Renewable and Sustainable Energy Reviews 43 (2015) 901–917

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

# The socio-economic, dwelling and appliance related factors affecting electricity consumption in domestic buildings

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A R T I C L E I N F O

*Article history:*
Received 10 June 2014
Received in revised form
14 November 2014
Accepted 17 November 2014
Available online 8 December 2014

*Keywords:*
Domestic electricity consumption
Domestic buildings
Socio-economic factors
Dwelling factors
Appliance factors

A B S T R A C T

This paper aims to investigate the socio-economic, dwelling and appliance related factors that have significant or non-significant effects on domestic electricity consumption. To achieve this aim, a comprehensive literature review of international research investigating these factors was undertaken. Although papers examining the factors affecting electricity demand are numerous, to the authors' knowledge, a comprehensive analysis taking stock of all previous findings has not previously been undertaken. The review establishes that no less than 62 factors potentially have an effect on domestic electricity use. This includes 13 socio-economic factors, 12 dwelling factors and 37 appliance factors. Of the 62 factors, four of the socio-economic factors, seven of the dwelling factors, and nine of the appliance related factors were found to unambiguously have a significant positive effect on electricity use. This paper contributes to a better understanding of those factors that certainly affect electricity consumption and those for which effects are unclear and require further research. Understanding the effects of factors can support both the implementation of effective energy policy and aid prediction of future electricity consumption in the domestic sector.



**Contents**



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http://dx.doi.org/10.1016/j.rser.2014.11.084

## 1. Introduction

Policy-makers have realised that without significant reductions in the electricity demand, and significant increases in the energy efficiency of the domestic sector, it will be impossible to lower carbon dioxide ($CO_2$) emissions and mitigate the risks of global climate change [1,2]. To support informed decisions about how to reduce electricity use and $CO_2$ emissions from the housing sector, it is essential to know which factors influence domestic electricity consumption.

Electricity use in domestic buildings results from occupants' need for energy services, such as light, comfort and entertainment, but the energy used results from a complex series of interlinked and interacting socio-economic, dwelling and appliance related factors.

This paper presents a literature review of the existing research investigating the socio-economic, dwelling and appliance related factors that affect domestic electricity consumption. The aim is to synthesise the results of previous studies to establish whether specific factors have a significant or non-significant effect.

This paper addresses the effects of factors at the household level only (i.e. at the individual household scale), including socio-economic factors, which refer to the characteristics of the occupants residing in a home (e.g. number of occupants, presence of children, annual household income); dwelling factors, which describe the characteristics of the dwelling (e.g. dwelling type, number of bedrooms, heating system type); and appliance factors, which are the ownership level, power demand and use of electrical appliances in the home.

Non-household level factors (i.e. at the regional, national or international scale), such as policy preference and regulatory factors, whilst they may affect domestic electricity demand, are outside of the scope of the current review. This paper seeks to investigate household level factors only so that effective energy policy can be devised, not to evaluate the effectiveness of existing or past national or international policies or regulatory frameworks on electricity consumption.

Although, papers examining the factors affecting electricity demand are numerous, to the authors' knowledge, a comprehensive analysis taking stock of all previous findings combined does not currently exist. It is hoped that this review will fill the gap, and provide evidence of the factors which are consistently stated as having either a significant or a non-significant effect on electricity use, those factors for which the literature disagrees with regard to their correlation, and those factors which have been infrequently studied.

This review begins with a description of the previous studies. It continues by outlining the socio-economic, dwelling and appliance related factors mentioned, then each factor is discussed separately, reporting on whether a significant (positive or negative) or non-significant effect on domestic electricity use was identified. In actual buildings, many of these factors will be correlated. The possible combined influences of factors are not presented, unless these combinations have been explicitly expressed in the literature. In each section a summary table is provided to combine the conclusions of all the studies investigating a specific factor. Throughout this review, significance is measured at the 90% ($p < 0.10$) level.

## 2. Previous studies investigating the factors affecting domestic electricity consumption

Previous studies of the factors that affect electricity consumption in residential buildings have been undertaken using either a top-down (e.g. [3]) or bottom-up approach (e.g. [4–8]). A top-down approach is used in studies which consider the national level and aim to attribute the electricity consumption of the housing stock to the characteristics of the dwellings [9]. A bottom-up approach is used in studies based at the individual dwelling level aimed at establishing relationships between household characteristics and electricity use, which are then extrapolated to the entire housing stock [5]. A number of studies also combine both the top-down and bottom-up approaches (e.g. [10,11]).

Statistical/regression and econometric methods are the most commonly implemented to investigate the influence of socio-economic, dwelling and appliance factors on domestic electricity consumption. The statistical/regression method can be considered both a top-down and bottom-up method of analysis and is particularly useful for analysing large datasets. Examples of statistical/regression studies are Sanquist et al. [6], Baker and Rylatt [7], Kavousian et al. [12], Brounen et al. [13], Bartiaux and Gram-Hanssen [14], and Tiwari [15]. A variant of the statistical/

regression approach is the econometric method based on a Conditional Demand Model (CDM) first developed by Parti and Parti [16]. This method, following a top-down approach, is used to forecast electrical energy demand as a function of macro-economic variables. Previous econometric studies include Blázquez et al. [3], Parti and Parti [16], Zhou and Teng [17], Larsen and Nesbakken [18], and Filippini and Pachauri [19].

Whilst National studies based on a top-down approach use aggregated data (e.g. national energy statistics, gross domestic product (GDP), and population figures), dwelling level studies based on a bottom-up approach use data at a higher level of detail. A number of dwelling level studies have analysed data from extensive national energy surveys: China [17], Denmark [20,28], India [19], Ireland [5,29], the Netherlands [13], Portugal [10],

**Table 1**
Summary of previous studies reviewed.

| Study | Country (Location) | Electricity consumption period | Sample size (dwellings) | Notes | Independent variable (s) studied | | |
|---|---|---|---|---|---|---|---|
| | | | | | SEF | DF | AF |
| **European studies** | | | | | | | |
| Haas et al. [39] | Austria | 1960–1995 | 500 | | x | x | |
| Bartiaux and Gram-Hanssen [14] | Belgium[1] and Denmark[2] | 2004 | 50,000[1], 500[2] | *Not including homes with electric space heating* | x | x | x |
| Gram-Hanssen et al. [20] | Denmark | 2004 | 50,000 | *Not including homes with electric space heating* | x | x | x |
| Nielsen [28] | Denmark | 1992 | 1,500 | | x | x | x |
| Santamouris et al. [32] | Greece (Athens) | 2004 | 945 | *4.6% homes with electric space heating* | x | | |
| Leahy and Lyons [29] | Ireland | 2004–2005 | 6,884 | | x | x | x |
| McLoughlin et al. [5] | Ireland | July 2009–Dec 2009 | 4,200 | | x | x | x |
| Bedir et al. [4] | Netherlands (Wateringse Veld and Leidsche Rijn districts) | Winter 2008 | 304 | | x | x | x |
| Brounen et al. [13] | Netherlands | 2007 | 305,001 | | x | x | |
| Yohanis et al. [24] | Northern Ireland | Dec 2003–Feb 2004 | 27 | *Not including homes with electric space heating; 50% homes with secondary electric heating* | x | x | |
| Halvorsen and Larsen [38] | Norway | 1976–1993 | 900–1,400 | | x | x | x |
| Larsen and Nesbakken [18] | Norway | 1990 | 1,453 | | x | x | x |
| Wiesmann et al. [10] | Portugal (Portuguese mainland) | 2001, 2005, and 2006 | 7,925 | | x | x | x |
| Blázquez et al. [3] | Spain (47 Spanish provinces) | 2000–2008 | 27,832 | | x | | |
| Bartusch et al. [23] | Sweden (Central Sweden) | 2008 | 595 | | x | x | |
| Baker and Rylatt [7] | UK (Leicester and Sheffield) | 2005 | 148 | | x | x | x |
| Druckman and Jackson [11] | UK (England and Wales) | 2004–2005 | 7,000 | | x | x | |
| Hamilton et al. [30] | UK | 2004–2007 | 13,000,000 | | x | x | |
| Summerfield et al. [33] | UK (Milton Keynes) | 1989, 1991 and 2005–2006 | 14 | *Not including homes with electric space heating* | x | x | |
| Wyatt [22] | UK (England) | 2004–2008 | 3528,100 | | x | x | |
| **Rest of the world studies** | | | | | | | |
| Ndiaye and Gabriel [21] | Canada (Oshawa, Ontario) | May 2007–May 2008 | 270 | | x | x | |
| Carter et al. [35] | Barbados | 1997 | 130 | | x | x | x |
| Lam [27] | China (Hong Kong) | 1971–1993 | – | | x | | |
| Tso and Yao [8,37] | China (Hong Kong) | 1999–2000 | 1,516 | | x | x | x |
| Zhou and Teng [17] | China (17 cities south west) | 2007–2009 | 5,980 | | x | x | x |
| Filippini and Pachauri [19] | India | 1993–1994 | 30,000 | | x | x | |
| Tiwari [15] | India (Bombay) | 1987–1988 | 6,358 | | x | x | x |
| Genjo et al. [26] | Japan | 1996 | 238 | | x | | x |
| Louw et al. [36] | South Africa (Antioch and Garagapola) | 2001–2002 | 92 | | x | | x |
| Carlson et al. [31] | USA | 2001 and 2005 | 4,382 | | | | x |
| Chong [40] | USA (Southern California) | 1998–2009 | 5300,000 | | | x | |
| Cramer et al. [34] | USA (California) | Summer 1981 | 192 | *90% homes with air conditioning* | x | x | x |
| Kavousian et al. [12] | USA | 238 days in 2010 | 952 | | x | x | x |
| Munley et al. [41] | USA (Washington D.C.) | 1978–1979 | 44 | | x | | |
| Parker [25] | USA (Central Florida) | 1999 | 171 | | x | x | x |
| Parti and Parti [16] | USA (San Diego) | 1975 | 5,286 | | x | x | x |
| Sanquist et al. [6] | USA | 2001[a] and 2005[b] | 2,690[a], 2,165[b] | | x | x | x |

*Note* 1: Unless specified, the electricity use of the dwellings in the studies may include electric space heating, electric water heating and electric space cooling.
*Note* 2: Socio-economic factors (SEF); Dwelling factors (DF); Appliance factors (AF).
[a,b] in column 3 relates to the sample size in column 4. (i.e. 2001a = 2,690a and 2005b = 2,165b).

