

Chapter 2

Occupancy and Occupants' Actions

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Abstract Occupants' presence and actions within the built environment are crucial aspects related to understanding variations in energy use. Within this chapter, first, a nomenclature for the field of research dealing with occupants in buildings is defined. This nomenclature distinguishes between occupants' presence and behavior, states and actions, adaptive triggers, non-adaptive triggers, and contextual factors. Second, an extensive list of occupant behaviors is provided and categorizations of occupants' actions are introduced. The list includes most of the possible phenomena that researchers may wish to study, measure, and ultimately model. The categories are physiological, individual, environmental, and spatial adjustments. Third, a list of adaptive and non-adaptive triggers together with contextual factors that could influence occupant behavior is presented. Individual elements are further grouped into physical environmental, physiological, psychological, and social aspects. Finally, a comprehensive table of studies related to occupant behavior and

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the corresponding significant and non-significant predictors, based on an extensive literature review, is shown. This table highlights areas of research where numerous studies have been conducted, as well as areas where hardly any research has been published. The conclusion highlights the importance of publishing future occupant monitoring campaigns with sufficient detail to inform future researchers and save redundant effort. Such detail is especially necessary in relation to the methodology, including, for example, a clear description of the type of variables monitored, and in relation to the results, where both the influencing factors that were found to be significant and insignificant should be documented.

2.1 Introduction

In most buildings, occupants have numerous options to interact with their built environment. This includes entering/leaving a room, adjusting thermal, visual, or aural indoor conditions (for example, via windows, doors, or blinds), and using other devices, such as electrical equipment. Thereby, an interaction which leads to a state change, and no interaction which leaves the current state unchanged are both aspects of occupants’ behavior (see Fig. 2.1). With the opportunity to interact with the building controls and building envelope, occupants are empowered to operate these systems in ways that may be inconsistent with design intent (Deuble and de Dear 2012; Schakib-Ekbatan et al. 2015). At the same time, the real use of electrical equipment and occupancy patterns may also be very different from the assumptions made in the design phase.

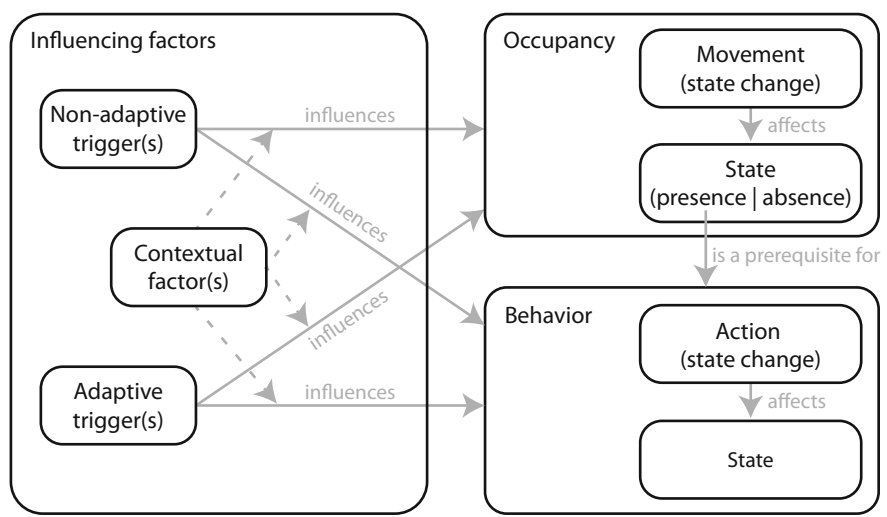


Fig. 2.1 Ontology of occupant-related phenomena

Uncertainties in the prediction of occupancy and occupants' actions increase the difficulty of predicting the performance of a building. Buildings' performance can be sensitive to the behavior and presence of occupants, and these aspects can result in large differences between actual performance and design (Bishop and Frey 1985; Macintosh and Steemers 2005; Majcen et al. 2013; Blight and Coley 2013; Andersen et al. 2016; Carlucci et al. 2016). Not surprisingly, identically-built homes have been found to vary in energy consumption by a factor of two or more as a result of occupants' behavior and occupancy patterns alone (Socolow 1978; Emery and Kippenhan 2006; Yun and Steemers 2008; Guerra Santin et al. 2009; Maier et al. 2009; Andersen 2012). The behavior of occupants may influence the variation in the actual energy use to a much larger degree than the thermal processes within the façade (Hoes et al. 2009) or the insulation measures (Schweiker and Shukuya 2010b). The influence may be asserted in many ways—for example, by opening/closing windows, adjusting thermostats, operating solar shading, light switching, etc. As insulation levels and airtightness of buildings increase as a consequence of stricter building regulations, occupants' control over window openings, thermostats, solar shading, etc. will have larger relative effects on the air change rate and temperature distribution in the buildings (Guerra Santin et al. 2009). For instance, occupant control of operable windows and window shading devices will significantly impact energy flows across façades (Hoes et al. 2009). Consequently, designers' inclusion of occupants' interactions with building controls and envelopes becomes increasingly important (Andersen 2012) and could lead to arguments for reducing opportunities for occupants to interact with their built environment.

On the other hand, occupants who have the possibility of controlling their own environment have been found, at least in office buildings, to be more content with the indoor environment and suffer fewer symptoms of sick building syndrome (SBS) than occupants who do not have the possibility of interacting with building controls and envelope devices (Toftum 2010). The same finding will likely be observed for other building types once investigated. Therefore, it is important to note that occupants should not be restricted in their behavior or forced to change their behavioral patterns, and that designers need to take more care to design buildings according to occupants' needs and likely to occupancy and behavioral patterns. However, leaving the control of a building and façade in the hands of its occupants demands that occupants' behavioral patterns be realistically represented in predictions of building performance.

In general, occupants can impact buildings in two ways: through the direct impact of their presence (heat production, carbon dioxide emission, moisture generation, etc.) and through their interactions with the building. In most circumstances, the presence of occupants is the prerequisite for any behavior, since occupants can only interact with the controls and the building envelope if they are present in the building. Occupants' presence and behavior can be modelled as states (e.g., state of light switch) and actions (e.g., the act of turning on or off a light switch) using different modeling approaches. In general, the action changes the state and the state remains constant until a new action is taken (e.g., the state of the

window will remain closed until an occupant opens it). Note that the state may refer to two or more levels (e.g., a window can have several states such as open/closed or fully open/half open, X% open/closed), depending on the modeling approach.

As described in detail in Sect. 2.3, state changes can be triggered by either adaptive triggers (those which are rooted in occupant discomfort or expectations of discomfort) or non-adaptive triggers (those which are part of occupant tasks, like using a computer). These triggers, as well as the resulting action or non-action, are moderated by contextual factors. The adaptive triggers activate adaptive behaviors, such as opening windows due to increasing carbon dioxide (CO₂) concentration (indication of deteriorating indoor air quality) or closing blinds due to glare. Non-adaptive triggers activate behavior that is not performed with the goal of adapting to the indoor environment—for example, events based on schedules. Note that the same type of action, e.g., closing the window, could be triggered by an adaptive trigger (undesirable cold air entering the room) or a non-adaptive trigger (leaving the room and securing the building beforehand).

In the context of this book, the authors are interested in all occupant-related phenomena that impact building energy performance, comfort, and occupant satisfaction. These phenomena are presented in Fig. 2.1 and defined in the next section. The purpose of this chapter is to introduce readers—whether fundamental occupant behavior or comfort researchers, occupant modelers, or even model users—to the diverse occupancy and occupant behavior-related phenomena that should be considered prior to conducting experimental, modeling, or simulation-based research studies. First, a definition for the nomenclature used in the field of research dealing with occupants in buildings is presented. Second, an extensive list of occupant behaviors is provided and categorizations of occupants' actions are introduced. The list includes most of the possible phenomena that researchers may wish to study, measure, and ultimately model. Then, a list of triggers and contextual factors that could influence occupant behavior is provided. Finally, a comprehensive table of studies related to occupant behavior and the corresponding significant and non-significant predictors, based on a comprehensive literature review, is presented.

2.2 Categorization of Occupants' Actions

Energy-related occupant behavior was previously defined as “human being’s unconscious and conscious actions to control the physical parameters of the surrounding built environment based on the comparison of the perceived environment to the sum of past experiences” (Schweiker 2010). As pointed out by Fabi et al. (2012), this definition is limited to actions related to the perceived environment, or as defined above to those actions caused by adaptive triggers. The aim of this section is to categorize all sorts of occupants' actions according to the distance between the occupant and the location the action takes place into physiological, individual, environmental, and spatial adjustments (Table 2.1).

Physiological adjustments are done unconsciously and cannot be actively influenced by thought alone. One group of physiological adjustments can be traced back to the human body's thermoregulation process. Thermoregulation processes occur within the human body in order to keep the core temperature within defined and narrow limits. The basic control of the thermoregulation system is done by the hypothalamus, which adjusts the body functions by discharging hormones into the bloodstream and activating the nervous system (e.g., for shivering). Human beings can develop a long-term adaptation to extreme environmental conditions. For example, people who grew up in a hot and humid climate show a higher number of sweat glands than people who grew up in a cold climate (Hori 1995). Thanks to a higher number of sweat glands, they sweat more effectively and can hence maintain their core temperature at a comfortable level in hot and humid conditions more easily compared to those with fewer sweat glands. It has been found that physiological adaptations do not only occur over a long time, but also over shorter periods, starting generally after four to five days of exposure to warm or cold conditions (Hori 1995; van der Lans et al. 2013). People who are exposed to severe climates adapt to the conditions prevailing in their environment and are thus able to accept a wider range of temperatures. As a consequence, people with more sweat glands may have a higher indoor temperature as triggering condition for opening a window or turning on a fan.

