duration of appliance use and DHES characteristics of the dwellings in the dataset to set up a final model for electricity consumption. This model explains 58% of the variance in electricity consumption (Table 10). According to this model, general appliances and household size are the most significant determinants of electricity consumption. These are followed by hobby appliances, years of residence in current house, number of bedrooms, number of study/hobby rooms, dwelling type (flats/maisonettes on ground floor and corner and semi-detached), number of showers per week and number of dryer loads per week.

We did not find any significant influence for food preparation appliances and duration of use of cleaning appliances, number of washing machine loads, dwelling type (flats/maisonettes on top floor) and outside working hours.

For all three models, there is no multicollinearity among variables. Durbin–Watson test for Model I appears as 1.96, for Model II as 2.05, and for Model III as 2.01. We ran analyses of residual statistics for all three models, where we saw almost always the same 9 cases were outside the ±2 standard residual. When we compare this number to our sample size 9/304, '2% of cases lie outside standard residual limits' puts us on the safe side (the statistically allowed threshold is 5%). Cook's distances for any of these 9 cases are above 1; in addition, the centered levarage values, and the Mahalanobis distance values are well around limits. Normality/homocedasticity of residuals: We took graphs of ZRESID and ZPRED, where the values look like a 'random array of dots with no curving, and evenly dispersed around zero'. Considering the collinearity statistics, all the VIF values are very close to 1, and there is no tolerance value below 0.2.

Model	B	Std. error	Beta
(Constant)	394.56	633.74	
Daily use/general appliances (min)	0.51	0.17	0.37**
Daily use/hobby appliances (min)	0.75	0.31	0.20*
Daily use/food preparation appliances (min)	0.08	0.21	0.05
Daily use/cleaning appliances (min)	1.25	0.79	0.14
Household size	335.77	166.24	0.33**
Gas consumption	0.04	0.07	0.05*
Years of residence in current house	23.55	1 34.36	0.06*
Number of bedrooms	-198.88	204.84	-0.15*
Number of study/hobby rooms	136.97	129.66	0.09*
Dummy (house type: flats and maisonettes on ground floor)	888.58	392.83	0.22*
Dummy (house type: corner and semi-detached)	540.91	240.48	0.21*
Dummy (house type: flats and maisonettes on top floor)	49.61	342.98	0.01
Number of showers taken per week	36.78	16.76	0.24*
Number of dryer loads per week	0.04	0.10	0.03*
Number of washing machine loads per week	0.46	0.87	0.05
Outside working hours/weekly (household)	-6.36	8.63	-0.07

R2 = 0.576.
* p < 0.05.
** p < 0.01, ***p < 0.001.

TABLE 4.10 B, standard error of B, and beta values of predictors in the combined regression model for duration of appliance use and DHES characteristics (Model III).

§ 4.5 Discussion

In this section, we will first discuss the results of the correlation and then the regression models. Considering the duration of use and the number of appliances; general appliances and hobby appliances are the most significantly correlated to electricity consumption ($p < 0.00$), followed by food preparation and cleaning. This shows a direction for designers, engineers, policy makers, and energy companies, about which appliances to focus on, for energy conservation. Considering presence, the hours of presence all day during the weekdays in room 1 and room 2, and in the mornings during the weekdays in bathroom, are the most significant rooms to study the variance in electricity consumption. Although number of standby appliances, battery chargers, halogen light bulbs, energy-saving light bulbs are found to be significantly correlated with electricity consumption, they do not appear in any of the regression models.

In terms of household and dwelling characteristics, household size, dishwasher, washing machine, and dryer use, number of baths, showers, and the duration of shower appear to be the most significantly correlated parameters ($p < 0.00$), number of study/hobby rooms, income of the household, hours of working outside, and the number of hot washes (90 C degrees) are also found to be correlated parameters with electricity consumption, but with less significance ($p < 0.01$). The last group consists of dwelling type, yearly gas consumption, heating system type, years of residence in the current house, and age groups of the household composition ($p < 0.05$). This result points out that household size and the patterns of use of water in dwellings could give important clues about electricity consumption in dwellings. This topic is articulated further below. Income and number of hot washes, and age groups of household composition are found to be correlated to electricity consumption; however, these parameters did not appear in regression models, either.

