Light, Comfort and Joy

User experience of light and darkness in Swedish homes

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Light, Comfort and Joy

USER EXPERIENCE OF LIGHT AND DARKNESS IN SWEDISH HOMES

LIGHT, COMFORT AND JOY

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Abstract

This thesis reports on user experience and behaviour relating to lighting, luminaires and window openings in Swedish homes. The aim is to increase understanding of how residents use their lighting from natural and fabricated sources, what they want from it, and when they do not want it. Another aim is to evaluate a new personalised home lighting system in terms of comfort and intention to use the system.

Saving energy, while maintaining people's health and wellbeing, through technology (e.g. using energy-saving lamps) and behaviour change (e.g. avoid wasting light) requires an understanding of residents' experiences, behaviour and technology acceptance relating to lighting. Such an understanding is essential to avoid a mismatch between users' needs and their indoor home environment, and thereby user discomfort.

The complexity of the lighting situation in the home motivated a mixed methods strategy of inquiry to collect both quantitative and qualitative data. Descriptive data regarding lamp purchasing behaviour and indoor lighting characteristics were obtained from a questionnaire survey (*Light at Home survey*). In parallel, residents' experiences with their home lighting were explored using photo-elicitation interviews with the participants at home (*My Home Lighting*). Later, the role of window openings in homes was explored in the same way, but with a new set of participants (*My Window Openings*). A final study investigated participants willingness to use a newly developed personalised home lighting system, based on wearable sensors, aiming to improve daily rhythm and sleep quality (*My Light Profile*). User evaluations included questionnaires and interviews in a full-scale model of an apartment.

Findings show what residents want from their indoor lighting (e.g. to see, show and tell, shape the space, and touch our feelings) and window openings (e.g. practical utilities, spatial brightness, spaciousness, visual openness to a view, visual privacy, observation), and what prevents them from having what they want (e.g. lack of knowledge, physical environmental features, technical infrastructure, product availability). Seemingly wasted light in people's homes, i.e. lights left on in unoccupied rooms, can serve a purpose for the residents, such as avoiding visual or aesthetic discomfort, making the home inviting, providing safety, and benefitting people outside. Window openings, serving as a different kind of illuminant, play several roles in residents' everyday lives. Provision of air, task light, and daily

rhythm in the home is essential but not sufficient. Window openings support visual delight, health and enjoyment, and mediate interactions between residents and people outside.

Findings identify multiple dimensions of comfort involved in participants' experiences of wearing sensors on the body and using a mobile phone for presence detection. Both physical wearable comfort and expectations of better performance during the day explained participants' willingness to use a personalised dynamic home lighting system in the future. Half of them were favourable to using the system.

The conclusion is that the indoor physical environment can be more supportive of residents' need for a regular 24-hour exposure to light and darkness, and dwelling comfort, e.g. by providing the appropriate technical infrastructure, a windowsill deep enough for a table luminaire, and easy installation of curtain rods and room-darkening solutions. Environmental indoor features, in turn, depend on decisions made by housing developers and landlords. Findings about user acceptance of a new lighting technology could be transferred to similar types of wearable technology and technological systems in the home, involving either wearable devices or the continuous use of a mobile phone.

Preface

The search for patterns and regularities when studying a particular social phenomenon is one of the characteristics of social science research. The broader topic in my doctorate is human and environment/technology interaction, and light and health in homes in particular. Allow me to speculate about why I ended up here at the School of Architecture in Lund once again, but this time as a doctoral student. In hindsight, it makes perfect sense that I would devote four years late in life to learning more about the multiple dimensions of light. Light, in various representations, has been a characteristic theme in my life (and probably for many others too as light touches upon everything).

The sun – the most powerful light source – has been a steady companion since my birth in the equatorial city of Nairobi, where day and night are equal length throughout the year. My given name 'Kiran' means ray of light in Hindi. A mixed Swedish-Afro-Asian upbringing included yearly celebrations of Diwali and Midsummer's Eve – festivals that both have light in common. When the family moved to a detached house in Stångby, near Lund, my sisters and I were allowed to choose the wallpaper in our rooms. I wanted a pattern with a stylised sun in various yellow hues, and it follows that my first budgie was yellow. Moving forward in time to my training as an architect, I am grateful to have had Krister Wiberg, a pioneering architect in ecological housing, as my tutor. He engaged me to set up a temporary exhibition about self-sustained communities, by contrasting the 'Sun Village' (Solbyn) with the 'Shadow Village' (Skuggbyn). After a decade as a practising architect, I was introduced to sun salutations in the yoga studio. Yoga practice has since been a regular activity in my mature adult life. On my way to yoga practice or training, I always checked whether lights were lit in my mum's apartment on the third floor while she was still alive.

Ten years ago, my husband and I had our present house built for us and our three children – Maurits, Irma and Carla – three bright and warm sunbeams. The most characteristic design features are the large south-west facing windows, thermal solar collectors on the roof and the add-on conservatory that makes it possible to enjoy the sun indirectly and directly for heating and daylighting. Interior surfaces were painted with a matt white paint or finished with natural wood to increase room brightness and create a warm cosy feeling. Curtains are made of sheer linen fabric that helps regulate, together with exterior sunscreens, the natural light entering the rooms. Fifty-five electric lamps and candlelight in winter complement the dynamic, unpredictable daylight. Black roller-blinds block out the sodium street lights at night to improve sleep.

We have let self-sown evening primrose spread in the gravel garden in front of the house in memory of my late father-in-law. In the summer evenings, the flowers open their petals and release a sweet fragrance to attract nocturnal pollinators. Like humans, plants have an internal clock that is synchronised to the 24-hour day by the light/dark cycle. When you approach the house, you are greeted by a yellow front door aimed at making you happy and warm.

While our new home was under construction, I intended to continue designing eco-friendly housing and drawing illustrations in educational books as a self-employed consultant. However, circumstances, personal choices and interest in life-long learning eventually led me to another path: doctoral studies and research on wellbeing connected to light/dark cycles and sleep/wake patterns. My dad and Tuija, the godmother of our youngest daughter, are experts on the workings of the human mind. Both encouraged me to apply for a doctorate at the university. Nevertheless, I am still a practitioner at heart, firmly convinced that the physical environment has a decisive influence on how we think, feel and act – as do our past experiences, individual characteristics, and the social world. However, my own and previous environmental psychology research have increased my awareness of how each factor often varies with the situation and context.

Personal experiences and observations have repeatedly confirmed my research findings. Here is one example. My mum's passing in October 2017 took all of us by surprise. After clearing her belongings, her apartment stood empty for a couple of months. I deliberately left the light turned on in her empty balcony during December and January, which was uncharacteristic considering how mindful I am about the environment and energy conservation. The light left on reminded me of her spirit being somewhere among us. I imagined a lit balcony would also look more pleasant for her neighbours than an utterly dark apartment in the evenings. So, light is powerful and touches upon everything, such as health, mood and memories. Light is not only about seeing. It can be loaded with various meanings to residents and can be used to send messages to others, both figuratively and literally through fibre.

Besides electric lighting, sleep has become highly valued in my personal life since 2013. Friends and family know I am early to bed and early to rise, even during free days to avoid social jetlag. I have always been happy to greet the sun in the mornings as I am a moderate early type, according to the Munich Chronotype Questionnaire (MCTQ).

One conclusion in my thesis is that lighting design must involve concerns about the psychology of light and its social impact, along with the environmental consequences of residents' lighting behaviour. I am thankful to all close to me who made this transdisciplinary travel on bumpy trails possible: my sisters, mother-in-law, brothers-in-law, sisters-in-law, relatives in Sweden and Birmingham, and

friends who have to put up with my often overly enthusiastic and inquisitive manner. Special thanks go to my husband, a writer and philosopher, for his sincere critique and loving support.

The light in me thanks the light in you. Namaste.