Physiological adaptations can also extend to visual aspects. For example, the human is able to adapt to a wide range of visual scenarios ranging from 1 lx at night with the moonlight to 100,000 lx during the daytime with sunlight. Physiological reactions to changes of visual conditions include optical (pupil dilation), neurological, and photochemical adaptations in order to regulate the amount of light passing through (Murdoch 2003; American Optometric Association 2016). With increasing age, the functionality of the eye is reduced (Lerman 1980; IJspeert et al. 1990; Winn et al. 1994; Van De Kraats and Van Norren 2007), so that visual requirements change (Moosmann 2014). This will also affect corresponding interactions with the building.

Individual adjustments include, for example, the change of body posture and the amount of clothes worn. Takahashi et al. (2000) found differences in individual adjustments pursued by subjects sitting in a natural ventilated room compared to those sitting in an air-conditioned room: those in the natural ventilated room were more active with respect to actions, such as “waving hands like a fan” or “making space under clothes with hands”.

The definition for environmental adjustments used here is broad. Environmental adjustments include all actions related to elements of the room. These can be those elements—also referred to as “controls”—which potentially lead to a change in the physical conditions of the indoor environment, such as windows, heating and cooling devices, and elements such as electronic devices, which may have a minor effect on internal gains, but are primarily not used to control indoor environmental conditions.

Spatial adjustments consist of those actions related to the active movement within the room or building, or between the building and outside. It can be assumed

that these actions are mainly driven by non-adaptive triggers, such as meetings in another room or the end of the workday. They could also include such adaptive actions as relocating away from daylight glare in a library. Related to adaptive triggers, a study found that the choice between sitting outside or inside a bar in Kassel, Germany, is very much dependent on the thermal outdoor conditions. Additionally, the expectation of weather and the activity planned have an influence on this decision (Katzschner et al. 2006).

Table 2.1 Categories of occupant actions (Schweiker 2010; Polinder et al. 2013)

Physiological adjustments	Individual adjustments	Environmental adjustments	Spatial adjustments
Sweating	Adjustment of clothing/bedding level	Use of heating, ventilation, and air-conditioning systems	Movement from one room to another
Relaxation of arrector pili muscles	Selection of clothing/bedding material	Thermostat adjustment	Change of position or orientation in a room
Arteriolar vasodilation (dilation of arteriole blood vessels)	Change of the body posture	Window opening/closing	(e.g., to a place further away from window to reduce problems with glare or direct solar radiation)
Piloerection (bristling of hairs due to cold)	Change of activity level (siesta in summer afternoons)	Door opening/closing	
Shivering		Solar shading devices adjustment	
Arteriolar vasoconstriction (narrowing of arteriole blood vessels)	Use of earplugs or earphones to avoid excessive aural discomfort	Light switching/dimming	
Thermogenesis	Drinking hot/cold beverages	Use of personal control devices for cooling effect (e.g., fan)	Relocation of activities to a different room
Pupillary light reflex		Use of personal control devices for heating effect (e.g., small heaters)	(e.g., sleeping in a basement)
Change in the sensitivity of the cones or rods of the eye	Eating high or low calorie food	Seasonal adjustment of building envelope components (e.g., placement of storm windows and plastic film on windows)	
Adjustment of ears' sensitivity to the noise level	Sleeping in family group with the bodies pushed up against each other		
	Fanning fresh air around the body	Use of electronic devices	
	Taking cold showers	Use of household appliances for cooking or water boiling	
		Use of work-related appliances	
		Domestic hot water usage (e.g., shower usage)	

2.3 Potential Triggers and Contextual Factors Influencing Occupant Behavior in a Building

Whether the focus is on existing buildings or new buildings, the factors influencing the behavior patterns and patterns of occupancy together with influencing contextual factors are important for modeling purposes, supporting design decisions, and choosing operation modes. In order to study occupancy and occupants' behavior in buildings, a researcher needs to be aware of which variables are most critical to measure. This knowledge helps inform the researcher of how best to allocate resources towards sensors and labor for installing sensors and collecting and analyzing data.

People live and work in buildings and use them by interacting with their envelope components, energy systems, and equipment, as outlined above. Potential influencing factors that drive occupant behavior were first classified as internal and external factors (Schweiker and Shukuya 2009). Internal factors are aspects related to the social sciences, such as preference, attitudes, cultural background, etc.; external factors are those aspects related to the building science or associated with the time of day or building characteristics. Later, Fabi et al. (2012) presented a more general explanatory framework to investigate the relationship between a multitude of potential adaptive and non-adaptive actions and influencing factors with the purpose of providing an outline to explore what stimulates occupants' behavior in a building. The authors proposed five categories of drivers for describing occupants' interaction with windows: physical environmental, contextual, psychological, physiological, and social. More recently, Polinder et al. (2013) categorized the influential factors that can be useful to explain occupant behavior into internal and external driving forces. Internal driving forces arise from the interaction between biological and psychological aspects and are investigated in the domains of biology, social science, and economics. Internal driving forces comprehend biological, psychological, and social factors. External driving forces act on the individual to stimulate their reaction and comprise three factors: building and building equipment properties, physical environment, and time.

In contrast to these approaches and as mentioned in the introduction, a given action (e.g., closing a window) could be identified as either an adaptive action or a non-adaptive action depending on the corresponding trigger. Therefore, this section aims at providing a framework to categorize factors influencing occupants' presence and actions into adaptive triggers, non-adaptive triggers, and contextual factors. As shown in Fig. 2.1, contextual factors are seen here as moderators of triggers and behavior. Sub-groups are defined based on the five categories mentioned by Fabi et al. (2012). An overview of those triggers and contextual factors that have been studied in the past, or based on discussions between the authors that can influence occupancy and/or occupants' behavioral patterns is given in Fig. 2.2.

Thereby, adaptive triggers are physiological triggers or physical environmental triggers. Physiological triggers originate from a signal in the body that prompts an occupant to take an action, e.g., the onset of shivering. Physical environmental

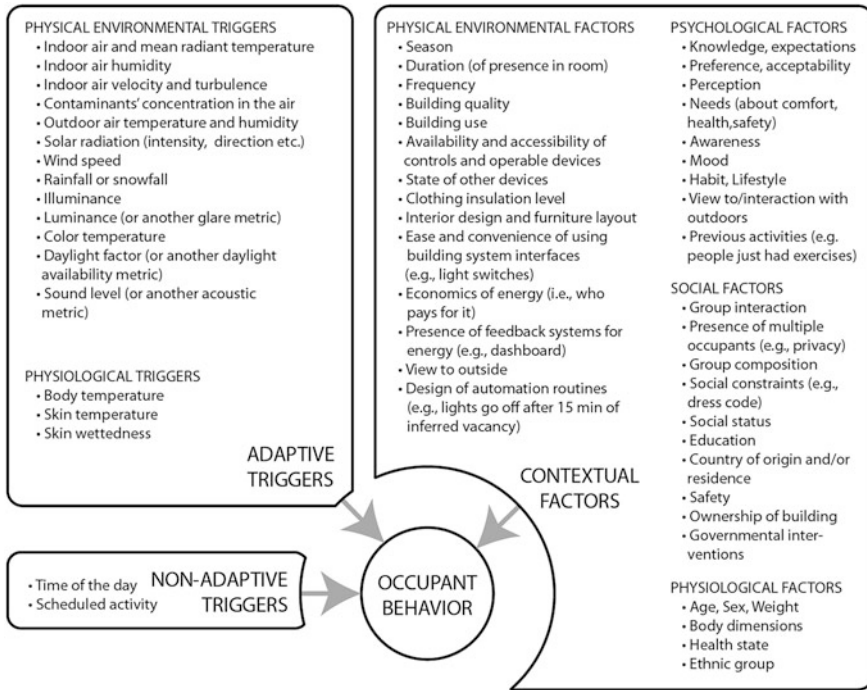


Fig. 2.2 Potential influencing factors driving occupants' behavior in a building

triggers are those physical properties that describe the indoor and outdoor environments and have been proven to stimulate occupant action in response to thermal, olfactory, visual, and aural stimulus (air and mean radiant temperatures, solar radiation, air pollutants, illuminance, sound pressure, etc.) with the aim of voluntarily modifying the surrounding built environment to restore or improve the comfort conditions. In contrast, non-adaptive triggers are factors that are independent of the physical environmental triggers (e.g., time of day, people leaving a room to attend a meeting elsewhere).

Contextual factors can be grouped into physical environmental factors, which remain unchanged over a period of time; psychological factors, which are related to individual and social factors; and physiological factors, which are not immediate triggers (O'Brien and Gunay 2014). Physical environmental contextual factors are fixed characteristics of the space and include things such as distance from the occupants' seated position to a control interface and ease of opening a window. Psychological factors "refer to thoughts, feelings and other cognitive characteristics that affect the attitude, behavior and functions of the human mind" (Sumpi and Amukugo 2016). They have been proven to explain occupants' interactions with building envelope, services, and equipment through expectation, awareness, preference, etc. Social factors refer to those items that affect a person's lifestyle and

his/her attitude in relating to others, such as group interaction, education, social status, etc. Physiological factors are all those aspects “relating to the branch of biology that deals with the normal functions of living organisms and their parts” (Stevenson 2010) and which have been related to the occurrence of an occupant action inside a building, such as age, sex, state of health, etc. All of these factors have a significant influence on the indoor environmental quality, overall building energy performance, effectiveness of control strategies, and, eventually, on occupants' satisfaction and productivity.

