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Driving forces of energy-related behavior in residential buildings

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Abstract: In the framework of the on-going project IEA ECBCS Annex 53, total energy use in residential buildings and the role of occupant behavior are being investigated. Aspects from natural sciences as well as social sciences are related to the energy use in residential buildings. Research on energy use in the last decades has progressed in both the natural and social sciences.

In this report, we present a review of energy-related behavior and the driving forces of energy-related behavior in residential buildings.

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1 Introduction

In western countries, households account for approximately thirty percent of the total energy consumption. In order to reduce the energy consumption in buildings, effort has been put in research on and development of more energy efficient technologies and buildings, especially during the last decades. Effort has also been placed on encouraging households to purchase more energy efficient technologies.

The physical aspects related to the energy consumption of buildings, such as the building envelope, building installations and climate, are well understood. However in practice, there is often a significant discrepancy between the designed and the real total energy use in buildings.

Monitoring studies for identical dwellings having the same type of installations have shown great variation in energy use. See for example Figure 1.1, which shows the variation in heating energy for identical dwellings having the same installations.

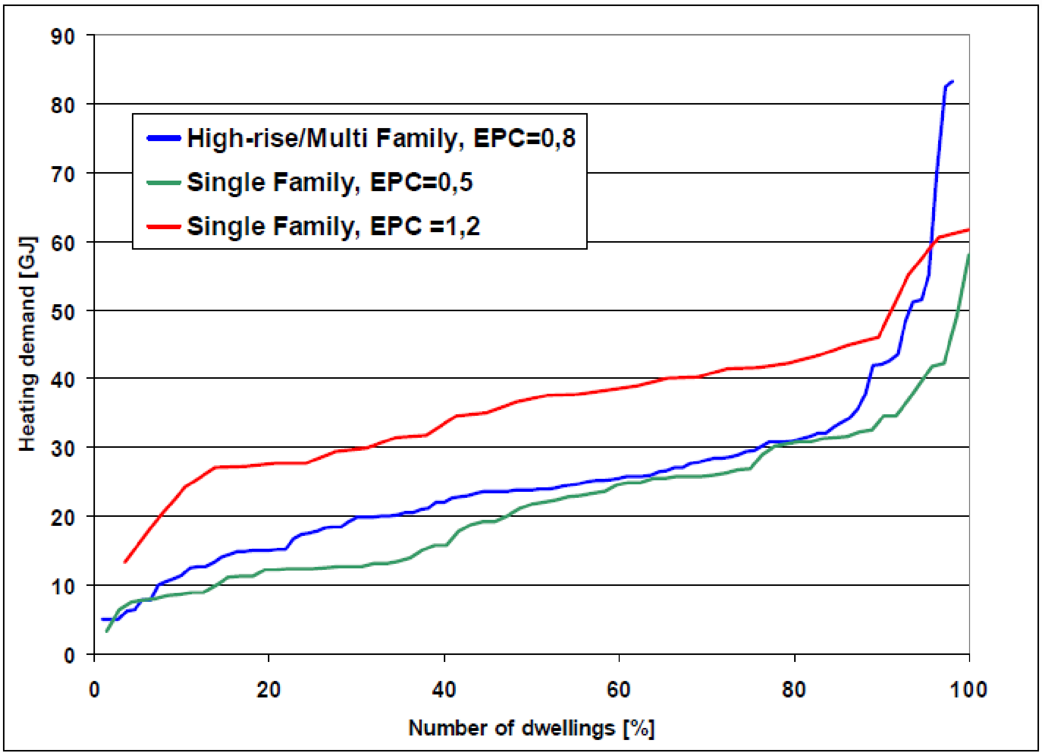

Figure 1.1: Variation in energy use in identical dwellings for three different projects. See Ref. [1].

The three curves in Figure 1.1 represent the heating energy use for three different types of dwellings / installation at three locations in The Netherlands, see Ref. [1]. For example, the single family buildings represented by the red curve display approximately a threefold difference in heating energy use. The other curves show an even greater variation in heating energy use. This variation in energy use is in this case completely related to the behavior of the occupants of the dwellings, since identical buildings and installations having the same energy efficiency have been considered in this study. Similar findings on the effect of occupant behavior have been reported by other authors in the literature, see e.g. Refs. [2] and [3].

Ref. [3] reports on a study of 1000 quite similar residential buildings in a suburb of Copenhagen, which in spite of their similarity show huge variation in energy consumption. The study has been reported in Ref. [4]. The comparison of heating energy use for completely identical houses showed that households using the greatest heating energy used a three time more heating energy than the households using the least energy for heating. For electricity use, an even larger variation was found; households using the greatest electricity used five times as much as the households using the least electricity.

Energy-related occupant behavior as meant in this report is related to building control actions (for controlling the indoor environmental quality), household and other activities. Occupant behavior related to the heating energy use concerns for example the temperature set point, the number of rooms that are heated, the heating duration, and window opening/closing.

Energy use in modern dwellings may show an increased sensitivity to occupant behavior. For example, for very well insulated dwellings the relative increase of heating energy use is quite sensitive to the set point temperature chosen by the occupant, see Figure 1.2.

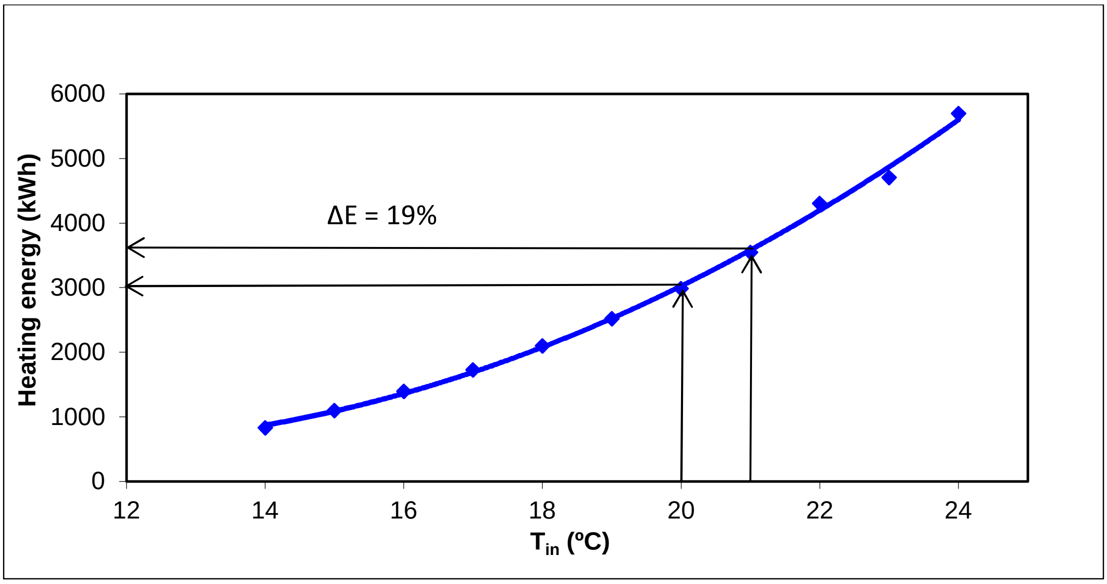

Figure 1.2: Increased sensitivity of heating energy for set point behavior. See Ref [5].

The increase of heating energy of a very well insulated dwelling as a function of the set point temperature is displayed in Figure 1.2. Increasing the set point with one degree, from 20ºC to 21ºC, results in a 19% increase of the heating energy. This example demonstrates the sensitivity of energy use in residential buildings to energy-related occupant behavior.

For modern dwellings with increased air tightness, the occupant behavior can have a larger effect on the air change rate and consequently the energy consumption of the dwelling.

As the requirements for energy use in buildings are tightened in national and international regulations, knowledge of physical aspects of energy efficiency is being implemented in new residential and office buildings. In order to fulfill the high expectations for energy savings in buildings in the future, better understanding of how energy-related occupant behavior influences building energy consumption is required. The above examples of the effect of occupant behavior on energy use and the sensitivity to occupant behavior illustrate the importance of acquiring more knowledge on energy-related occupant behavior for understanding and realistically predicting the total energy use in present and future residential buildings.

In the framework of the IEA ECBCS Annex 53 project, total energy use in buildings and the role of occupant behavior are being investigated. Aspects from natural sciences as well as social sciences are related to the energy use in buildings and are addressed in the project. In this Annex 53 report we focus on energy-related occupant behavior in residential buildings. The report contains categorization of the most relevant types of energy-related occupant behavior for residential buildings. In addition, the influencing parameters, referred to as *driving forces*, for the various types of energy-related occupant behavior will be identified in this literature review based report.

Quantitative modeling approaches for describing energy-related occupant behavior and energy use in residential buildings are discussed in another separate Annex 53 report titled "*Total energy use in residential buildings – the modeling and simulation of occupant behavior*".

2 Driving forces of energy-related behavior

Energy use in residential buildings is influenced by the behavior of occupants in various ways. Energy-related occupant behavior as meant in this report is related to building control actions (for controlling the indoor environmental quality), household and other activities. These actions and activities are driven by various factors.

The influence of occupant behavior on the energy use in buildings has been investigated in various domains such as natural sciences, social sciences, and economics. Many investigations in natural science publications focus on (statistical) relations between energy-related behavior and mostly physical parameters influencing this behavior, such as outdoor temperature, indoor temperature and solar radiation. Examples are given in Ref. [6] and Ref. [7].

Various research fields have different foci or requirements for occupant behavior. Determination and regulation of occupant behavior are the foci in social or physiological science. In natural (or building) science, more attention is paid to the quantitative description of occupant behavior based on physical parameters.

However, there is no well-defined relation between physical parameters and control actions such as outdoor temperature and window opening. In reality, an occupant decides to open or close a window and the decision is based on a number of influencing parameters that can be categorized as physical, biological, and psychological, as well as social (the interaction between occupants) to name a few. Figure 2.1 illustrates parameters influencing occupant behavior.

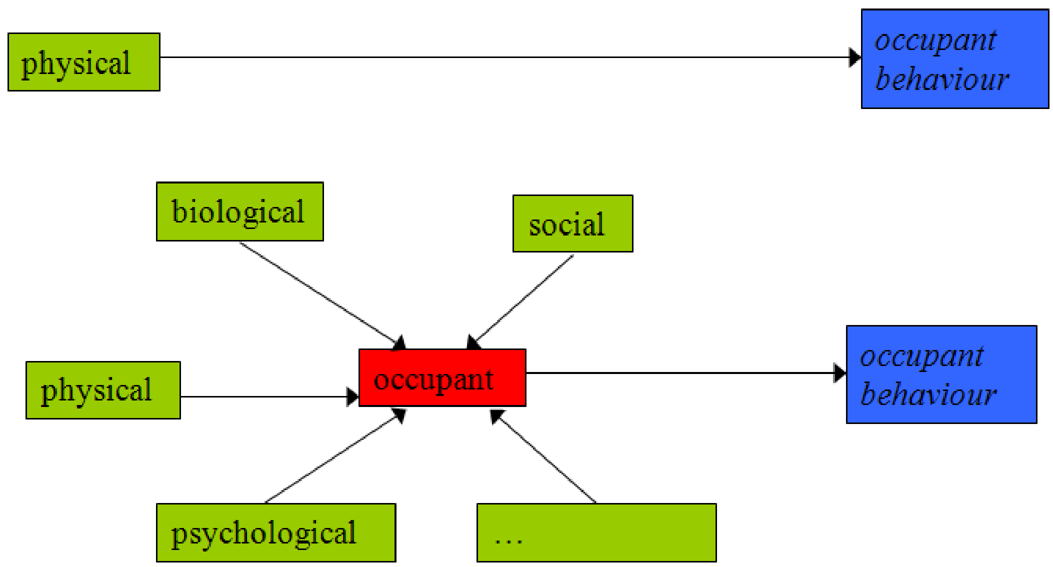

Figure 2.1: Parameters influencing occupant behavior.

This complex relationship between occupants and their environment is elaborated further in Figure 2.2.

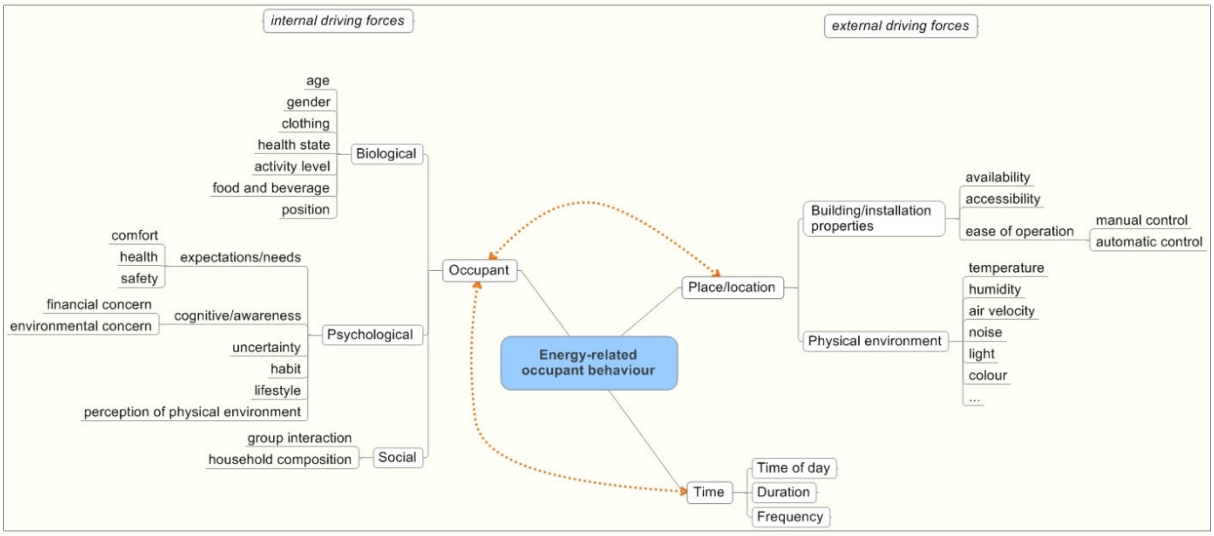

Figure 2.2: Driving forces of energy-related occupant behavior.

This scheme is based on the presence of an occupant at a specific time at a specific location having access to specific building controls. Occupants experience a specific physical environment due to their location, biological, and psychological states, and by the interaction with their environment.

Information about occupant presence and activities may be obtained from time-use surveys and occupancy sensing. The interaction between humans, buildings, and building control systems result from a combination of influencing parameters, from now on referred to as *driving forces*. These driving forces can be regarded as *internal* and *external* driving forces, see Ref. [8] and Ref. [9] for examples. The internal and external driving forces of energy-related occupant behavior as shown in Figure 2.2 are ordered according to the following categories: *biological*, *psychological*, *social*, and *time*, *building and building equipment properties*, *physical environment (indoor and outdoor)*.