Kiran Maini Gerhardsson, March 2020

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Pursuing a doctorate degree has much in common with yoga practice, as it is a journey of the self, through the self. But there is a significant difference – the dependency on other people's support and guidance. I would like to express thanks to my main supervisor Thorbjörn Laike and co-supervisor Maria Johansson. Thorbjörn's inspiring public talks sparked my interest in electric lighting and human perception of light. Over the years, I have come to appreciate Maria's way of pushing my writing forward and thinking about theory. Thank you also, Eja Pedersen, for unknowingly serving as my informal mentor. Many other seasoned researchers have, through conversations knowingly or unknowingly, helped me navigate in new terrains: Mark Rea and Mariana Figueiro, Arne Lowden, Steve Fotios, Chris Baber, Debra J. Skene, Kenneth Wright, Malcolm von Schantz, Claudia Moreno, Susan Carter, Nanet Mathiasen, Myriam Aries, Barbara Szybinska Matusiak, and Wendy Rogers.

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Finally, I would like to give my special thanks to the research participants for taking the time to help advance research on lighting in homes.

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List of original articles

Article 1
Gerhardsson, K. M., Laike, T., & Johansson, M. (2019). Residents' lamp purchasing behaviour, indoor lighting characteristics and choices in Swedish homes. *Indoor and Built Environment, 28*(7), 964–983.

Article 2
Gerhardsson, K. M., Laike, T., & Johansson, M. (2020). Leaving lights on – a conscious choice or wasted light? Use of indoor lighting in Swedish homes. *Indoor and Built Environment*. Advance online publication.
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Article 3
Gerhardsson, K. M. & Laike, T. (2019). Window openings: A study of residents' perceptions and uses in Sweden. Manuscript submitted for publication.

Article 4
Gerhardsson, K. M. & Laike, T. (2019). User acceptance of a personalised home lighting system based on wearable technology. Manuscript submitted for publication.

Article 5
Gerhardsson, K. M. (2019). Multiple benefits of adding participant photography to qualitative residential research. Manuscript submitted for publication.

Author's contribution

Article 1
Kiran Maini Gerhardsson (KMG) and Thorbjörn Laike (TL) designed the survey study and Maria Johansson (MJ) contributed. KMG initiated and designed the interview study, and TL and MJ contributed. KMG collected and interpreted all data and drafted the article. TL and MJ made critical revisions.

Article 2
KMG initiated, conceptualised and designed the study, and TL and MJ contributed. KMG collected and interpreted all data and drafted the article. TL and MJ made critical revisions.

Article 3
KMG initiated, conceptualised and designed the study, and TL contributed. KMG collected and interpreted all data and drafted the article. TL made critical revisions.

Article 4
KMG designed the study, and TL contributed. KMG collected and interpreted all data and drafted the article. TL made critical revisions.

Article 5
KMG analysed the method used in the interview studies and wrote the article.

Abbreviations

ALLEA	All European Academies
CIE	Commission International de l'Eclairage (International Commission on Illumination)
CCT	Correlated colour temperature
CFL	Compact Fluorescent Lamp
GFT	Goal Framing Theory
GLS	General Lighting Service
ipRGCs	Intrinsically photosensitive retinal ganglion cells
IES	The Illuminating Engineering Society
LED	Light-emitting Diode
SDGs	The Sustainable Development Goals
UTAUT	The Unified theory of Acceptance and Use of Technology
UV	Ultraviolet

1 Introduction

This thesis reports on user experience and behaviour relating to lighting, luminaires and window openings in homes. It concludes with some pointers for ways in which light and darkness can be used to promote health. The broader phenomenon under study is human and environment/technology interaction.

Studying conditions for light and darkness in homes is particularly relevant for at least two reasons that will be further described in the background section: 1) consequences relating to urban densification, such as the obstruction of much of the sky and thereby less exposure to daylight indoors (Tregenza & Wilson, 2011), and 2) consequences relating to the rapid advances in lighting technology for homes since the broad introduction of light-emitting diode (LED) lamps and luminaires for consumers. The proposition of this thesis is to recognise residents' needs and desires as a starting point instead of the inherent possibilities of new lighting technologies to avoid 'technological solutionism' (Morozov, 2013). The term reflects the idea that any social problem can be fixed through technology, thereby ignoring the complexity of person-environment interaction problems.

Field research on lighting preferences and use in ordinary homes is limited. In a review of research on the effects of windows on residents, it was concluded that much remains to be done until we understand the role of daylight in residential buildings (Veitch & Galasiu, 2012). Recent work in Scandinavia includes studies of, e.g. the relationship between window size and electricity use for lighting (Logadottir et al., 2013), the low uptake of energy-efficient lighting technologies in low-energy housing (Jensen, 2014), the relationship between placement of light sources and activities based on visual analyses of images in interior magazines for non-professionals (Stidsen et al., 2014), lighting design and culture from a historical perspective (Lytken, 2016), people's relationship to window openings and light in profane buildings during the middle ages (Qviström, 2019), and the cultural and social role of contemporary home lighting (Bille, 2019). Missing in these pioneering studies in a Scandinavian context is the inclusion of light from both natural and fabricated sources, and the varying conditions during the day and night.

1.1 Background

This sections contains a description of the contextual factors influencing conditions for light and darkness by situating the home in the physical and cultural environment (dwelling types, urban setting, climate conditions, housing design features, and home comfort qualities), followed by the ways light/dark cycles impact on the individual and how, in turn, people's light-related behaviour affects the environment.

1.1.1 Homes in cities

One reason for directing attention to light and darkness in home environments is because of the time spent at home. One study showed that German people spend an average of 15.7 hours per day (65%) indoors at home (Brasche & Bischof, 2005). Older persons (19.5 h) and pre-school children (17.6 h) are those who spend the most time at home. Similar results have been reported in North America (Leech et al., 2002) and for Swedish households living in single-family houses (Hiller, 2015).

A home is not necessarily a house (Rykwert, 1991; Douglas, 1991). Throughout the thesis, homes represent dwellings in physical structures with a permanent address. Forty percent of all households in Sweden are single-person households (Statistics Sweden, 2019a). A majority (53%) of the Swedish population live in one- or two-dwelling buildings (i.e. detached, semi-detached, or terraced houses), 42% in apartments in multi-dwelling buildings (i.e. including three or more apartments), and the rest in special housing (assisted living or student housing). For comparison, 60% of the population in the 28 member states of the EU lived in a detached, semi-detached, or terraced house, and 40% in apartments in 2014 (Eurostat, 2016). The largest proportion of the Swedish population living in apartments live in rented apartments (60%), with the remainder living in tenant-owned apartments (40%) (Statistics Sweden, 2019b). In this tenure model, common in Sweden, tenants own a share of the housing association which in turn owns the building.

Most Swedish people (63%) live in dwellings in urban areas with at least 10,000 inhabitants (Statistics Sweden, 2019c). Living in cities has several benefits that are addressed in the 2030 Agenda for Sustainable Development (goal 11) (UN, 2015). Urban living means access to essential services, energy, housing, and transportation. For example, electricity from shared grids means dwellings can be illuminated with electric light sources during evening hours. (Globally, it is estimated that 840 million people still live without electricity, and are instead dependent on, e.g. kerosene or candles (World Bank, 2019.))

Urbanisation is a prominent trend in urban development, globally as well as in Sweden, and is estimated to continue (Eurostat, 2016). However, densification of urban areas involves several challenges of different types and to varying degrees depending on location and local conditions.

1.1.2 Dense cities and climate conditions

One challenge in dense new or re-developments is the spacing between buildings because buildings obstruct access to daylight by reducing the amount of light from the sky entering a room and blocking sunlight.

A rule of thumb for cloudy climates is to keep the average height of external obstructions below a line 25 degrees above the horizon, measured from the centre of window, see Figure 1.1a (Tregenza & Wilson, 2011). In recent infill developments and large new urban developments, the obstruction angle can be closer to 45 degrees and above, in rooms at ground level. It is difficult to achieve sufficient daylight conditions indoors when obstructions are as high as 45 degrees. Other obstructions affecting daylight levels indoors are, e.g. roof overhangs and protruding balconies above the window. The density of surroundings and building configuration are therefore of great concern for the indoor use of daylight and compliance with daylight regulations (see Figure 1.1.b,c) (Bournas & Dubois, 2019).