A literature review was conducted in order to build a framework of triggers and contextual factors. The review, summarized in Table 2.2 through Table 2.4, provides the grounds for a list of factors (with examples) that influence occupancy and occupants' behavior in buildings. This list gathers together items from the final report of the IEA Annex 53, Total Energy Use in Buildings: Analysis & Evaluation Methods (Polinder et al. 2013) and additional contributions collected by the authors of this chapter. The items were grouped according to the framework described above, as represented in Fig. 2.2.

2.4 Literature Review of Relationship Between Action Types and Influencing Factors

In an ideal world, a monitoring campaign with respect to occupancy and occupants' actions would include all potential influencing factors described in the previous section. In reality, however, financial resources and therewith the number of observed factors are limited. Before starting a monitoring campaign it is thus important to balance the cost of potentially necessary devices (data points) and the results potentially obtained by their implementation. The decision to include or exclude a certain variable is best made based on results from previous studies.

An overview of the type of actions and their influencing factors as studied in the past is presented in Tables 2.2, 2.3 and 2.4. They present behavioral actions and identified influencing factors related to individual, personal, and spatial adjustments, respectively. These tables may serve as an important guide for selecting the type of actions to investigate, as well as deciding on the data points to include in data collection and analysis. The first two columns describe the action and context analyzed. The last two columns state whether an influencing factor was found to have a statistically significant influence on the action, a potentially significant influence (a significance level was not reported in the literature or a significance test was not conducted), or a non-statistically significant influence. Note that the statistical method used to determine the statistical significance of an influencing variable and/or the sample size may vary between studies depending on the field and publication, and so that significance levels are not necessarily comparable (refer to Chap. 3 for a more in-depth treatment of statistical significance). In addition, it is important to mention that the quality and depth of conveyed surveys vary. To give

Table 2.2 Behavioral actions and influencing factors identified related to individual adjustments

Name of action	Building type ^a	Factors found to have influence on behavior ^b	Factors found to have no influence on behavior
<i>1. Individual adjustments</i>			
Selection of clothing	Office	Indoor air temperature*** (Haldi and Robinson 2008) Outdoor air temperature*** (De Carli et al. 2007; Haldi and Robinson 2008; Schiavon and Lee 2013; Schweiker and Wagner 2015) Daily mean outdoor air temperature* (Haldi and Robinson 2011)	Sex (De Carli et al. 2007)
Adjustment of clothing	Residential	Time of day* (Gauthier 2016)	Indoor air temperature (Gauthier 2016) Outdoor air temperature (Gauthier 2016) Weekend/weekday schedule (Gauthier 2016)
Adjustment of clothing	Office	Thermal comfort [†] (Baker and Standeven 1994) Number of persons in room [†] (Schweiker and Wagner 2016) Personality traits [†] (Schweiker et al. 2016)	Indoor air temperature (Haldi and Robinson 2011) Outdoor air temperature (Haldi and Robinson 2011)
Adjustment of clothing	Retail	Outdoor air temperature [†] (Morgan and de Dear 2003) Sex [†] (Morgan and de Dear 2003)	
Adjustment of body posture	Any or none	While people can reduce heat loss by becoming more compact (e.g., crossing arms) to decrease effective body surface area—and this is a common adaptive action—no behavioral studies were found in the literature	
Activity level	Residential	Indoor air temperature* (Gauthier 2016) Probability of heating on/off* (Gauthier 2016)	Outdoor air temperature (Gauthier 2016) Weekend/weekday schedule (Gauthier 2016)

(continued)

Table 2.2 (continued)

Name of action	Building type ^a	Factors found to have influence on behavior ^b	Factors found to have no influence on behavior
Activity level	Office		Indoor air temperature (Haldi and Robinson 2011) Outdoor air temperature (Haldi and Robinson 2011)
Change in orientation or position to improve visual comfort	Any or none	While it is generally understood that occupants may change their orientation or position to improve visual comfort, no experimental/in situ results were found in the literature	
Using earplugs or earphones to avoid excessive aural discomfort	Any or none	While it is generally understood that occupants use earplugs or earphones to improve comfort, no experimental/in situ results were found in the literature	
Drinking hot/cold/beverages	Residential	Time of day* (Gauthier 2016)	Indoor air temperature (Gauthier 2016) Outdoor air temperature (Gauthier 2016) Weekend/weekday schedule (Gauthier 2016)
Drinking cold drinks	Office	Indoor air temperature*** (Haldi and Robinson 2008)* (Haldi and Robinson 2011) Outdoor air temperature*** (Haldi and Robinson 2008)* (Haldi and Robinson 2011)	
Drinking hot drinks	Office	Weighted running mean of outdoor air temperature* (Haldi and Robinson 2011)	Indoor air temperature (Haldi and Robinson 2011)

^aBuilding types can be office, residential, hotel, educational, retail

^bSignificance levels are *** = $p < 0.001$, ** = $p < 0.01$, * = $p < 0.05$, [†] = significance level not stated

Table 2.3 Behavioral actions and influencing factors identified related to environmental adjustments

Name of action	Building type ^a	Factors found to have influence on behavior ^b	Factors found to have no influence on behavior
<i>2. Environmental adjustments</i>			
2.1. Use of heating, ventilation and air-conditioning (AC) systems			
Thermostat adjustments for heating	Residential	Indoor relative humidity* (Fabi et al. 2013) Outdoor air temperature*** (Fabi et al. 2013; van der Lans et al. 2013) Outdoor air humidity** (Hori 1995) Solar radiation* (Fabi et al. 2013) Wind speed* (Fabi et al. 2013) Time of day* (Fabi et al. 2013) Interaction frequency with heating controls*** (Hori 1995; Fabi et al. 2013) Window opening* (Hori 1995) Building insulation level*** (Müller et al. 2010) Ventilation type* (Keul et al. 2011) Type of metering (sub-metered vs. bulk-metered) [†] (Gunay et al. 2014) Expectations* (Keul et al. 2011) Ownership** (Keul et al. 2011) Sex [†] [8] Clothing** (Hori 1995; Fabi et al. 2013)	Time of day (Hori 1995)
Heating duration	Residential	Outdoor air temperature*** (Hori 1995) Outdoor air humidity*** (Hori 1995) Wind speed** (Hori 1995) Building insulation level*** (Müller et al. 2010) Heating system type*** (Hori 1995) Window opening* (Hori 1995) Level of control*** (Hori 1995) Understanding how controls function** (Hori 1995; Peeters et al. 2008; Keul et al. 2011) Clothing** (Hori 1995; Keul et al. 2011)	Ownership (Hori 1995) Government interventions (Müller et al. 2010)

(continued)

Table 2.3 (continued)

Name of action	Building type ^a	Factors found to have influence on behavior ^b	Factors found to have no influence on behavior
Switch on heating	Office	Outdoor air temperature (Nicol 2001) Country (Nicol 2001)	
Number of rooms heated	Residential	Interaction frequency with heating controls*** (Hori 1995) Level of control (Hori 1995) Type of metering (sub-metered vs. bulk-metered) [†] (Gunay et al. 2014)	
Type of rooms heated	Residential	Level of control*** (Hori 1995)	Sex (Hori 1995)
Percentage of times AC unit used	Residential	Indoor air temperature [†] (Jian et al. 2015) Indoor/outdoor temperature difference** (Stephens et al. 2011) Outdoor air temperature*** (Asawa et al. 2005; Schweiker and Shukuya 2009) Outdoor air humidity** (Asawa et al. 2005; Schweiker and Shukuya 2009) Wind direction** (Asawa et al. 2005) Wind speed* (Asawa et al. 2005) Season** (Asawa et al. 2005) Time of day** (Asawa et al. 2005; Schweiker and Shukuya 2009; Stephens et al. 2011) Cooling degree days* (Yun and Steemers 2011) Set point temperature of system [†] (Stephens et al. 2011) South orientated window*** (Schweiker and Shukuya 2009) Top floor*** (Schweiker and Shukuya 2009) Number of rooms with AC unit*** (Yun and Steemers 2011) Daily length of use [†] (Jian et al. 2015) Daily frequency of use [†] (Jian et al. 2015)	Indoor air temperature (Jian et al. 2015) AC unit used at home during childhood (Schweiker and Shukuya 2009) Climatic background (Schweiker and Shukuya 2009) Geographic background (Schweiker and Shukuya 2009) Household income (Yun and Steemers 2011) Occupancy patterns (Jian et al. 2015)

(continued)

Table 2.3 (continued)

Name of action	Building type ^a	Factors found to have influence on behavior ^b	Factors found to have no influence on behavior
		Preference for AC on*** (Hori 1995) Sex*** (Schweiker and Shukuya 2009) Origin moderate climate*** (Schweiker and Shukuya 2009) Geographic background* (Schweiker and Shukuya 2009) Health [†] (Kempton et al. 1992; Iwashita and Akasaka 1997)	
Switching on AC device	Residential	Indoor air temperature (Ren et al. 2014) [†] (Schweiker and Shukuya 2010a) Comfort range [†] (Bae and Chun 2009) Guests coming [†] (Schweiker and Shukuya 2010a)	
Switching off AC device	Residential	Leaving room [†] (Schweiker and Shukuya 2010a)	
Set point temperature adjustments for cooling	Residential	Outdoor air temperature*** (Schweiker and Shukuya 2010b) Geographical background*** (Schweiker and Shukuya 2010b) South orientation window*** (Schweiker and Shukuya 2010b) Preference for AC on*** (Schweiker and Shukuya 2010b) Sex* (Schweiker and Shukuya 2010b) Climatic background*** (Schweiker and Shukuya 2010b)	Floor (top, middle, ground) (Schweiker and Shukuya 2010b)
Existence of AC unit	Residential	Climate*** (Yun and Steemers 2011) Household income*** (Yun and Steemers 2011)	
No. of rooms with AC unit	Residential	Type of AC*** (Yun and Steemers 2011) Floor area*** (Yun and Steemers 2011)	Climate (Yun and Steemers 2011)