Spain [3], the UK [11,22,30], and the USA [6,31]. Others, have investigated smaller samples of households using more disaggregated and detailed information [7,8,12,14,21,23,32–38], which in some instances has allowed the researchers to study the effects of socio-economic, dwelling and appliance factors on specific electrical end-uses (e.g. lighting, appliances and electric space heating) [25,26]. Common data collection methods used in dwelling level studies are personal interviews [8,20], phone surveys [21], electricity meter readings provided by energy providers [14,22,23], household electricity monitoring [5,12,21,24], including sub-metering of appliances [20,25], questionnaires [7,12,20,23,26], energy audits [21], national household surveys [5,6,20,22,24], and utility bills [6,26].

Table 1 and the following sections describe the essential features of each study reviewed in this paper. Table 1 acts as a reference sheet to ascertain the weight that should be placed on each study in relation to the reader's specific interests (e.g. European or UK studies only, large sample sizes, studies since 2000 only, etc).

### 2.1. European studies

Haas et al. [39] applied a cross-section analysis on a sample of about 500 households in Austria between 1960 and 1995. Monthly electricity bills were regressed against electricity price, socio-economic (both income and number of occupants), and dwelling parameters (living area) to assess the impact of these factors on the electrical energy demand for appliances.

Bartiaux and Gram-Hanssen [14] extended the research developed by Gram-Hanssen et al. [20] to Belgium and compared household electricity consumption (excluding heating) in both Denmark and Belgium on the basis of survey data, national statistics and consumption data provided by the utilities. The database of approximately 50,000 households in Denmark [20] and data from nearly 500 households in Belgium collected in 2004 were used in the analysis. The study aimed to understand which socio-economic and dwelling factors influence the level of household electricity consumption. The study also looked at whether ownership or use of appliances explained the greater electricity consumption in Belgium compared with Denmark. The results revealed that type and size of dwelling, as well as number of occupants can explain 30–40% of the variation in Danish electricity consumption, whereas the Belgian data could only explain 10–30% of the variation. Moreover, the analysis showed that the number and use of appliances better explains which households consume most electricity rather than the energy efficiency of the appliances.

Gram-Hanssen et al. [20] studied the impact of socio-economic background variables on household electrical energy use (excluding electric space heating), taking into account the practices of the families' everyday life in Denmark. The study was based on the combination of two different sets of data: (i) a dataset of over 50,000 households coupling electricity use with socio-economic data on the household members (obtained from the Danish personal data net), and data on the buildings (from the Danish national building data net); (ii) a dataset created as part of the European Project EURECO of 100 households with electricity consumption collected every 10 min during one month in either 1999 or 2000 for each appliance and most lamps. A detailed analysis of the use of appliances was combined with socio-economic and building data collected using a questionnaire and with qualitative interviews on everyday life and electricity use in 10 households. The results concluded that background variables such as type and size of dwelling, as well as number of occupants, can only describe 30–40% of the variation in household electricity consumption.

Nielsen [28] analysed the results of a research project undertaken by the Danish Ministry of Energy on electricity saving in the domestic sector. Using a multiple regression analysis, the study assessed the influence of number of children and adults, dwelling size, household income and stock of electrical appliances on annual electricity consumption in approximately 1500 households in Denmark in 1992. The results revealed that 64% of electricity consumption can be attributed to the number of adults in the house, the number of children, appliance consumption and the total floor area.

Santamouris et al. [32] studied the relationship between family income and annual expenditure on electricity for 945 households located in Athens, Greece, in 2004. Data were collected through interviews with family members and inspections of each building. The sample was divided into seven income groups and a detailed analysis of the influence of family income on electricity demand, annual electricity cost per person, and annual electricity cost per unit floor area was undertaken.

Leahy and Lyons [29] applied an ordinary linear least squares regression using the Irish Household Budget Survey (2004–2005), which contains data regarding 6884 private households in Ireland. Using estimates of the amount of energy used by households from previous energy bills, the authors identified the determinants of energy use while controlling for household characteristics and the ownership of domestic appliances.

McLoughlin et al. [5] examined the influence of dwelling, occupant characteristics and cooking type on domestic electricity consumption in Ireland. The study analysed data obtained from a smart metering survey of a sample of approximately 4200 dwellings. The study collected the electricity consumption of the households at half hourly internals for a 6 month period. In addition, detailed socio-economic and technical characteristics of each home were recorded. A multiple linear regression model was applied to total electricity consumption, maximum demand, load factor and time of use of maximum electricity demand for different socio-economic and dwelling variables.

Bedir et al. [4] aimed to define the influence of lighting and appliance use on total electricity consumption in a dataset of 304 Dutch dwellings, and identify determinants of use. The study covered household characteristics, individual characteristics, economic characteristics, occupancy (number of people and duration of occupation in each room), dwelling characteristics, appliance use and lighting devices. The data were collected by questionnaires in the winter of 2008. Three regression models were built for the direct and indirect determinants: the first was based on the total duration of use of appliances (direct) and dwelling and room occupancy (indirect); the second was based on the number of lights and household appliances (direct) and the characteristics of the dwelling (indirect), and the third was based on the total duration of use of appliances (direct) and the characteristics of the dwelling (indirect).

Brounen et al. [13] conducted an analysis on more than 300,000 homes in the Netherlands aimed at quantifying the extent to which electricity use was determined by the technical specifications of the dwelling rather than the demographic characteristics of the residents. The dwelling and socio-demographic data (collected in 2008 and 2009) and annual electricity consumption (collected in 2007) of each household was provided by the Bureau of Statistics in the Netherlands.

Yohanis et al. [24] studied the effect of occupancy and dwelling characteristics on domestic electric use in 27 representative dwellings in Northern Ireland. For this study, electricity measurements were collected using a half-hour load meter installed in series with the normal utility meter in each home. The average electricity consumption was calculated by averaging consumption for each day over the year. The duration of the study was 2 months (between December 2003 and February 2004). The socio-economic and dwelling data was collected by questionnaire with the householders.

Halvorsen and Larsen [38] applied an econometric analysis to identify the factors determining residential electricity consumption in Norway between 1976 and 1993. The data set (of an annual net sample of between 900 and 1400 households) contained information about the household's annual expenditure on electricity, income and other household characteristics and appliance ownership.

Larsen and Nesbakken [18] applied an econometric conditional demand model to estimate domestic electricity consumption for different end-uses. The study used data for appliance ownership, demographic and economic variables collected from 1453 households in Norway during a 1990 energy survey. The electricity consumption of each household was obtained from the utility supplier or from a home survey.

Wiesmann et al. [10] undertook an econometric study of Portuguese residential electricity consumption with a focus on the influence of household, dwelling and appliance characteristics. The study also estimated the relationship between dwelling and household characteristics on per capita residential electricity consumption. Two different databases were used for the analysis: municipality level data for 2001, and data from a Portuguese consumer expenditure survey collected in 2005 and 2006 which included 7925 households in the Portuguese mainland.

Blázquez et al. [3] undertook an empirical analysis of residential electricity demand in 47 Spanish provinces for the period 2000 to 2008. The study aimed to establish the characteristics affecting Spanish residential electricity use, specifically, electricity price, income, and weather conditions.

Bartusch et al. [23] applied statistical analysis to assess the variance in annual electricity consumption of Swedish single-family homes, as well as to estimate the impact of household and building characteristics. 595 households from three geographically separated areas in Central Sweden were included in the study. The analyses were based on hourly electricity meter readings of the individual households, which were subsequently used to estimate their annual electricity consumption. These data were provided by the local distribution system operators. Household and building features were collected by questionnaire survey.

Baker and Rylatt [7] used multiple regression to determine the strength of the relationships and identify the most statistically significant indicators of differences in electricity consumption in 148 households in the UK cities of Leicester (48 terraces) and Sheffield (52 detached and 48 semi-detached dwellings). The study was based on a dataset collected by means of a questionnaire survey in 2005, supported by annual gas and electricity meter data obtained from the energy suppliers and floor-area estimates derived from a GIS.

Druckman and Jackson [11] sought to understand how residential energy use is related to the socio-economic characteristics of UK households at three different levels: (a) national level; (b) specific small geographical areas; and (c) 'typical' types of households. For electricity consumption at the national level, the analysis used a national dataset for 2004 and 2005 to explore the relationship of domestic electrical energy use with income and household composition. At the lower levels, the study also observed the relationship between domestic electricity use and the type of dwelling, tenure, household composition and rural/urban location.

Hamilton et al. [30] conducted an analysis on approximately 13 million homes in the UK included in the Homes Energy Efficiency Database (HEED), along with annual metered gas and electricity use for the period 2004 to 2007. The study examined the influence of dwelling characteristics and tenure type on domestic energy demand.

Summerfield et al. [33] undertook a follow-up study in 2005–2006 of 14 low-energy dwellings in Milton Keynes, UK, that were originally monitored for energy consumption between 1989 and 1991. The results from both periods were compared by classifying the dwellings into three groups of low, middle, and high-energy users. The study investigated the effects of floor area, income and number of occupants on the changes in electricity use.

Wyatt [22] undertook a statistical analysis to examine the drivers of domestic electricity consumption in relation to the technical characteristics of the dwellings and socio-economic characteristics of the occupants in 3528100 English households. Annual electricity consumption data from 2004 to 2008 was provided by UK energy suppliers. Modelled data for the property attributes and socio-economic characteristics of occupants were supplied by the information company Experian's consumer survey.

### 2.2. Rest of the world studies

Ndiaye and Gabriel [21] used data collected in 270 dwellings in Oshawa (Ontario, Canada) to generate regression models of the electricity consumption of the city's residential dwellings. Data regarding the socio-economic and technical characteristics of the households were collected by phone surveys and energy audits. From May 2007 to July 2008, total electricity consumption data was gathered hourly by smart meters installed in the dwellings. The final model obtained in the study explained 75% of the variance in electricity consumption.

Carter et al. [35] estimated an electricity demand function using survey data for a sample of 130 Barbadian households in 1997. The home interviews collected information about the dwelling characteristics, appliance stock and household demographics. Each household's metered energy consumption data were sourced directly from the utility provider. The model accounted for 85% of the cross-sectional variation in electricity consumption.

Lam [27] performed regression and correlation analyses to investigate the relationships between domestic electricity consumption and economic variables and climatic factors in Hong Kong, China. The study used economic and energy data for the 23 year period from 1971 to 1993.

Tso and Yau [8] applied three modelling techniques for the prediction of electrical energy consumption (regression analysis, decision tree and neural network) on a dataset of 1516 households in Hong Kong, China. Data was collected by means of a two-phase survey carried out in the summer and winter of 1999–2000 reported in [37]. During an in home interview and questionnaire, household characteristics, dwelling type and appliance ownership and power rating data was collected. A diary was then used to record usage patterns of selected major appliances every half-hour for one week. The approximate weekly electricity consumption for appliances was calculated using the recorded power ratings of the appliances and operating hours. A regression analysis was undertaken to investigate the relationships between the average electricity consumption and the housing type, household characteristics and appliance ownership factors.