Current Swedish regulations require a daylight factor of at least 1% measured in a single point in the middle of a habitable room (Swedish National Board of Housing, Building and Planning, 2019a). The daylight factor, which gives a general impression of daylight conditions in a room, is the illuminance on an internal surface expressed as a percentage of the external illuminance with an unobstructed view of the sky (see Figure 1.1d). Illuminance, or the light level, is measured in lux (lx), which equals lm/m^2, and describes the visual content of the radiation received by a surface per unit area, whereas global horizontal irradiance is measured in W/m^2 and concerns the total content of radiation received by a surface per unit area.

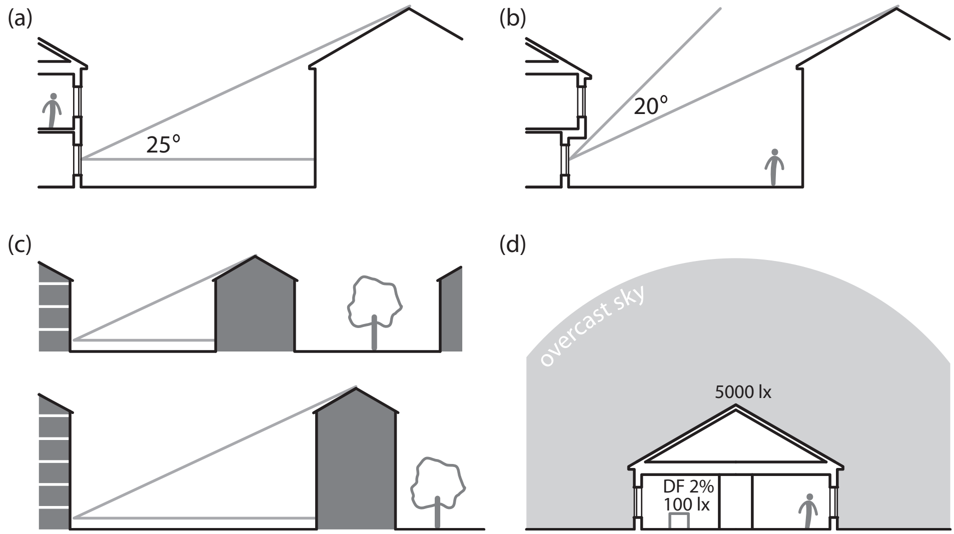

Figure 1.1 Illustration of (a) obstruction angle, (b) angle of visible sky, (c) spacing of buildings, and (d) daylight factor.

The most important factors relating to the provision of daylight in a room are: 1) the luminance (brightness), of the section of the sky as seen from behind the window, 2) the angle of the visible sky, and 3) the capacity of the window to admit daylight (glazing area and transparency) (Fontoynont, 2013). A recent study found that residents perceive indoor brightness to be high when outdoor global horizontal irradiance is high (Bournas et al., 2019), which means that observer-based assessments of brightness can be used in post-occupancy evaluations of daylight.

Illuminance from direct sunlight in high-latitude regions is lower than in places closer to the Equator. At 55° N (e.g. Copenhagen) sunlight on the ground is around 70,000 lx at noon on 23 June, but only 5,000 lx on 23 December (Tregenza & Wilson, 2011, p. 67). At midday in December, in an office room (2 x 4 m) with a daylight factor of 2%, daylight will contribute 100 lx on a desk placed in the middle of the room, which can be compared to the recommended light level of 500 lx on desks in a general office (European Committee for Standardization, 2011). Close to the window, however, daylight levels can be five times higher.

One field study compared light levels between homes, workplaces and public places, as well as light levels during the day and evening, and the influence of age (Charness & Dijkstra, 1999). Measured brightness at favourite reading locations in the homes, was almost twice as high on average during the day compared to the evening (calculated median illuminance values on reading task pages ≈ 170 lx and 90 lx respectively). This suggests that daylight may contribute to a significant proportion of indoor lighting during the day where reading activities take place, while the home is insufficiently lit in the evening for reading tasks.

The local climate in Scandinavia is characterised by a low frequency of sunny skies during the year, ranging from 20% to 40% (see Figure 1.2). Cloudy skies are especially frequent in winter resulting in lower sky luminance. Other typical features are the low solar elevation angle during the year because of the location at higher latitudes, and long periods of twilight (Matusiak, 2017). In Sweden, daylight hours vary greatly over the year and with latitude, between 0–24 h in the north (69° N) and 7–17.5 h (55° N) in the south (SMHI, 2011).

The lack of daylight at higher latitudes may be involved in reported problems with seasonal changes in mood and sleep in winter (Adamsson et al., 2018; Küller et al., 2006; Lowden et al., 2018; Wirz-Justice, 2018), although the exact causes are still not known (Lowden & Favero, 2017; Blume et al., 2019). Approximately 40% of the adult Swedish population have problems with feeling tired and less energetic during autumn and winter, and one-third report insufficient sleep (SLOSH, 2014).

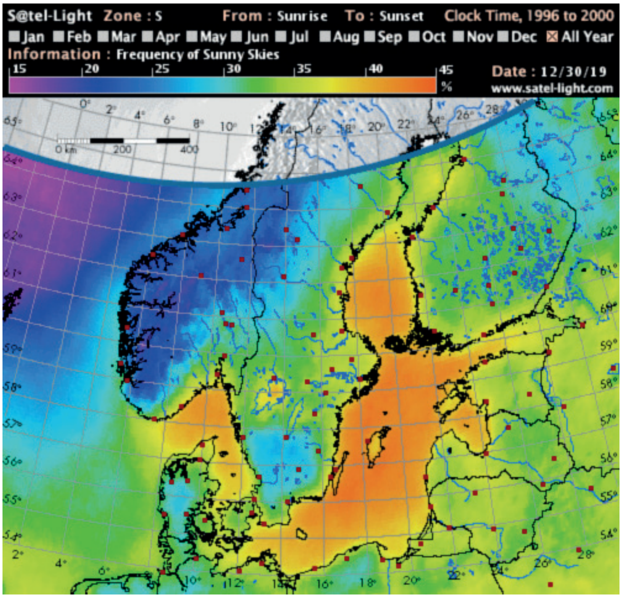

Figure 1.2 Sunny skies in Scandinavia. Map showing the frequency (%) of sunny skies from sunrise to sunset throughout the year, based on data collected 1996–2000. The frequency ranges from 20% to 40%, which can be compared to Italy where skies are sunny around 60% of the time. (Satel-Lite, 2019).

1.1.3 Healthy homes and home comfort

In Sweden, many of the multi-dwelling buildings that are still in use were planned according to the principles of functionalism that characterised new housing developments from the late 1920s to the 1970s. Essential elements were, e.g. sufficient daylight, sunlight, natural ventilation and a view to outside greenery. Such concerns were partly a reaction to poor living conditions at that time. Dwellings for ordinary people in cities around 1900 lacked sanitation, and courtyards were dark and dense with side and rear wings. In the 1920s, new urban developments featured large courtyard blocks, and living conditions gradually improved (e.g. access to running hot water, bathrooms, electric lighting in the dwelling, and waste disposal systems). After 1930, residential developments were characterised by open or semi-open arrangements of buildings and front yards (Nylander, 2018). These types of buildings (e.g. semi-open courtyard blocks, high-rise and low-rise towers), commonly built between 1930 and 1960, have been found to perform better with regard to daylight (Bournas & Dubois, 2019). Performance, in terms of the daylight factor, was assessed using simulations in the habitable rooms of a representative sample of multi-dwelling buildings in Sweden.

The principles of functionalism were main concerns of the architects involved in the modernist, or functionalist architecture movement that grew after the First World War and later spread around the world (e.g. Chandigarh and Brasilia). One milestone was the founding of the Staatliches Bauhaus (1919–1933), formed by Walter Gropius in Weimar. Courses in architecture at the Bauhaus promoted the idea of buildings as the product of function and economics (Musgrove, 1987). Another milestone was the influential writings by Le Corbusier, such as 'Vers une Architecture' (1923) and 'Ville Radieuse' (first presented in 1924, published in 1933). The principal idea was the use of widely spaced high-rise buildings and separating dwellings from workplaces, enabling ordinary people to live with light, air and foliage (Furneaux Jordan, 1985), or as expressed by Le Corbusier (1936/1976): "Sunlight, air and green trees are the 'elementary pleasures'". Housing design and planning was based on a rational order similar to machines. To Le Corbusier, the house served as a tool for the provision of necessities, "a machine for living".