(continued)

Table 2.3 (continued)

Name of action	Building type ^a	Factors found to have influence on behavior ^b	Factors found to have no influence on behavior
2.2. Window opening/closing			
Window state	Residential	Indoor air temperature* (Rijal et al. 2007; Yun and Steemers 2008; Andersen et al. 2013)[†] (Dick and Thomas 1951; Rijal et al. 2007, 2008a, b; Schweiker et al. 2012a) Indoor air relative humidity* (Andersen et al. 2013) CO₂ concentration* (Andersen et al. 2013)[†] (Andersen et al. 2009) Outdoor air temperature*** (Herkel et al. 2008)* (Andersen et al. 2013)[†] (Dick and Thomas 1951; Brundrett 1978; Dubrul 1988; Fritsch et al. 1990; Rijal et al. 2007) Outdoor air temperature during day* (Yun and Steemers 2008) Outdoor air relative humidity* (Andersen et al. 2013) Solar radiation* (Andersen et al. 2013)[†] (Dubrul 1988; Andersen et al. 2011) Wind speed[†] (Dubrul 1988) Time of day* (Andersen et al. 2013)[†] (Dubrul 1988; Johnson and Long 2005) Season* (Andersen et al. 2013)[†] (Karava et al. 2007; Rijal et al. 2007; Herkel et al. 2008) Dwelling type[†] (Dubrul 1988; Johnson and Long 2005) Room orientation[†] (Dubrul 1988) Ventilation type[†] (Brundrett 1978; Dubrul 1988; van Dongen 2004) Heating system[†] (Dubrul 1988) Room type* (Andersen et al. 2013)[†] (Dubrul 1988; Andersen et al. 2009) Perceived illumination[†] (Andersen et al. 2009)	Indoor air temperature on arrival (Yun and Steemers 2008) Indoor air temperature during day (Yun and Steemers 2008)

(continued)

Table 2.3 (continued)

Name of action	Building type ^a	Factors found to have influence on behavior ^b	Factors found to have no influence on behavior
		Preference in terms of temperature [†] (Dubrul 1988) Smoking behavior [†] (Dubrul 1988) Presence at home [†] (Dubrul 1988) Age [†] (Dubrul 1988; Kvisgaard and Collet 1990) Sex [†] (Andersen et al. 2009)	
Window state	Office	Indoor air temperature*** (Haldi and Robinson 2008)* (Yun et al. 2008) [†] (Yun and Steemers 2008; Yun et al. 2009) Outdoor air temperature*** (Haldi and Robinson 2008) Time of day/arrival (Yun et al. 2009) Number of persons in a room [†] (Schweiker and Wagner 2016) Attitude towards actions (active/medium/passive window user) (Yun et al. 2009) Personality traits [†] (Schweiker et al. 2016) Perceived control over temperature* (Yun et al. 2008)	Indoor air temperature (Yun et al. 2008)
Window opening	Educational	Outdoor air temperature (Dutton and Shao 2010)	
Window opening	Office	Indoor temperature (Haldi and Robinson 2008) Outdoor air temperature (Haldi and Robinson 2008; Zhang and Barrett 2012a)	
Window closing	Office	Indoor air temperature (Haldi and Robinson 2009) Outdoor air temperature (Haldi and Robinson 2009) Arrival/intermediate/departure (Haldi and Robinson 2009)	
Degree of opening	Residential	Indoor air temperature* (Schweiker et al. 2012b) Outdoor air temperature* (Schweiker et al. 2012b) [†] (Dubrul 1988)	Indoor air temperature (Schweiker et al. 2012b) Outdoor air temperature (Schweiker et al. 2012b)

(continued)

Table 2.3 (continued)

Name of action	Building type ^a	Factors found to have influence on behavior ^b	Factors found to have no influence on behavior
2.3. Solar shading device adjustments			
Shading device position adjustment	Office	Outdoor daylight level [†] (Van Den Wymelenberg 2012) Direct sunlight from outdoors [†] (Maniccia et al. 1999), (Van Den Wymelenberg 2012) Indoor luminance contrast (glare) [†] (Van Den Wymelenberg 2012) Design of automation systems (e.g., lights go off after 15 min of inferred vacancy) [†] (Van Den Wymelenberg 2012) Orientation of the workstation [†] (Van Den Wymelenberg 2012) View to outside [†] (Van Den Wymelenberg 2012)	
Blind state	Residential	Solar radiation** (Andersen et al. 2009) Ownership* (Andersen et al. 2009) Perceived indoor air quality*** (Andersen et al. 2009) Age* (Andersen et al. 2009)	Outdoor air temperature (Andersen et al. 2009) Floor area (Andersen et al. 2009) Perceived illumination (Andersen et al. 2009) Thermal sensation (Andersen et al. 2009) Perceived noise (Andersen et al. 2009) Sex (Andersen et al. 2009)
Blind state	Office	Indoor air temperature*** (Haldi and Robinson 2008), (Inkarojrit 2008) Mean radiant temperature (Inkarojrit 2008) Outdoor air temperature*** (Haldi and Robinson 2008) Indoor solar intensity (Newsham 1994)	

(continued)

Table 2.3 (continued)

Name of action	Building type ^a	Factors found to have influence on behavior ^b	Factors found to have no influence on behavior
		Average luminance of the window or source luminance (Inkarojrit 2008) Background luminance (Inkarojrit 2008) Maximum luminance of the window (Inkarojrit 2008) Brightness sensitivity (Inkarojrit 2008) Solar penetration depth (Newsham 1994) Number of persons in room [†] (Schweiker and Wagner 2016) Personality traits [†] (Schweiker et al. 2016)	
Blind closing	Office	Indoor air temperature (Haldi and Robinson 2008) Indoor solar radiation (Mahdavi et al. 2008) Outdoor air temperature (Haldi and Robinson 2008) Solar radiation (Zhang and Barrett 2012b) Solar altitude (Zhang and Barrett 2012b) Glare (indicated by indoor illuminance or irradiance)*** (Haldi and Robinson 2010) Depth of solar penetration (Inoue et al. 1988; Reinhart and Voss 2003) Exterior solar irradiance (Reinhart and Voss 2003; Mahdavi et al. 2008) Availability of AC (Inkarojrit 2005) Façade orientation (Inoue et al. 1988; Mahdavi et al. 2008) Current shade position (Haldi and Robinson 2010) Number of occupants in space (Haldi and Robinson 2010)	Indoor air temperature (Lindsay and Littlefair 1992; Haldi and Robinson 2010) Outdoor air temperature (Haldi and Robinson 2010)
Blind opening	Office	Outdoor illuminance*** (Haldi and Robinson 2010) Solar radiation (Zhang and Barrett 2012b)	View to outside (Rubin et al. 1978)

(continued)

Table 2.3 (continued)

Name of action	Building type ^a	Factors found to have influence on behavior ^b	Factors found to have no influence on behavior
		Solar altitude (Zhang and Barrett 2012b) Morning upon arrival (Newsham 1994) Occupancy events (e.g., first daily arrival) (Haldi and Robinson 2010) Façade orientation (Inoue et al. 1988; Mahdavi et al. 2008) Current shade position*** (Haldi and Robinson 2010)	
Blind opening	Residential	Time of day (Bennet et al. 2014) Day of week (Bennet et al. 2014) Façade orientation (Bennet et al. 2014) Window size (Bennet et al. 2014)	Solar radiation (Bennet et al. 2014) Season (Bennet et al. 2014)
Blind closing	Residential	Time of day (Bennet et al. 2014) Day of week (Bennet et al. 2014) Façade orientation (Bennet et al. 2014) Window size (Bennet et al. 2014)	
2.4. Light switching/dimming			
Light switching/dimming	Residential	Outdoor air temperature** (Andersen et al. 2009) Solar radiation*** (Andersen et al. 2009) Perceived illumination** (Andersen et al. 2009) Thermal sensation* (Andersen et al. 2009) Weekend schedule [†] (Jian et al. 2015) Daily length of use [†] (Jian et al. 2015) Daily frequency of use [†] (Jian et al. 2015) Sex* (Andersen et al. 2009) Age* (Andersen et al. 2009)	Perceived noise (Andersen et al. 2009) Ownership (Andersen et al. 2009) Floor area (Andersen et al. 2009)

(continued)

Table 2.3 (continued)

Name of action	Building type ^a	Factors found to have influence on behavior ^b	Factors found to have no influence on behavior
	Office	Workplace illuminance [†] (Newsham et al. 2008) Outdoor daylight level [†] (Newsham et al. 2008) Interior design and furniture layout [†] (Maniccia et al. 1999) Ease and convenience of using building system interfaces (e.g., light switches) [†] (Maniccia et al. 1999)	
Light switch on	Office	Work plane illuminance [†] (Hunt 1979; Newsham 1994; Love 1998; Reinhart and Voss 2003; Lindelöf and Morel 2006) Time of day/events: morning arrival, after lunch, leaving [†] (Newsham 1994)	
Light switch off	Office	Departure [†] (Lindelöf and Morel 2006)	Workplace illuminance (Lindelöf and Morel 2006)

2.5. Fan usage

Ceiling fan usage	Office	Efficiency of ceiling fan [†] (Schweiker et al. 2014) Number of persons in room [†] (Schweiker and Wagner 2016) Personality traits [†] (Schweiker et al. 2016)	
Desk fan usage	Office	Indoor air temperature*** (Haldi and Robinson 2008) Outdoor air temperature*** (Haldi and Robinson 2008)	