2.1 Internal driving forces

The first three types of driving forces of energy-related behavior are *internal* driving forces of the occupant, *biological, psychological, and social*, and are depicted on the left side of Figure 2.2. These are being investigated in the domain of social sciences, economics, and biology. There is strong interaction between biological and psychological aspects, resulting in disciplines such as biopsychology and psychophysiology. Health can be considered as a biopsychosocial unit combining biological, psychological and social elements. Eating or drinking habits are strongly influenced by cultural aspects. Thus, strict differentiation between these driving forces is difficult to handle. A short section on behavioral thermoregulation representing an interface between biological and psychological driving forces with thermal comfort-related interactions with heating, cooling, ventilating, and window opening is included.

a) Biological driving forces:
Examples of biological driving forces are age, gender, health condition, activity level, hunger, and thirst. These factors together determine the physiological condition of the occupant.

b) Psychological driving forces:
Occupants tend to satisfy their needs concerning thermal, visual, and acoustic comfort requirements, along with health and safety, to name a few. Furthermore, occupants may have certain expectations of e.g. the indoor environmental quality (such as temperature). Other examples of psychological driving forces are awareness (e.g. financial and environmental concerns), cognitive resources (e.g. knowledge), habits, lifestyle, perceptions, emotions, and self-efficacy (e.g. environmental control).

> Behavioral thermoregulation: Apart from autonomous biological processes, there is a variety of deliberate regulation options which are listed below. Adequate behavioral thermoregulation can be considered result of learning processes, experiences, and/or culturally-driven factors.

1) Clothing: relevant in hot as well as in cold climate conditions, adequate clothing fosters reducing convection;
2) Thirst as the deliberate regulation of hydration is a crucial issue in people being in need for care or old persons drinking too little (this is of special interest regarding demographic change);
3) Use of external sources for convection or thermal heat;
4) Looking for places which, which are more convenient, e.g. shade, areas with more or less natural convection;
5) Sleep (siesta) as an option to reduce metabolic heat production;
6) Acclimatization: the process by which an individual becomes physiologically, behavioral, and psychologically adjusted to the temperature of the environment. This is of importance regarding the degree by which the individual tolerates actual sensitized temperatures especially when it comes to extreme and unfamiliar climates; acclimatization can be a result of repeated exposure to hot climates.

c) Social driving forces:
Social driving forces refer to the interaction between humans. For example for residential buildings, this depends on household composition which is linked to the primary decision maker in the household, i.e. which household member determines the thermostat set point or the opening/closing of windows.

2.2 External driving forces

The *external* driving forces depicted at the right-hand side of Figure 2.2 (*building and building equipment properties, physical environment, and time*), are being investigated in the field of natural (or building) science.

d) Building and building equipment properties:
Examples of building and building equipment properties are the insulation level of buildings, orientation of façades, heating system type, and thermostat type (e.g. manual or programmable), to name a few.

e) Physical environment:
Examples of physical environment aspects that drive energy-related occupant behavior are temperature, humidity, air velocity, noise, illumination, and indoor air quality.

f) Time:
Examples of this type of driving forces that affect energy-relates occupant behavior are season of the year, week or weekend day, time of the day.

2.3 Energy-related occupant behavior

The energy-related occupant behavior block in Figure 2.2 refers to actions and activities related to the categories *heating, cooling, ventilation and window operation, domestic hot water, electric appliances / lighting, and cooking*. These categories are briefly introduced underneath and are discussed in greater detail in the subsequent sections of this report.

1) Heating:
The activities of occupants have become more important within energy efficient buildings. Studies have shown that user behavior and lifestyle can affect energy consumption by up to a factor of three. Occupant behavior related to heating concerns temperature set point, number of heated rooms, heating duration, gender, age, expectations, knowledge of control function and meteorological conditions.

2) Cooling:
Depending on the type of system, occupant behavior has a significant influence on the use of cooling. From the general to the detailed, this starts in some cases with the choice of cooling system, the duration and frequency of usage, the choice of set-point temperatures, and the frequency of maintenance.

3) Ventilation and window operation:
Investigations on window opening behavior and natural ventilation have mainly been carried out with two aims: to find whether or not occupants are provided with adequate fresh air and to find the influence on energy consumption. The former category of studies has usually been carried out in dwellings and has a health or a comfort perspective, while the latter category has mostly been studied in offices with a comfort and energy performance perspective. Occupant behavior concerns mechanical ventilation operation, natural ventilation inlet operation, window opening or closing.

4) Domestic hot water:
Occupant behavior can significantly influence the use of hot water in residential buildings. Examples of energy-related occupant behavior related to domestic hot water use are the frequency of taking a shower, duration and intensity of showers; frequency of taking a bath; frequency of sink use; frequency and temperature of washing machines and dishwashers, and efficiency of water usage.

5) Electric appliances / lighting:
The use of electric appliances and lighting in residences is strongly influenced by occupant behavior. When the energy consumptions for appliances and lighting are considered, large variations are found, which partly relates back to socioeconomic parameters such as income, persons per household, age, education etc. The number of appliances and their energy efficiency, as well as the usage frequency and duration determine the energy use.

6) Cooking:
Many different appliances can be used for cooking purposes, such as microwave ovens, ovens, stoves, pressure cookers, kettles, etc. The type of equipment used and their corresponding energy consumption as well as the number of meals prepared will determine energy use for cooking.

Energy-related occupant behavior may be use, purchase, or building maintenance related. The effects of energy-related occupant behavior (e.g. building control actions) on residential energy use and indoor environmental quality may be calculated quantitatively using building simulation software packages.

In this report, the driving forces for the above mentioned categories of energy-related occupant behavior will be identified based on a literature review and will be discussed in greater detail in the following chapters. Quantitative modeling approaches for describing energy-related occupant behavior and energy use are discussed in another separate report titled "*Total energy use in residential buildings – the modeling and simulation of occupant behavior*".

The notation used in the summary tables in the subsequent sections to indicate the importance of these driving forces is explained in Table 2.1. The coding system is based on a range varying form very highly significant to not significant, based on investigations in the literature.

Importance	
Description	Symbol
Very highly significant (p≤0.001)	***
Highly significant (p≤0.01)	**
Moderately significant (p≤0.05)	*
Lowly significant (p≤0.1)	’
Not significant	n.s.
Not stated	x

Table 2.1: Notation used for importance of driving forces; the p-value refers to the statistical significance level.

3 Heating

The activities of occupants have become more important within buildings when considering heating energy use in energy use predictions. Studies have shown that user behavior and lifestyle can affect energy consumption by up to a factor of three, as stated in Ref. [2, 3]. Firsthand data about user behavior has been collected in various studies. Often, secondary factors combine to affect the set-point temperature and heating schedule of a building.

Low-energy, passive house, and zero energy (including energy autarkic) buildings, are designed to minimize the heating load to supply only the required heat when occupants are present that cannot otherwise be gained through passive solar and internal heat gains. Studies have found that improving the efficiency of the building envelope and building systems significantly reduces overall energy consumption, thus increasing the importance of the role or actions of the occupant [10, 11]. How the set-point temperature is determined, the correlating factors for temperature, and the overall operation of the heating system must also be understood to define the driving forces for energy-related behavior for heating.

3.1 Identification of driving forces

The adaptive principle is based upon the assumption that "if a change occurs such as to produce discomfort, people react in ways which tend to restore their comfort", see Ref. [12]. When the goals of thermal comfort and energy savings conflict, it has been found that occupants make decisions regarding their own comfort that may have a negative effect on overall energy consumption.

As low energy houses have higher air tightness and thermal insulation, and use balanced mechanical ventilation with heat recovery, occupant behavior becomes less dependent upon environmental and building/building system factors. Internal factors such as clothing and activity levels, perceived indoor environmental quality (IEQ), and established habits, especially window opening and ventilation, have greater effect on the overall heating energy consumption than set point temperatures.

3.1.1 Biological

Temperature set-point

Night setback temperatures are shown to have a significant impact on room heating energy consumption partially due to the large variance of preferred sleeping temperatures, see Ref.[13].

Number of occupants

Household size has been found to be significant in Ref. [13].

Which rooms are heated

The effect of partial heating in single-family houses on estimating total energy use was studied in Ref. [14], and indicated that estimations were higher than actual consumption due to different heating habits for different rooms. Ref. [13] found that the number of heated bedrooms had a large influence on energy use.

Gender:

In Fanger's experiments using two test groups of university students in Denmark and the USA and a test group of older, retirement-aged people, it was found that men preferred a warmer environment, but the findings were not statistically significant (5%), see Ref. [15]. Fanger compared various literature studies and found that women are more sensitive to changes in temperature, but the results were inconclusive with some studies concluding that women preferred higher temperatures, while other studies showed that men preferred higher temperatures. The effect of gender was also questioned by Ref. [2]; the questionnaire results illustrated a trend that women desired higher set-point temperatures than men. The questionnaire was distributed to a Danish population sample in Copenhagen twice. There were 933and 636 respondents for the first and second groups distributed four months apart in September to October 2006, and then in February to March 2007.

Karjalainen cited in Ref. [2], found that women were more dissatisfied with room temperatures than men, and preferred higher set-point temperatures. In the same study, it was also found that men controlled the set-point temperatures more often than women.

Age:

Ref. [13] has found that heating energy consumption increases with age.

Clothing:

Of the factors that influence behavior, a pattern was found where inhabitants decided their daily clothing level based on the exterior weather conditions at 6 a.m. and made little alterations to the clothing level afterwards. However, exterior weather conditions were not the only influential factors.

As occupants spend more than 90% of the time indoors, climate parameters as defined by Fanger determine their subjective wellbeing. Many studies have been conducted about clothing levels in relation to various activities such as work, shopping, and leisure at home Refs. [16], [17], and [18]. Ref. [18] finds that people actively change their clothing at home corresponding with Andersen's residential questionnaire results finding that clothing adjustment was the main adaptive action, Andersen Ref. [2]. The laboratory tests by Fanger, which used the same clothing ensemble for all experimental groups [5], is disproven in the opinion of Keul et al., as social, cultural, and historic aspects must also be considered, Ref. [18].

3.1.2 Psychological

Expectations:

Ref. [19] looked at the perceived winter occupant comfort and indoor air quality in low energy brick residences in Vienna and Salzburg. Amongst the important factors listed, were the occupants' expectations. Previous studies to the type of occupant in low energy residences have shown that they do not have a propensity to high energy conservation behavior, but rather are within the social mainstream of tenants and owners. Ref. [19] has found that training occupants about the new technologies and correction of incorrect heating use soon after moving-in are very important for maintaining high satisfaction with living quality in low energy houses. Media discussions about climate change also influence quality assessments and housing preferences as stated in Ref. [3].

The subjective perceptions of occupants have also been found to be influenced by occupant thermometer and hygrometer readings. The study in Ref. [19] involved 20 Viennese participants divided into three test groups who made diary observations every three hours for 14 days:

a) 7 residents who noted in a diary the subjective temperature and humidity perceptions, assessments, behavior, and measurements from data loggers;
b) 11 residents who noted in a diary the subjective temperature and humidity assessments, behavior, and measurements from their own thermometers and hygrometers (which had an accuracy of ±3°C, and +6% to -28% respectively);
c) 2 residents who noted in a diary the subjective temperature and humidity assessments without any measurement devices.

The questionnaire results showed higher dissatisfaction for both winter temperature and room humidity when occupants had their own thermometers and hygrometers.

	Satisfaction with temperature	Satisfaction with room humidity
Residents with data loggers	94%	68%
Residents with their own thermometers and hygrometers	73%	12%
Residents without any devices	84%	43%

Table 3.1: Residents' satisfaction with room temperature and room humidity.

As the winter air supplied in passive houses commonly ranges between 30% and 45% RH, it is understandable that the satisfaction was so low in the test group with their own hygrometers. The humidity would likely show a range hovering below 20% RH.

Ref. [20] and [21] as cited by Refs. [14] and [13] respectively, mention an "economic rebound effect" whereby occupant expectations and heating energy use increases with higher comfort levels achieved by thermal renovations, resulting in achieving only a partial potential of cost and energy savings.

Understanding of how controls function:

Several authors see Refs. [22], [23], [24] and [25], have conducted studies that have determined that many users do not understand how to use thermostats and thermostatic radiator valve (TRV) controls properly. Ref. [25] also found that overheating occurred as a result of misunderstanding the operation of TRV's. Ref. [2] concludes that users' TRV control decisions are habit-based and misconceptions are widespread. The frequency by which occupants control heating coupled with the depth of understanding how the heating functions suggests a correlation with the energy used for heating.

The combination of training and changing habits based on incorrect information can have a widespread positive effect, as misunderstanding heating controls has been shown to exist for different heating control types and in different countries from the works of Refs. [22], [23] and [24] as shown in Ref. [2]. Questionnaire results in Belgium by Ref. [25], also find a large number of occupants who have poor understanding of heating controls, leading to improper use, working against advances in energy efficiencies. The concept of heating over the ventilation system has found to be counterintuitive for laypeople, and training has found to also be important to correct false theories, e.g. only occupants are needed to heat a passive house, Ref. [19].

Interaction frequency with heating controls:

In Ref. [2], many studies into establishing set-point temperature using TRV's have been conducted. The studies of Ref. [26] found that individual households have constant heating set-point temperatures that vary from each other, and Ref. [27] has questionnaire results that indicate that there is large variance in the frequency a user decides to control their environment.

Memory:

Morgan and de Dear state that outdoor exposure from the previous day influences clothing selection upon waking, Ref. [17]. Weather conditions from the previous day also influence the current day's adjustments made to heating; either set-point temperature or degree of heating valve opening.

3.1.3 Social

Ownership (owning/cooperative/renting):

The results of two questionnaire surveys in Austria of 933 and 636 participants showed that solar radiation, type of housing ownership, and perception of indoor environmental values were factors affecting heating use, see Ref. [2]. Ref. [28] and [13] also acknowledge the importance of home ownership on domestic energy use, indicating that more energy is used when energy costs are shared collectively in the rent.

Ref. [19] investigates the differences between owned (condominiums) and cooperative apartments within the same apartment complex. The investigation was carried out in Salzburg, and similarly compared data logger readings, occupants' own thermometers and hygrometers, self-recorded diary entries and interviews. An empty apartment was also logged as a reference point. The results of a satisfaction survey are in Table 3.2.

Table 3.2: Difference in satisfaction levels between owners and renters (cooperative apartments).

	Satisfaction with temperature	Satisfaction with room humidity	Satisfaction with IAQ
Owners	79%	85%	73%
Renters	84%	85%	73%

It was found that the perception of better IEQ was higher with higher humidity, despite the fact that measurements recorded higher CO_2 concentrations with higher humidity levels. The dissatisfaction with occupants' own measurement devices was not repeated in Salzburg. The study by Ref. [19] found that overall satisfaction was very high for temperatures from both owners and renters.