The housing estate Siemenstadt in Berlin, built between 1929 and 1931, serves as an example of what architects at the time wanted to achieve: affordable and democratic access to the same daylight, sunlight and fresh air. Hans Sharoun, who was responsible for the overall planning, included only multi-dwelling buildings with apartments (2–2½ rooms per unit). All apartments were equipped with private bathrooms, windows in two directions to ensure adequate conditions for light and ventilation, and balconies. Unlike the existing closed block-edge developments with dark courtyards in Berlin, the Siemenstadt estate was characterised by an open arrangement of buildings facing either east-west or north-south, in long and short rows (see Figure 1.3).

Architects practising the ideas of functionalism had good intentions for ordinary people. Their ideals characterised much of the post-war housing in Sweden and countries in Europe. Through urban planning and architectural design, their goal was similar to the sustainable development goal 3, "to ensure healthy lives and promote wellbeing for all at all ages" (UN, 2015).

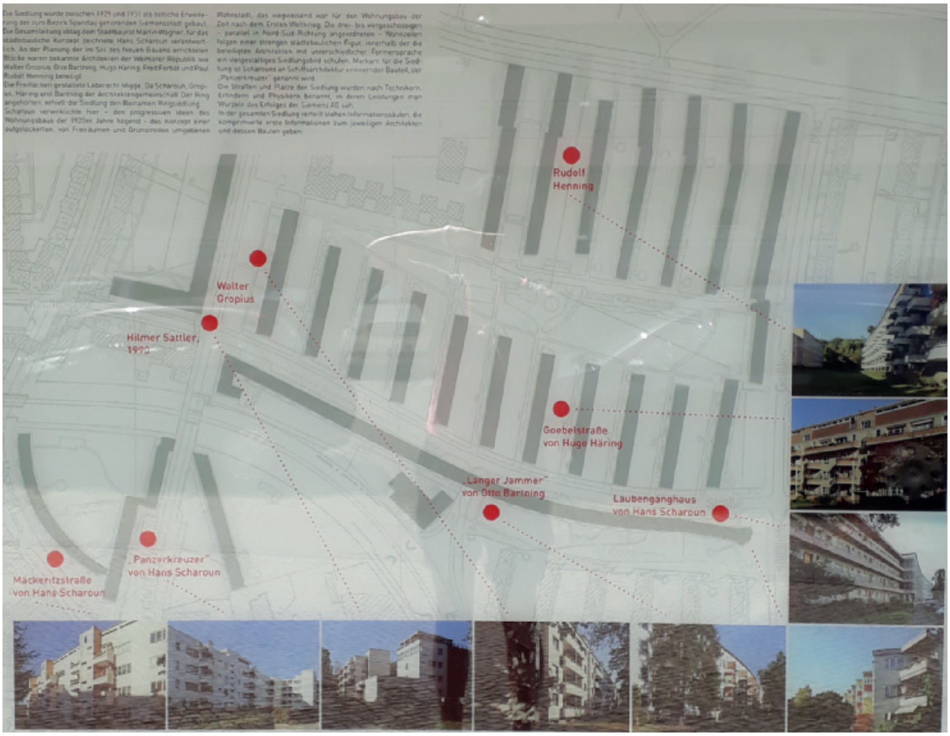

Figure 1.3 A site plan of the housing estate Siemenstadt (1929–1931), showing the open arrangement and equal spacing between the rows of buildings (designed by Hans Scharoun, Walter Gropius, Otto Bartning, Hugo Häring, Paul Rudolf Henning, and Fred Forbat). (Photograph taken by the author at the information point in the estate.)

The principles of functionalism resulted in design features and comfort qualities that are still much appreciated by residents. In a Danish study, factors such as light/sun, temperature/warmth, fresh/clean air, sound level, peace/silence, nature and view were reported to contribute to perceived home comfort. The purpose of the room together with daylight conditions were especially important for creating a cosy atmosphere (Frontczak et al., 2012). Similarly, in a study among homeowners living in detached or semi-detached houses in Scotland, a thematic analysis of comfort resulted in five physical-psychological meanings, one of which relates to lighting. These meanings concern thermal comfort, relaxation, visual comfort (e.g. looking at nice things and having appropriate lighting), control (e.g. doing what you want), mental wellbeing (e.g. at ease) and familiarity (e.g. having your stuff and usual routines) (Ellsworth-Krebs et al., 2019).

Homes in Sweden are particularly well suited for exploring residents' light-related needs and desires because of the extent to which residents are free to choose their interior lighting. Unlike some countries, the responsibility to choose and mount the luminaires in Swedish homes lies with the resident, except for a few fixed luminaires in the kitchen, walk-in closets, bathroom and the laundry.

However, in rented homes, the tenant has an obligation to repair any holes and must cover the repair costs of any alterations. There are recommendations but no detailed national regulations concerning the specific light levels (illuminance) or room brightness (luminance) for dwellings, unlike workplaces (Swedish Institute for Standards, 2011). There are legal requirements for daylight conditions (a daylight factor of at least 1% at a specific point) but are not measured after occupancy, unlike the obligatory ventilation control in residential buildings (Swedish National Board of Housing, Building and Planning, 2019b).

1.1.4 Body-mind and a 24-hour cycle of light and darkness

Human perception of light is the process by which the brain organises and makes sense of environmental visual information. Other sensory systems essential to human functioning and experiences besides vision are hearing, taste, smell, touch (pressure, pain and temperature), balance and body position (Holt et al. 2015). The perceptual process is dependent on the context, which means sensory information can be perceived in different ways at different times. A brightly lit bathroom can be perceived as unpleasant and dazzling early in the morning but pleasant in the evening while you are doing the same activity. Responses to light also depend on people's expectations, formed by previous experiences, culture and climate (Tregenza & Wilson, 2011). One example is the usual colours of a space where the floor and ground surfaces are dark, while ceilings are light-coloured. Light usually flows downwards, either from the sky or from overhead electric lighting. The opposite may trigger different perceptual reactions to the lighting situation (Tregenza & Wilson, 2011). Another example of cultural preferences is the strong appreciation of sunlight among Danish homeowners (Hauge, 2015). Expectations about daylit rooms may vary depending on whether it concerns a permanent home or a temporary home (e.g. a windowless guest room in a hotel).

Visual perception is affected by the properties of light, matter (e.g. air molecules and surfaces causing light waves to change direction) and the visual system (the eyes and connecting neural pathways to the visual cortex and other parts of the brain). Light is defined as "radiant energy that is capable of exciting the retina and producing a visual sensation" (IES, 2018). The total solar energy distribution on the surface of the earth extends from about 300 to 3,000 nanometers (nm), of which around 5% is ultra-violet radiation (UV), slightly more than half is light (380–780 nm), and slightly less than half is near-infra-red, or heat (Josefsson, 1986).

When light reaches the eye, photons activate two different photoreceptors in the retina. A third type of photoreceptor was identified early this century – intrinsically photosensitive retinal ganglion cells (ipRGCs) containing the light-sensitive pigment melanopsin (with a peak spectral sensitivity between 460 and 480 nm) (Berson et al., 2002; Freedman et al., 1999; Hattar et al., 2002; Lucas & Foster, 1999; Lucas et al., 1999; Provencio et al., 2000; Lucas et al., 2014). The ipRGCs are directly involved in the regulation of circadian rhythm, and recent findings in an animal study suggest that they may also have direct effects on mood (Fernandez et al., 2018).

Figure 1.4 shows a simplified model of two neural pathways in the brain influenced by light. The image-forming pathway produces images. Bright light and contrast facilitate visibility and the ability to see details, as do the size, location and colour of the object perceived by the observer. Four factors affect visual task performance, i.e. the ability to perform a visual task: 1) task illuminance (light level and distribution), 2) contrast within the task, 3) contrast between the task and its surroundings, and 4) absence of disability glare (Tregenza & Loe, 2014). Visual comfort is the absence of feelings of discomfort, which may occur when a light source or a surface is too bright compared to its surroundings. Visual experience can be described by factors such as spatial brightness, pleasantness, variation and colour (Johansson et al., 2014; Küller & Wetterberg, 1993), or by its socio-cultural message (Bille, 2019).