2.6. Occupancy (schedule driven)

	Residential		–
		Time of day [†] (Johnson 1981; Al-Mumin et al. 2003; Yao and Steemers 2005) Time of week [†] (Johnson 1981) Season (and its effect on time spent outdoors)** (Marino et al. 2012) Number of persons in household [†] (Yao and Steemers 2005)	Elderly status [†] (Johnson 1981)

(continued)

Table 2.3 (continued)

Name of action	Building type ^a	Factors found to have influence on behavior ^b	Factors found to have no influence on behavior
		Building type (detached house, apartment, etc.) [†] (Farley 1978) Age [†] (Papakostas and Sotiropoulos 1997) Gender [†] (Papakostas and Sotiropoulos 1997) Marital status [†] (Johnson 1981) Culture [†] (Al-Mumin et al. 2003) Employment status [†] (Papakostas and Sotiropoulos 1997)	
	Office		
		Time of day [†] (Page et al. 2008; Duarte et al. 2013) Weekday vs. weekend [†] (Page et al. 2008; Davis and Nutter 2010; Duarte et al. 2013) Weekday (Monday, Tuesday, etc.) [†] (Davis and Nutter 2010; Duarte et al. 2013) Holidays [†] (Duarte et al. 2013) Season [†] (Duarte et al. 2013) Profession [†] (Feng et al. 2015) Office type (open plan vs. private) [†] (Duarte et al. 2013) Room type (e.g., break room, conference room, office) [†] (Duarte et al. 2013; Feng et al. 2015) Business/activity type [†] (Davis and Nutter 2010) Culture and occupant density [†] (Van Meel 2000) Culture and working hours (Iwasaki et al. 2006)	

2.7. Use of electronic devices

Level of electricity consumption	Residential	Persons per dwelling*** (Jensen 2004; Gram-Hanssen 2005) Income** (Gram-Hanssen 2005) Area of the dwelling** (Gram-Hanssen 2005) Teenagers in the household** (Gram-Hanssen 2005) Age** (Gram-Hanssen 2005)	Sex (Gram-Hanssen 2005)
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(continued)

Table 2.3 (continued)

Name of action	Building type ^a	Factors found to have influence on behavior ^b	Factors found to have no influence on behavior
Electricity consumption	Residential	Heating degree days* (Mora et al. 2015) Area of the dwelling*** (Mora et al. 2015) Income* (Mora et al. 2015) Number of household members* (Mora et al. 2015) Average age** (Mora et al. 2015) Age of household head** (Mora et al. 2015)	Type of house (Mora et al. 2015) Type of external wall (Mora et al. 2015) Year of construction (Mora et al. 2015) Structure (Mora et al. 2015) Type of windows (Mora et al. 2015) Energy saving lamps (Mora et al. 2015) Sex (Mora et al. 2015)
Number of appliances	Residential	Income (Gram-Hanssen 2005)	
Use of appliances	Residential	Household size [†] (Lutz et al. 1996) Education [†] (Vine et al. 1987)	
Use of appliances	Office	Duration of vacancy period following a departure [†] (Gunay et al. 2016) Computer type [†] (Webber et al. 2006; Moorefield et al. 2008) Company size [†] (Roberson et al. 2002) Occupancy rate [†] (Nordman et al. 1996; de Menezes 2013) Power management program settings [†] (Kawamoto et al. 2004; Lobato et al. 2011) Habits—non-behavioral factors [†] (Tetlow et al. 2015) Awareness, peer pressure, and competition [†] (Yun et al. 2013; Lasternas et al. 2014)	Indoor and environmental conditions (Tetlow et al. 2015)
Use of appliances	Educational	Awareness and peer pressure, competition, and economics [†] (Brewer et al. 2011)	

(continued)

Table 2.3 (continued)

Name of action	Building type ^a	Factors found to have influence on behavior ^b	Factors found to have no influence on behavior
2.8. Domestic hot water usage			
Shower duration	Residential	Weekday or weekend [†] (Aguilar et al. 2005) Season [†] (Kondo and Hokai 2012) Household size [†] (Ministerie of VROM 2009) Low-flow shower head [†] (Campbell et al. 2004; Ministerie of VROM 2009) Boiler [†] (Ministerie of VROM 2009) Income [†] (Ministerie of VROM 2009) Geographic background [†] (Foekema et al. 2007) Age [†] (Ministerie of VROM 2009) Sex [†] (Foekema et al. 2007)	
Frequency of bath/shower	Residential	Geographic background [†] (van Dongen 2004) Household composition [†] (Ministerie of VROM 2009) Age [†] (Ministerie of VROM 2009) Sex [†] (Foekema et al. 2007)	

^aBuilding types can be office, residential, hotel, educational, retail

^bSignificance levels are *** = $p < 0.001$, ** = $p < 0.01$, * = $p < 0.05$, [†] = significance level not stated

an example, the authors of this chapter prefer a consistent and meticulous usage of terms; however, many studies neither report the exact approach used in survey data collection, nor specify whether they collected data of, for example, indoor air temperature or indoor operative temperature. In these cases of ambiguity the terms used in the original source are used.

In addition to the results of previous studies related to specific actions or influencing factors, Table 2.2, 2.3 and 2.4 show the variation in the number of studies dealing with one action or another. This organization can help in choosing the type of action to be investigated—for example, numerous studies have dealt with window opening and closing behaviors in both residential and office settings, whereas individual adaptive actions, such as drinking behaviors, change of activity levels, etc. have not been investigated as extensively and solely in the residential context. Therefore, based on all three tables, some of the major research gaps requiring additional study could be identified. That said, even for those cells with

Table 2.4 Behavioral actions and influencing factors identified related to spatial adjustments

Name of action	Building type ^a	Factors found to have influence on behavior ^b	Factors found to have no influence on behavior
<i>3. Spatial adjustments</i>			
3.1. Movement from a room to another			
	Any or none	While it is generally understood that occupants may relocate within a building to improve comfort, no experimental/in situ results were found in the literature	–
3.2. Rotation or minor movements within a room			
	Any or none	While it is generally understood that occupants may rotate, change their posture, and relocate within a room to improve comfort, no experimental/in situ results were found in the literature	–

^aBuilding types can be office, residential, hotel, educational, commercial (shopping)

^bSignificance levels are *** = $p < 0.001$, ** = $p < 0.01$, * = $p < 0.05$, † = significance level not stated

numerous references, it might be meaningful to conduct additional studies that include other predictor variables, whether based on data from a distinctive cultural background, geographic context, or building characteristics. Comparative studies (e.g., Schweiker and Shukuya 2009; Schweiker et al. 2016; Schweiker and Wagner 2016) have demonstrated that many actions are contextually sensitive or differing due to personal characteristics, and that numerous studies in different contexts (e.g., climates, cultures, building types, mechanical systems) are required to properly understand a particular action.

Regarding the data points to include in data collection and analysis, it seems obvious to include those variables which have been found to be significant predictors for the respective action. At the same time, it should be noted that a variable found to be non-significant in a given context in one specific study (e.g., residential buildings in cold climates) could have a significant influence on the given action in the same context in a second study. Only by repetition can preliminary results deriving from one experiment or field study be either confirmed or challenged.

By all means, the authors recommend that the reader not make decisions based only on these tables, but also refer to the corresponding studies in order to learn more about their data collection process, analysis methods, general circumstances, and limitations. Such a step is important and necessary before deciding whether predictor variables should be included or not. In addition, the presented tables are not exclusive in the sense that important predictors might not be listed or studies reporting different results may have been overlooked. The authors recommend that researchers use this comprehensive literature review prior to embarking on major occupant monitoring campaigns, but that they also perform an additional review on their own as new research continually emerges.

Research exploration of influencing variables for seldom explored domains, such as spatial movements or changes in body posture, are particularly difficult. Tables 2.2, 2.3 and 2.4 offer some guidance for such exploration. It is important to analyze which predictors are found to be influencing a particular action and/or comparable actions the most. For example, indoor thermal conditions appear to influence most thermal comfort-related adaptive actions. A thorough analysis of Tables 2.2, 2.3 and 2.4, together with rational thinking of potential pathways and influences, would facilitate the research exploration of these and other unexplored actions

Importantly, the number of variables reported to have no influence on action is rather small compared to those reported to have an influence. Based on this chapter's literature review, it remains unknown whether in fact there are few variables that have no influence on specific actions, or whether this is a matter of known scientific bias due to a higher probability of significant results being reported. It is highly recommended that researchers report all variables measured and analyzed, regardless of their significance, in order to improve the knowledge of the research area and to avoid repetitive, fruitless work.

2.5 Conclusion

This chapter has summarized previous occupant behavior research with a focus on providing basic definitions and a comprehensive list of occupant actions and their influencing factors. The chapter should be interpreted in the context that the field of occupant behavior monitoring and modeling is in active development, where many domains have been studied in only a few buildings and contexts or by only a few researchers, if at all. Accordingly, researchers who are embarking on new monitoring campaigns should combine the information that was presented in this chapter and in the most recent literature with common sense and an appreciation for balancing research rigor with practicality (costs, time, etc.). Moreover, for monitoring campaigns that are destined to support modeling and simulation, researchers should be familiar with the modeling capabilities of common building simulation tools because simulation tools must actually calculate the model predictors for the model to be of use. For instance, even if individual occupant sensitivity to glare is a good predictor for window blind actions, metrics capable of quantifying this phenomenon are either too complex to be calculated (e.g., the daylight glare probability, DGP) or unavailable as an output in many building performance simulation (BPS) tools. Similarly, most BPS tools do not model odor; thus, this would not be a practical predictor for window opening action models. On the other hand, variables such as age can still be useful in order to select modeling parameters for specific design tasks—for example, the design of a retirement home.

The studies reviewed in this chapter strongly support the notion that occupant behavior is influenced by a large number of complex variables that extend well beyond physical phenomena to include social and psychological factors.