Government Interventions:

Ref. [29] looks at heat demand and heat supply from the year 2000 to 2050 in Austria. Based on simulations, the report indicates that widespread implementation of thermal renovations and new build to the low energy and passive standards will have a significant impact on the energy consumption for heating, and that the heat demand for space and hot water heating has already peaked in the last decade. The study concludes that government intervention is an influential factor for maintaining the trend of thermally renovating residences, especially for buildings built between 1945 and 2000. Encouraging further innovation in heating technologies, especially those that use renewable sources, and thermally activated building systems are further incentives that may be implemented. Suggested forms of regulatory interventions include taxes for CO_2 emissions, financial incentives for installing renewable-based heating systems, and updating building regulations to improve use of renewable and low energy systems. Thermal renovations are seen to become increasingly important for the Austrian building stock in the upcoming decades, see Ref. [29]. Government regulations also play a part in reducing building energy use in the Netherlands, however, the strived for innovations were not reached [30]. Refs. [26, 29, and 30] are within the European framework of the Energy Performance of Buildings Directive (EPBD), Ref. [31]. Regulations for calculating and displaying building energy use are also in countries such as Brazil (RTQ-R, Ref. [32]), the USA (Energy Star), Canada (EnerGuide), and Japan (CASBEE).

The estimated increasing number of thermal renovations of existing buildings will most likely lower the impact of external environmental factors as driving forces, and increase the importance of internal driving forces in the future. Ref. [2] also recognizes the correlation between the greater impact of occupant behavior, with stricter building regulations for energy use, tighter buildings, and higher insulation levels.

3.1.4 Time

Time of day:

Time of day is related to both clothing and outdoor conditions. Clothing decisions have been shown to be made upon waking for the day, Ref. [17]. This indirectly influences the selected residential set-point temperature as higher clothing values are generally correlated with lower set-point temperatures. On heating systems without thermostatic controls, it is also possible for occupants to either activate the heating system or increase heating in the evenings when the outdoor temperature is cooler.

3.1.5 Physical environment

As stated in Ref. [2], the physical aspects of the building play a greater role than occupant behavior in an approximate ratio of ten to one. In lowest energy buildings, where all building systems have been maximized for energy efficiency, the role of the occupant plays a larger role in determining whether or not the lowest energy targets are achieved. The comparative energy behavior variance can be up to a factor of three, see Ref. [2].

Meteorological conditions:

The most influential factors for conventional residential buildings were found to be outdoor temperature, outdoor air humidity, and wind speed, see Ref. [3]. Climate was also stated as an influential factor on indoor set-point temperature in Ref. [11].

3.1.6 Building/equipment properties

Heating System Type:

Reilly and Shankle (1988) as cited in Ref. [28] state that it is common for a combination of heating systems to be used in buildings, and that there is a large variety of types used in different ways by homeowners. Ref. [28], which examines heating system types in German homes, finds a positive correlation between education and gas heating. However, decisions related to socioeconomic factors are secondary to location (urban/rural, East/West Germany) with preference for solid fuels in rural areas, thermal quality of the building envelope, and storage space for solid fuels. The relationships between choice of heating to household income and number of persons in the household are shown in Figure 3.1. Building quality, heating system type, and climate together can influence set-point temperature and thermal comfort perception by occupants [11].

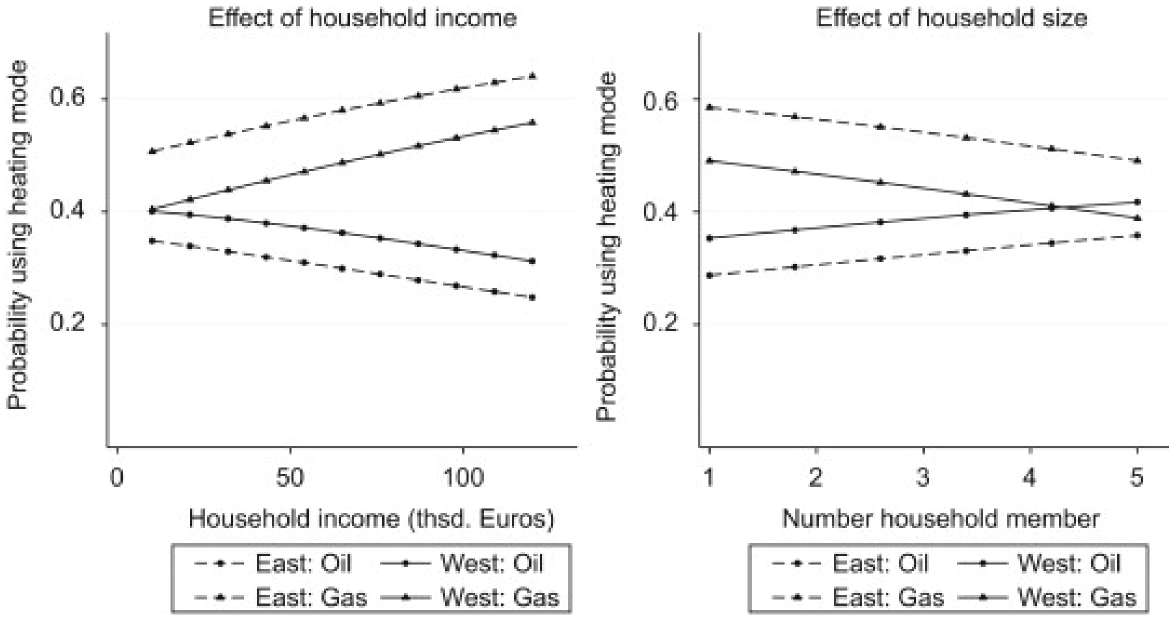

Figure 3.1: Probability of heating type use in the former East Germany and West Germany. Ref. [28].

Level of control:

Studies by Refs [33] , [34], [35] and [36] cited in Ref. [2] have shown that taking control out of the hands of the inhabitant leads to dissatisfaction with the indoor environment, and it can be concluded that control of one's own indoor environment is very important.

In Ref. [2], window opening and heating behavior within Danish residences is studied. Among the main findings, it was found that there was great variance in the individual behavior patterns, and that the difference in behavior can affect overall energy consumption by up to a factor of three, see Ref. [2].

3.2 Summary

In summary the previously identified driving forces for energy-related behavior with respect to heating are grouped and listed in Table 3.3.

Table 3.3: Driving forces for energy-related behavior with respect to space heating.

	biological	**psychological**	**social**	**time**	**physical environment**	**building/equipment properties**
Temperature Set Point	Gender [2]	Expectations [19]	Ownership (owning/coop/renting) [19]	Time of day [2]	Exterior air temperature [3]	Building insulation level [29]
	Clothing [2,19]	Interaction frequency with heating controls [2]			Outdoor air humidity [2]	Ventilation type [19]
		Window opening [2]				
Heating Duration	Clothing [2,19]	Understanding how controls function [2, 19,25]	Ownership (owning/coop/renting) [2]		Exterior air temperature [2]	Building insulation level [29]
					Outdoor air humidity [2]	Heating system type [2]
		Window opening [2]	Government interventions [29]		Wind speed [2]	Level of control [2]
# of Rooms Heated		Interaction frequency with heating controls [2]				Level of control [2]
Which Rooms are Heated	Gender [2]					Level of control [2]

Importance	***	**	*	’	n.s.	x

4 Cooling

Depending on the type of system, occupant behavior has a significant influence on the use of cooling. From the general to the detailed, this starts in some cases with the choice of cooling system, the duration and frequency of usage, the choice of set-point temperatures, and the frequency of maintenance.

4.1 Identification of driving forces

Research on the air conditioning unit (AC-unit) usage was first conducted in the frame of studies about the use of electricity in residential buildings. Seligman et al. stated in 1977 that personal comfort and health concerns were the best predictors of electricity demand, Ref. [37]. Up to now, especially in the Japanese research environment, the research on AC-unit usage is set in relation to general behavior patterns, Ref. [38], and the lifestyle of the occupant, Ref. [39]. An exception is the article by Ref. [40], which analyzed the AC-unit usage and window-opening behavior of eight dwellings for three days each in Japan and found large difference in the time and usage pattern between the dwellings.

A questionnaire survey with 554 responses on AC-unit usage during the sleeping hours in Hong Kong revealed that 83% of the occupants use their AC-unit for more than five hours during the sleeping period [41], but did not state any driving forces. Ref. [42] used the 2001 RECS data set to analyze the factors affecting cooling energy and found that "*occupant behavior is the most significant issue related to choices about how often and where air conditioning is used*", which is followed by physical parameters such as the climate and the AC-unit type as well as socioeconomic aspects, such as income, household size and age of the occupant.

Ref. [8] observed the AC-usage and window opening behavior of 39 student rooms in a Japanese dormitory through a continuous six week measurement for one summer. They found varies individual and building related driving forces for the usage of the AC-unit for cooling as included in Table 4.1 and the following sub-chapters. Based on the same data from the dormitory building in Tokyo, Japan, Ref. [43], analyzed driving factors for the choice of set-point temperature.

Ref. [44] conducted a worldwide survey with 435 participants of which one third was Japanese, one third German and the other third distributed to more than 40 countries in the summer version.

The 106 participants possessing a cooling device were asked about their reason for the last and hypothetical next start or stop of their cooling device.

There was no literature found related to the frequency of maintenance, assuming it to be another factor influencing the energy demand once the device is switched on.

4.1.1 Biological

Duration and frequency of usage (mainly percentage of usage)

Seligman et al. stated in 1977 that personal comfort and health concerns were the best predictors of electricity demand [45]. Health reasons for not using an AC-unit during the night were stated by 50% of the respondents in Ref. [40]. Ref. [46] observed 13 AC-units in eight apartments of a multi-family building in New Jersey, USA from June through September 1986. They also found that health reasons were claimed for reducing the frequency of usage together with safety reasons (due to a hot extension cord) and a general fear of electrical appliances. The latter two will not be dealt with here in detail, believing that they depend on the period of the survey and the then probably not fully developed technology of residential cooling devices.

Ref. [8] observed the duration and frequency AC-usage for cooling, and found that the way the AC unit was used at home during childhood, gender, and climatic origin have significant influences on AC-usage. Ref. [42] found that the age of occupants influences their usage patterns.

Choice of set-point temperature

Ref. [43] analyzed driving factors for the choice of set-point temperature: the origin from a moderate climate together with the running mean of the outdoor temperature increased the set-point temperature.

4.1.2 Psychological

Duration and frequency of usage (mainly percentage of usage)

Ref. [8] observed a significant influence of the perceived effectiveness of AC and the cultural background on the duration and frequency of the AC-usage for cooling.

Choice of set-point temperature

Preference for air-conditioned rooms was among the main factors to lower the set-point temperature according to Ref. [47]. Origin from an East-Asian country increased the set-point temperature.

4.1.3 Social

Duration and frequency of usage (mainly percentage of usage)

Ref. [42] found that household income has no significant influence on the frequency of AC-unit usage.

Switching on and off the cooling device

Ref. [39] concludes that switching off the cooling device depends more on the schedule, i.e. when leaving a room or going to bed, than the thermal environment.

Number of rooms equipped with a cooling system

Ref. [42] found that socioeconomic factors are significant driving forces related to the number of air conditioned rooms accounting together with climatic and physical factors for 48% of the variation in this parameter.

4.1.4 Time

Duration and frequency of usage (mainly percentage of usage)

Ref. [39] observed the control behavior of air conditioners in living rooms in 79 residential houses in the Osaka region of Japan. They found that usage varies according to the period of the day – the percentage of AC-units being switched on is lower during midday and evening compared to nighttime and morning. Whether this is related to variations in occupancy levels was not reported. Ref. [48] analyzed the AC-unit usage and window-opening behavior of 8 dwellings for three days each in Japan and found large difference in the time and usage patterns between the dwellings. Based on data from four dwellings situated in the Kawasaki area in Japan and a measurement period of four months from June to October, Ref. [38] found that the air conditioning use is mainly influenced by the time of day.

Ref. [8] also observed differences in AC-usage for cooling between morning, daytime, evening, and night times.

4.1.5 Physical environment

Duration and frequency of usage (mainly percentage of usage)

Ref. [42] found that the climatic conditions (represented by the cooling degree days (CDD)) and the number of rooms equipped with an AC-unit were the most influential factors. However, only 26% of the variation in usage frequency could be explained by these factors.

Ref. [38] found that air conditioning use is influenced by season and outdoor air temperature. Ref. [39] also recognized outdoor temperature as the main factor. Usage increases with higher outdoor air temperatures. Ref. [49], observing 17 residential and light-commercial AC-systems, found a 6% increase of operation time for every 1°C rise in indoor-outdoor temperature difference. Ref. [8] observed a significant influence of outdoor temperature and humidity on the duration and frequency of AC-usage for cooling.

A one year study observing 8 single-family residences in Austin, USA (Ref. [50]) showed that there was a 6% increase in the hourly fractional operation time for every degree increase in the difference between the indoor and outdoor temperature, and that lower set-point temperatures were related to longer usage periods.

Switching on and of the cooling device

Ref. [51] monitored 24 Korean dwellings (six dwellings for nearly two months and 18 for one week). According to their results, the indoor thermal environment was above the comfort zone according to ASHRAE Standard 55/2010, most of the time the AC-unit was switched on. However, no percentage or further analysis is stated regarding this statement.

With respect to starting the device, 65% stated temperature as the reason, followed by around 15% stating humid conditions according to Ref. [44]. Reasons to stop the device were habit (25%), temperature (22%), and leaving the room (15%).

Ref. [39] concludes that switching off the cooling device depends more on the schedule, i.e. when leaving a room, or going to bed, than the thermal environment.

Choice of set-point temperature

Ref. [39] observed variations in the set-point temperature between 24°C and 29°C, but did not state an explanation. However, they found a positive relationship between the set-point temperature and the temperature at which the AC-unit was switched on, i.e. when the set-point temperature was 1°C higher, the indoor temperature at the time of switching on the AC-unit was observed to be 1-2°C higher.

Ref. [47] analyzed driving factors for the choice of set-point temperature: the running mean of the outdoor temperature increased the set-point temperature.

Existence/Choice of cooling system

Ref. [42] states that there is a close relationship between the ownership of an AC-unit and the climate in which the building is situated.

Number of rooms equipped with a cooling system

Ref. [42] found that climatic factors have a significant influence on the number of air conditioned rooms accounting together with physical and socio-economic factors for 48% of the variation in this parameter.

4.1.6 Building/equipment properties

Duration and frequency of usage (mainly percentage of usage)

Ref. [42] found that the AC-unit type affects the cooling energy. Ref. [8] observed a higher use frequency of the AC-unit for cooling for top floor rooms and rooms having a south-oriented window compared to an east or west facing one. Ref. [42] found that the number of rooms equipped with an AC-unit was the most influential factor together with climatic conditions (represented by the CDD). However, only 26% of the variation of the usage frequency could be explained by these factors.

Choice of set-point temperature

Ref. [47], analyzed driving factors for the choice of set-point temperature; a south-oriented window was among the main factors to lower the set-point temperature.