Changes in vision occur at around the age of 40 because the lens and cornea stiffen and become yellowed. Age-related visual impairment involves trouble with focusing on nearby objects, switching focus between near and far, reduced ability to distinguish small differences in contrast, and greater susceptibility to glare (Tregenza & Loe, 2014).

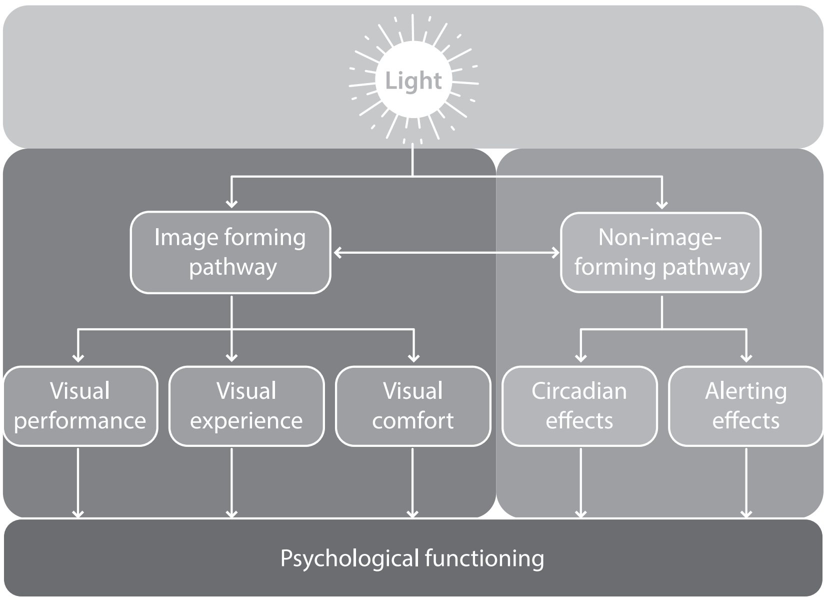

Figure 1.4 Neural pathways of light, or routes in the brain, relevant to psychological functioning, such as perception, cognition, affect, communication, comfort, and sleep (adapted from de Kort & Veitch, 2014).

The non-image-forming pathway involves effects on the circadian system (an internally generated rhythm of nearly 24 hours) and acute effects on structures related to wakefulness and alertness (Cajochen et al., 2014; Figueiro & Rea, 2010; Sahin & Figueiro, 2013, Figueiro et al., 2018; Blume et al., 2019). The responses of the circadian system are mediated primarily by the ipRGCs, while alerting effects of light involve the visual photoreceptors. The alerting effects of light are quick, similar to having a cup of coffee, whereas circadian entrainment is a slow process.

Several biological processes show a 24-hour variation, such as core body temperature, blood pressure, heart rate, cortisol, growth hormone, alertness, and mood (Foster & Kreitzman, 2017). What defines circadian changes is that they continue in the laboratory under constant conditions, in which individuals must be kept in isolation without any external 24-hour time cues for multiple days. Individuals stay in a half-seated position, eat small meals frequently under dim lighting conditions, and either stay awake or are allowed short naps (Duffy & Dijk, 2002).

Since the internal biological (circadian) clock is slightly longer on average (about 24 hours and 10 minutes) in both young and older adults, the clock needs resetting every day to prevent daily activity patterns from drifting, or free running, over time (Czeisler et al., 1999; Duffy et al. 2011). Light, meal timing or physical activity can act as environmental time cues, i.e. adjusting the internal body clock to the 24-hour day. However, the external light/dark cycle is the most powerful external synchroniser that can shift the phase of the circadian rhythm and regulate the timing and quality of sleep (CIE, 2019).

For diurnal species like humans, exposure to light at dawn will generate earlier sleep time and an advance in activity the next day. In contrast, exposure to light around dusk will cause delayed sleep time and a delay in activity the next day (Khalsa et al., 2003). The shifting effects on circadian rhythm depend on whether the individual is exposed to light before or after minimum core body temperature, which occurs early in the morning, about two to three hours prior to habitual wake time (Khalsa et al., 2003). The timing of light exposure is, however, not the only lighting characteristic that influences the circadian system. Other factors are the duration of the light, quantity, spectrum and the individual's prior light history (which seems to reduce the sensitivity of the circadian system) (Chang et al., 2011; CIE, 2015; Rea et al., 2002).

The circadian clock is one of three 'competing' clocks structuring people's lives (see Figure 1.5). Misalignment between internal circadian time and external time has consequences for sleep quality, daily performance and mood. One example is travel jetlag caused by rapid trans-meridian travel across several time zones, or shift work. Symptoms of jetlag are problems in sleep, digestion and performance because the internal clock cannot move immediately and synchronise to local time. Circadian entrainment is a slow process that requires repeated shifting stimuli over several days (Foster & Kreitzman, 2017). Another example is social jetlag because of a mismatch between working hours in weekdays and internal time (Wittman et al., 2006). Often, such a mismatch causes a sleep debt and results in sleep-ins during free days (Roenneberg et al., 2012; Roenneberg et al., 2019a). According to a large survey, only 13% of the people who responded are free from social jetlag. About two-thirds suffer from 1 hour of social jetlag and a third from 2 hours or more (Roenneberg et al., 2012).

Figure 1.5 Three clocks structuring people's daily lives (Roenneberg et al., 2003): (a) a biological (circadian) clock driven by peripheral clocks in the body and a master clock – the suprachiasmatic nuclei, (SCN), (b) a social clock (social obligations and evening engagements, e.g. work hours), and (c) a solar clock showing environmental time (a 24-hour day with light and darkness because of the rotation of the earth).

The ability of adults to handle differences between wake times during workdays and natural wake times during free days is related to morningness and eveningness chronotypes (as measured on a spectrum ranging from extremely early to extremely late types). An individual's chronotype can be estimated from the halfway time between sleep onset and wake time on free days, which is then corrected for oversleep on free days because of short workday sleep duration (Roenneberg et al., 2007a; Roenneberg, 2012). Late types have more trouble getting up early in the morning on workdays, while early types have difficulties with evening engagements on free days because they still get up early the next morning. Chronotype is linked with the timing of sleep and only indirectly to the duration of sleep. Late types who experience too short workday sleep will accumulate a considerable sleep debt and sleep longer on free days (Roenneberg et al., 2007a).

Chronotype is partly influenced by genetics (biological day length), but also by the natural light/dark cycle within a particular time zone. Early types are more frequent in the eastern part of a time zone (e.g. Central European time) compared to the western part, where more late types are more frequent (Roenneberg et al., 2007b; Foster & Kreitzman, 2017). A third factor influencing an individual's chronotype is age. The internal clock has a later phase from late childhood to young adulthood. Lateness peaks at around the age of 20, whereas earliness is more frequent among older adults over 60 (Roenneberg et al., 2007a).

The circadian clock is not the only driver for sleep in humans. A homeostatic process is also responsible for regulating sleep. The pressure to sleep increases with increasing time awake, which for some is manifested by the post-lunch dip (Lockley & Foster, 2012). These two bodily processes are shown in Figure 1.6.