No correlation was found between electricity consumption and mechanical ventilation systems, probably because these systems were seldom used in our sample (people disabled them or hardly used them at all) (Guerra Santin, 2010). Similarly, there was no correlation between the use of extra ventilation appliances and electricity consumption, because usage was too low (14% of the respondents said they had a fan). Lastly, we could not check the impact of renewable energy because of the insufficient response to the question (10%) in the survey.

The first regression model, with duration of appliance use and presence patterns, explains 37% of the variance in electricity consumption; the second, with number of lamps and appliances and DHES characteristics, explains 52%, and the third and last model, with duration of appliance use and DHES characteristics, explains 58%. In the first regression model, the most important groups of appliances are the general, cleaning, and hobby appliances. In the second, these are general and hobby appliances. This difference may be due to the fact that although every household possesses approximately the same number of cleaning appliances, the duration of use may vary strongly depending on lifestyle preferences and values. Food preparation appliances do not contribute to the electricity consumption in either model, probably because they are owned by all households and they are used for only short periods. In the third model, general and hobby appliances again appear to be the most significant predictors (in terms of appliances). The importance of general appliances may be attributable to the very different duration of use and the specific energy consumption levels of TVs. In cleaning appliances, the dryer makes the biggest difference. There is a straightforward explanation for the significant share of hobby appliances in the variance in electricity consumption: it differs widely per household and may consume large amounts of energy. Our results show a similarity with the model of Ndiaye et al., which explains 75% of the variance in electricity consumption. It should be noted, however, that the sample size of Ndiaye et al. was relatively smaller (62 dwellings) and included additional predictors such as the use of renewable energy systems, air conditioning, and vacation weeks in a year. Another study with similar results, Bartiaux and Gram-Hanssen's regression model, was able to explain 30–40% of the variance in electricity consumption in Denmark and 10–30% in Belgium. Our model provided a better explanation. Fuks and Salazar's bottom-up model predicted 53% of electricity consumption, but their research was methodologically different from ours. Genjo's regression model on Japanese households explains 60% of electricity consumption with lighting and appliances. The methodological approach closest to our own was applied by Cramer et al. whose model explained 51% of electricity consumption with number of appliances, 34% with the indirect determinants and 58% in total. It should be mentioned that their indirect determinants model included social aspects that we did not take into account, such as knowledge, educational level, etc.

Having briefly explained the capacity of our model and com- pared it with existing models, we shall now discuss the predictors that we found. In Model I, presence in rooms 1 and 2 all day, bathroom in the morning, and room 3 during the day explain 14% of the variance in electricity consumption and appear to be the most important indirect predictors. This result runs parallel with the decreasing influence of number of bedrooms and the increasing influence of number of study/hobby rooms on electricity consumption in Models II and III. According to Model I, electricity consumption rises only if rooms 1 and room 2 are occupied for more hours all day and if room 3 is occupied for more hours during the day (rooms 1 and 2 are used mostly as bedrooms, and room 3 as a study/hobby room). However, in contrast with the direct predictor 'Duration of Appliance Use', 'presence at home or in the rooms' does not contribute to the combined model (explained 37% of the variance). These results show that hourly data on presence at home or in rooms do not help to explain electricity consumption with regression analysis. It could therefore be argued that hourly data on presence is not necessarily valuable for further research on electricity consumption, when the total duration of use of each appliance is known.