4.2 Summary

In summary, the previously identified driving forces for energy-related behavior with respect to cooling are grouped and listed in Table 4.1.

	biological	**psychological**	**social**	**time**	**physical environment**	**Building / equipment properties**
Percentage of usage	*Health* [40], [46]	*Preference for AC on* [2]	*Household income* [42]	*Season* [38]	*Outdoor temperature* [38], [8]	*South oriented window* [8]
	AC unit used at home during childhood [8]	*Perceived effectiveness of AC* [8]		*Time of day* [38], [50], [8]	*Outdoor humidity* [38], [8]	*Top floor* [8]
	Male [8]	Origin from Middle Eastern country [8]			*Wind speed* [38]	*No. of rooms with AC-unit* [42]
	Origin hot&dry country [8]	*Origin from East-Asian country* [8]			*Wind direction* [38]	*Set point temperature of system* [50]
	Origin moderate climate [8]				*CDD* [42]	
					Indoor outdoor temperature difference	

					[50,50]	
Switching on	*Comfort range [51]*		*Guests coming* [44]		*Temperature* [44]	
Switching off			*Leaving room* [44]			
Set point temp.	*Male* [43]	*Preference for AC on* [43]			*Outdoor temperature* [43]	*South orientation of window* [43]
	Origin moderate climate [43]		*Origin East-Asian country* [43]			*Floor (top, middle, ground)* [43]
Existence of AC-unit			*household income* [42]		*Climate* [42]	
No. of rooms with AC-unit					*Climate* [42]	*Type of AC* [42]
						Floor area [42]

Table 4.1: Driving forces for energy-related behavior with respect to cooling. For the explanation of the colors used we refer to the legend underneath, the symbols used in the legend are explained in Table 2.1.

Importance	***	**	*	’	n.s.	x

5 Ventilation and window operation

Investigations on window opening behavior and natural ventilation have mainly been carried out with two aims: to find whether or not occupants are provided with adequate fresh air and to find the influence on energy consumption. The former category of studies has usually been carried out in dwellings and has a health or a comfort perspective, while the latter category has mostly been studied in offices with a comfort and energy performance perspective. So far, there are only a few investigations regarding residential buildings and the studies that are aiming at implementing realistic behavior patterns in simulation programs have been based on occupant behavior in offices. Moreover, no investigations regarding the mechanical ventilation driving forces in residential buildings have been found in the literature so far. For this reason, only the topic of natural ventilation and window opening behavior in particular, has been dealt with in this chapter.

5.1 Identification of driving forces

The use of windows affects ventilation rates in dwellings and consequently influences the amount of energy required in buildings and the indoor climate. Since the air change rate has a big impact on energy consumption, it is evident that different behavior patterns will result in different energy consumptions.

Ref. [52] conducted 358 air change rate measurements in six properties in London using the decay of coal-gas (containing about 50% of hydrogen) liberated into the air. This reference discussed the effects of flues, air gratings, cracks, and leakages on the air change rate in the houses and finally noted that any reasonable amount of ventilation could be obtained if liberal window openings were provided. They obtained as many as 30 air changes per hour by means of cross-ventilation in experimental rooms. Since then, houses have been tightened and sealed, increasing the relative effect of window opening on the air change rate. In fact, when Ref. [53] measured air change rates in a house in Virginia over a year, they found that the window opening behavior had the largest effect on air change rates, causing increases ranging from a few tenths of an air change per hour to approximately two air changes per hour. Another paper describing the same measurements, Ref. [47], stated that opening a single window increased the air change rate by an amount roughly proportional to the width of the opening, reaching increments as high as 1.3 h^{-1}. Multiple window openings increased the air change rate by amounts ranging from 0.10 to 2.8 h^{-1}.

While Ref. [52] found an average air change rate of 0.8 h^{-1} and with only 11% of the measurements under 0.4 h^{-1} in London, Ref. [54] found that 75% of dwellings without mechanical ventilation had air change rates lower than 0.35 h^{-1}, suggesting that these dwellings had been tightened to such an extent that occupants needed to actively adjust building controls to obtain adequate supply of fresh air. Ref. [55] also found that, depending on the season, between 50% and 90% of the Californian dwellings in the study had air change rates lower than 0.35 h^{-1}.

According to Keiding et al., Ref. [56], who conducted a questionnaire survey in Danish dwellings, 53.1% of the occupants slept with an open window during autumn while 25.2% had a window open during the night in winter, which in most situations should ensure an air change rate of more than 0.35 h^{-1}. They found that 91.5% of the respondents vented by opening one or more windows each day throughout the year. The results showed that a large proportion of Danish occupants use windows to adjust the supply of fresh air to the dwelling. The effects of this behavior on the energy consumption might be substantial. Ref. [57] measured the air change rate and temperature in 16 Danish dwellings and found an average air change rate of 0.68 h^{-1}.

In a study, Ref. [58], it was noted that there was a considerable difference in the total air change between the individual dwellings. As the basic air change was fairly similar in the dwellings, it was concluded that the user influenced air change (i.e. the behavior of the occupants) caused these large differences. This conclusion was confirmed by Ref. [59], who concluded that a substantial variation in ventilation behavior found among seven households, reflected different occupant functions and management strategies.

The authors of Ref. [40] were able to quantify the effect of occupant behavior on air change rate. They investigated the relationship between occupant behavior and the energy consumption used for air conditioning, by means of tracer gas measurements and questionnaire surveys in Japan, and concluded that 87% of the total air change rate was caused by the behavior of the occupants.

One aspect that affects the air change rate is how often and for how long the windows are opened but also the degree of opening will have an impact.

Window opening and closing

The window opening and closing behavior in dwellings is strictly connected to the building characteristics since the effectiveness of natural ventilation is strongly dependent on the characteristics of ventilation openings and their controllability (aspects which are closely related to the type and size of the windows and its placement within the facade). The type of dwelling (single house or apartment), orientation, and type of the room (bedroom, living room or kitchen) are the main parameters found to have an influence on occupant behavior related to window opening and closing.

5.1.1 Biological

The interaction between the occupant's gender and perceived illumination had a statistical impact on the window opening behavior, Ref. [63].

The investigation in Ref. [13] on households in the Netherlands that took place in autumn 2008 showed that the behavior of elderly people significantly differed from that of younger people, and the results fit with the Annex 8 results, Ref. [65]. A chi-squared test showed that presence was associated with fewer hours per day of open windows in living rooms and bedrooms, while the presence of children at home was associated with keeping windows closed in the living room.

5.1.2 Psychological

Ref. [65] highlighted that indoor climate preferences in terms of temperature are one key driver of the behavior of the occupants, but this driver is strongly connected to the occupant's perception of comfort.

5.1.3 Social

The Annex 8 project, Ref. [65], highlighted a clear correlation between smoking behavior and the airing and ventilation of living rooms: in smoking households, the living room is ventilated twice as long on average than non-smoking households. Moreover, the longer the dwelling is occupied the longer the windows were kept open, especially the bedroom windows, and in this way the Annex 8 project concluded that the presence of occupants in a dwelling and the use of windows were related.

5.1.4 Time

Investigations have shown different daily patterns for the different types of rooms, see Figure 5.1. Typically, the maximum number of open windows occurs during the morning, but during early afternoon (when cooking) the number of open windows is still relatively high but gradually decreases during the afternoon until the return of working inhabitants to the home (at about 5 p.m.). The time of day was found to determine window transition probabilities (closed to open and open to closed) in the aforementioned study in Ref. [66].

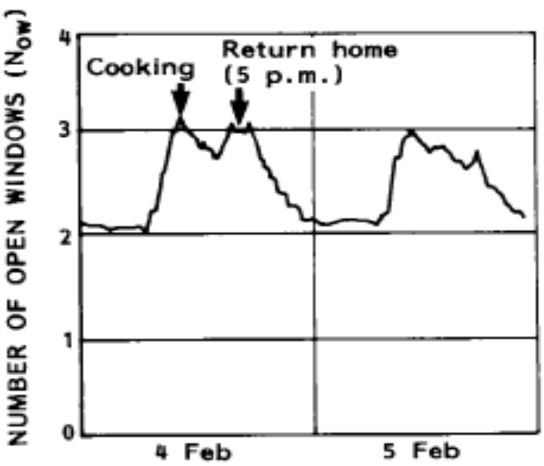

Figure 1.4: Average winter days (Schiedam project) (Total of 1280 windows and doors)

Figure 5.1: Daily profile of window opening, Ref. [65].

Season has been found to be correlated with window opening behavior in Ref. [67], i.e. windows are open longest in summer and shortest in winter. While in August the overall opening period for all windows amounts to about 25% on average, it decreases to about 5% in winter. This finding is supported by a successive study conducted in office buildings in 2008, Ref. [60], where the percentages of open windows are highest in summer, lowest in winter, and intermediate in autumn and spring.

5.1.5 Physical environment

Window opening behavior is strongly related to the perception of comfort and the microclimate in dwellings. Due to this correlation, the most important environmental parameters have been investigated in many studies.

Not surprisingly, the outdoor temperature had a considerable impact on window opening behavior. An earlier study, Ref. [61], found that the outdoor temperature was the single most important explanatory variable when investigating the number of open windows in 15 dwellings. The investigation in the Annex 8 project, Ref. [65], has shown that in the temperature range between -10˚C to 25˚C, a direct linear correlation exists between window use and outdoor temperature, see Figure 5.2.

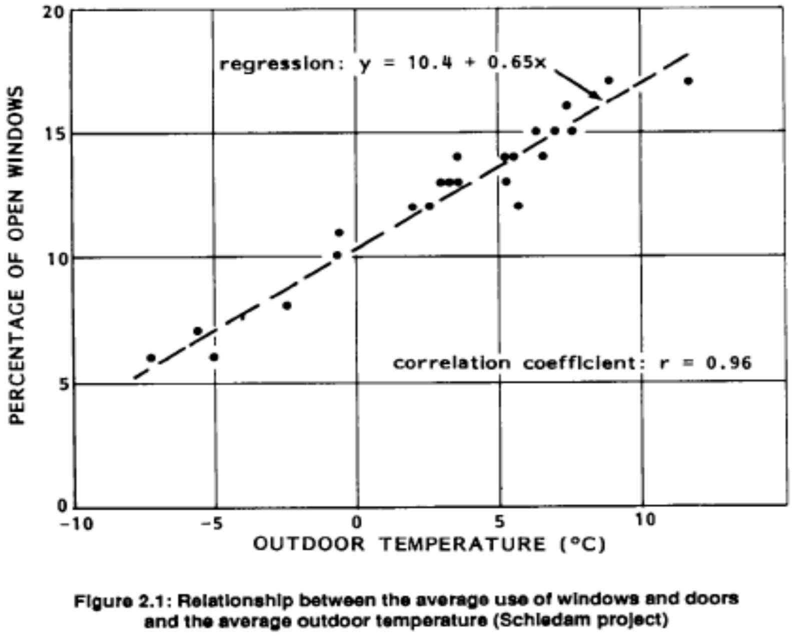

Figure 5.2: Relationship between the average use of windows and doors and the average outdoor temperature, Ref. [65].

Ref. [62] found that temperature (mean monthly temperature and average temperature swing) is an important explanatory factor for window opening. Ref. [67] found a change in ventilation behavior around 12˚C: generally, below 12˚C, daytime ventilation increases by approximately 75% per degree temperature difference, above 12˚C, ventilation increases by about 1.1% per degree. In terms of ventilating frequency, this represents an increase of about 50%. The results of Ref. [63] are consistent with the findings in Ref. [67]. The statistical analysis related to the questionnaire survey carried out in 2006 and 2007 in Danish dwellings has shown that window opening behavior is strongly linked to outdoor temperature. Recently, the results of the logistic regression model based on long-term monitoring of behavior and environmental variables in 15 dwellings confirm that outdoor temperature, indoor temperature, solar radiation, and indoor CO_2 concentration were the most influential variables to determining window opening/closing probability.

The Annex 8 project, Ref. [65], showed that windows are open more often and for longer periods during sunny weather, the findings of Ref. [64] fit with these earlier studies. In Ref. [67], a distinct dependence on solar radiation could not be confirmed, as the influences of outdoor air temperature and global irradiance are superimposed.

The influence of wind speed was investigated in all the aforementioned studies, and the results are coherent in finding a significant decrease in the prevalence of open windows at high wind speeds: above a wind speed of about 8 m/s, nearly all windows were closed.

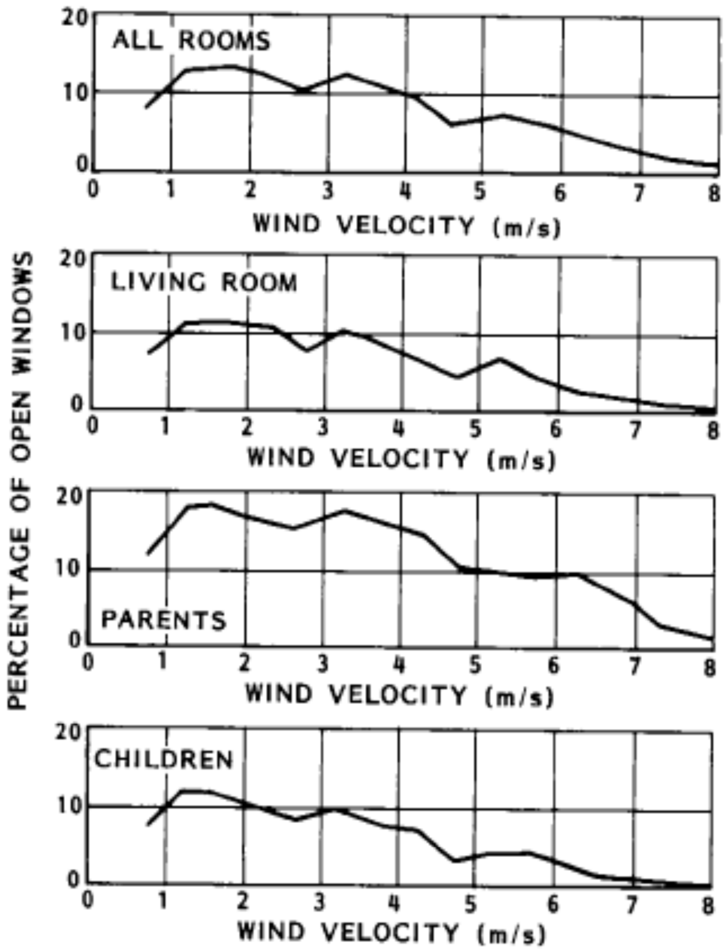

Figure 5.3: Percentage of open windows as a function of wind speed, Ref. [65].

Based on an average wind velocity of 3 m/s, Ref. [67] proposed to introduce the wind influence as a correction term for temperature-related window ventilation periods with the following equation:

$$t_{\text{open (w)}} = \frac{10 - W}{7} \times t_{\text{open (3 m/s)}} \quad (\%) \tag{1}$$

5.1.6 Building/equipment properties

As early as 1988, the study of Annex 8 on occupant behavior with respect to Ref. [65] focused on a combination of questionnaires and observations to determine which action is taken by occupants to ventilate their homes and to evaluate the reasons for their actions. The study has shown that the type of dwelling (house or apartment) influences the length of time windows are open and also has an effect on the degree of window opening. In the same investigation, it appeared that windows in living rooms and kitchens were open on average for shorter periods, whereas windows in bedrooms were open for longer periods in houses compared to apartments. The type of the dwelling (detached one-story residence) was found to affect the degree of window opening in residences in the pilot study conducted by the authors of Ref. [66] in North Carolina between October 2001 and March 2003.