Researchers should take considerable care and rigor in both measuring and documenting these phenomena. Model users must be made aware of the contexts upon which observational studies and models were built, otherwise models may be applied in entirely different and inappropriate building contexts.

Among the occupant action domains explored in this chapter, some have benefitted from decades of research in diverse contexts, while others have been seldom researched. The actions that have been studied more extensively include: window opening in both commercial and residential buildings, occupant control of heating and cooling in homes, and window blind and lighting control in office buildings. Many domains require much more research, including: occupant posture, occupant repositioning in response to discomfort, and lighting use in residential buildings, to name a few.

One of the conclusions of this chapter is that it is crucial for future occupant monitoring campaigns to be published with sufficient detail to inform future researchers and save redundant effort. Contrary to common practice, as evidenced in Tables 2.2, 2.3 and 2.4, both the influencing factors that were found to be significant and those found to be insignificant should be documented. If several comprehensive studies indicate that a given variable is not a significant predictor in a particular domain, future studies can avoid diverting limited resources towards that variable. Moreover, the statistical significance of predictive variables should be determined and reported, as currently there is a large degree of variability in the literature in this regard. It is likewise critical to have consistent reporting of other technical terms. For instance, this chapter's literature review revealed that numerous papers did not specify whether "interior temperature" refers to indoor air temperature, operative temperature, mean radiant temperature, or even internal body temperature. Precision and consistency in the usage of terms is essential for the field of occupant research to move forward.

This chapter also introduced the most commonly studied occupant domains and provided a summary of existing literature in this area. The authors attempted to summarize the existing literature so that researchers can maintain focus in the potentially overwhelming sea of literature that has built over the last decades. The next chapters provide practical and fundamental guidance on research methods for collecting occupant data using a variety of unique approaches.

References

- Aguilar C, White DJ, Ryan DL (2005) Domestic water heating and water heater energy consumption in Canada
- Al-Mumin A, Khattab O, Sridhar G (2003) Occupants' behavior and activity patterns influencing the energy consumption in the Kuwaiti residences. *Energy Build* 35:549–559
- American Optometric Association (2016) How your eyes work. <http://www.aoa.org/patients-and-public/resources-for-teachers/how-your-eyes-work?sso=y>. Accessed 20 Oct 2016

- Andersen RK (2012) The influence of occupants' behaviour on energy consumption investigated in 290 identical dwellings and in 35 apartments. In: *Proceedings of Healthy Buildings 2012*, Brisbane, Australia
- Andersen RV, Toftum J, Andersen KK, Olesen BW (2009) Survey of occupant behaviour and control of indoor environment in Danish dwellings. *Energy Build* 41:11–16. doi:[10.1016/j.enbuild.2008.07.004](https://doi.org/10.1016/j.enbuild.2008.07.004)
- Andersen RV, Olesen BW, Toftum J (2011) Modelling window opening behaviour in Danish dwellings. In: *Proceedings of Indoor Air 2011*
- Andersen RK, Fabi V, Toftum J et al (2013) Window opening behaviour modelled from measurements in Danish dwellings. *Build Environ* 69:101–113. doi:[10.1016/j.buildenv.2013.07.005](https://doi.org/10.1016/j.buildenv.2013.07.005)
- Andersen S, Andersen RK, Olesen BW (2016) Influence of heat cost allocation on occupants' control of indoor environment in 56 apartments: studied with measurements, interviews and questionnaires
- Asawa T, Hoyano A, Takezawa H, Shimizu K (2005) Analysis of the behavioral characteristics of both window opening and air conditioning use at detached houses: Relationship between outdoor microclimate and residents' living open to outdoor. Part 2. *J Environ Eng AIJ* 87–94
- Bae C, Chun C (2009) Research on seasonal indoor thermal environment and residents' control behavior of cooling and heating systems in Korea. *Build Environ* 44:2300–2307. doi:[10.1016/j.buildenv.2009.04.003](https://doi.org/10.1016/j.buildenv.2009.04.003)
- Baker N, Standeven M (1994) Comfort criteria for passively cooled buildings a pascool task. *Renew Energy* 5:977–984
- Bennet I, O'Brien W, Gunay HB (2014) Effect of window blind use in residential buildings: observation and simulation study
- Bishop RC, Frey DJ (1985) Occupant effects on energy performance of monitored houses. In: *Proceedings of the 10th National Passive Solar Conference*, the solar, pp 395–400
- Blight TS, Coley DA (2013) Sensitivity analysis of the effect of occupant behaviour on the energy consumption of passive house dwellings. *Energy Build* 66:183–192. doi:[10.1016/j.enbuild.2013.06.030](https://doi.org/10.1016/j.enbuild.2013.06.030)
- Brewer RS, Lee GE, Johnson PM (2011) The Kukui Cup: a dorm energy competition focused on sustainable behavior change and energy literacy. In: *2011 44th Hawaii International Conference on System Sciences (HICSS)*, pp 1–10
- Brundrett GW (1978) Window ventilation and human behaviour. In: *Proceedings of the First International Indoor Climate Symposium in Copenhagen: Indoor Climate, Effects on Human Comfort, Performance and Health in Residential, Commercial and Light-Industry Buildings*, p 31
- Campbell HE, Johnson RM, Larson EH (2004) Prices, devices, people, or rules: the relative effectiveness of policy instruments in water conservation. *Rev Policy Res* 21:637–662. doi:[10.1111/j.1541-1338.2004.00099.x](https://doi.org/10.1111/j.1541-1338.2004.00099.x)
- Carlucci S, Lobaccaro G, Li Y et al (2016) The effect of spatial and temporal randomness of stochastically generated occupancy schedules on the energy performance of a multiresidential building. *Energy Build* 127:279–300. doi:[10.1016/j.enbuild.2016.05.023](https://doi.org/10.1016/j.enbuild.2016.05.023)
- Davis JA, Nutter DW (2010) Occupancy diversity factors for common university building types. *Energy Build* 42:1543–1551
- De Carli M, Olesen BW, Zarrella A, Zecchin R (2007) People's clothing behaviour according to external weather and indoor environment. *Build Environ* 42:3965–3973. doi:[10.1016/j.buildenv.2006.06.038](https://doi.org/10.1016/j.buildenv.2006.06.038)
- de Menezes ACK (2013) Improving predictions of operational energy performance through better estimates of small power consumption. Anna Carolina Kossmann de Menezes
- Deuble MP, de Dear RJ (2012) Green occupants for green buildings: the missing link? *Build Environ* 56:21–27. doi:[10.1016/j.buildenv.2012.02.029](https://doi.org/10.1016/j.buildenv.2012.02.029)
- Dick JB, Thomas DA (1951) Ventilation research in occupied houses. *J Inst Heat Vent Eng* 19:279–305
- Duarte C, Van Den Wymelenberg K, Rieger C (2013) Revealing occupancy patterns in an office building through the use of occupancy sensor data. *Energy Build* 67:587–595

- Dubrul C (1988) Inhabitant behaviour with respect to ventilation—a summary report of IEA Annex VIII
- Dutton S, Shao L (2010) Window opening behaviour in a naturally ventilated school. In: Proceedings of 4th National Conference of IBPSA-USA, pp 260–268
- Emery AF, Kippenhan CJ (2006) A long term study of residential home heating consumption and the effect of occupant behavior on homes in the Pacific Northwest constructed according to improved thermal standards. *Energy* 31:677–693. doi:[10.1016/j.energy.2005.04.006](https://doi.org/10.1016/j.energy.2005.04.006)
- Fabi V, Andersen RV, Corgnati S, Olesen BW (2012) Occupants' window opening behaviour: a literature review of factors influencing occupant behaviour and models. *Build Environ* 58:188–198
- Fabi V, Andersen RV, Corgnati SP (2013) Influence of occupant's heating set-point preferences on indoor environmental quality and heating demand in residential buildings. *HVAC&R Res* 19:635–645. doi:[10.1080/10789669.2013.789372](https://doi.org/10.1080/10789669.2013.789372)
- Farley J (1978) High rise apartment or detached house: what are the implications for children's behavior? *New Dir Environ Des Res* (EDRA 9 Proc) Wash Environ Des Res Assoc 145–161
- Feng X, Yan D, Hong T (2015) Simulation of occupancy in buildings. *Energy Build* 87:348–359
- Foekema H, van Thiel L, Lettinga B (2007) Watergebruik thuis 2007 (Drinking water use at home 2007)
- Fritsch R, Kohler A, Nygård-Ferguson M, Scartezzini J-L (1990) A stochastic model of user behaviour regarding ventilation. *Build Environ* 25:173–181
- Gauthier S (2016) Investigating the probability of behavioural responses to cold thermal discomfort. *Energy Build* 124:70–78. doi:[10.1016/j.enbuild.2016.04.036](https://doi.org/10.1016/j.enbuild.2016.04.036)
- Gram-Hanssen K (2005) Husholdningers elforbrug-hvem bruger hvor meget, til hvad og hvorfor?. Statens Byggeforskningsinstitut, SBI
- Guerra Santin O, Itard L, Visscher H (2009) The effect of occupancy and building characteristics on energy use for space and water heating in Dutch residential stock. *Energy Build* 41:1223–1232. doi:[10.1016/j.enbuild.2009.07.002](https://doi.org/10.1016/j.enbuild.2009.07.002)
- Gunay HB, O'Brien W, Beausoleil-Morrison I, Perna A (2014) On the behavioral effects of residential electricity submetering in a heating season. *Build Environ* 81:396–403. doi:[10.1016/j.buildenv.2014.07.020](https://doi.org/10.1016/j.buildenv.2014.07.020)
- Gunay HB, O'Brien W, Beausoleil-Morrison I, Gilani S (2016) Modeling plug-in equipment load patterns in private office spaces. *Energy Build* 121:234–249. doi:[10.1016/j.enbuild.2016.03.001](https://doi.org/10.1016/j.enbuild.2016.03.001)
- Haldi F, Robinson D (2008) On the behaviour and adaptation of office occupants. *Build Environ* 43:2163–2177. doi:[10.1016/j.buildenv.2008.01.003](https://doi.org/10.1016/j.buildenv.2008.01.003)
- Haldi F, Robinson D (2009) Interactions with window openings by office occupants. *Build Environ* 44:2378–2395. doi:[10.1016/j.buildenv.2009.03.025](https://doi.org/10.1016/j.buildenv.2009.03.025)
- Haldi F, Robinson D (2010) Adaptive actions on shading devices in response to local visual stimuli. *J Build Perform Simul* 3:135–153. doi:[10.1080/19401490903580759](https://doi.org/10.1080/19401490903580759)
- Haldi F, Robinson D (2011) Modelling occupants' personal characteristics for thermal comfort prediction. *Int J Biometeorol* 55:681–694. doi:[10.1007/s00484-010-0383-4](https://doi.org/10.1007/s00484-010-0383-4)
- Herkel S, Knapp U, Pfaffert J (2008) Towards a model of user behaviour regarding the manual control of windows in office buildings. *Build Environ* 43:588–600
- Hoes P, Hensen JLM, Loomans MGLC et al (2009) User behavior in whole building simulation. *Energy Build* 41:295–302. doi:[10.1016/j.enbuild.2008.09.008](https://doi.org/10.1016/j.enbuild.2008.09.008)
- Hori S (1995) Adaptation to heat. *Jpn J Physiol* 45:921–946
- Hunt DRG (1979) The use of artificial lighting in relation to daylight levels and occupancy. *Build Environ* 14:21–33. doi:[10.1016/0360-1323\(79\)90025-8](https://doi.org/10.1016/0360-1323(79)90025-8)
- IJspeert JK, De Waard PWT, Van den Berg T, De Jong P (1990) The intraocular straylight function in 129 healthy volunteers; dependence on angle, age and pigmentation. *Vision Res* 30:699–707
- Inkarojrit V (2005) Balancing comfort: occupants' control of window blinds in private offices. University of California, Berkeley