On the other hand, the only research in the literature that takes account of presence is a study by Baker and Rylatt which states that presence in the dwelling has an increasing influence on electricity consumption. They only considered weekly hours of presence at home, however, our point in investigating the parameter 'presence' in dwelling/room detail was that 'presence in a room' could give more information than 'presence in dwelling' because activities that lead to electricity consumption could be related to the rooms with certain functions. In the second regression model the most important indirect predictors are household size, gas consumption, number of dryer loads per week, dwelling type (ground floor flats, and corner/semi-detached houses), number of study/hobby rooms, number of bedrooms, years of residence in the dwelling, number of washing machine loads per week, and number of showers per week. Dwellings on the ground floor appeared to have a significant influence on the variance in electricity use, possibly because more artificial lighting was needed to compensate for the loss of natural light, and the corner/semi- detached/detached houses, because of the household and dwelling size. Bartiaux and Gram-Hanssen, Yohannis, Fuks and Salazar, and O'Doherty emphasize the significant influence of dwelling type on electricity consumption, but they do not consider the variable 'dwelling type' as we did in our research. We did not test the variables of dwelling age and dwelling location because all the dwellings in our sample were in the same neighborhoods and built around the same time. We found no correlation between floor area and electricity consumption, probably because the floor area was similar for all the dwellings in the sample. Baker and Rylatt also pointed out that number of rooms and number of bedrooms have an incremental impact on electricity consumption. Contrary to their results, we could say that the number of bedrooms has a decreasing impact and the number of study/hobby rooms an increasing impact on electricity consumption. This finding may be attributable to the fact that a bedroom is normally used only in the evening-at night and early in the morning for a short while, whereas a study or hobby room is used more often and contains more electrical appliances.

Electricity consumption increases with household size. These results correspond with those of Nnidaye, Bartiaux and Gram- Hanssen, Yohannis, and Genjo, who claimed that household size is an important predictor of electricity consumption in dwellings. The households that consume more gas also seem to consume more electricity. A variable that has proven significant in other research but not in ours is 'age'. Although we tested this variable in various forms (elderly people, infants in the household, the respondent's age, and age groups) we found no correlation. This could be a reflection of similarities in appliance use among the different age groups in our sample.

Another variable that was found in the literature to have a decreasing impact on electricity consumption (see Ndiaye et al.) is the 'number of vacation days'. The responses to our question about weeks in the year when nobody is at home were not enough for analysis, however. Our questionnaire did not ask respondents about their expectations of rising electricity rates, but it did check whether electricity tariff influences electricity consumption and found no correlation. The number of showers per week has an increasing influence on electricity consumption, thus suggesting a comfort-related dimension. Both Baker and Rylatt and the ODYSSEE reports mention that increasing comfort-related preferences (showers per week, greater use of hot water) result in higher levels of electricity consumption. Our sample displays an average self-cleaning habit of taking a shower 2 times a day per person that lasts 20 min in total, but less than once a week bathing. Although we found a strong relationship between number of showers taken per week and electricity consumption, the duration of shower did not appear significant. Bathing times a week, and duration did not appear significant either.

‘Showers taken per week’ gives the clue of a comfort related aspect of electricity consumption, considering the evolution of personal cleaning habits from bathing to showering in the last century. It seems like changes in lifestyle preferences might have an increasing influence on consumption patterns. Supporting these findings, Shove describes the contemporary enthusiasm for regular power showering as “an emphasis on image and appearance, on the curative and therapeutic properties of invigoration, and on a distinctive blending of pleasure and duty.” (Shove, 2003). Here we should add that, the 8/40 h working day/week also might be influencing the preferences for showering. This topic also requires further investigation.

Fuks and Salazar found that new residents in dwellings consume more electricity, which is contrary to our result that households that have resided in dwellings for longer periods consume more electricity. This may be because the longer people stay in the same house, the older and less energy-efficient the appliances become. Lastly, we did not find any correlation between education, background of the occupant and electricity consumption, probably because the respondents had similar educational levels and the majority were Dutch (86%). Similarly, household incomes in the sample were within the same range and most of the homes were owner-occupied (79%). Electricity was included in the rent in only one dwelling. This might explain why we did not find household income as a significant determinant of electricity consumption.

The number of dryer and washing machine loads in Model I and the number of dryer loads in Model III appear to be significant. The influence of number of dryer loads per week on electricity consumption corresponds with the first model, where the duration of use of cleaning appliances appeared important. In addition, after the TV, the dryer is potentially the most energy-consuming appliance in the market.