Table 5.1 shows the room type ranked according to window use for each of the investigated dwellings. These results could be summarized as follows: according to the study of Annex 8, Ref. [65], the main ventilation zones are bedrooms, while the greatest percentages of windows which are never opened are in living rooms, kitchens, and bathrooms.

This finding is consistent with a study for 24 identical flats in Germany, Ref. [67]. Even in the extreme winter weather, bedrooms are ventilated more frequently than all rooms on average: during the entire measuring period the window opening time in bedrooms exceeded the average for all rooms by approximately 50%. The room orientation is also important. The Annex 8 project, Ref. [65], found that when the sun was shining, south facing living rooms and bedrooms were more likely to be ventilated for longer periods than similar rooms orientated in other directions.

Project / Rank Order	La Chaumière (CH)	Empa/ Bus (CH)	Worms (D)	Namur (n=40) (B)	Namur (n=3000) (B)	B.B.R.I. (B)	Schiedam (NL)	Surrey (UK)
1	Parents bed. + 2nd bed. (0.26)	Parents bed. (0.66)	Parents bed. (0.58)	Parents bed. (0.193)	Parents bed. (0.109)	Mean bedroom (.13)	Parents bed. (1.3)	Mean bedroom (.27)
2	Kitchen (0.04)	2nd bedroom (0.53)	Small bedroom (0.42)	2nd bedroom (0.106)	2nd bedroom (0.074)	Kitchen (.05)	2nd bedroom (0.63)	Kitchen (.03)
3	Living (0.02)	Living (0.37)	2nd bed. (0.35)	Kitchen (0.43)	Kitchen (0.46)	Living (.02)	Small bed. (0.51)	Living (.02)
4	—	Kitchen (0.1)	Living (0.13)	Bathroom (0.039)	Bathroom (0.038)		Kitchen (0.38)	
5	—		Kitchen (0.10)	Living (0.035)	Living (0.028)		Living (0.29)	

N.B. Values in brackets are the number of open windows per dwelling (N_)

Table 1.4: Rank order of window use per type of room

Table 5.1: Rank order of window use per type of room, Ref. [65].

The investigations have shown different daily patterns for different room types. Typically, the maximum number of open windows takes place during the morning, but during early afternoon (when cooking) the number of open windows is still relatively high but gradually decreases during the afternoon until the working inhabitants return home at about 5 p.m. The time of the day is found to determine the window transition probabilities (closed to open and open to closed) in the aforementioned study in Ref. [66].

Degree of opening

In the various projects conducted for the Annex 8 project, Ref. [65], three levels of window opening were examined (closed, slightly open, and wide open). Large variations among the degree of window opening were found. The Dutch research findings showed a tendency towards a larger percentage of wide open windows, while the Belgian research findings based on interviews with the occupants in 2400 social houses, showed a trend towards slightly open windows.

Weather also influences the degree of window opening. The studies conducted for the Annex 8 project showed that when the outside temperature was 5˚C and -8˚C, fanlights were left open for more than eight hours in 17% and 8% of living rooms respectively. Moreover, an outside temperature change from 15˚C to -5˚C produced changes in the percentage of open or slightly open windows from 41% to 34% in the mornings and from 32% to 24% in the afternoons. For the main bedrooms, these figures are 70% to 64% and 55% to 44% respectively.

Ventilation type

The study in Ref. [67], compared the duration of window ventilation with naturally ventilated flats. Ref. [62] concluded that windows in flats without mechanical ventilation systems are open about four times longer than in flats with mechanical ventilation. Actually, this result is inconsistent with the Annex 8 project, Ref. [65], where only small differences are found between dwellings without mechanical ventilation and dwellings with various types of ventilation systems. However, the interviews showed that the occupants had no understanding of how to use their mechanical ventilation systems.

The IEA Contributed Report 08, Ref. [68], examined the influence of specific ventilation systems on the active ventilation behavior. From the report it is concluded that ventilation by behavior is only partly related to the type of ventilation device installed in the dwellings; the mechanical ventilation system in living rooms tends to influence the ventilation by behavior; in bedrooms, behavior tends to be independent of the installed system.

Moreover, the Annex 8 project, Ref. [65], found that windows in centrally heated dwellings were less likely to be opened for long periods than those in non-centrally heated dwellings, and that dwellings with warm-air central heating were ventilated less than dwellings with radiator systems.

Clothing

Ref. [69] carried out a field study in a 17 story office building. The author found that the anticipated outdoor environmental conditions influenced the choice of clothing worn on a specific day more than the anticipated indoor office temperature. These two studies suggest that the outdoor temperature has a very high impact on the choice of clothing. This was further investigated by the authors of Ref. [70] who analyzed the relationship between clothing behavior and the indoor and outdoor temperatures based on field investigations in 28 cities all over the world. They found that the outdoor temperature at 6 o'clock in the morning influenced the clothing insulation the most. The influence of outdoor temperature was larger in naturally ventilated buildings than in mechanically ventilated buildings.

Since thermal comfort is thought to be one of the main determinants of temperature set-point and may have a significant impact on window opening behavior, clothing behavior will also influence these parameters. Consequently, the occupants' clothing choice will affect the energy performance of a building. However, clothing behavior is an occupant's adaptation means to the indoor environment and as such does not affect energy consumption directly.

5.2 Summary

In summary, the previously identified driving forces for energy-related behavior with respect to ventilation/window operation are grouped and listed in Table 5.2. Unfortunately, studies regarding driving forces related to mechanical ventilation usage in residential buildings were not found in the literature. For this reason, only window opening behavior has been dealt with in this chapter on ventilation.

Table 5.2: Driving forces for energy-related behavior with respect to ventilation/window operation. For the explanation of the colors used we refer to the legend underneath, the symbols used in the legend are explained in Table 2.1.

	biological	**psychological**	**social**	**time**	**physical environment**	**building/equipment properties**
Windows opening and closing	Age [13,65]	Perceived illumination [63]	Smoking behavior [65]	Season [67]	Outdoor temperature [61, 62, 63, 65, 67]	Dwelling type [65,66]
	Gender [63]	Preference in terms of temperature [65]	Presence at home [65]	Time of day [65,66]	Indoor temperature [61]	Room type [65,67]
					Solar radiation [64,65]	Room orientation [65]
					Wind speed [65,67]	Ventilation type [62, 65, 67, 68]
					CO_2 concentrations [63]	Heating system [65]
Degree of opening					Outdoor temperature [65]	

Importance	***	**	*	'	n.s.	x

6 Domestic hot water

Occupant behavior can significantly influence the use of hot water in residential buildings. Showering frequency, duration and intensity of showering, bathing frequency, sink use frequency, washing machine and dishwasher use frequency and running temperatures, and appliances' water use efficiency are examples of domestic hot water energy-related occupant behavior. Domestic hot water use patterns vary on different time scales: time of day, time of the week, month, and year. In the literature, several detailed modeling approaches for domestic hot water use can be found, see e.g. Refs. [71], [72], [73], and [74]. Domestic hot water modeling approaches will be discussed in more detail in the separate report on modeling.

A typical example of the (measured and modeled) variation of domestic water use during the time of day is displayed in Figure 6.1.

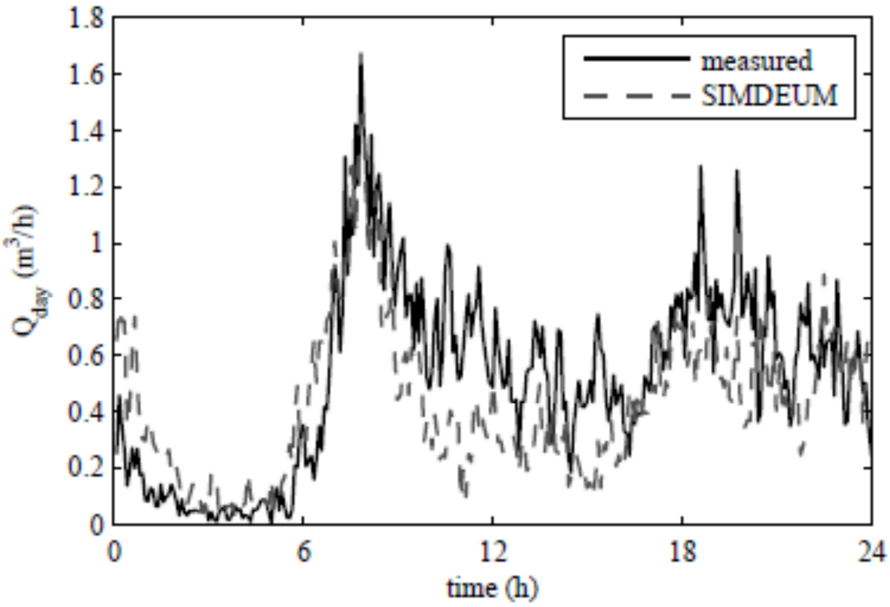

Figure 6.1: Residential water flow rate during the course of a day showing modeled and measured values based on 43 dwellings, Ref. [73].

6.1 Identification of driving forces

A study of domestic hot water use has been reported in Ref. [75] based on data from seven dwellings in the United States. The findings of this study show that bathing accounts for the largest use, while the kitchen accounts for the second largest use. The variation in energy use per person is primarily attributed to behavioral differences among the occupants. In this study, the variation in individual water use behavior is greater than the variation in the total domestic hot water use in all houses.

The authors of Ref. [76] reported the largest daily hot water use was for bathing and showering (43%) and the second largest use was by washing machines (30%). This study is based on American data. Various household characteristics have been analyzed in this study, such as *age*, *education*, *number of children*, *satisfaction with hot water temperature, and hot water conservation index*. In this study, *education* was found to be the only significant variable explaining hot water use. The higher the education level, the more hot water was used. Since education is usually correlated with *income*, it is likely that these households owned more water-using appliances. A positive correlation between *income* and domestic hot water use was also found in [77]. However, in Ref. [78] it was found that people having a higher education, higher income, and a higher status job were more likely to apply water saving strategies.

The model in Ref. [77] suggests that renter-occupied dwellings consume less domestic hot water than owner-occupied dwellings. However, research in Ref. [79] suggests that homeowners are more likely to save energy than renters.

Residential water use monitoring by water companies often provides interesting statistics of water use behavior. For example, research by the Dutch association of drinking water companies, Ref. [80], showed that showering accounts for the greatest water use. The increase in water use observed in the last few years in the Netherlands is primarily due to changing showering habits: shower *duration* is increasing and the showers with higher water *intensities* are increasingly used. Water use for showering depends on the occupant's *gender*: shower frequency and duration are higher for women than for men. The lower the occupant's *education level* and *job status*, the more water is used for showering.

Average per-capita domestic hot water use may be quite different for different countries, Ref. [81].

Important aspects of energy-related behavior for domestic hot water use are the *duration* and *intensity* (water flow rate) of a shower and the *frequencies* of showering and bathing. These will be discussed below.

6.1.1 Biological

A Dutch study, Ref. [82], showed that shower duration is strongly related to *age*, see Figure 6.2. The shower duration is relatively long for people around 20 years old and for people older than 65 years.

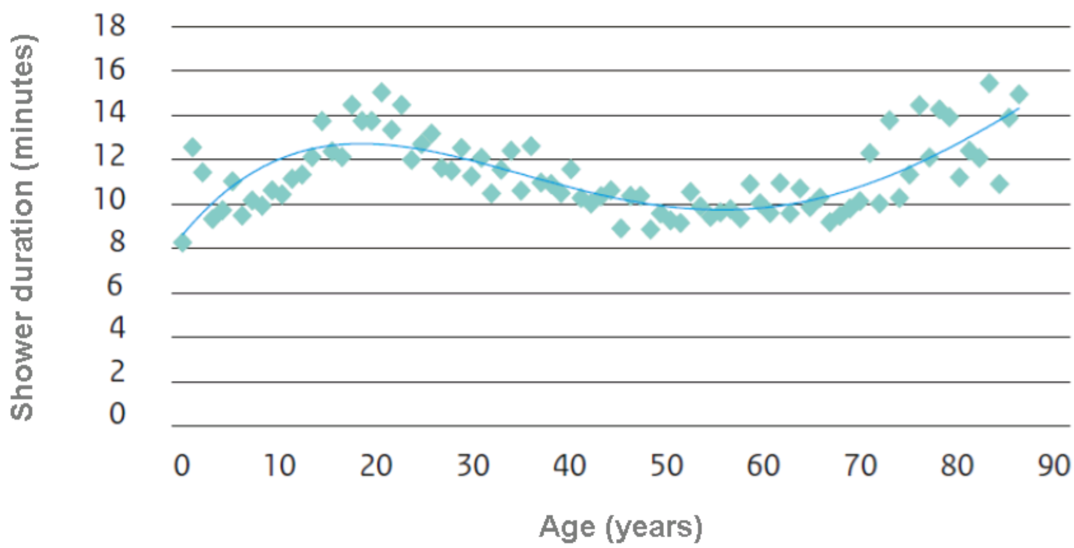

Figure 6.2: Shower duration in minutes as a function of the age of occupants in years in the Netherlands. See Ref. [82].

Shower frequency is also strongly related to *age*, as can be found in the report of a Dutch study, Ref. [82]. The reported shower frequencies are shown in Figure 6.3. The shower frequency is highest for ages between 20 and 45 years; the corresponding average shower frequency is six to seven times per week. Lower frequencies are found for younger and older people.

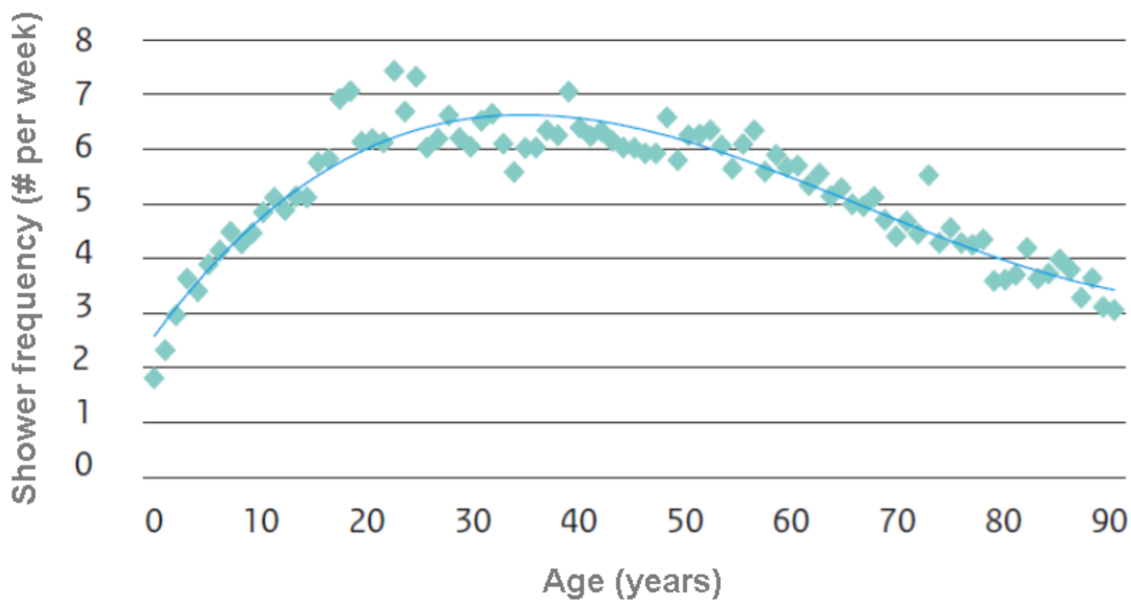

Figure 6.3: Shower frequency per week as a function of the age of occupants in years in the Netherlands. See Ref. [82].