- Inkarojrit V (2008) Monitoring and modelling of manually-controlled Venetian blinds in private offices: a pilot study. *J Build Perform Simul* 1:75–89. doi:[10.1080/19401490802021012](https://doi.org/10.1080/19401490802021012)
- Inoue T, Kawase T, Ibamoto T et al (1988) The development of an optimal control system for window shading devices based on investigations in office buildings. *ASHRAE Trans* 94:1034–1049
- Iwasaki K, Takahashi M, Nakata A (2006) Health problems due to long working hours in Japan: working hours, workers' compensation (Karoshi), and preventive measures. *Ind Health* 44:537–540
- Iwashita G, Akasaka H (1997) The effects of human behavior on natural ventilation rate and indoor air environment in summer—a field study in southern Japan. *Energy Build* 25:195–205. doi:[10.1016/S0378-7788\(96\)00994-2](https://doi.org/10.1016/S0378-7788(96)00994-2)
- Jensen JO (2004) *Livsstil, boform og ressourceforbrug*. Aalborg Universitetsforlag
- Jian Y, Li Y, Wei S et al (2015) A case study on household electricity uses and their variations due to occupant behavior in Chinese apartments in Beijing. *J Asian Archit Build Eng* 14:679–686. doi:[10.3130/jaabe.14.679](https://doi.org/10.3130/jaabe.14.679)
- Johnson BM (1981) DBR INTERNAL REPORT NO. 464
- Johnson T, Long T (2005) Determining the frequency of open windows in residences: a pilot study in Durham, North Carolina during varying temperature conditions. *J Expo Sci Environ Epidemiol* 15:329–349
- Karava P, Stathopoulos T, Athienitis AK (2007) Wind-induced natural ventilation analysis. *Sol Energy* 81:20–30
- Katzschner L, Bosch U, Röttgen M (2006) Behaviour of people in open spaces in dependence of thermal comfort conditions. In: Weber W (ed) *Proceedings of 23rd Conference on Passive and Low Energy Architecture*
- Kawamoto K, Shimoda Y, Mizuno M (2004) Energy saving potential of office equipment power management. *Energy Build* 36:915–923. doi:[10.1016/j.enbuild.2004.02.004](https://doi.org/10.1016/j.enbuild.2004.02.004)
- Kempton W, Feuermann D, McGarity AE (1992) “I always turn it on super”: user decisions about when and how to operate room air conditioners. *Energy Build* 18:177–191. doi:[10.1016/0378-7788\(92\)90012-6](https://doi.org/10.1016/0378-7788(92)90012-6)
- Keul A, Salzmann R, Lehmden A (2011) Komfort und Luftqualität im Niedrigenergie-Ziegelgebäude. *Mauerwerk* 15:176–178. doi:[10.1002/dama.201100497](https://doi.org/10.1002/dama.201100497)
- Kondo S, Hokai S (2012) A model for predicting daily hot water consumption. In: *Proceedings of the 5th IBPC*, pp 867–873
- Kvisgaard B, Collet PF (1990) The user's influence on air change. In: *Air Change Rate and Airtightness in Buildings*. ASTM International
- Lasternas B, Zhao J, Yun R et al (2014) Behavior oriented metrics for plug load energy savings in office environment. In: 2014 American Council for an Energy-Efficient Economy (ACEEE) Summer Study on Energy Efficiency in Buildings, pp 160–172
- Lerman S (1980) *Radiant energy and the eye*. Macmillan
- Lindelöf D, Morel N (2006) A field investigation of the intermediate light switching by users. *Energy Build* 38:790–801. doi:[10.1016/j.enbuild.2006.03.003](https://doi.org/10.1016/j.enbuild.2006.03.003)
- Lindsay C, Littlefair PJ (1992) Occupant use of venetian blinds in offices
- Lobato C, Pless S, Sheppy M, Torcellini P (2011) Reducing plug and process loads for a large scale, low energy office building: NREL's Research Support Facility; Preprint
- Love JA (1998) Manual switching patterns in private offices. *Light Res Technol* 30:45–50. doi:[10.1177/096032719803000107](https://doi.org/10.1177/096032719803000107)
- Lutz JD, Liu X, McMahon JE et al (1996) Modeling patterns of hot water use in households, 25 Macintosh A, Steemers K (2005) Ventilation strategies for urban housing: lessons from a PoE case study. *Build Res Inf* 33:17–31. doi:[10.1080/0961321042000322771](https://doi.org/10.1080/0961321042000322771)
- Mahdavi A, Mohammadi A, Kabir E, Lambeva L (2008) Occupants' operation of lighting and shading systems in office buildings. *J Build Perform Simul* 1:57–65. doi:[10.1080/19401490801906502](https://doi.org/10.1080/19401490801906502)
- Maier T, Krzaczek M, Tejchman J (2009) Comparison of physical performances of the ventilation systems in low-energy residential houses. *Energy Build* 41:337–353

- Majcen D, Itard L, Visscher H (2013) Actual and theoretical gas consumption in Dutch dwellings: what causes the differences? *Energy Policy* 61:460–471. doi:[10.1016/j.enpol.2013.06.018](https://doi.org/10.1016/j.enpol.2013.06.018)
- Maniccia D, Rutledge B, Rea MS, Morrow W (1999) Occupant use of manual lighting controls in private offices. *J Illum Eng Soc* 28:42–56. doi:[10.1080/00994480.1999.10748274](https://doi.org/10.1080/00994480.1999.10748274)
- Marino AJ, Fletcher EN, Whitaker RC, Anderson SE (2012) Amount and environmental predictors of outdoor playtime at home and school: a cross-sectional analysis of a national sample of preschool-aged children attending Head Start. *Health Place* 18:1224–1230
- Ministerie of VROM (2009) Energiegedrag in de woning
- Moorefield L, Frazer B, Bendt P (2008) Office plug load field monitoring report
- Moosmann C (2014) Visueller Komfort und Tageslicht am Bueroarbeitsplatz: Eine Felduntersuchung in neun Gebaeuden. KIT Scientific Publishing
- Mora D, Carpinio C, De Simone M (2015) Behavioral and physical factors influencing energy building performances in Mediterranean climate. *Energy Procedia* 78:603–608. doi:[10.1016/j.egypro.2015.11.033](https://doi.org/10.1016/j.egypro.2015.11.033)
- Morgan C, de Dear RJ (2003) Weather, clothing and thermal adaptation to indoor climate. *Clim Res* 24:267–284
- Müller A, Biermayr P, Kranzl L et al (2010) Heizen 2050: Systeme zur Wärmebereitstellung und Raumklimatisierung im österreichischen Gebäudebestand: Technologische Anforderungen bis zum Jahr 2050
- Murdoch JB (2003) Illuminating engineering: from Edison's lamp to the LED. *Visions Communications*
- Newsham GR (1994) Manual control of window blinds and electric lighting: implications for comfort and energy consumption. *Indoor Environ* 6:135–144. doi:[10.1177/1420326X9400300307](https://doi.org/10.1177/1420326X9400300307)
- Newsham GR, Aries MBC, Mancini S, Faye G (2008) Individual control of electric lighting in a daylight space. *Light Res Technol* 40:25–41
- Nicol F (2001) Characterising occupant behavior in buildings: towards a stochastic model of occupant use of windows, lights, blinds heaters and fans. In: *Seventh International IBPSA Conference*, 1073–1078
- Nordman B, Piette MA, Kinney K (1996) Measured energy savings and performance of power-managed personal computers and monitors
- O'Brien W, Gunay HB (2014) The contextual factors contributing to occupants' adaptive comfort behaviors in offices—a review and proposed modeling framework. *Build Environ* 77:77–87
- Page J, Robinson D, Morel N, Scartezzini J-L (2008) A generalised stochastic model for the simulation of occupant presence. *Energy Build* 40:83–98
- Papakostas KT, Sotiropoulos BA (1997) Occupational and energy behaviour patterns in Greek residences. *Energy Build* 26:207–213
- Peeters L, der Veken J, Hens H et al (2008) Control of heating systems in residential buildings: current practice. *Energy Build* 40:1446–1455
- Polinder H, Schweiker M, van der Aa A et al (2013) Occupant behavior and modeling
- Reinhart CF, Voss K (2003) Monitoring manual control of electric lighting and blinds. *Light Res Technol* 35:243–258. doi:[10.1191/1365782803li064oa](https://doi.org/10.1191/1365782803li064oa)
- Ren X, Yan D, Wang C (2014) Air-conditioning usage conditional probability model for residential buildings. *Build Environ* 81:172–182. doi:[10.1016/j.buildenv.2014.06.022](https://doi.org/10.1016/j.buildenv.2014.06.022)
- Rijal HB, Tuohy P, Humphreys MA et al (2007) Using results from field surveys to predict the effect of open windows on thermal comfort and energy use in buildings. *Energy Build* 39 (7):823–836
- Rijal HB, Tuohy P, Nicol F et al (2008a) Development of an adaptive window-opening algorithm to predict the thermal comfort, energy use and overheating in buildings. *J Build Perform Simul* 1:17–30
- Rijal HB, Tuohy PG, Nicol F et al (2008b) Development of adaptive algorithms for the operation of windows, fans and doors to predict thermal comfort and energy use in Pakistani buildings. *ASHRAE Trans* 114:555–573