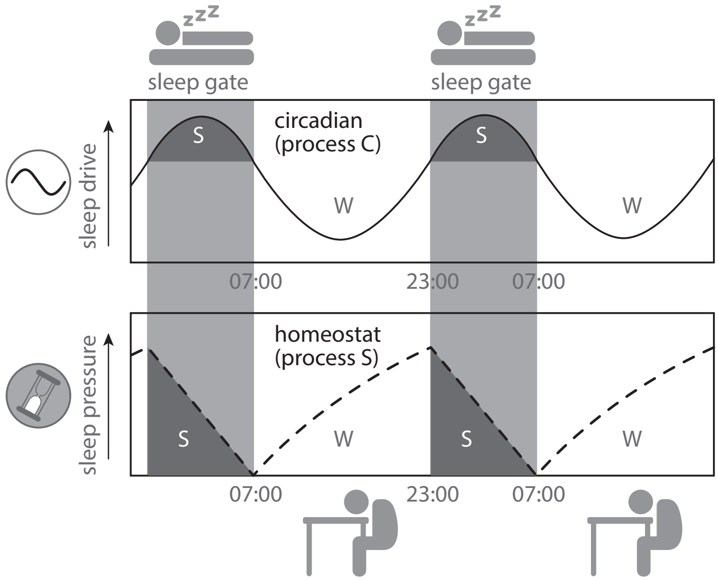

Figure 1.6 The two-process model of sleep regulation – the circadian process (top) and the homeostatic process (bottom). The biological marker for the circadian process is melatonin, while adenosine is one of the markers for the homeostatic process. The circadian clock (process C) drives wake (W) during the day but is opposed by the homeostatic process (process S). Process S describes the process in which sleep pressure rises until sleep (S) is initiated late in the evening, and then dissipates at night. The ideal time for sleep (sleep gate) occurs as a result of the combined effects of both processes (adapted from Lockley and Foster, 2012, p. 18).

Sleep is central to health and wellbeing because sleep affects, e.g. daytime alertness, mood and performance patterns, and several factors, in turn, influence sleep. Figure 1.7 illustrates how sleep as behaviour can be studied from different angles: biological, psychological or environmental.

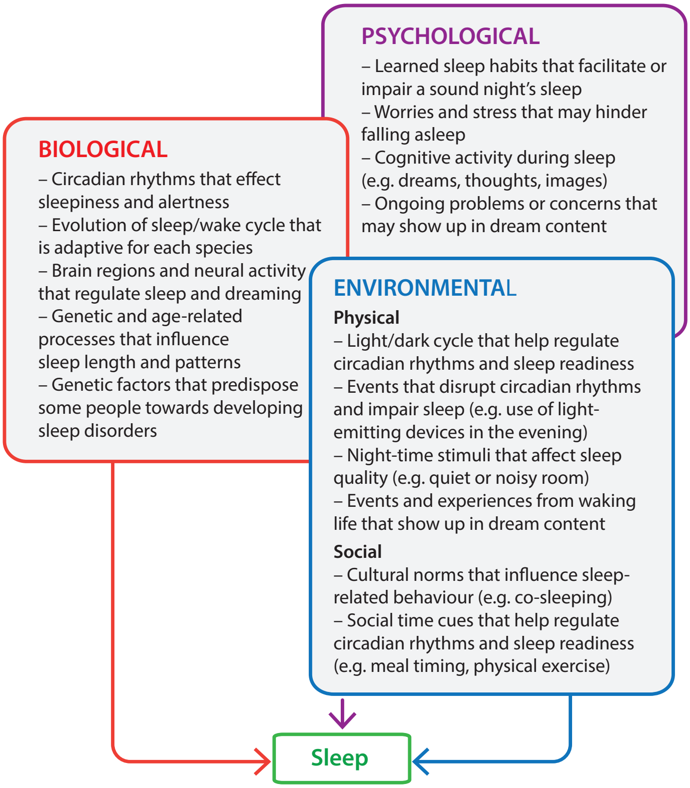

Figure 1.7 Sleep as behaviour can be studied from different angles (adapted from Holt et al., 2015, p. 244. The original version of the figure does not distinguish between the physical and social environment, and the output includes 'sleep and dreaming').

Figure 1.8 is a timeline showing a selection of seminal research on circadian regulation and technical advances leading up the development of a personalised home lighting system based on sensors and a mobile phone app. The figure is extremely simplified. I have, for example, not included the achievements of Wetterberg and Küller (see Küller, 1981), who at an early stage recognised the significance of non-image-forming effects of light, or the lighting research in various domains conducted by the Lighting Research Center in Troy, New York. Swedish biologists and physicians played an essential role in the early development of the international society for biological rhythms (Shackelford, 2013). The Internationale Gesellschaft für Biologische Rhythmusforschung (later known as the Society for Biological Rhythms) was, for example, initiated in 1937 in Ronneby, Sweden. The timeline starts, however, with the meeting in Cold Spring Harbour, since it is considered to be a turning point in the history of chronobiology, and because the systematic study of circadian rhythms started in the 1950s (Foster & Kreitzman, 2017).

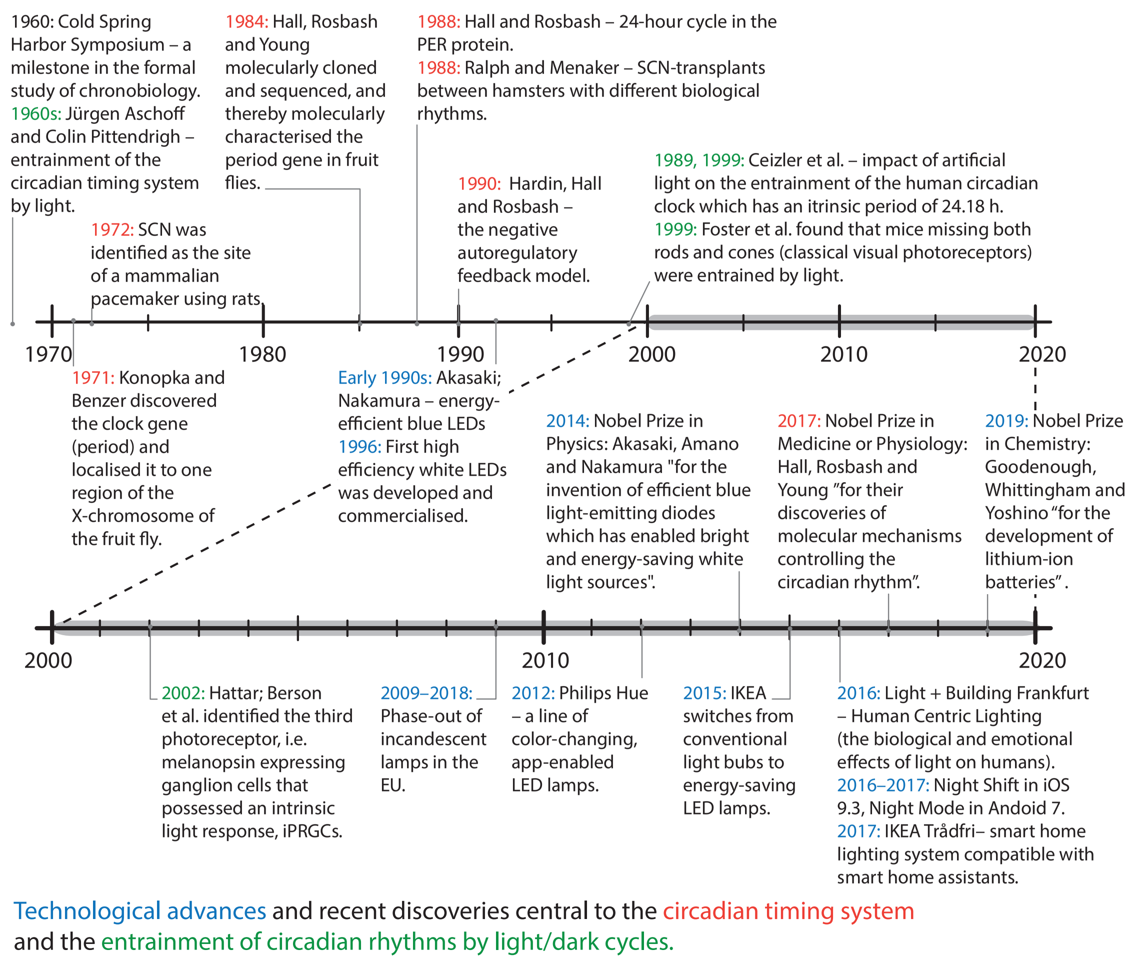

Figure 1.8 Timeline showing a condensed summary of seminal research and events relating to dynamic LED applications in the home. (SCN – suprachiasmatic nuclei; iPRGCs – third class of photoreceptors called intrinsically photosensitive retinal ganglion cells; LEDs – light-emitting diodes.)