6.1.2 Psychological

A negative correlation was found between shower duration and *income* in the study of Ref. [82]. A possible explanation is that people with a high income may have less time for taking a shower.

The frequency of using a bath depends upon *income*, see Ref. [82]. Households that frequently use their bath are mainly families with children and a relatively high income. Ref. [77] also finds a positive correlation between *income* and domestic hot water use.

People with a higher education, higher income, and a higher status job are more likely to conserve water according to Ref. [78]. The lower the *education level* and *job status*, the more water is used for showering according to Ref. [80].

6.1.3 Social

The frequency of using the bath also depends on *household composition* and *household size*, Ref. [82]. Households that frequently use their bath are mainly families with children.

6.1.4 Time

Shower duration is different for weekdays and weekend days, Ref. [81].

6.1.5 Physical environment

The authors of Ref. [83] found seasonal differences in hot water consumption up to a factor of three based on data from 10 families in Japan, which could be related to changes in outdoor weather conditions. In winter, daily consumption was around 30 MJ/day, while in summer hot water consumption was below 10 MJ/day.

6.1.6 Building/equipment properties

Intensity of water use events can be influenced by specific properties of the applied equipment (water saving devices). For example, the use of *low-flow showerheads* can reduce energy use for domestic hot water. However, off-setting behavior such as an increase in shower length after installing a low-flow showerhead may undo the positive effects of water saving technologies, Ref. [84].

6.2 Summary

In summary, the driving forces for energy-related behavior with respect to domestic hot water use are categorized according to Figure 2.2 and listed in Table 6.1.

	biological	**psychological**	**social**	**time**	**physical environment**	**building/equipment properties**
Shower duration	*Age* [82]	*Income* [82]	*household size* [82]	*Weekday or weekend* [81]	Outdoor conditions [*83*]	*low-flow showerhead* [84], [82]
	Gender[1)] [80]	*Origin Turkey, Morocco, Suriname* [80]		time of day[1]		*Boiler* [82]
	health[2]	comfort[2]				
Frequency bath/shower	*Age* [82]	comfort[2]	household composition: [82]			ease of operation[2]
	Gender[1)] [80]	*Origin Turkey, Morocco, Suriname* [80]				
		hygiene[2]				
Intensity shower						*low-flow showerhead* [84]
Other appliances		*Education* [76]	Household size [85]			

1) Duration and frequency is higher for women than for men.

Table 6.1: Driving forces for energy-related behavior with respect to domestic hot water use. For the explanation of the colors used we refer to the legend underneath, the symbols used in the legend are explained in Table 2.1.

Importance	***	**	*	'	n.s.	x

[1] Not based on references, yet.

7 Electric appliances / lighting

The use of electric appliances and lighting in residences is strongly influenced by occupant behavior. In the literature, investigations of energy-related behavior and its driving forces are very rarely separated between appliances and lighting, but information from studies in office buildings can be used to some extent.

7.1 Identification of driving forces

When the energy consumptions for appliances and lighting are considered, large variations are found, partially relating to socioeconomic parameters such as income, persons per household, age, and education, etc. 30-40% of the variation in electricity consumption can be explained by these parameters, see Ref. [86]. Research to find other ways to describe the occupant behavior related to energy consumption is ongoing, although a final and perfect model is way ahead of us at the moment.

Another suggestion for understanding occupants comes from social sciences, where the practices of the occupants are used as indicators for their energy consumption. This model is suggested by Ref. [87]. It is based on practice theory where the routines, ways of thinking and acting of the occupants form the basis for different energy related behaviors varying from high energy consumption families to low energy consumption families who effectively implement energy conserving strategies. In Ref. [88], it is concluded that routines are influenced by norms and ethics learned in childhood, conscious reasoning about economic or ecological aspects, design of new technologies, and changes in social relations. Figure 7.1 shows the electricity use in 1068 residences in a suburb of Copenhagen.

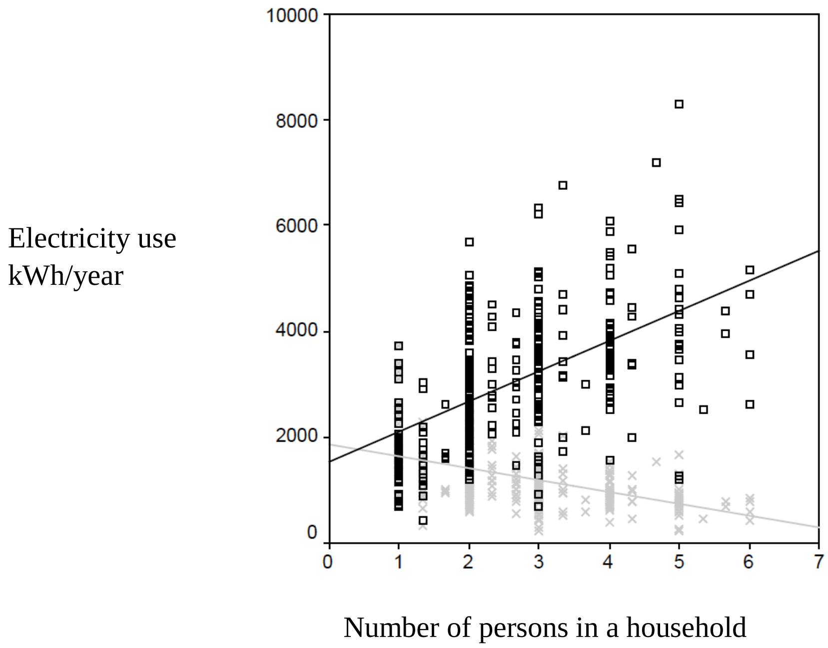

Figure 7.1: Electricity use per year per person in the household (grey); electricity use per year per household (black), Ref [4].

Figure 7.1 illustrates both the large variation in electricity use between households of equal size, and that electricity use per person decreases as household size increases as not all electricity use in a household is dependent on household size.

In the following tables the households are divided into three different categories – low use, average use, and high use households – to find explanations for the differences in electricity use. Generally, energy efficiency of appliances and lighting (Table 7.1 and Table 7.2) could not explain the differences in electricity use; however, the number and use of appliances could (Table 7.3 - Table 7.6).

Table 7.1: Relation between electricity use per household and the energy efficiency of refrigerators/freezers, Ref. [4].

	Low use	Average use	High use	Total
No low energy refrigerator/freezer	38%	26%	37%	100%
Low energy refrigerator/freezer	26%	35%	29%	100%

Table 7.2: Relation between electricity use per household and the energy efficiency of light bulbs, Ref. [4].

	Low use	Average use	High use	Total
Less than 25% high efficiency light bulbs	32%	35%	33%	100%
25-50% high efficiency light bulbs	35%	28%	37%	100%
More than 50% high efficiency light bulbs	36%	23%	41%	100%

Table 7.3: Relation between electricity use per household and the number of refrigerators/freezers, Ref. [4].

	Low use	Average use	High use	Total
1 Refrigerator/freezer unit	41%	31%	28%	100%
2 Refrigerator/freezer units	21%	37%	42%	100%
3 Refrigerator/freezer units	17%	35%	48%	100%

Table 7.4: Relation between electricity use per household and possession of a tumble dryer, Ref. [4].

	Low use	Average use	High use	Total
Do not have tumble dryer	45%	36%	19%	100%
Have tumble dryer	16%	30%	55%	100%

Table 7.5: Relation between electricity use per household and use of the tumble dryer, Ref. [4].

Use of tumble dryer	*Low use*	*Average use*	*High use*	*Total*
1 time per week	28%	33%	38%	100%
2 times per week	13%	39%	48%	100%
3 times per week	14%	28%	58%	100%
4 times per week	8%	28%	64%	100%
5 times or more per week	9%	21%	70%	100%

Table 7.6: Relation between electricity use per household and number of TV/video units, Ref. [4].

	Low use	*Average use*	*High use*	*Total*
1 TV/Video unit	50%	30%	20%	100%
2 TV/Video units	31%	40%	29%	100%
3 TV/Video units	22%	32%	46%	100%
4 TV/Video units	16%	36%	48%	100%
5 or more TV/Video units	7%	13%	80%	100%

To get an idea of how electricity is used per household, an analysis of end use was made in Ref. [86] in 100 different households. The results are displayed in Figure 7.2. The group for "other" consumptions also includes electricity for cooking, which according to Ref. [86] typically amounts to 10% of total electricity consumption.

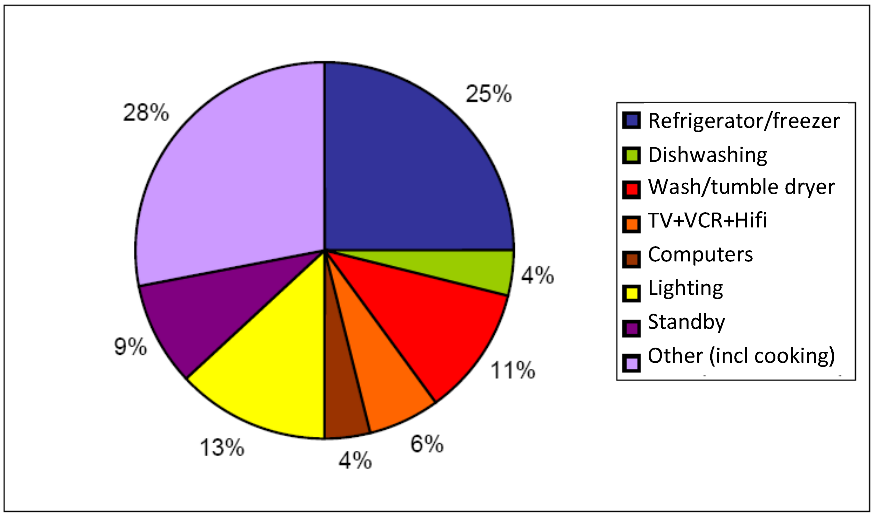

Figure 7.2: Distribution of household electricity consumption based on measurements in 100 dwellings, Ref. [86].

Different electrical appliances uses have different routines and driving forces. Lighting practices (number and type of lamps and operation) are strongly influenced by cultural norms of comfort and interior decoration style, see Ref. [89], and also habits from childhood seem to influence electricity use routines, see Ref. [88]. Interviews in Ref. [88] showed that occupants reflected much more about lighting energy use than on all other aspects of electricity consumption, which was not very rational as it typically accounted for less than 15% of total electricity use. The use of electric lighting in the domestic sector also depends on the level of natural light coming in from outdoors coupled with the activity of the household residents. The number of people who are at home and awake (active occupancy) is the other key factor for domestic lighting use.

Energy use for clothes washing is not questioned and few consider the environmental cost, see Ref. [88]. However, tumble dryer use differs greatly from family to family ranging from non-use to constant use for every wash load, as illustrated in Table 7.4 and Table 7.5.

Routines and energy use for cooking including the use of freezers and microwaves differs greatly from household to household, as does the use of information and communication technologies (ICT) (computers, television, hi-fi, etc.). Investigations have shown that up to 90% of electricity use for ICT is used in standby mode and only a minor percentage is derived from actual use , see Ref. [90].

7.1.1 Biological

A Danish investigation of 100 families showed that gender had no significantly influence on electric energy use, Ref. [86]. However, an age influence was found, reflecting the different stages in life and consequent changes in energy use. It was shown that people above 60 years had relatively larger energy use for refrigerators/freezers and for lighting, while energy use for ICT was at an average level, and the energy use for washing, dishwashing and clothes drying was considerably lower.

Small children below the age of six have slightly lower electricity use than adults, while teenagers used 20-30% more.

7.1.2 Psychological

No documentation on the influence of these driving forces has been found in the literature.

7.1.3 Social

In the following, some of the most important socioeconomic parameters are described.

Persons per household

One of the very important parameters influencing the electricity consumption is the number of persons per household. It is found that electricity consumption increases with the number of people in the household, which is documented by Refs. [91] and [86].

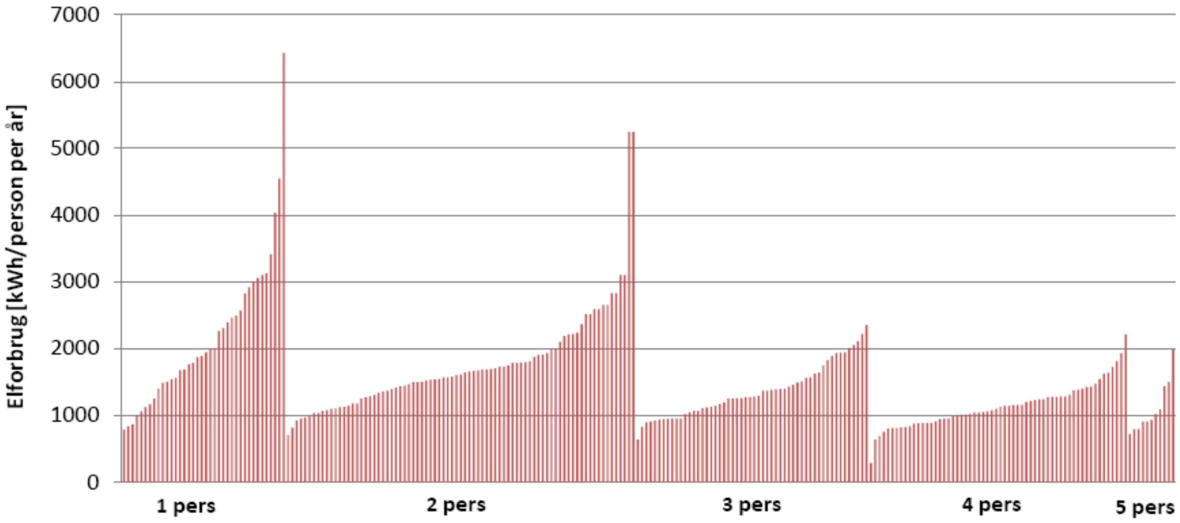

Figure 7.3: Electricity consumption in kWh/person per year as a function of the number of persons per household in a larger area with dwellings in Århus, Denmark, Ref. [91].