Zhou and Teng [17] used annual urban household survey data from 5980 households located in 17 cities in south west China from 2007 to 2009 to estimate the income and price elasticities of residential electricity demand, along with the effects of socio-demographic and dwelling related variables. The empirical results were estimated by an ordinary least squares model.

Filippini and Pachauri [19] developed three electricity demand functions using disaggregated level survey data for about 30,000 households in India for the period 1993 to 1994, to understand the extent to which household characteristics influence variations observed in households' electricity demand.

Tiwari [15] developed a regression model using a household survey undertaken in 1987–1988 by the Bombay Metropolitan Regional Development Authority, which included a total of 6358 dwellings in Bombay, India. The study analysed the influence of dwelling, socio-economic and appliance related factors on annual electricity consumption.

Genjo et al. [26] performed a multivariate analysis to evaluate the relationship between predicted end-use electricity consumption on lighting and appliances and influencing factors in 238 Japanese households in 1996. Total electricity consumption data was obtained from the households' electricity bills and a questionnaire survey was conducted to collect data on household characteristics and ownership of electric appliances. Sixty-seven appliances were included in the analysis, which were classified in the categories cooking (18 appliances), cooling and space heating (13), audio visual and information (14), household and sanitation (12) and others (10). The final regression model explained 60% of electricity consumption from lighting and appliances.

Louw et al. [36] studied the determinants of electricity demand for 92 newly electrified low-income households in a rural site in South Africa. Using an econometric regression model, metered electricity consumption data, socio-economic survey data and appliance ownership data collected in 2001 and 2002 were analysed to determine the drivers of electricity consumption within these households.

Carlson et al. [31] analysed how many domestic appliances contribute to household electricity use reported in the End-Use Residential Energy Consumption Survey (RECS) completed in the USA in 2001 and 2005. The survey contained data from 4382 houses.

Chong [40] examined whether electricity use in newer or older residential buildings increases more in response to high temperature in a region of Southern California, USA. The study combined four large datasets of building and household characteristics, weather data, and utility data to estimate the electricity–temperature response of different building ages. The study was undertaken between 1998 and part of 2009, and included 5.3 million households.

Cramer et al. [34] analysed the summer electricity consumption for appliances and air conditioning use in 192 dwellings in California, USA, in 1981. Two linear regression analyses were carried out to identify the influence of engineering and social determinants on summer electricity consumption. The analysis included appliance ownership, frequency of use, location in the dwelling, published average efficiencies, and estimated seasonality factors.

Kavousian et al. [12] studied structural and behavioural determinants of residential electricity consumption by developing a regression model. The electricity consumption and socio-economic, dwelling and appliance related characteristics of 952 households in the USA were analysed. Total electricity consumption of the household was collected by smart meters at a 10 min interval for 238 days in 2010. The study included an online survey of household data, including climate and location, building characteristics, appliance stock, demographics, and occupants' behaviour.

Munley et al. [41] focused on the factors that influence domestic electricity consumption for appliance use of multi-family, renter-occupied households. During a 12 month period (1978–1979), the electricity consumption of 44 households in Washington D.C., USA, was metered and recorded.

Parker [25] undertook a load monitoring study collecting total and end-use electricity load data in 171 residences in Central Florida, USA, in 1999. The data collected was analysed applying a linear regression to study the effect of socio-economic and dwelling characteristics on electricity consumption in a hot climate. Electric demand data was collected on a fifteen minutely basis on several end-uses, including space cooling, heating, water heating, range and cooking, clothes drying, and swimming pools electricity use. The electricity consumption of "other" appliances such as lighting, refrigerator, ceiling fan, and plug loads were subtracted from the total. It is important to note that this study was carried out in a hot climate where electricity is commonly used to cool as well as heat homes.

Parti and Parti [16] developed an econometric method for estimating appliance-specific energy consumption. The study analysed monthly electricity bills from 1975 of 5286 households in San Diego, USA, against appliance ownership figures and demographic variables. The electricity demand was disaggregated into a set of component demand functions for electricity usage in 16 appliance categories.

Sanquist et al. [6] applied a multivariate statistical approach to investigate the influence of lifestyle factors on residential electricity consumption in the USA. The study used data collected by the national household energy survey conducted by the US Energy Information Administration in 2001 and 2005. The survey included data regarding the physical characteristics of the dwellings, household demographic characteristics, appliance information (such as age, size and use), fuel types and energy consumption. Annual electricity bills were provided by 2690 households in the 2001 survey and 2165 households in the 2005 survey.

**Table 2**
Summary of the effects of socio-economic factors on electricity consumption in domestic buildings studied in the literature.

| Factors | Total number of citations | Significant positive effect on domestic electricity consumption | Significant negative effect on domestic electricity consumption | No effect on domestic electricity consumption |
|---|---|---|---|---|
| Number of occupants | 23 | 19 [4,8,10–15,17,20,21,24,26,27,29,34,37–39] | 1 [19] | 3 [23,35,36] |
| Family composition | | | | |
| *Presence of children* | 10 | 4 [5,10,13,28] | 2 [14,20] | 4 [4,14,29,34] |
| *Presence of teenagers* | 5 | 4 [14,20,23,41] | 0 | 1 [14] |
| *Presence of adults* | 1 | 1 [17] | 0 | 0 |
| *Number of adults* | 2 | 2 [22,28] | 0 | 0 |
| *Presence of elderly people (over 65 years old)* | 4 | 0 | 2 [13,29] | 2 [4,34] |
| Age of HRP | 8 | 8 [4,5,12,13,15,19,24,29] | | 0 |
| Employment status of HRP | 2 | 0 | | 2 [24,34] |
| Education level of HRP | 5 | 2 [17,29] | 1 [20] | 2 [4,34] |
| Socio-economic classification of HRP | 2 | 1 [5] | 0 | 1 [29] |
| Tenure type | 12 | 7 [8,10,21,22,24,30,37] | | 5 [4,8,12,29,37] |
| Household income | 21 | 18 [4,6,10,14–17,20,22,24,26,27,32–34,36,39,41] | 0 | 3 [8,12,35] |
| Disposal income | 5 | 5 [3,11,13,29,38] | 0 | 0 |

## 3. Socio-economic factors

The studies outlined in the previous section have identified a range of socio-economic factors that affect the electricity consumption of domestic buildings. These factors can be classified as: (i) number of occupants; (ii) family composition, including presence of children, presence of teenagers, presence of adults, number of adults, and presence of elderly people (over 65 years old); (iii) age of household responsible person (HRP); (iv) employment status of household responsible person; (v) education level of household responsible person; (vi) socio-economic classification of household responsible person; (vii) tenure type; (viii) household income; and (ix) disposal income.

The following subsections provide a synthesis of the socio-economic factors identified in the literature, citing those authors that have observed a positive or negative significant effect on domestic electricity use as well as those that have not found a significant correlation. A list of the socio-economic factors found to affect domestic electricity consumption is provided in Table 2, along with an indication of those studies which indicated either a significant positive or significant negative effect or non-significant effect.

### 3.1. Number of occupants

The effect of the number of occupants on the electricity consumption of residential buildings has been extensively studied. Most previous research that has examined the matter concluded that there is a significant positive relationship between the household size and domestic electricity use, suggesting that as the number of people living in a dwelling increases, the more electricity that is used [4,8,10–15,17,20,21,24,26,27,29,34,37–39].

Leahy and Lyons [29] established that Irish households occupied by only one person consumed significantly less electricity than households with two or more occupants, calculating that a one person household uses approximately 19% less electricity per week than a two person household. Yohanis et al. [24] examined the average daily annual electricity consumption per unit floor area for dwellings occupied by one, two, three or four or more occupants in Northern Ireland and established that households with four or more occupants consumed the largest amount of electricity and there was a small difference between the consumption in households with two or three occupants. In addition, Tiwari [15] recognised that a five-member family in India would have 23% more electricity expenditure compared to a two-member family. The study also quantified the effect of an additional household member on electricity consumption and concluded that it increased use by 7.7%. Similarly, Zhou and Teng [17] in their study in China found an increase of 8% for every additional family member. In comparison, Brounen et al. [13] established that an additional occupant in Dutch households increased electricity use by about 21%.

Other authors have focused on the effect of household size and dwelling type on electricity consumption. Bartiaux and Gram-Hanssen [14] and Gram-Hanssen et al. [20] determined that the number of people living in Danish households was the single most significant explanation for electricity consumption and established that the effect of household size was similar for three types of dwelling (detached, semi-detached and apartment). In Belgium, the number of occupants made a significant difference both for detached and semi-detached houses, but not in apartments [14].

The effect of number of occupants on particular electrical end-uses has also been considered. The studies of Genjo et al. [26] in Japan and Haas [39] in Austria, determined that the number of occupants significantly influences the electricity consumption for lighting and appliances. In particular, Genjo et al. [26] calculated that electricity consumption for lighting and appliances would increase by 230 kW h per person with the growth of household size.

Contrary to previous studies, Filippini and Pachauri [19] determined that household size had a negative correlation with electrical energy consumption in India, stating that houses with a large number of members (greater than 6) had lower electricity consumption than those with fewer members.

Other authors have concluded that the effect of household size on electricity demand is insignificant [23,35,36]. Louw et al. [36] established that the number of household members did not affect the electricity consumption of newly electrified low-income South African households, as most of the electrical end-uses of household members were shared simultaneously between occupants (e.g. cooking or watching TV). Bartusch et al. [23] studied the effect of the number of household members on the annual electricity consumption per $m^2$ of heated living space in Sweden and concluded that there was no significant variance between those households using an electric heating system.

In addition, several studies have investigated the correlation between per capita electricity use and size of household. Druckman and Jackson [11] in the UK found that per capita electrical energy use was negatively correlated to household size, suggesting that a household with more people was generally more efficient in terms of per capita energy use, demonstrating the economies of scale that were achieved by a larger household. Yohanis et al. [24] also studied the electricity consumption per unit floor area per occupant in Northern Ireland and, on this basis, established that electricity consumption per person decreased as the number of occupants increased, this effect was more significant in large dwellings, as the number of occupants per dwelling get smaller. Similarly, Kavousian et al. [12] found a non-linear relationship between US household electricity consumption and number of occupants, leading to the conclusion that larger households had higher total electricity consumption but lower per capita consumption. Similar results were found by Blázquez et al. [3] (Spain), Wiesmann et al. [10] (Portugal), Bartiaux and Gram-Hanssen [14] (Belgium and Denmark), Zhou and Teng [17] (China), and Gram-Hanssen et al. [20] (Denmark).