The variables for electricity consumption in the Dutch research literature are household size, household composition, dwelling size (type of dwelling and number of rooms), floor area, and income. We found household size, appliance ownership, and increased comfort preferences as important parameters for electricity consumption, but no significance for floor area, income, and education (see the potential reasons stated previously in this section). Age groups in household are found to be correlated to electricity consumption, but it did not appear in the regression models. In our research we found a difference between bedrooms and study/hobby rooms, former having a decreasing, latter having an increasing influence on electricity consumption. In addition, we also found dwelling type is significantly related to electricity consumption.

One possible limitation in this research is the low response rate to the questionnaire (5%). This may be connected with the number and intricacy of questions. Except for the twelve blank forms, the returned questionnaires were filled in almost completely.

The general characteristics of the sample were representative of the Netherlands (The National Survey: WOON Database (2009)) with the exception of income and education, which were higher than the national average. On the other hand, the fact that 'income' and 'education' were not found significant in our study may be due to the absence of variation in the levels in our sample. The same could apply to 'floor area': the survey was conducted in two neighborhoods with similar architectural characteristics, so there was very little variation in the floor areas of the dwellings.

Another limitation relates to the tracking and recording system for electricity consumption in the Netherlands. Electricity providers ask occupants to send in their meter readings once a year. These providers actively check the meter readings as well, but they have different schedules. If the occupant fails to send in the meter readings, the electricity consumption is calculated on the basis of the previous reading by the provider, which may be up to three years ago (more than 3 years is not allowed under the Dutch regulations). This could create a bias in the accuracy of the electricity consumption data.

Lastly, the use of appliances such as the TV, washing machine and dryer, the energy labels of appliances, and the influence of lifestyle on the electricity consumption in dwellings require further investigation. In this research we could only take account of the number of light bulbs in the living room and in the rest of the house. Further research is needed on the duration of use of lighting devices.

§ 4.6 Conclusion

This research aimed to ascertain how far the use of lighting and electrical appliances are responsible for electricity consumption and to identify the determinants of use. The data used in the survey were collected via questionnaires completed by 323 dwellings in two neighborhoods in the Netherlands. Three regression models were built for the direct and indirect determinants, one based on the duration of appliance use (direct) and presence (indirect), one on the number of appliances (direct) and DHES characteristics (indirect), and one on the total duration of appliance use and DHES characteristics.

We found that, in the first model, total duration of appliance use alone explained 37% of the variance in electricity consumption. Presence in rooms explained 14% alone and 37% in the combined model. This means that hourly data on presence did not con- tribute to modelling electricity consumption in dwellings, when it was considered together with the total duration of appliance use. Study/hobby rooms emerged as important factors in the relationship between presence and electricity consumption, whereas living room and kitchen did not.

In the second model the number of appliances explained 21% of the variance in electricity consumption alone and 42% when combined with DHES characteristics. Household size, dwelling type, the number of showers, use of dryer and washing cycles appeared significant. The significant connection that was identified between electricity consumption and ground-floor dwellings points to the need for a detailed study on lighting. The number of showers is an interesting output, pointing to a possible relationship between the occupants' perception of comfort and electricity consumption. Use of the washing machine and dryer suggest a need for a study on the cleaning patterns of users, including the washing and drying durations, temperatures, cycles and loads as well as the appliance labels.

The final (third) model, with the total duration of appliance use and DHES characteristics, was quite close to the second in terms of the DHES characteristics that were found to be significant. The main difference was that gas consumption and the number of washing machine loads were not found to be significant in the third model. As this model explained 58% of the variance in electricity consumption, it may be possible to set up a model on occupant behavior and electricity consumption with duration of appliance use and DHES characteristics. The specific consumption of appliances and the duration of use of lighting devices would enhance this model.

Comparing all three models, this research showed that duration of appliance use and dwelling and household characteristics are important predictors in models of electricity consumption. Further research on the functions of appliances (cleaning, food preparation, hobby, etc.) and the activity patterns of occupants would provide deeper insight into electricity consumption in housing. A follow- up study could be based on a detailed analysis of the relationship between gas and electricity consumption and the lifestyles and comfort preferences of occupants.

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