As seen in Figure 7.3, there is large consumption variation for different household sizes. Common for the largest and smallest consumption for each household size is a decreasing tendency with a greater number of persons. If the electricity consumption per person is calculated, it is decreasing with the number of persons per household, which is illustrated in Figure 7.4.

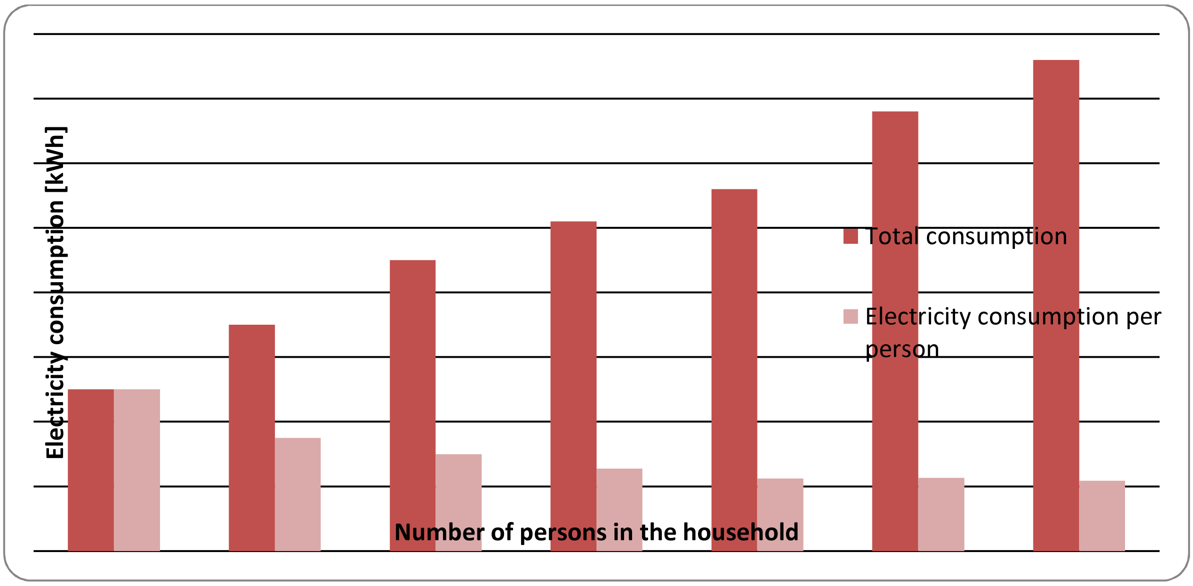

Figure 7.4: Electricity consumption as a function of persons in the household based on Ref. [86].

The decreasing consumption per person can be explained by the basic electricity consumption which is common for all households despite household size. Included is electricity use by the refrigerator, freezer, and partly by cooking, and lighting.

Ref. [92] showed that the energy use for artificial lighting was also strongly dependent on household size, see Table 7.7.

Household size	Number of households	Lighting, kWh	Lighting/person, kWh
1	20	405	405
2	27	586	293
3	7	735	245
4	11	941	235
⩾5	4	1113	223
All	69	636	

Table 7.7: Electricity consumption by lighting; annual average for different household sizes. The data are seasonally and geographically standardized, Ref. [92].

Income and dwelling area

The importance of income and area changes according to Ref. [86] whether one looks at apartments or detached single family houses. Income has a larger impact than area on energy consumption of detached single family houses. The opposite is found for apartments, where the area has the largest influence. The analysis is based on data from more than 50,000 Danish dwellings.

Figure 7.5 and Figure 7.6 show the clear dependency between income and electricity consumption. The income is in Danish Kroner (€1 is approximately 7.5 DKr) and is before taxes (tax approximately 40%).

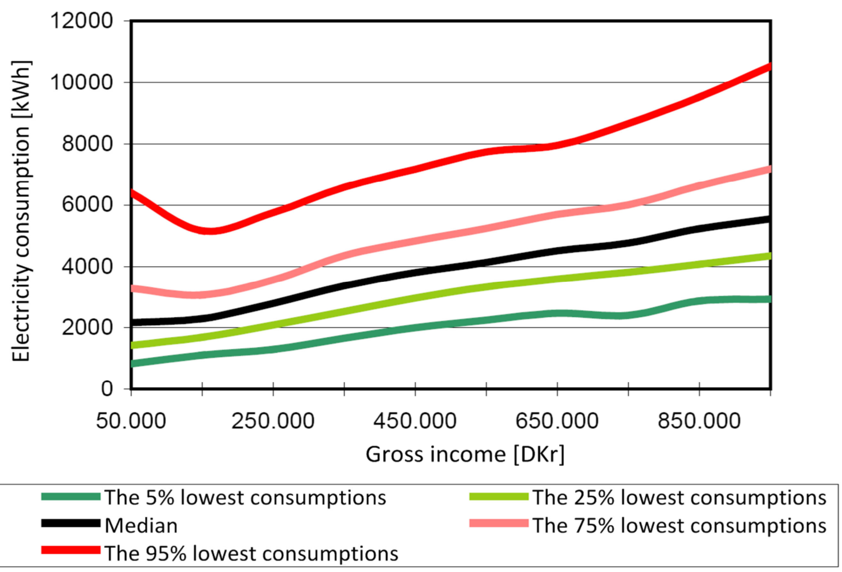

Figure 7.5: Electricity consumption as a function of income for detached single-family houses, Ref. [86].

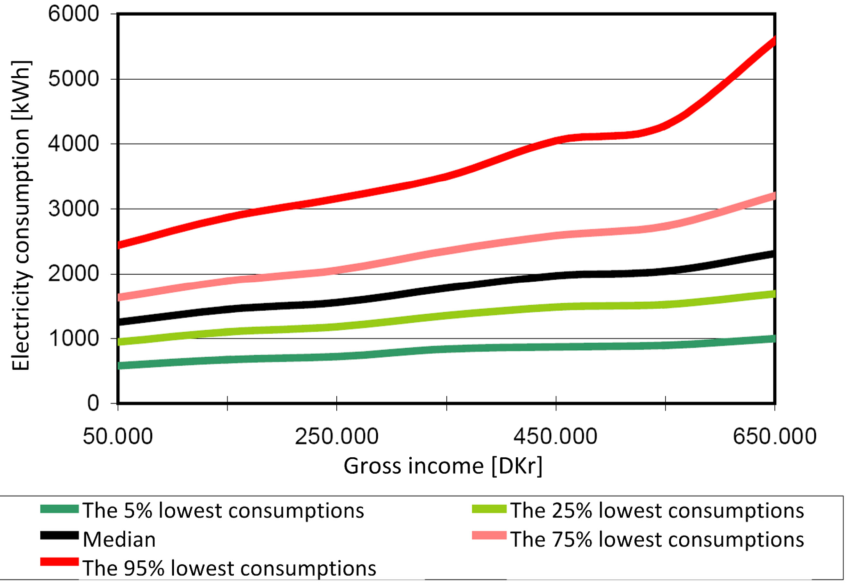

Figure 7.6: Analysis of electricity consumption as a function of income for apartments, Ref. [86].

The same electricity consumption analysis is made as a function of the dwelling area. The results from this analysis are shown in Figure 7.7 and Figure 7.8.

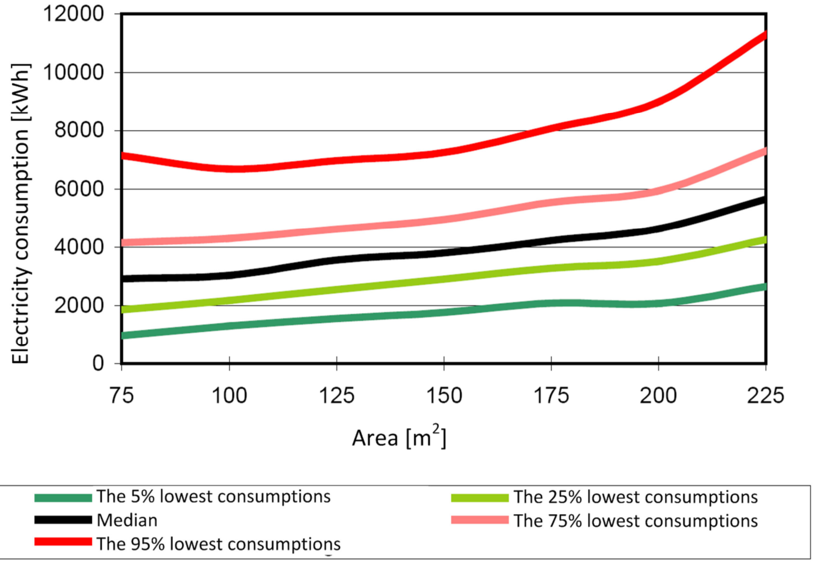

Figure 7.7: Electricity consumption as a function of area for single-family detached houses, Ref. [86].

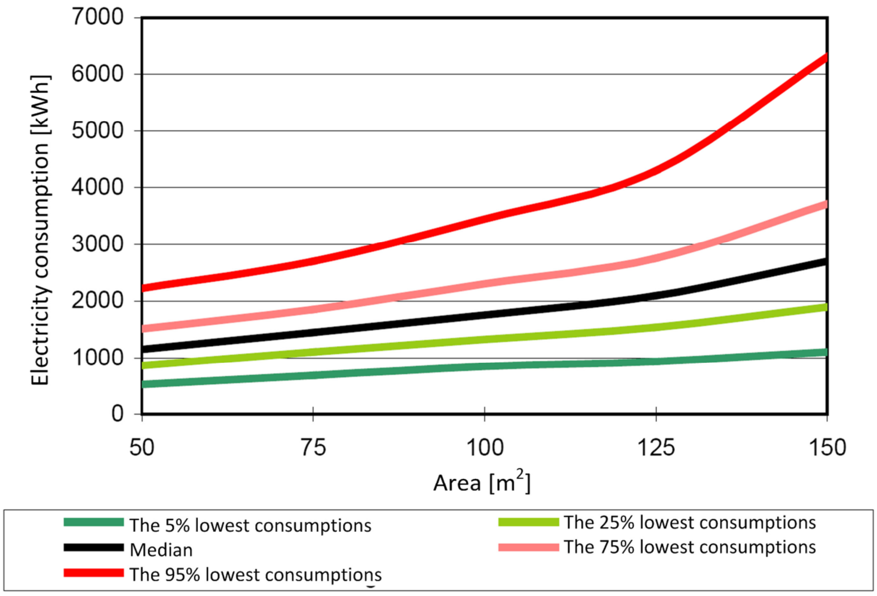

Figure 7.8: Electricity consumption analysis as a function of apartment area, Ref. [86].

7.1.4 Time

In office and school buildings, occupants switch on artificial lighting upon arrival and while present in a room as a function of the natural *illumination*, and rarely switched off artificial lighting until departing a room if the room was completely empty, see Ref [93]. Figure 7.9 shows the probability of switching on artificial lighting as a function of work plane illuminance. Similar results have been found by other authors, see e.g. Ref. [7].

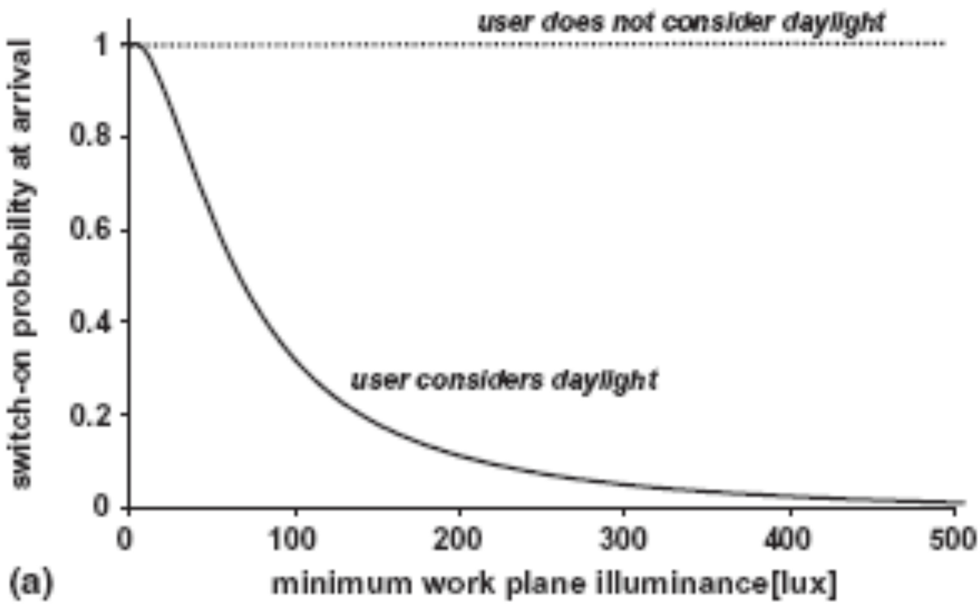

Figure 7.9: Measured switch-on probability function upon arrival in office buildings. Hunt's original function (solid line) describes the average switching behavior of a group of users, see Ref. [93].

Ref. [94] obtained similar results through measurements in five different office buildings. Figure 7.10 shows the probability of switching the lights on upon arrival in two of the offices as a function of the prevailing task illuminance level, while Figure 7.11 shows the probability of switching the lights off as a function of the duration of absence in minutes. Similar results have also been found by Ref. [95].

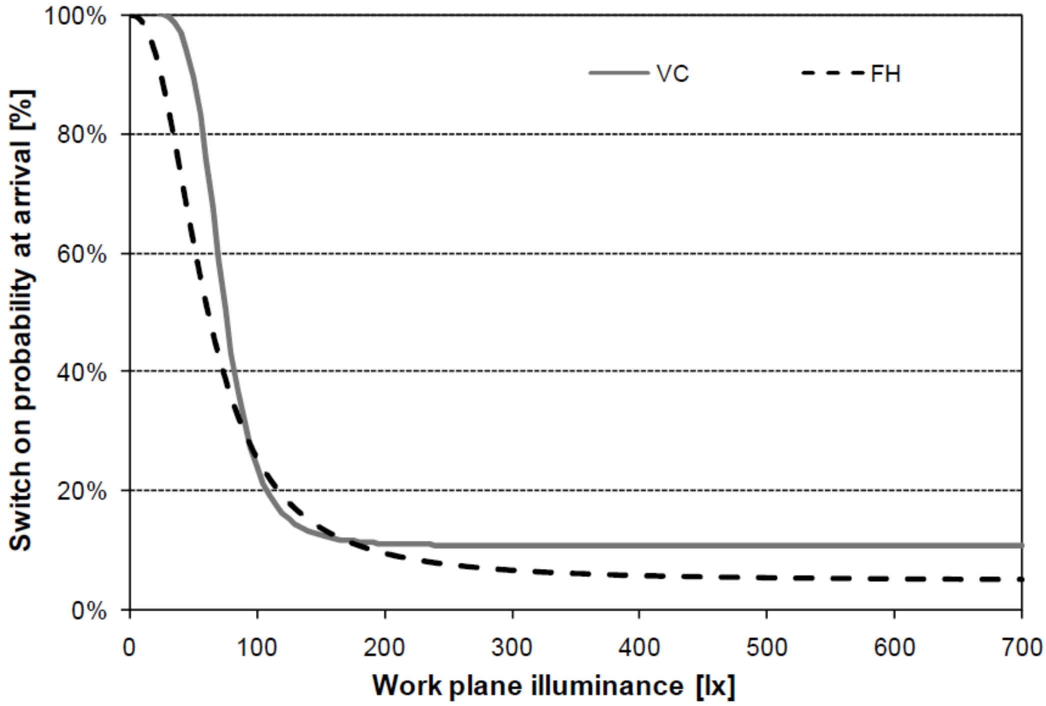

Figure 7.10: Probability of switching the lights on upon arrival in the office in VC and FH as a function of the prevailing task illuminance level, Ref [94].