### 3.2. Family composition

A significant effect of family composition (i.e. presence of children, teenagers, adults and elderly people) on electricity consumption in residential buildings has been widely acknowledged in the literature [5,10,13,14,17,20,22,23,28,41]. In contrast, other studies have reported no significant effect on electricity demand [4,14,29,34].

The presence of children and its influence on electricity consumption was shown to be significant by McLoughlin et al. [5], who determined that adults living with children in Ireland consumed considerably more electricity than those living alone or with other adults. Brounen et al. [13] revealed that households in the Netherlands with children consumed almost one-fifth more electricity than families without children, and this effect was stronger when the age of the children increased. The authors believed that this was because older children watch more television, use personal computers, and are frequent users of gaming devices. Similar results were published in Wiesmann et al. [10] (Portugal) and Nielsen [28] (Denmark).

Contrary to previous studies, Bartiaux and Gram-Hanssen [14] and Gram-Hanssen et al. [20] revealed that the presence of one or more small children (0–9 years old) in a household had a negative effect on consumption, indicating that the presence of children decreased mean electricity consumption. This effect was found to be significant in the Danish household sample in Bartiaux and Gram-Hanssen [14] and Gram-Hanssen et al. [20], but not significant in the Belgian households in Bartiaux and Gram-Hanssen [14]. For US households, Cramer et al. [34] found that the presence of children under 3 did not have a significant influence on electricity consumption, but children greater than 3 had a significant positive effect. Bedir et al. [4] in the Netherlands and Leahy and Lyons [29] in Ireland also reported that there was no significant difference between the electricity use in households occupied by families with children and households comprised of adults only.

The impact of presence of teenagers has also been reported in five studies. Bartiaux and Gram-Hanssen [14] and Gram-Hanssen et al. [20] revealed that mean electricity consumption was significantly higher in households with teenagers (13–19 year olds) than without. This effect was significant in Danish households [14,20], but not significant in Belgian households [14]. Additionally, Bartusch et al. [23] found a significant increase in annual electricity consumption per $m^2$ of electrically heated living space for families with teenagers in Sweden.

Leahy and Lyons [29] determined that single parent households used significantly more electricity than two parent households in Irish households. The results suggested that a one parent household used 10.4% more electricity per week than a two parent household. In contrast, Wyatt [22] and Nielsen [28] stated that there was a positive relationship between the number of adults residing in dwellings in the UK and Denmark and the amount of electricity consumed. Similarly, Zhou and Teng [17] established that Chinese households with a household responsible person older than 50 years consumed approximately 3% more electricity consumption than younger households. The authors argued that the electricity consumption of old households was higher because old people generally stay at home longer than young people. Brounen et al. [13] however determined that elderly households in the Netherlands consumed about 2–4% less electricity than middle-aged married couples, it was suggested that although the elderly may spend more time at home, they seem to have fewer energy-consuming appliances. Leahy and Lyons [29] also found that as the age of the household responsible person increases past 64 years old, the electricity consumption decreases. Bedir et al. [4] and Cramer et al. [34] recognised that the presence of elderly people over 65 in Dutch and US households had no significant effect on electricity demand.

Brounen et al. [13] extended the analysis of family composition and determined that per capita electricity use was significantly lower in dwellings occupied by female or non-native households. According to the authors, this might be due to an unobserved wealth effect. Gram-Hanssen et al. [20] found that the citizenship of a family affected the annual electricity consumption of semi-detached houses in Denmark, with non-western citizens using on average 800 kW h $pa^{-1}$ less than Danish or Western citizens.

### 3.3. Age of HRP

According to Yohanis et al. [24], the household responsible person (HRP) dictates a household's behaviour and consequently has an influence on electricity consumption. For this reason, the HRP's age and its effect on domestic electricity consumption has been the focus of a number of previous studies, which have reported very similar effects for different age ranges. In general, the literature suggests that there is a significant relationship between the HRP age and electricity consumption and that consumption is higher in those households where the HRP age is approximately in the range of 50 and 65 years. For households with a HRP under 50 and over 65 years the electricity consumption is consistently reported to be lower.

Leahy and Lyons [29] indicated that households in Ireland with HRPs between 45 and 64 years used significantly more electricity than HRPs in the range of 35–44 years. However, as the age of the HRP increased past 64, electricity use significantly decreased. Similar results were reported by Yohanis et al. [24] for Northern Ireland, who found that households occupied by a HRP in the range 50–65 years consumed the largest amount of electricity during the day and households with HRPs older than 65 years used the smallest amount. The authors believed that this is because the 50–65 years bracket includes those with higher household incomes, bigger houses and a broad range of appliances. Correspondingly, McLoughlin et al. [5] found that electricity consumption in Irish households with younger HRPs (aged between 18 and 35 years) was significantly lower when compared to the other age categories, 36–55 and 56 plus. In this case, the authors believed that this could be attributed to middle aged HRPs having more children living at home (thus having a higher number of occupants) and increased occupancy patterns (i.e. occupants at home for longer periods of the day). Consistent with previous authors, Kavousian et al. [12] revealed that US households with HRPs older than 55 and between 19 and 35 had lower electricity consumption. The authors suggested that older household members tend to be more conscious about the way they use electricity, and also tend to use fewer electric gadgets, whereas household members between 19 and 35 are more likely to have a full-time job and therefore spend less time at home. Filippini and Pachauri [19] found that Indian households with a younger HRP (less than 45 years old) had lower electricity consumption than those which had older household heads. The significant effect of HRP age on electricity consumption was also acknowledged by Bedir et al. [4], Brounen et al. [13] and Tiwari [15] for Dutch and Indian households.

### 3.4. Employment status of HRP

The effect of the HRP's employment status on domestic electricity demand has consistently been reported as insignificant [24,34]. Although, Yohanis et al. [24] did not find any significant effect of the HRP's employment status on electricity consumption in Northern Irish homes, they observed that homes that were occupied during the day by unemployed or retired people had generally smaller electricity consumptions than homes unoccupied during the day. Cramer et al. [34] studied the influence of the two main HRPs being employed, but did not find any significant effect.

### 3.5. Education level of HRP

Differing effects of the HRP's education level on domestic electricity demand have been reported. Gram-Hanssen et al. [20] observed that electricity consumption decreased significantly with the level of education in Denmark, whereby, households occupied by family members with an education longer than primary school (up to 12 years of age) appeared to use significantly less electricity than households occupied by family members educated to primary school level. Households educated to primary school level used on average over 200 kW h $pa^{-1}$ more than households with higher education. In contrast, Zhou and Teng [17] determined that families with longer education than primary school (up to 12 years of age) in China had higher electricity consumption. Leahy and Lyons [29] revealed that those Irish households with only a primary education (up to 12 years of age) use 6.4% less electricity per week than those who have completed the secondary school Leaving Certificate (18 years of age).

According to Bedir et al. [4] and Cramer et al. [34], education level did not significantly affect electricity use in Dutch and US dwellings.

### 3.6. Socio-economic classification of HRP

While the social group of the HRP has been observed to have a significant effect on electricity demand in Irish homes by McLoughlin et al. [5], Leahy and Lyons [29] reported that the socio-economic status of the HRP did not significantly affect electricity use in Irish homes.

Specifically, McLoughlin et al. [5] revealed that the HRP's social class had a positive effect on total electricity consumption, suggesting that higher professionals were inclined to consume more electricity than lower professionals, with the former tending to live in larger dwellings and have a greater number of electrical appliances, suggesting a possible income effect.

### 3.7. Tenure type

Different significant and non-significant effects of tenure type on electricity consumption of residential buildings have been reported. While some studies have observed a significantly higher consumption in privately owned houses [10,22,24,30], others have reported a significantly higher demand in rented dwellings [21]. Other studies have concluded that tenure type has no significant effect on electricity use [4,8,12,29,37].

Yohanis et al. [24] established the impact of private ownership on electricity use in Northern Ireland. According to the authors, houses that were privately owned had a significantly higher electricity demand than rented homes. They believed that this effect was because in Northern Ireland the majority of social housing is rented by lower income families from the Northern Ireland Housing Executive. Similarly, Wyatt [22] observed that council housing and housing association homes in the UK had the lowest average consumption for electricity at 3737 kW h, and owner-occupied households had the highest at 4607 kW h, whilst, privately rented homes were in the middle at 4047 kW h. The author mentions that tenure is likely to be correlated with wealth and that rented properties are generally smaller than privately owned dwellings. Hamilton et al. [30] determined that owner occupied dwellings in the UK used 25% more electricity than rented houses. The results also established that electricity demand in private rental dwellings had a very similar demand to social rentals. Wiesmann et al. [10] also concluded that Portuguese households that own their own home consumed significantly more electricity than those living in rented homes.

Ndiaye and Gabriel [21] also identified that tenure type had a significant influence on electrical energy demand in Canadian homes but, in this case, higher electricity consumption was observed in rented rather than owned houses. The authors believed that this effect was because, often, rented homes have all utilities included in the rent, so renters do not necessary pay the extra cost associated with higher electricity consumption and thereby have less incentive to save energy.

### 3.8. Household income

The relationship between household income and electrical energy consumption has been the subject of extensive research. A large number of studies have concluded that electrical energy consumption increases significantly with income [4,6,10,14–17,20,22,24,26,27,32–34,36,39,41].

In particular, Yohanis et al. [24] determined that Northern Irish households with incomes over £30,000 per annum use 2.5 times more electricity on average in the evenings than low-income households (less than £10,000 per annum). The authors argued that higher income households commonly have a greater number of occupants and larger homes, as well as a diverse range of electric appliances. Similarly, Wyatt [22] found that the electricity consumption of the highest income group in the UK (more than £75,000 per annum) was 1.9 times higher than the lowest income group (less than £10,000 per annum). In addition, Santamouris et al. [32] found an almost linear relationship between annual expenditure on electricity and family income in Greece, whereby the expenditure on electricity of high income families was 1.6 times higher than that of low income families.

Genjo et al. [26] also determined that in Japan, electrical energy consumption increased linearly with annual income. In this case, the authors specifically studied the influence of income on electricity consumption for lighting and appliances and found a significant relationship, estimating that electricity consumption for lighting and appliances increased by 350 kW h for every US $27,000 increase in annual household income.

In addition, Bartiaux and Gram-Hanssen [14] and Gram-Hanssen et al. [20] observed the effect of income on electricity use was significant for three dwelling types (detached, semi-detached and apartment). A comparative analysis undertaken by Bartiaux and Gram-Hanssen [14] revealed that in Belgium, net-income was the only variable always significant for the three dwelling types.