1.1.5 Environmental impact from indoor lighting

Both natural light sources and electric lamps impact people's behaviour, such as daily performance and sleep time. However, the use of electric light has environmental consequences. The second decade of this century saw the broad introduction of light-emitting diode (LED) lamps and luminaires for consumers. LED lamps deliver more light relative to the power input (70–200 lm/W) than incandescent lamps (15 lm/W), can be dimmed and change colour (the correlated colour temperature, CCT), and last longer. (For comparison, global luminous efficacies of daylight are around 105 lm/W for overcast skies (Littlefair, 1985)).

The downside of rapid technological change, although necessary for energy-saving reasons, can be poor performance quality because tests and standards are insufficient. Poor lamp quality, in turn, may lead to user dissatisfaction, or less acceptance of future technological transitions. Other potential worries are the rebound effects of energy-efficient lamp technologies, i.e. offsetting some of the energy savings because of changes in people's behaviour (Hicks et al, 2015). For example, electricity consumption will rise if consumers use more lamps or leave lights on much longer than traditional incandescent lamps.

The electricity used for lighting in homes depends on household size. In a metering campaign conducted in Swedish households before the phase-out of incandescent lamps, consumption ranged from about 650 to 940 kWh/year in houses and 240 to 690 kWh/year in apartments (Zimmerman, 2009). In the current period of transition, there are no up to date figures, but it is estimated that replacement of incandescent lamps will save 10% of the total electricity use in households (Swedish Energy Agency, 2015).

Another characteristic of the use of lighting in high-latitude regions is a seasonal variation in electricity for residential lighting because daylight hours are shorter in winter. Compared to the approximate time of the March equinox, when day and night are of equal length, electricity consumption for lighting in Swedish homes is raised by a factor of 1.8 in winter, and is reduced by a factor of 0.6 in summer (Zimmerman, 2009).

Relating to the sustainable development goals, 'Responsible consumption and production' (goal 12), and 'Climate action' (goal 13), the use of electric light from LED lamps impacts negatively on the environment. Rare earth metals, e.g. yttrium and cerium, are used in the phosphor coatings of blue light-emitting diodes that convert blue short-wavelength light to white light. Although light-emitting diodes contain minimal amounts of rare earth metals, resources are threatened by the increasing consumption of electronic products. Future scarcity is not included in life cycle assessments, as they only consider currently available resources and recycling of rare earth metals is limited (Tähkämö et al., 2014). The most significant environmental impact is associated with the energy consumption during the use phase (85%), followed by manufacturing and disposal (15%), and transportation (1–2%). Consequently, the two most critical performance factors of LED lamps are high luminous efficacy (lumens per watt) and long lamp life (Tähkämö et al., 2014).

1.2 Problem statement and purpose

Promoting healthy, resource- and energy-efficient home lighting through technology (e.g. using energy-saving lamps) and behaviour change (e.g. avoid wasting light) requires an understanding of residents' experiences, behaviour and technology acceptance relating to lighting. However, this topic is poorly understood in home settings. Improved understanding is essential to avoid a mismatch between users and their indoor home environment and thereby user discomfort.

The aim of this thesis project is to increase understanding of how residents use their lighting from natural and fabricated sources, what they want from it, and when they do not want it. Another aim is to evaluate a new personalised home lighting system in terms of comfort and intention to use the system.

1.2.1 Research questions

In an attempt to address the need described above, the thesis sets out to answer the following research questions:

1. What lights do Swedish residents have in their homes, and what factors influence their illumination choices?
2. How do residents perceive and use daylight and their window openings during the day and night?
3. How willing are residents to use a sensor-based and energy-efficient home lighting system aimed at improving health, in terms of daily rhythm and sleep quality?

Four field studies were conducted to answer the research questions: *Light at Home survey*, *My Home Lighting* (interview study), *My Window Openings* (interview study), and *My Light Profile* (a combined lab and field study). Theoretical underpinnings and the research design are described in the following chapters.

2 Theoretical considerations

Opting for a contextual research approach, two theoretical perspectives served as a point of departure for understanding the range of factors that are likely to be involved in perception and behaviour relating to light and darkness in the home: *embodied cognition* and *the ecological perspective of human and environment interaction* (Robinson, 2017; Stokols, 1987). The conceptual *Framework to Understand Motivation and Emotion,* proposed by Reeve (2018), underlies the overall viewpoint I have taken when analysing and interpreting the data. Three existing theories linked to the concept of motivation were used in the empirical work, namely *Goal Framing Theory*, *Unified Theory of Acceptance and Use of Technology*, and *Basic Needs Theory*.

2.1 Theoretical perspectives

Central to *embodied cognition* is that all human actions depend on the brain functioning as an organic member of the body, which in turn is engaged in the environments where humans dwell (Robinson, 2017). In other words, our mind dwells in a body, which is situated in both the physical and social world. Body senses, peripheral vision and movement, are essential to people's experiences of the physical world (Pallasmaa, 2005; Rasmussen, 1964). All senses interact and shape people's experience of the environment they inhabit. People's expectations of the world are formed by individual characteristics, previous sensory experiences, social interactions, and cultural practices.

Accepting that the mind includes aspects of the physical and social world implies that the design of the environment can affect the mind and its capacity for thought, emotion and behaviour (Robinson, 2017). Importantly, the self is not separate from the environment and does not operate in isolation from its environment (Dewey, in Johnson, 2017).

Another way of understanding people's interaction with their environment is the *ecological perspective*, which has been applied in the field of environmental psychology (Stokols, 1987). Central to this perspective is the dynamic interplay between people and their everyday environmental settings (contexts). Stokols (1993) regards adaptation and optimisation as core themes in such ecological/contextual analyses of human behaviour. The analytical focus is on the ways in which people adapt to their socio-spatial surroundings and ideally strive to improve the degree of fit, or match, between their individual and collective needs, and the quality and structure of their environments. Interactions can be either reactive (adjusting the existing environment) or active and goal directed (modifications according to plans). Stokols proposes the concept of 'human-environmental optimisation', that is, the processes of achieving higher degrees of fit between needs and environmental conditions. Interactions are bi-directional, meaning that the environment influences people's behaviour, but when conditions are unsatisfactory people will modify their environment. Outcomes can be disappointment, satisfaction or enjoyment.

2.2 Framework to Understand Motivation and Emotion

Motivation can be defined as "any internal process that energizes, directs, and sustains behaviour" (Reeve, 2016, p. 31), while Miller (1967) regarded motivation as "all those pushes and prods – biological, social and psychological – that defeat our laziness and move us, either eagerly or reluctantly, to action". Different reasons may push (e.g. hunger) or pull (e.g. personal goal) a person to act (approach) or not to act (avoidance) and different types of motives are needs, cognitions and emotions (Reeve, 2016; 2018). *The Framework to Understand Motivation and Emotion* describes the causes of motivation, the internal motivational state, expressions of motivation, and why the study of motivation and emotion is so central to people's lives (Figure 2.1, Reeve, 2018). Outcomes concern, e.g. health and wellbeing. The former often refers to both functional efficiency of mind and body, and to the absence of illness (Reeve, 2018). The latter refers to positive mental health, including positive emotionality, having a sense of purpose and life satisfaction (Deci & Ryan, 2000; Ryan & Deci, 2001; Ryan et al., 2008), or what people choose to do for their own sake (Jayawickreme et al., 2012).