- Roberson JA, Homan GK, Mahajan A et al (2002) Energy use and power levels in new monitors and personal computers
- Rubin AI, Collins BL, Tibbott RL (1978) Window blinds as a potential energy saver: a case study. US Department of Commerce, National Bureau of Standards
- Schakib-Ekbatan K, Zakici FZ, Schweiker M, Wagner A (2015) Does the occupant behavior match the energy concept of the building? Analysis of a German naturally ventilated office building. *Build Environ* 84:142–150. doi:[10.1016/j.buildenv.2014.10.018](https://doi.org/10.1016/j.buildenv.2014.10.018)
- Schiavon S, Lee KH (2013) Dynamic predictive clothing insulation models based on outdoor air and indoor operative temperatures. *Build Environ* 59:250–260. doi:[10.1016/j.buildenv.2012.08.024](https://doi.org/10.1016/j.buildenv.2012.08.024)
- Schweiker M (2010) Occupant behaviour and the related reference levels for heating and cooling. Tokyo City University, Japan
- Schweiker M, Shukuya M (2009) Comparison of theoretical and statistical models of air-conditioning-unit usage behaviour in a residential setting under Japanese climatic conditions. *Build Environ* 44:2137–2149
- Schweiker M, Shukuya M (2010a) A critical review on thermal factors as predictors for occupant behaviour: towards a purpose-rank based model of reference levels. In: Windsor Conference 2010
- Schweiker M, Shukuya M (2010b) Comparative effects of building envelope improvements and occupant behavioural changes on the exergy consumption for heating and cooling. *Energy Policy* 38:2976–2986
- Schweiker M, Wagner A (2015) A framework for an adaptive thermal heat balance model (ATHB). *Build Environ* 94:252–262
- Schweiker M, Wagner A (2016) The effect of occupancy on perceived control, neutral temperature, and behavioral patterns. *Energy Build* 117:246–259
- Schweiker M, Brasche S, Bischof W et al (2012a) Development and validation of a methodology to challenge the adaptive comfort model. *Build Environ* 49:336–347
- Schweiker M, Haldi F, Shukuya M, Robinson D (2012b) Verification of stochastic models of window opening behaviour for residential buildings. *J Build Perform Simul* 5:55–74
- Schweiker M, Brasche S, Hawighorst M et al (2014) Presenting LOBSTER, an innovative climate chamber, and the analysis of the effect of a ceiling fan on the thermal sensation and performance under summer conditions in an office-like setting. Proceedings of 8th Windsor conference: counting the cost of comfort in a changing world Cumberland Lodge. Windsor, UK, pp 924–937
- Schweiker M, Hawighorst M, Wagner A (2016) The influence of personality traits on occupant behavioural patterns. *Energy Build* 131:63–75. doi:[10.1016/j.enbuild.2016.09.019](https://doi.org/10.1016/j.enbuild.2016.09.019)
- Socolow RH (1978) The twin rivers program on energy conservation in housing: Highlights and conclusions. *Energy Build* 1:207–213. doi:[10.1016/0378-7788\(78\)90003-8](https://doi.org/10.1016/0378-7788(78)90003-8)
- Stephens B, Siegel JA, Novoselac A (2011) Operational characteristics of residential and light-commercial air-conditioning systems in a hot and humid climate zone. *Build Environ* 46:1972–1983. doi:[10.1016/j.buildenv.2011.04.005](https://doi.org/10.1016/j.buildenv.2011.04.005)
- Stevenson A (2010) Oxford dictionary of English, 3rd edn. Oxford University Press
- Sumpi N, Amukugo HJ (2016) A conceptual framework as basis for the development of a psychosocial educational programme to facilitate the reintegration of incarcerated women who had dumped babies and/or committed infanticide. *Int J Health* 4:102–111
- Takahashi I, Saito M, Matsuoka H et al (2000) Difference in thermal sensation and behavioral pattern of occupants between passive and active cooling strategies. In: Proceedings of PLEA 2000, Cambridge, UK 593–598
- Tetlow RM, van Dronkelaar C, Beaman CP et al (2015) Identifying behavioural predictors of small power electricity consumption in office buildings. *Build Environ* 92:75–85. doi:[10.1016/j.buildenv.2015.04.009](https://doi.org/10.1016/j.buildenv.2015.04.009)
- Toftum J (2010) Central automatic control or distributed occupant control for better indoor environment quality in the future. *Build Environ* 45:23–28

- Van De Kraats J, Van Norren D (2007) Optical density of the aging human ocular media in the visible and the UV. *JOSA A* 24:1842–1857
- Van Den Wymelenberg K (2012) Patterns of occupant interaction with window blinds: a literature review. *Energy Build* 51:165–176
- van der Lans AA, Hoeks J, Brans B et al (2013) Cold acclimation recruits human brown fat and increase nonshivering thermogenesis. *J Clin Invest* 3395–3403
- van Dongen JEF (2004) Occupant behaviour and attitudes with respect to ventilation of dwellings
- Van Meel J (2000) The European office: office design and national context. 010 Publishers
- Vine E, Diamond R, Szydlowski R (1987) Domestic hot water consumption in four low-income apartment buildings. *Energy* 12:459–467. doi:[10.1016/0360-5442\(87\)90005-3](https://doi.org/10.1016/0360-5442(87)90005-3)
- Webber CA, Roberson JA, McWhinney MC et al (2006) After-hours power status of office equipment in the USA. *Energy* 31:2823–2838. doi:[10.1016/j.energy.2005.11.007](https://doi.org/10.1016/j.energy.2005.11.007)
- Winn B, Whitaker D, Elliott DB, Phillips NJ (1994) Factors affecting light-adapted pupil size in normal human subjects. *Invest Ophthalmol Vis Sci* 35:1132–1137
- Yao R, Steemers K (2005) A method of formulating energy load profile for domestic buildings in the UK. *Energy Build* 37:663–671
- Yun GY, Steemers K (2008) Time-dependent occupant behaviour models of window control in summer. *Build Environ* 43:1471–1482. doi:[10.1016/j.buildenv.2007.08.001](https://doi.org/10.1016/j.buildenv.2007.08.001)
- Yun GY, Steemers K (2011) Behavioural, physical and socio-economic factors in household cooling energy consumption. *Appl Energy* 88:2191–2200. doi:[10.1016/j.apenergy.2011.01.010](https://doi.org/10.1016/j.apenergy.2011.01.010)
- Yun GY, Steemers K, Baker N (2008) Natural ventilation in practice: linking facade design, thermal performance, occupant perception and control. *Build Res Inf* 36:608–624
- Yun GY, Tuohy P, Steemers K (2009) Thermal performance of a naturally ventilated building using a combined algorithm of probabilistic occupant behaviour and deterministic heat and mass balance models. *Energy Build* 41:489–499. doi:[10.1016/j.enbuild.2008.11.013](https://doi.org/10.1016/j.enbuild.2008.11.013)
- Yun R, Lasternas B, Aziz A et al (2013) Toward the design of a dashboard to promote environmentally sustainable behavior among office workers. In: Berkovsky S, Freyne J (eds) *Persuasive Technology: 8th International Conference, PERSUASIVE 2013*, Sydney, NSW, Australia, April 3–5, 2013. Proceedings. Springer, Berlin, pp 246–252
- Zhang Y, Barrett P (2012a) Factors influencing the occupants' window opening behaviour in a naturally ventilated office building. *Build Environ* 50:125–134. doi:[10.1016/j.buildenv.2011.10.018](https://doi.org/10.1016/j.buildenv.2011.10.018)
- Zhang Y, Barrett P (2012b) Factors influencing occupants' blind-control behaviour in a naturally ventilated office building. *Build Environ* 54:137–147. doi:[10.1016/j.buildenv.2012.02.016](https://doi.org/10.1016/j.buildenv.2012.02.016)

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