Santamouris et al. [32] analysed the annual electricity cost by income group and dwelling floor area in Greece and determined that the high income group (more than €100,000 per annum) paid for almost 38% more electricity per m$^2$ of floor area than the low income group (less than €9000 per annum). The authors speculated that this increased cost may be explained by the considerably higher installed power and use of electrical appliances and equipment in households of the richest groups. Haas [39] and Munley et al. [41] also suggested in their in their studies of Austria and the USA that higher income households generally consumed more electricity due to a higher number of appliances owned.

In addition, Santamouris et al. [32] examined the annual electricity cost per m$^2$ per person and revealed that the lower the income, the higher the electricity consumption per person. Their analysis indicated that households with a low income paid almost 67% per m$^2$ more per person than those with a high income. Wiesmann et al. [10] also established that an increase in income results in higher per capita electricity consumption in Portuguese households.

Other studies have also identified a statistically significant effect of household income on electricity consumption, but determined that electricity demand rises relatively little with income, suggesting that electricity consumption in low and high income households does not differ much because electricity, at least at the levels used, is a necessity for both groups [17].

Other authors have not identified any significant relationship between domestic electricity demand and household income [8,12,35]. Carter et al. [35] added that the effect of income on electricity demand may be better predicted by the rate of appliance purchasing (number and efficiency) in the Barbados. Kavousian et al. [12] did not observe any statistical effect of income on electricity consumption in the USA and argued that this could be explained by the similar socio-economic status of the households in the study.

### 3.9. Disposable income

The effect of disposable income on electricity demand of residential buildings has been consistently reported as significant and positive, indicating that electricity demand increases with increased disposable income of the household [3,11,13,29,38].

In particular, Leahy and Lyons [29] indicated that in Ireland as the log of household disposable income increased by one unit, electricity use increased by 4% per week. Similarly, Brounen et al. [13] found that a 1% increase in disposable income in Dutch

**Table 3**
Summary of the effects of dwelling factors on electricity consumption in domestic buildings reported in the literature.

| Factors | Total number of citations | Significant positive effect on domestic electricity consumption | Significant negative effect on domestic electricity consumption | No effect on domestic electricity consumption |
|---|---|---|---|---|
| Dwelling type (by degree of detachment) | 12 | 12 [4,5,10,12–15,20,22,24,29,30] | 0 | 0 |
| Dwelling age | 15 | 7 [10,13,22,23,25,26,29] | 4 [7,15,38,40] | 4 [8,12,30,37] |
| Number of rooms | 6 | 4 [4,7,15,29] | 1 [13] | 1 [10] |
| Number of bedrooms | 6 | 5 [5,7,24,30,35] | 0 | 1 [4] |
| Number of floors | 1 | 0 | 0 | 1 [23] |
| Total floor area | 22 | 19 [7,8,10,12–14,17,19,20,22–26,28,33,37–39] | 0 | 3 [4,8,37] |
| Use of HVAC systems | | | | |
| *Presence of electric space heating system* | 9 | 8 [4,7,12,18,21,23,29,38] | 0 | 1 [5] |
| *Presence of air-conditioning* | 9 | 6 [6,8,17,21,34,37] | 0 | 3 [8,12,37] |
| *Presence of mechanical ventilation* | 1 | 0 | 0 | 1 [4] |
| Use of electric water heating system | | | | |
| *Presence of an electric water heating system* | 9 | 7 [5,8,12,18,21,29,37] | 0 | 2 [8,37] |
| *Number of electric showers and baths per week* | 2 | 2 [4,7] | 0 | 0 |
| Presence of low-energy lighting | 3 | 0 | 2 [4,12] | 1 [14] |

households was associated with an 11% increase in household electricity use.

## 4. Dwelling factors

Several dwelling factors have been studied in the literature. These factors are: (i) dwelling type; (ii) dwelling age; (iii) number of rooms; (iv) number of bedrooms; (v) number of floors; (vi) total floor area; (vii) presence of HVAC systems, including electric space heating, air-conditioning and mechanical ventilation; (viii) presence of electric water heating systems, including ownership of an electric water heating system and number of showers and baths per week; and (ix) presence of low-energy lighting.

The following subsections provide an overview of the dwelling factors reported in the literature, citing those authors that have observed a significant or non-significant effect on domestic electricity demand. A summary of the dwelling factors affecting domestic electricity consumption is provided in Table 3.

### 4.1. Dwelling type

The relationship between dwelling type and electrical energy consumption in residential buildings has been the subject of extensive research. A large number of studies have concluded that, electrical energy consumption increases with the degree of detachment of the dwelling, suggesting that families residing in detached houses consume more electricity than semi-detached houses, and these consume more than terrace houses and apartments [4,5,10,12–15,20,22,24,29,30].

In particular, Leahy and Lyons [29] identified that Irish households living in semi-detached, terrace houses and apartments used significantly less electricity than those in detached houses. According to the study, families residing in semi-detached and terrace houses used 6.9% less electricity per week than those in detached houses, and those in apartments 10.7% less electricity per week than detached houses. Bartiaux and Gram-Hanssen [14] and Gram-Hanssen et al. [20] also observed a higher average consumption of households living in detached houses than semi-detached houses and apartments in both Denmark and Belgium and determined the annual electricity use of families in detached houses was, on average, approximately twice that of apartments. Similarly, Wyatt [22] established that, on average, households residing in detached houses in the UK are responsible for significantly higher consumption than those living in other dwelling types: purpose-built flats and mid-terrace houses consume the least electricity, and bungalows, semi-detached and end-of-terrace houses use similar amounts of electricity. Similar results were also reported by Bedir et al. [4] (Netherlands), McLoughlin et al. [5] (Ireland), Wiesmann et al. [10] (Portugal), Kavousian et al. [12] (USA), Brounen et al. [13] (Netherlands), Tiwari [15] (India), Yohanis et al. [24] (Northern Ireland), and Hamilton et al. [30] (UK).

In general, the literature suggests that the influence of dwelling type on electricity consumption is related to the differences in floor area [5,13,22]. However, Yohanis et al. [24] observed the monthly electricity consumption normalised by floor area for different types of dwellings and the results indicated a similar variation in the average consumption for each type of house (between 2.5 and 5.0 $\mathrm{kW\,h\,m^{-2}}$). The profile of the building occupants has also been identified as a possible reason for variations in electricity use between dwelling types. Wyatt [22] found that bungalows in the UK had low electricity consumption, and attributed this to the fact that bungalows are often occupied by elderly residents who have lower electricity demands than families. Similar results were found by Firth et al. [42] for the UK.

### 4.2. Dwelling age

Previous studies have observed higher domestic electricity consumption in newer houses [7,15,38,40], which has commonly been attributed to the penetration of air conditioning and other high-consumption appliances. Other studies have observed the opposite, reporting a decrease in household electricity consumption for newer houses, associating the pattern to improved insulation and use of more efficient appliances, lighting and air conditioning [10,13,22,23,25,26,29]. A non-significant effect was reported by Tso and Yau [8], Kavousian et al. [12], Hamilton et al. [30] and Tso and Yau [37].

Wiesmann et al. [10] found that newer homes in Portugal consumed significantly less electricity than older ones. Leahy and Lyons [29] observed that Irish homes built before 1918 used significantly more electricity per week (6.1%) than those built between 1918 and 1960, due to increased heat loss associated with less insulation and use of electric heating and power showers instead of gas central heating. Homes built later than 2000 used significantly less electricity than dwellings built in the period

1918–1960. Similar results were reported by Parker [25] for the USA, who concluded that older homes had greater electrical energy use for both space heating and cooling and revealed that older houses were often less well insulated and had less efficient equipment, which could explain the effect. Brounen et al. [13] observed that Dutch houses built in the periods 1980–1990 and 1990–2000 consumed 3.7% and 1.3% more electricity respectively, than houses built later than 2001. Contrary to previous studies, the authors attributed the positive relationship between property age and electricity consumption to the wealth of the occupants and the availability of more energy-efficient appliances in modern homes. A similar correlation was also found by Genjo et al. [26] between dwelling age and the electricity consumed by lighting and appliances in Japan. A significant and negative correlation between dwelling age and electricity demand was also reported by Wyatt [22] (UK) and Bartusch et al. [23] (Sweden).

Differing from other research, Chong [40] determined that electricity consumption was higher in newer rather than older US dwellings. In particular, the study found that new buildings (1970–2000) had significantly higher electricity consumption than old buildings (pre 1970) in a region of Southern California. The authors comment that although newer buildings are subject to stricter building energy codes, they are larger and more likely to have air conditioning. Halvorsen and Larsen [38] also found that electricity consumption declines with the age of the dwelling in Norway, suggesting newer dwellings consume more electricity than older ones. This finding was attributed to a higher wiring capacity in newly built houses and the greater use of appliances.

Contradicting other studies, some authors have found that the effect of dwelling age is insignificant [8,12,30,37]. Hamilton et al. [30] determined that there was no age effect on electricity consumption in UK dwellings. Electricity use appeared to be very similar in old and new dwellings, with only a slight increase in newer dwellings. Kavousian et al. [12] attributed the insignificant effect to the fact that the physical conditions of the buildings in the sample of the study had been maintained through time, possibly due to the enforcement of building regulations. However, the results suggested that US houses built before 1975 on average consumed less electricity than those built between 1993 and 2003. According to the authors, a potential explanation for this trend was the increased penetration of air conditioning and other high consumption appliances in newer houses.

### 4.3. Number of rooms

A significant positive relationship between the numbers of rooms and electricity consumption in domestic buildings has been reported in the literature, which suggests that as the number of rooms increases, more electricity is used [4,7,15,29]. Leahy and Lyons [29] determined that Irish dwellings with only one or two rooms used significantly less electricity than five room houses. Similarly, Bedir et al. [4] found that the number of rooms in Dutch homes, and in particular the number of study/hobby rooms were significantly positively correlated with electricity consumption. Tiwari [15] observed that each additional room in Indian dwellings led to 11% more electricity expenditure.

In contrast, Brounen et al. [13] determined that an additional room in Dutch homes decreased electricity consumption by 0.5%, whilst, Wiesmann et al. [10] found that the number of rooms per dwelling in Portugal had no significant effect on electrical energy demand.

### 4.4. Number of bedrooms

Previous research has reported that there is a significant and positive relationship between the number of bedrooms and domestic electricity consumption [5,7,24,30,35]. Whereby, an increase in the number of bedrooms results in an increase in household electrical energy demand.