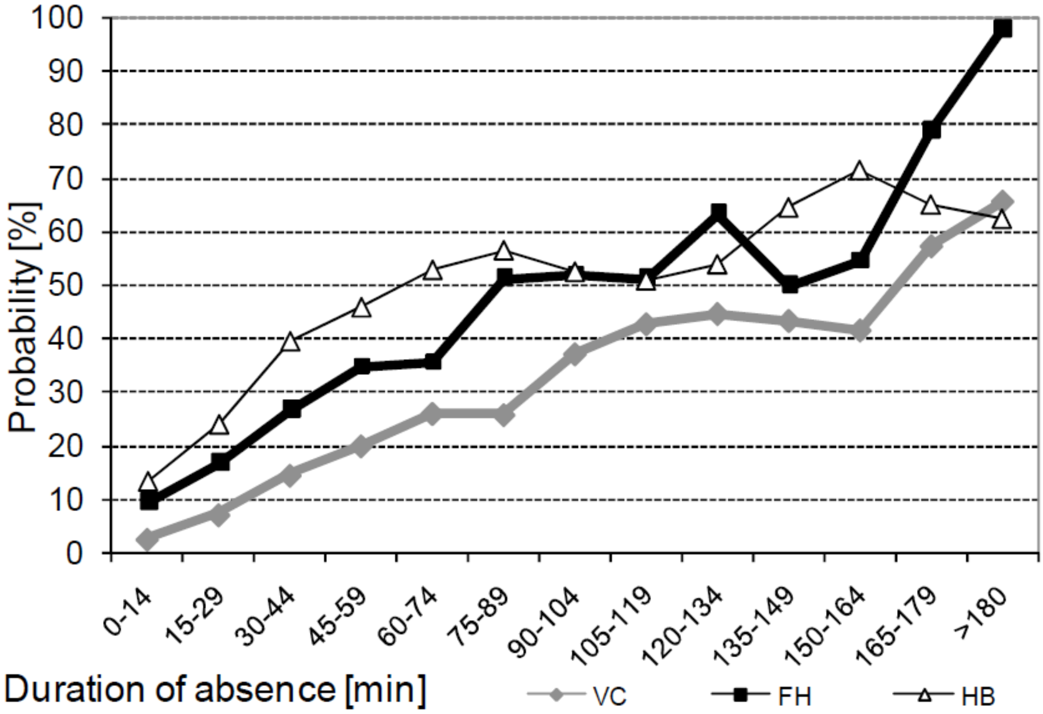

Figure 7.11: Probability of switching the lights off as a function of the duration of absence (in minutes) from the offices in VC, FH, and HB, Ref. [94].

Similar results could be expected to be valid for residences, although the relationships might be quite different. Moreover, the number of people who are at home and awake (active occupancy) is the other key factor for domestic lighting use. This is supported by results obtained from a lighting demand survey taken in 100 UK residences, which shows how the lighting demand during a typical weekday changes with season, Ref. [96].

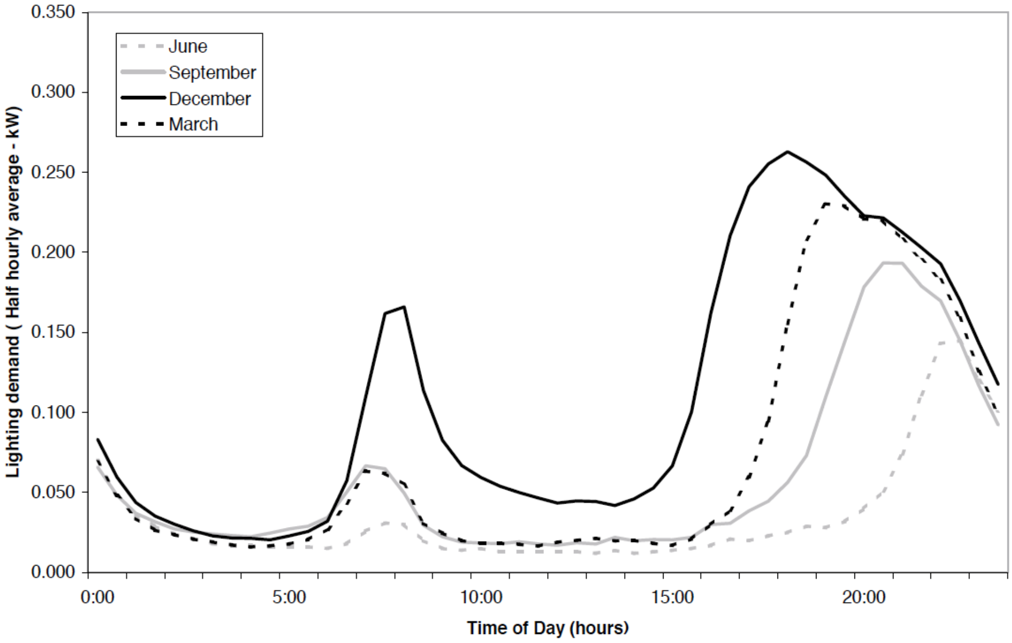

Figure 7.12: Daily lighting profile (monthly averages, weekdays) at different times of the year averaged over 100 homes showing demand in June (dashed grey line), September (solid grey line), December (solid black line) and March (dashed black line), Ref. [96].

7.1.5 Physical Environment

In a residential study, Ref. [63], the operation of lighting is found to correlate strongly with solar radiation, perceived illumination, and outdoor temperature. The age, gender, and thermal sensation of occupants also had an influence on the lighting use probability in residential buildings.

No documentation has been found in the literature on the influence of the physical environment on other electricity uses in residences.

7.1.6 Building/equipment properties

No significant relationship has been found in the literature on the influence of building/equipment properties on electricity use for appliances and lighting. Actually, the opposite was found regarding equipment properties; see Table 7.1 and Table 7.2.

7.2 Summary

In summary the previously identified driving forces for energy-related behavior with respect to electricity/lighting use are grouped and listed in Table 7.8.

d)

	biological	psychological	social	time	physical environment	building/equipment properties
Level of electricity consumption	Age [86]		Income [86]			*Area of the dwelling* [86]
	Gender		Persons per			Efficiency of equipment

	[86]		dwelling [91], [86]			
			Teenagers in the household [86]			Use of high efficient light bulbs
				Extent of the use of appliances		Number of appliances
Number of appliances			Income [86]			

Table 7.8: Driving forces for energy-related behavior with respect to electricity use. For the explanation of the colors used we refer to the legend underneath, the symbols used in the legend are explained in Table 2.1.

Importance	***	**	*	'	n.s.	x

8 Cooking

For cooking purposes, many different appliances can be used such as microwave ovens, ovens, stoves, pressure cookers, kettles, etc. The type of equipment used, their corresponding energy consumption, and the number of meals prepared will determine energy use for cooking.

Cooking activities are usually performed around meal times. Based on time-use data, cooking patterns have been modeled in the literature, see e.g. Ref. [97]. In this investigation, it is shown that the measured and modeled curves for cooking correspond quite well, despite the simple modeling schemes that have been applied.

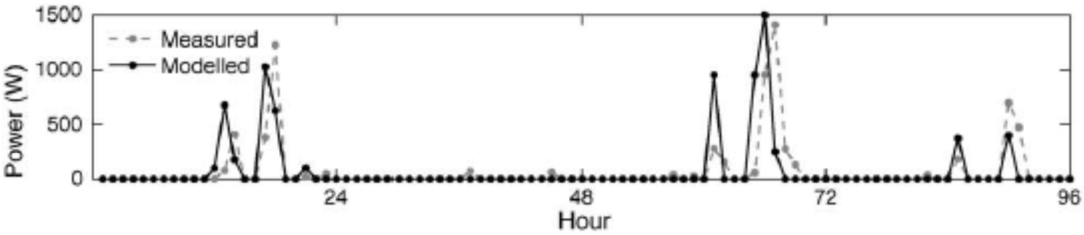

Figure 8.1: Example of modeled and measured cooking demand during four successive days for one household, see Ref. [97].

8.1 Identification of driving forces

Only very limited information on driving forces for occupant behavior related to cooking has been found in the literature.

A recent study on electricity use by European households, Ref. [98], showed the following: Pressure cookers, which are very *energy efficient*, are not widely used in Europe. The use of a lid on the pan while cooking can have a significant impact on the energy used for cooking. The best behavior of always using a lid while cooking varies from 8% in Denmark to 71% in Belgium and Portugal.

The presence of an open kitchen leads to a reduction of energy use compared to the absence of an open kitchen, probably due to the heat gain by cooking and the use of kitchen appliances. An energy reduction of 1.7 GJ per year is possible. See Ref. [13].

9 Interactions between behavior and other issues

Information in the literature on the relationship between different types of energy-related occupant behavior is limited. Some aspects found on the relationship between different types of behavior are discussed in this chapter as well as other issues not mentioned in previous chapters.

Occupant behavior related to heating is not an isolated phenomenon, but rather a combination of driving forces that must be analyzed in relation to each other. Ref. [2] finds that heating behavior is typically influenced by the combination of set-point temperature combined with window opening in Danish homes without mechanical ventilation.

The homes used in the measurement portion of Ref. [2] were mostly naturally ventilated and used thermostatic radiator valves as heating controls. A strong correlation was also found between window opening behavior and indoor temperature set-point during the cold season, making it difficult to ascertain which influences which behavior: indoor set-point temperature or degree of window opening. Homes have become increasingly airtight since post-WW2 construction making it increasingly important for occupants to open windows for sufficient fresh air supply. However, as the indoor temperature is affected by the extent and duration of window operation and vice versa, it is difficult to study these two parameters in isolation from one another.

Similar to the findings in Ref. [2] that occupants have established behavioral patterns that are not coupled with environmental factors, some interviewed occupants in the Viennese low energy cooperative also opened windows due to established morning and evening routines, as opposed to opening windows as a reaction to microclimate conditions. The time of day then becomes a driving factor, see Ref. [19].

In Ref. [99], multivariate regression models have been developed for window opening, fan usage and interactions with the sun shading device based on data from a semi-controlled climate chamber experiment in an office environment. They found that for the window opening behavior, the fan state has a significant influence as well as vice versa (i.e. the window state influences the fan state). The usage of the sun shading device was influenced by the state of the window, but not by that of the fan. The state of the sun shading device did not have a statistically significant influence on the other two interactions.

There are several studies dealing with the use of shading systems in office environments, see e.g. Refs. [100], [101], [102], [103], and [104]. Nevertheless, a literature review on the use of sun shading devices in a residential environment did not reveal a substantial amount of publications regarding the topic of occupant behavior. A variety of literature could be found dealing with simulation, advices, effects on energy consumption, or experimental studies on automatic sun shades.

According to those studies related to the office environment, the devices are not often used. In Ref. [101] it has been found that 60% of blinds are not being used during their investigation. The authors of Ref. [100] observed 1.5 actions a day on average, with remotely controlled systems leading to higher usage (2.1 times a day vs. 0.7 times). When used, venetian blinds were found to be either totally raised or lowered – an intermediate stage was chosen for only 6.5% of time. Once a shading device is lowered, a drastic change of external luminous conditions is needed to raise the system, see Ref. [102]. In Ref. [104] it has been observed that 45% of the changes made by an automated system were rejected by the occupant. The authors of Ref. [100] extracted the influence of the type of control system (manual, remotely controlled, or automated) on usage.

Whether and to what extent these findings are true for the residential environment cannot be concluded. The significant influence of sun shading on the energy demand (e.g. 32% cooling energy savings according to Ref. [105]), suggests that more research dedicated to this type of energy-related occupant behavior should be performed.

10 Summary and conclusions

A better understanding of how energy-related occupant behavior influences residential building energy consumption is required for a realistic prediction of total energy use in buildings. Energy-related occupant behavior is related to building control actions (i.e. in order to control the indoor environmental quality) as well as household or other activities.

These actions and activities may be driven by various driving factors. For a better understanding of total energy use in residential buildings, the relevant driving factors of energy-related occupant behavior must be identified as along with a quantitative approach to describe energy-related occupant behavior.

In this report, a literature review of relevant driving forces of energy-related occupant behavior is given. Quantitative modeling approaches for describing energy-related occupant behavior and energy use are discussed in another separate report.

In general, multiple driving forces may (simultaneously) affect a specific type of energy-related occupant behavior. For example the frequency of taking a shower depends of biological, psychological, and social driving forces such as age, gender, country of origin, and household composition as discussed in the chapter on domestic hot water. This example illustrates the complexity of accurately modeling and predicting the relationship of shower frequency to domestic hot water energy use.

In this report, the energy use of occupants in residential buildings has been classified in the following categories corresponding to the previous chapters: heating, cooling, ventilation and window operation, domestic hot water, electrical appliances and lighting, and cooking. For the residential energy use categories, the relevant types of occupant behavior (i.e. building control actions) have been discussed in the previous chapters.

Furthermore, the various types of driving forces of energy-related occupant behavior in residential buildings that have been found in the literature have been reviewed in this report. The categories for driving forces of energy-related occupant behavior that are distinguished in this report are the following: biological, psychological, and social contexts, time, physical environment, and building/installation properties.

The identified driving forces for the various types of energy-related occupant behavior that have been discussed in this report are summarized in various tables throughout this paper. These summary tables also give a clear overview of the references in the literature in which the specific types of energy-related occupant behavior and their driving forces have been investigated.

The identified driving forces can or are being used in a quantitative understanding and modeling of energy-related occupant behavior and energy use.

In this report, many different driving forces have been identified for various types of energy-related occupant behavior. However, this report has also shown that knowledge on some types of energy-related behavior and their corresponding driving forces is missing. For example, no literature has been found on driving forces of occupant behavior related to mechanical ventilation. In addition, very limited information has been found in the literature on energy use for cooking and the related driving forces.

As mentioned before, the various types of energy-related occupant behavior are not isolated phenomena, but rather a combination that should be investigated in relation to each other. Information in the literature on the relationships between different types of energy-related occupant behavior is however limited; more research is needed for a better understanding of the relationships.

Furthermore, several studies deal with the use of shading devices in office environments; Whereas, a literature review on the use of sun shading devices in residential buildings did not reveal many publications regarding the topic of user behavior. To what extent the findings for office buildings are applicable to residential buildings cannot be said. More research dedicated to this type of energy-related occupant behavior should be performed.

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