In particular, McLoughlin et al. [5] established that for each additional bedroom in Irish dwellings, total electricity consumption on average increased 15.4% over a six month period. In addition, Hamilton et al. [30] in the UK found that electricity demand increased linearly from 1 to 4 bedrooms and that the increase from 4, to more than 5 bedrooms was 12%. Yohanis et al. [24] observed that load peaks of five bedroom Northern Irish households were over three times more than those of two bedroom households. The authors explained the influence of number of bedrooms on electricity use by arguing that households with more bedrooms have more appliances and so greater consumption of electricity for lighting.

Contrary to previous studies, Bedir et al. [4] revealed that the number of bedrooms in Dutch homes did not have a significant impact on electricity consumption: attributed to the fact that a bedroom is normally used only in the evening, at night and early in the morning for a short while and do not contain a lot of electrical appliances, compared with other rooms.

### 4.5. Number of floors

Bartusch et al. [23] determined that the number of floors in Swedish dwellings did not represent any statistically significant variance in annual electricity consumption per $m^2$ of living space.

### 4.6. Floor area

The significant influence of the floor area of a dwelling on domestic electricity consumption has been widely reported in the literature. Previous research consistently suggests that dwellings with a larger floor area have higher absolute electricity consumption.

Bartiaux and Gram-Hanssen [14] and Gram-Hanssen et al. [20] observed that total floor area was the variable with the third largest explanatory power for electricity consumption in residential buildings in Denmark. Similar results were found by Baker and Rylatt [7] in a UK-based study. This variable was found to be significant for three dwelling types (detached, semi-detached and apartment). In Belgium, the floor area was only significant for detached houses [14]. Nielsen [28] quantified the relationship between floor area and electricity consumption in Denmark and established that when dwelling size increased by 1%, the electricity consumption raised by 0.61%. Similarly, Zhou and Teng [17] observed that a 1% increase in dwelling size resulted in a 0.1% increase in Chinese household electricity consumption. Filippini and Pachauri [19] studied the electricity consumption of urban Indian households and established that a 1% increase in floor area resulted in a 0.2% increase in household electricity consumption.

Comparable results are reported by Wiesmann et al. [10] (Portugal), Kavousian et al. [12] (USA), Brounen et al. [13] (Netherlands), Wyatt [22] (UK), Bartusch et al. [23] (Sweden), Yohanis et al. [24] (Northern Ireland), Genjo et al. [26] (Japan), Summerfield et al. [33] (UK), Tso and Yau [37] (China), Halvorsen and Larsen [38] (Norway), and Haas et al. [39] (Austria).

The influence of floor area has been often related to the demand for space heating and cooling. For example, Zhou and Teng [17] stated that dwelling size positively affects household electricity consumption in China, because larger houses need more electrical cooling in the summer, and heating in the winter. Tso and Yau [8,37] established in their study of Chinese dwellings that floor area was statistically significant in relation to summer domestic electric consumption due to cooling systems but not the winter period. Similarly, Parker [25] concluded that larger homes in the USA had greater electrical energy use and demand for both space heating and cooling. Bartusch et al. [23] also determined that there was an influence of the area of the heated living space on annual electricity consumption in Swedish homes. In particular, the results suggested that this influence was stronger in households where the main heating system was an electric boiler and weakest in those homes where the main heating system was a combined electric and non-electric boiler.

Contrary to previous studies, Bedir et al. [4] determined that total floor area had a very small influence on the electricity consumption. The author believed that this insignificant effect was because of the similarity of the architecture of the dwellings in the sample.

### *4.7. Presence of electric space heating, ventilation and air-conditioning systems*

Several authors have studied the influence of different space heating systems on total household electricity consumption [4,7,12,18,21,23,29,38]. The results consistently agree that there is a significant and positive effect of the use of an electric space heating system on electricity use. Larsen and Nesbakken [18] estimated the difference in electricity consumption for Norwegian households with portable electric heaters, electric under floor heating and electric central heating with other households and found that all had a significant impact on electricity consumption. The results revealed that households with portable electric heaters and/or electric under floor heating used 3700 kW h $pa^{-1}$ more electricity than households without such a system. In contrast to previous studies, McLoughlin et al. [5] found that space heating type had no significant influence on the electricity consumption of Irish homes. However, the authors believed that these conflicting results are due to a very low penetration of electric heating (less than 3%) in the household sample.

The significant and positive effect of air conditioning on electrical energy demand in residential buildings has been consistently reported by earlier studies primarily based in locations with a hot summers, such as the South–East of Canada [21], hot climatic zones in the USA [6,34], south west China [17], and Hong Kong [8,37]. In particular, Tso and Yau [8] observed that air conditioning consumed on average 59% of the electricity in a typical household in Hong Kong during the summer. On the contrary, Kavousian et al. [12] did not find any correlation between electricity consumption and the number of air conditioning systems in California, USA.

Bedir et al. [4] in their study in the Netherlands found that mechanical or balanced ventilation is not a significant predictor of electricity consumption.

### *4.8. Presence of electric hot water heating systems*

Several studies have observed a significant influence of the use of electric hot water heating systems on the electrical energy demand of residential buildings [5,8,12,18,21,29,37]. Consistently, the results suggest that the use of electric water heating is positively correlated with electrical energy demand. In particular, Larsen and Nesbakken [18] concluded that electricity consumption was 2684 kW h $pa^{-1}$ higher for households taking showers and 1014 kW h $pa^{-1}$ higher for households taking baths which are heated using an electric water heater compared with other households in Norway. Tso and Yau [8,37] established in their study of Chinese dwellings that the presence of electric hot water heating was a statistically significant factor in relation to summer domestic electric consumption but not in the winter.

Other authors have also observed a statistically significant correlation between the number of showers per week heated using an electric hot water heating system and domestic electricity demand [4,7]. Bedir et al. [4] added that there was also a significant correlation between electricity consumption and the number of baths per week heated using an electric hot water heating system, as well as the duration of each shower in Dutch dwellings.

### *4.9. Presence of low-energy lighting*

While Bedir et al. [4] and Kavousian et al. [12] concluded that the use of energy-efficient lights is correlated with lower electrical energy consumption in the Netherlands and USA, Bartiaux and Gram-Hanssen [14] determined that there was no significant correlation between the presence of low-energy lights and electricity consumption in Belgium and Denmark.

## 5. Appliance factors

Electrical appliances make a very significant contribution to a household's electricity consumption. This impact not only relates to the number of each type of appliance owned, but also to the power demand and frequency of use.

The following subsections present the appliance related factors: (i) ownership of appliances; (ii) use of appliances; and (iii) power demand of appliances. Each type of appliance mentioned in previous studies is included in the review, indicating whether its influence on domestic electricity consumption is significant (Table 4).

### *5.1. Appliance ownership*

#### *5.1.1. Total number of appliances*

The relationship between total number of appliances owned and electricity consumption has been the subject of extensive research.

A significant and positive effect of the total number of appliances owned on domestic electricity demand has been acknowledged by several authors. Nielsen [28] determined that a 1% increase in the number of appliances owned in Danish homes resulted in a 0.35% rise in electricity consumption. Moreover, Carlson et al. [31] concluded that 12 specific appliances types explained up to 80% of a US household's electricity consumption and between 3 and 5 appliance types described 50% of household electricity use. According to Bedir et al. [4], number of appliances explained 21% of the variance in electricity consumption between dwellings in the Netherlands. In addition, Cramer et al. [34] observed that the location of appliances in US dwellings was also a significant contributing factor. Wiesmann et al. [10] also reported a significant influence of the number of appliances on domestic electricity use in Portugal.

The significant influence of the ownership of specific types of appliances on domestic electricity use has also been studied. Studies have examined the ownership of (i) IT appliances, (ii) entertainment appliances, (iii) HVAC appliances, (iv) cooking appliances, (v) preservation and cooling appliances, (vi) washing appliances, (vii) laundry appliances, (viii) building maintenance appliances and (ix) hygiene and leisure appliances.

#### *5.1.2. Ownership of IT equipment*

The significant effect of the ownership of IT appliances such as desktop computers and laptops has been acknowledged by McLoughlin et al. [5] (Ireland), Baker and Rylatt [7] (UK), Bartiaux and Gram-Hanssen [14] (Belgium and Denmark), and Zhou and Teng [17] (China). In particular, Zhou and Teng [17] determined that Chinese households that own a computer consumed approximately 10% more electricity compared with those without a computer. McLoughlin et al. [5] concluded that computers (both

**Table 4**
Summary of the effects of appliance factors on electricity consumption in domestic buildings reported in the literature.

| Factors | Total number of citations | Significant positive effect on domestic electricity consumption | Significant negative effect on domestic electricity consumption | No effect on domestic electricity consumption |
|---|---|---|---|---|
| Total number of appliances | 5 | 5 [4,10,28,31,34] | 0 | 0 |
| Ownership of office IT appliances | | | | |
| *Desktop computer* | 5 | 4 [5,7,14,17] | 0 | 1 [29] |
| *Laptop computer* | 1 | 1 [5] | 0 | 0 |
| Ownership of entertainment appliances | | | | |
| *TV* | 6 | 6 [5,7,12,14,16,18] | 0 | 0 |
| *Portable TV* | 1 | 0 | 0 | 1 [29] |
| *Video player/recorder* | 3 | 2 [14,18] | 0 | 1 [29] |
| *Video console* | 1 | 1 [5] | 0 | 0 |
| *CD player* | 1 | 0 | 0 | 1 [29] |
| *Digiboxes* | 1 | 1 [7] | 0 | 0 |
| Ownership of HVAC appliances | | | | |
| *Desk fan* | 3 | 0 | 0 | 3 [8,35,37] |
| *Dehumidifier* | 1 | 0 | 0 | 1 [8] |
| *Portable electric-heaters* | 1 | 1 [7] | 0 | 0 |
| Ownership of major cooking appliances | | | | |
| *Electric oven* | 6 | 5 [5,12,16,29,38] | 0 | 1 [35] |
| *Range hood* | 2 | 2 [8,37] | 0 | 0 |
| Ownership of minor cooking appliances | | | | |
| *Microwave* | 1 | 0 | 0 | 1 [29] |
| *Kettle* | 2 | 0 | 0 | 2 [8,37] |
| Ownership of preservation and cooling appliances | | | | |
| *Refrigerator* | 8 | 6 [12,14,16–18,38] | 0 | 2 [29,35] |
| *Size of refrigerator* | 1 | 1 [26] | 0 | 0 |
| *Fridge-freezer* | 1 | 1 [29] | 0 | 0 |
| *Chest freezer* | 6 | 4 [5,12,16,29] | 0 | 2 [35,38] |
| Ownership of washing appliances | | | | |
| *Dishwasher* | 7 | 6 [5,14,16,18,29,38] | 0 | 1 [12] |
| Ownership of laundry appliances | | | | |
| *Washing machine* | 6 | 3 [18,35,38] | 0 | 3 [8,29,37] |
| *Size of washing machine* | 1 | 1 [26] | 0 | 0 |
| *Tumble dryer* | 11 | 8 [5,8,12,14,16,18,29,37] | 0 | 3 [8,35,37] |
| *Iron* | 1 | 1 [36] | 0 | 0 |
| Ownership of building maintenance appliances | | | | |
| *Vacuum cleaner* | 1 | 1 [29] | 0 | 0 |
| *Water pump* | 1 | 1 [5] | 0 | 0 |
| Ownership of hygiene and leisure appliances | | | | |
| *Swimming pool pump and spa* | 2 | 2 [12,25] | 0 | 0 |
| *Sauna* | 1 | 1 [18] | 0 | 0 |
| Use of office IT appliances | | | | |
| *Desktop computer* | 1 | 1 [6] | 0 | 0 |
| Use of entertainment appliances | | | | |
| *TV* | 1 | 1 [6] | 0 | 0 |
| Use of major cooking appliances | | | | |
| *Electric oven* | 2 | 0 | 0 | 2 [5,25] |
| Use of washing appliances | | | | |
| *Dishwasher* | 2 | 2 [4,14] | 0 | 0 |
| Use of laundry appliances | | | | |
| *Washing machine* | 3 | 3 [4,6,14] | 0 | 0 |
| *Tumble dryer* | 4 | 4 [4,6,14,25] | 0 | 0 |
| *Number of hot (90 °C) and cold washes (30 °C)* | 1 | 1 [4] | 0 | 0 |
| Power demand of appliances | 1 | 1 [12] | 0 | 0 |

desktop and laptop) had a significant effect on Irish domestic electricity use. Desktop computers were found to be the third largest contributors to electricity consumption, behind dishwashers and tumble dryers. Moreover, Baker and Rylatt [7] established that the number of PCs in use had a stronger correlation with total electricity consumption than other home appliances. However, Leahy and Lyons [29] observed that the ownership of a home computer was not a statistically significant predictor of electricity use in Irish dwellings.

### 5.1.3. *Ownership of entertainment appliances*

In relation to entertainment appliances, several authors have observed a significant influence for the ownership of television, portable television, video player/recorder, video console and CD player on the electrical energy demand of residential buildings. Regarding the effect of the ownership of televisions, several studies consistently agreed that households owning a TV had significantly higher electricity consumption than those without [5,7,12,14,16,18]. Specifically, Larsen and Nesbakken [18] estimated that owning a TV increased electricity consumption in Norwegian homes, on average, 1301 kW h $pa^{-1}$. Electricity consumption has also been estimated as significantly higher in households owning a video player/recorder [14,18], a digibox [7] and a video console [5]. However, the ownership of a portable television and CD player has been reported to have little effect [29].

#### 5.1.4. Ownership of HVAC appliances

The significant effect of the use of electric space heating, air-conditioning and ventilation systems has been widely mentioned in the literature. However, apart from portable electric heaters which were found to be significant in the studies of Baker and Rylatt [7] in the UK and Larsen and Nesbakken [18] in Norway, very little or no influence of the ownership of smaller HVAC appliances such as desk or wall fans or dehumidifiers has been observed [8,35].

#### 5.1.5. Ownership of major and minor cooking appliances

The effect of cooking appliances, such as electric oven, range hood and microwave, has also been researched. A significant and positive effect of the ownership of electric ovens and stoves has been reported by McLoughlin et al. [5] (Ireland), Kavousian et al. [12] (USA), Parti and Parti [16] (USA), Leahy and Lyons [29] (Ireland), and Halvorsen and Larsen [38] (Norway). It is worthwhile mentioning that Halvorsen and Larsen [38] observed that the purchase of a new electric oven resulted in a reduction in electricity consumption; this was attributed to the replacement of an old inefficient appliance with a more energy efficient one. Differing from previous studies, Carter et al. [35] did not find any correlation between electricity consumption and the use of electric stoves in Barbados. In relation to the ownership of a range hood, a significant influence on electricity use in Chinese homes was established by Tso and Yau [8,37]. In addition, Tso and Yau [8,37] and Leahy and Lyons [29] established that the ownership of a microwave and a kettle had no influence on the variation in electricity use of domestic buildings in China and Ireland.

#### 5.1.6. Ownership of preservation and cooling appliances

Extensive research has been undertaken aimed at exploring the influence of ownership of preservation and cooling appliances, including refrigerators, fridge-freezers and chest freezers [5,12,14,16–18,26,29,35,38]. The significant effect of the ownership of refrigerators on electricity demand has been consistently acknowledged [12,14,16–18,38] as one of the most important predictors of electricity demand compared to other appliances. According to Zhou and Teng [17], Chinese households with a refrigerator had electricity consumption 22.2% higher than that of households without a refrigerator. Leahy and Lyons [29] and Carter et al. [35] did not observe any significant relationship between the ownership of refrigerators and electricity use in Ireland and Barbados. In addition to the effect of ownership, Genjo et al. [26] also determined that the size of the refrigerator owned had a significant effect on the electricity consumption for appliances and lighting in Japan.

Regarding the ownership of a fridge-freezer, Leahy and Lyons [29] found that electricity consumption was significantly higher in Irish households owning a fridge-freezer compared to those without. In particular, the study revealed that households with a fridge-freezer used approximately 6.7% more electricity per week than households that do not have such an appliance.

Several studies have also acknowledged the impact of having a chest freezer on electricity demand [5,12,16,29]. Leahy and Lyons [29] concluded in their study of Irish dwellings that the effect of having a chest freezer was stronger than having a fridge-freezer, accounting for over 11.3% more electricity per week than households that do not have such an appliance.

Halvorsen and Larsen [38] studied the effect of both owning a freezer and purchasing a new freezer and revealed that a new freezer resulted in a reduction in electricity consumption in Norwegian homes, however, no significant effects of purchasing or owning a freezer were found. Carter et al. [35] also concluded that the ownership of a freezer was not a good predictor of electricity consumption in Barbadian homes.

#### 5.1.7. Ownership of washing appliances

The ownership of washing appliances (i.e. dishwasher), and its impact on electricity demand, has been the focus of extensive research [5,12,14,16,18,29,38]. Apart from Kavousian et al. [12] in the USA, who did not find any significant influence, all other authors found a significant relationship between the ownership of a dishwasher and increased electricity demand. McLoughlin et al. [5] determined that, with a household penetration of 67%, dishwashers were the largest contributors to Irish domestic electricity consumption. In addition, Leahy and Lyons [29] established that having a dishwasher increased electricity consumption in Irish homes by over 10.5% per week. Similarly, Larsen and Nesbakken [18] added that those households in their study in Norway which owned a dishwasher used 2015 kW h more electricity per year on average than households that did not have such an appliance.

#### 5.1.8. Ownership of laundry appliances

Several authors have also explored the influence of the ownership of laundry appliances, including washing machines, tumble-dryers and irons, on domestic electricity demand [5,8,12,14,16,18,26,29,35–38]. While the significant contribution of the ownership of a washing machine has been acknowledged by Larsen and Nesbakken [18] (Norway), Carter et al. [35] (Barbados), and Halvorsen and Larsen [38] (Norway), other studies have reported little or no effect in China and Ireland [8,29,37]. Specifically, Larsen and Nesbakken [18] established that Norwegian households with a washing machine used 2099 kW h more electricity per year than households that did not have such an appliance. Moreover, Halvorsen and Larsen [38] not only found a significant effect of the ownership of a washing machine but also a significant relationship between the purchasing of a new washing machine and electricity consumption in Norway. In particular, the authors found that the purchase of a washing machine resulted in an increased electricity use. Apart from the effect of ownership, Genjo et al. [26] also determined that the size of the washing machine owned was a significant influential factor on the electricity consumption for appliances and lighting in Japan.

The high impact of the ownership of a tumble dryer on electrical energy demand has been the focus of extensive research [5,12,14,16,18,29,37]. In particular, Leahy and Lyons [29] established that Irish households owning a tumble dryer consumed over 10.5% more electricity per week than those without the appliance. Similarly, Larsen and Nesbakken [18] found that Norwegian households with a tumble dryer used 2338 kW h more electricity per year than households that did not own one. McLoughlin et al. [5] added that, with a household penetration of 90% and 68% respectively, the ownership of a tumble dryer was one of the three largest contributors to electricity consumption in Ireland. Tso and Yau [8,37] established that the ownership of tumble dryer was statistically significant factor in relation to summer domestic electric consumption but not during the winter period in Chinese dwellings. Differing from previous studies, Carter et al. [35] (Barbados) did not find any correlation between electricity consumption and the number of tumble dryers owned.

Regarding the ownership of an iron and its influence on electricity use, Louw et al. [36] found a significant and positive relationship in newly electrified low-income African households.

#### 5.1.9. Ownership of building maintenance appliances

In relation to the ownership of building maintenance appliances, Leahy and Lyons [29] agreed on the significant positive effect of the ownership of a vacuum cleaner in Irish homes. In particular, Leahy and Lyons [29] found that Irish households with a vacuum cleaner used 6.2% more electricity per week than households that did not have such an appliance. In addition, McLoughlin et al. [5] concluded that water pumps (used in residential areas with low water pressure) had a significant positive effect on domestic electrical energy demand in Ireland.

#### 5.1.10. Ownership of hygiene and leisure appliances

Other studies have also looked at the influence of the ownership of specific hygiene and leisure appliances. Generally, the choice of appliances studied and the results obtained, are highly influenced by the climatic aspects of the country where the research was undertaken. For example, Kavousian et al. [12] and Parker [25], both US-based studies, found a significant effect of the use of swimming pool pumps and spas on household electricity use. Moreover, Larsen and Nesbakken [18], whose study was located in Norway, estimated that electricity consumption was significantly higher for households with a sauna than those without.

### 5.2. Use of appliances

According to Zhou and Teng [17], the number of appliances only partially reflects the effects of electrical appliances on household electricity consumption. It is also necessary to consider the frequency of appliance use. Bedir et al. [4] established that the duration of use of appliances (including IT, entertainment, HVAC, washing and laundry appliances) explained 37% of the variance in electricity consumption between domestic buildings in the Netherlands. However, little research has been undertaken to assess the influence of the use of appliances on the total electrical energy demand of residential buildings [4,6,14,34].

In relation to the use of IT appliances, Sanquist et al. [6] determined a strong correlation between the use of a desktop computer and the annual electrical energy demand of US households. The study suggested that the use of IT appliances in a household may be a manifestation of higher disposable income.

The use of entertainment equipment, and in particular TVs, has also been studied. According to Sanquist et al. [6], there was a significant effect between the use of a TV and domestic electricity use in US households. The authors observed that this impact was higher in larger households which tended to own and use more televisions.

McLoughlin et al. [5] and Parker [25] also determined that the use of major cooking appliances, such as electric oven, did not have a significant influence on electricity consumption in Irish and US dwellings.

A significant positive correlation between the duration and frequency of use of washing appliances (i.e. dishwasher) and electricity demand has been reported in Bedir et al. [4] and Bartiaux and Gram-Hanssen [14] for homes in the Netherlands, Belgium and Denmark.

The same authors [4,6,14,25] have also reported a significant influence of the use of laundry appliances, both washing machines and tumble dryers on domestic electricity demand. Sanquist et al. [6] adds that there was a modest relationship between the number of household members and the use of laundry equipment in the USA, as larger households would have more frequent laundering needs. In addition, Bedir et al. [4] reported a significant correlation between the number of hot (90 °C) and cold washes (30 °C) and total electricity use in Dutch homes.

### 5.3. Power demand of appliances

The effect of the power demand of domestic appliances on the total electricity consumption of residential buildings has had little previous research attention. Kavousian et al. [12] established that US households purchasing energy-efficient Energy Star appliances and air conditioners had higher levels of daily minimum consumption, after adjusting for all other variables, meaning these dwellings had a higher overall electrical energy demand. The authors attributed this finding to the "rebound effect" [43], where an increase in the efficiency of appliances results in increased use, hence an increase in overall energy consumption.

## 6. Discussion

This paper provides a literature review of the socio-economic, dwelling and appliance related factors that affect domestic electricity consumption. The review has combined the results of previous studies to establish whether specific factors have a significant or non-significant effect on domestic electricity use.

The study has found no less than 62 factors in the literature as potentially having an effect on domestic electricity use. This includes 13 socio-economic factors related to the characteristics of the building occupants, 12 dwelling factors describing characteristics of the dwelling, and 38 appliance related factors, describing appliance ownership level (29 factors), use of electrical appliances in the home (7 factors) and power demand (1 factor). The conclusions regarding the causal effect of some of these factors has varied between previous studies and some factors were found to have been studied more frequently than others.

Although the number of existing studies on each factor varies, the review suggests that more occupants, the presence of teenagers, and increased household income and disposable income lead to a significant increase (positive effect) in residential electricity consumption. For all these factors, the number of papers confirming a positive effect is much higher (more than 3 studies) than the number of papers indicating a significant negative or non-significant effect. None of the socio-economic factors have clearly been identified as having a significant negative effect on electricity use, i.e. contributing to a reduced electrical energy demand. The effect of the presence of children in a household, the presence of and number of adults, the presence of elderly people (over 65 years old), education level and socio-economic status of the HRP, have either been studied infrequently (less than 3 papers) or, taken as a whole, the studies are inconclusive; i.e. they show a mix of effects or no effect at all.

In relation to the socio-economic factors, age of the HRP and tenure type, the effects could not be established as positive or negative because they were specified using categorical data. The conclusions of the previous studies did however show that the age of the HRP does have a significant effect on the electricity consumption of residential buildings. The impact of tenure type is inconclusive as the studies show a mix of effects.

Regarding the dwelling factors investigated in the previous studies, dwelling age, number of rooms, number of bedrooms, and total floor area, indicated a significant positive effect on domestic electricity use; i.e. electricity use increases as homes get older and bigger, either as measured by floor area, number of rooms or number of bedrooms. The study also suggested that electricity use increases significantly in homes with an electric space heating system, air-conditioning or an electric water heating system. The effect of the number of electric showers and baths per week, number of floors and presence of mechanical ventilation, and presence of low-energy lighting have either been studied infrequently (less than 3 papers) or, taken as a whole, the studies are inconclusive; i.e. they show a mix of effects or no effect at all.

The level of detachment of the residence was also seen to have a significant effect on the electricity consumption of domestic buildings, but as the data was categorical this effect could not be classified as either positive or negative.

For the appliance factors, the results of the existing studies demonstrated that a higher number of appliances, the ownership of a desktop computer, television, electric oven, refrigerator, dishwasher and tumble dryer, as well as a greater use of washing machines and tumble dryers result in an increased electricity use in residential buildings.

The effect of other appliance factors such as the ownership of a laptop computer, video console, digibox, portable electric-heater, range hood, fridge-freezer, iron, vacuum cleaner, water pump, swimming pool pump and spa, and sauna, the size of the refrigerator and washing machine, usage of a desktop computer, television and dishwasher, the number of hot and cold washes of the washing machine, and the power demand of appliances have been studied infrequently (less than 3 papers) so their effect on electricity use cannot be concluded. In addition, the ownership of a portable television, CD player, desk fan, dehumidifier, microwave, kettle, a video player/recorder, chest freezer and washing machine, and the use of electric ovens suggest an inconclusive effect on electricity demand.

The socio-economic, dwelling and appliance factors which cannot be unambiguously confirmed as having either a significant positive, significant negative or non-significant effect require further investigation to fully establish their effects on domestic electricity use. Therefore, at this time, from the possible 62 factors studied in the literature, it is only possible to state that four of the socio-economic factors, seven of the dwelling factors, and nine of the appliance related factors were found to have a significant positive effect on electricity use.

Given that this paper presents, to the authors' knowledge, the first comprehensive analysis taking stock of all previous studies investigating the socio-economic, dwelling and appliance related factors affecting electricity consumption in domestic buildings, it is useful to dwell on the contributions and limitations of these earlier studies and to suggest directions in which the wider research community can improve and further the current body of literature.

First, it is apparent from the previous studies that researchers need to establish a standardised classification for socio-economic, dwelling and appliance related factors to allow easier comparison between studies. For example, different classifications are currently used for investigating the effect of the spatial area of a dwelling on electricity consumption, such as, number of rooms [4,7,10,13,15,29], number of bedrooms [4,5,7,24,30,35], number of floors [23] and total floor area [4,7,8,10,12–14,17,19,20,22–26,28,33,37–39].

Second, when reviewing the published articles, it was clear that, important contextual information about the sample of dwellings from which the models were developed was often poorly reported. Many studies did not state whether the sample of dwellings included homes with electric space heating or cooling, electric water heating or mechanical ventilation. This information is clearly important for interpreting the effects established in the studies. For instance, did the studies that reported no effect of floor area on electricity consumption [4,7,8] exclude electrically heated or cooled homes? If electrically heated or cooled homes had been included in the studies' samples, would a different result have been obtained?

In addition, few studies stated whether the sample of dwellings analysed was representative of the national or local building stock for the country in which the study was conducted. This limits the studies from providing useful support for the design and implementation of effective energy policy and to predict and plan for the future electricity consumption of the domestic sector.

Third, the methods used to gather data about the electricity consumption of the dwellings and the socio-economic, dwelling and appliance information varied significantly between the previous studies. The combination of methods used in the individual studies would have introduced different levels of uncertainty into the results obtained. For example, the studies that used household electricity monitoring [5,12,21,24] instead of electricity meter readings provided by the energy supplier [14,22,23] or utility bills [6,26] should be much more reliable than those using the latter methods, which are likely to be based on estimated meter readings. Furthermore, the studies employing building professionals to undertake detailed energy audits of the dwellings [21] are likely to have more accurate information about the dwelling characteristics than those studies relying on the building occupants to self-report this data through personal interviews [8,20], phone surveys [21] and questionnaires [7,12,20,23,26]. In addition, the studies which sub-metered the electrical appliances [20,25] will have more accurate power demand and usage data than those studies in which the occupants estimated this information. As the domestic sector moves towards smart metering, more accurate and reliable electricity data will become available at the individual dwelling level, future studies should seek to exploit this improved data and couple it with data from detailed household surveys gathering socio-economic, dwelling and appliance information.

Finally, with the exception of the UK [7,11,30,33,22] and USA [6,12,16,25,31,34,40,41] there are lack of studies which investigate the effects of socio-economic, dwelling and appliance related factors on domestic electricity demand. Further research may seek to investigate those countries where few or no national studies have currently been undertaken.

## 7. Conclusion

This paper aimed to investigate the socio-economic, dwelling and appliance related factors that have significant or non-significant effects on domestic electricity consumption. To achieve this aim, a comprehensive literature review of international research investigating these factors was undertaken. Although papers examining the factors affecting electricity demand are numerous, a comprehensive analysis taking stock of all previous findings has not previously been undertaken.

This study has found that no less than 62 factors have been studied in the literature as potentially having an effect on domestic electricity use. This includes 13 socio-economic factors, 12 dwelling factors and 37 appliance factors. Of the 62 factors, four of the socio-economic factors, seven of the dwelling factors, and nine of the appliance related factors were found to unambiguously have a significant positive effect on electricity use. For all these factors, the number of papers confirming a positive effect is much higher (more than 3 studies) than the number of papers indicating a significant negative or non-significant effect.

The review has identified that some factors have been studied less frequently than others, this is particularly pertinent for the appliance related factors, where only a few previous studies have analysed the effects of the ownership, use and power demand of appliances.

This paper contributes to a better understanding of those factors that certainly affect electricity consumption and those for which effects are unclear and require further research. Understanding the effects of factors can support both the implementation of effective energy policy and to predict and plan for the future electricity consumption of the domestic sector.

Future research should seek to understand the effects of those socio-economic, dwelling and appliance factors where little previous research has been undertaken or their effects are unclear. In addition, further research may seek to investigate non-household level factors, such as, policy and regulatory, macro-economic, electricity price, and environmental factors that were beyond the scope of the current review.

Due to the limited number of total studies currently published investigating the effects of household level factors, it is not currently possible to undertake further analysis at the scale of individual countries or for developed or developing countries. In future, when more studies are published this could be an avenue for further analysis.

## Acknowledgements

This research was supported in parts by the 4M Project: Measurement, Modelling, Mapping and Management (4M): An Evidence-Based Methodology for Understanding and Shrinking the Urban Carbon Footprint, funded by the Engineering and Physical Sciences Research Council (EPSRC) under the Sustainable Urban Environments programme (grant reference EP/F007604/1) and the eViz project: Energy Visualisation for Carbon Reduction, funded by the EPSRC under the Transforming Energy Demand in Buildings through Digital Innovation programme (grant reference EP/K002465/1). For further details, see http://mmmm.lboro.ac.uk/ and http://www.eviz.org.uk/.

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