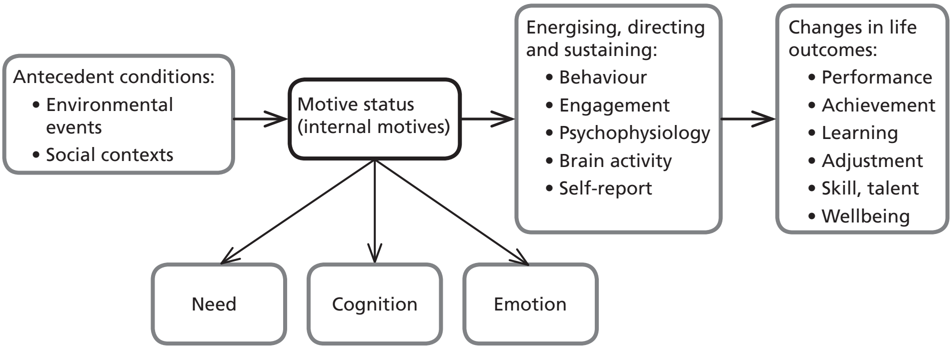

Figure 2.1 Framework to Understand Motivation and Emotion (modified from Reeve, 2018, p. 13). Internal motives are preceded by external environmental events, such as reward or praise. The social context includes a general situation, such as a workplace climate, the home or the culture at large. The internal motivational state energises, directs and sustains behaviour and the three types of motives are needs, cognitions and emotions. Motives are expressed as behavioural, engagement, psychophysiological, neural and subjective (self-reported) activities. These activities may contribute positively to important life outcomes.

Basic needs can be biologically essential nutriments for growth and sustaining life (e.g. hunger and sleep). Equally essential are three basic psychological needs, highlighted in *Basic Needs Theory* (Deci & Ryan, 2000): competence, autonomy and relatedness. They express needs for environmental mastery or being effective in interactions with the environment (competence), decisions that originate from the self (autonomy), and warm interpersonal relationships (relatedness), and are all necessary for personal growth and wellbeing.

Cognitions are mental events (e.g. thoughts, goals, appraisals, expectations, beliefs). Emotional experience involves feeling (subjective verbal descriptions of the experience), arousal (bodily reactions to cope with situational demands), purposive (motivational urge to accomplish something specific at that moment), and expressive reactions (nonverbal communication of the experience) (Reeve, 2018).

Included in the framework is the variation in intensity of motivation (Reeve, 2018). Sometimes a desire might be strong and other times weak, and behaviours can vary both within the person and among different persons.

The theories applied in the studies involve different types of motivation: basic psychological needs, as described above, or goals.

2.2.1 Goal Framing Theory

Goal Framing Theory (GFT) is based on a social psychology perspective and holds that different goals are activated depending on the individual's focus in a particular situation, and will affect their environmental behaviour (Lindenberg and Steg, 2007; Steg et al., 2015). There are three overarching goals: hedonic goals (feeling good at the moment or reducing effort), gain goals (saving money or time), and normative goals (acting appropriately and feeling morally obliged to act in a certain way). Different goals are activated depending on people's focus in a given situation, and the goals will affect how people handle the information provided and act upon it. Central to the theory is how the goals interact – one of the overarching goals is strong and central, while others remain in the background. Even so, the other two goals can influence the central goal, by strengthening or weakening it. In a given situation, the activated goal will typically be affected by cost, i.e. a low-cost decision will favour a normative goal while a high-cost decision will favour a gain goal. In turn, the strength of goals will be influenced by values, i.e. more stable guiding principles in people's lives (Schwartz, 1992). Cues present in the situation, e.g. if other people respect or violate norms, can weaken or strengthen normative considerations (Steg et al., 2014).

GFT considers the influence of both the individual and the situation, such as external social environmental events. For example, a change in weather from cloudy to sunny sky may evoke different responses depending on the individual. An environmentally concerned person might open the blinds and turn off the electric lighting to save energy because it is the appropriate behaviour (normative goal), whereas another person might leave the blinds closed because of the effort involved in opening the blinds and turning off lights (hedonic goal). The importance given to the situation in GFT is similar to the antecedent conditions in *The Framework to Understand Motivation and Emotion*. For example, the individual might act differently in different situations – recycling waste at home but not when away from home on holiday, depending on, e.g. social cues (behaviour displayed by others in a particular situation).

2.2.2 Unified Theory of Acceptance and Use of Technology

Motivation also plays a central role when people choose to use a particular technology. Several models have been developed over the past years to predict technology acceptance (Davis, 1989; Kim, 2012; Li et al., 2019; Venkatesh et al., 2003). The *Unified Theory of Acceptance and Use of Technology* (UTAUT) has been used successfully in predicting user acceptance of various technologies (Williams et al., 2015). The UTAUT was further developed to predict technology acceptance in a consumer context (UTAUT2) (Venkatesh et al., 2012). The UTAUT2 explains consumers' intention to use a certain technology depending on the following key factors: *performance expectancy* (the degree to which a technology will provide benefits to the user in performing certain activities), *effort expectancy* (the ease of using a technology), *social influence* (the extent to which the user perceives that significant others, e.g. family and friends, believe they should use a particular technology), *facilitating conditions* (consumer perceptions of the resources and support available to perform a certain behaviour), *hedonic motivation* (perceived enjoyment, affect), *habit* (concerns automatically performed behaviours and reflects prior experiences), and *price value* (benefits of using a technology in relation to the monetary cost). Behavioural intention directly affects actual technology use, but intention becomes less important with increasing habit.

2.2.3 Applying the theories

Table 2.1 provides an overview of the ways each theory was applied in the studies, either as explanations for certain behaviours, as a lens when analysing qualitative data, or as an initial sensitising concept, i.e. those background ideas that inform the interviews (Blumer, 1969; Charmaz, 2006). Motivation was not directly measured but was inferred from participants' behaviour and reported reasons. Interviews were characterised by questions addressing residents' light-related behaviour and use, or experiences of using wearable devices. In the subsequent thematic analyses, the author's interpretation of data resulted in underlying motives for residents' self-reported behaviour (i.e. expressions of motivation). Themes and categories in the interviews were not determined before data were collected, but instead took form when interviews were transcribed and coded by the author.

Table 2.1 Application of theories.

Theory	Study	How the theory was used in the study
Goal Framing Theory[a]	*The Light at Home survey* + *My Home Lighting*	Goal Framing Theory (GFT) was used in the *Light at Home survey* to study the motives that guide residents' lamp purchasing behaviour. A paper-and-pencil questionnaire was adapted from the PremiumLight market survey. Response options in the first section addressed reasons for buying or not buying a particular lamp type. In the analysis, responses were categorised by the author according to motives (hedonic, gain or normative goals). In the interview study (*My Home Lighting*), aimed at exploring factors that influence residents' illumination choices, GFT helped explain why residents do not act on their desired improvements of their home lighting. Identified reasons by the author in the thematic analysis were, e.g. because of the effort involved (hedonic goal) and not wanting to waste fully functional lamps (normative goal) even though the colour tone is perceived to be too cool white.
Basic Needs Theory[b]	*My Window Openings*	Theory was used as lens when analysing qualitative data. First, 'Basic needs' was the broad idea guiding the exploratory inquiry of the role of window openings in people's everyday lives, and their needs and wants regarding windows. Later, when analysing the interview data certain light-related behaviours in the home were interpreted by the author to have psychological and social origins, and reflected needs for autonomy and relatedness in a broad sense, i.e. elements of 'basic psychological needs'.
Unified Theory of Acceptance and Use of Technology (UTAUT2)[c]	*My Light Profile*	To measure acceptance of an early prototype of a personalised home lighting system, a questionnaire was used consisting of 17 items that have been found to strongly predict technology acceptance in a consumer context. The level of agreement was expressed on a 7-point Likert scale ('strongly disagree' to 'strongly agree'). Items were used to determine: 1) the degree of acceptance, and 2) the most important factor in a hierarchical linear regression analysis that influenced participants' willingness to use the system in the future. Several predictors included in the model can be interpreted to reflect various motives: 'performance expectancy' (goal), 'social influence' (normative goal), and 'hedonic motivation' which concerns perceived enjoyment (intrinsic motivation). In the analysis of the interviews, the author identified factors influencing wearable comfort, e.g. concerns about what the wearables represent to the wearer (value).

[a] Lindenberg and Steg, 2007; Steg et al., 2014; Steg et al., 2015.

[b] Deci and Ryan, 2000.

[c] Venkatesh et al., 2012.

3 Methodology

Taking a pragmatic stance, I chose to adopt a mixed methods strategy of inquiry. Quantitative and qualitative data were combined to gain broader perspectives, which allowed for both statistical generalisations and a deeper understanding of the complexity of the lighting situation in the home. The plan of the study depended on the three components shown in Figure 3.1 – philosophical assumptions, strategies of inquiry, research methods – as well as the research problem.

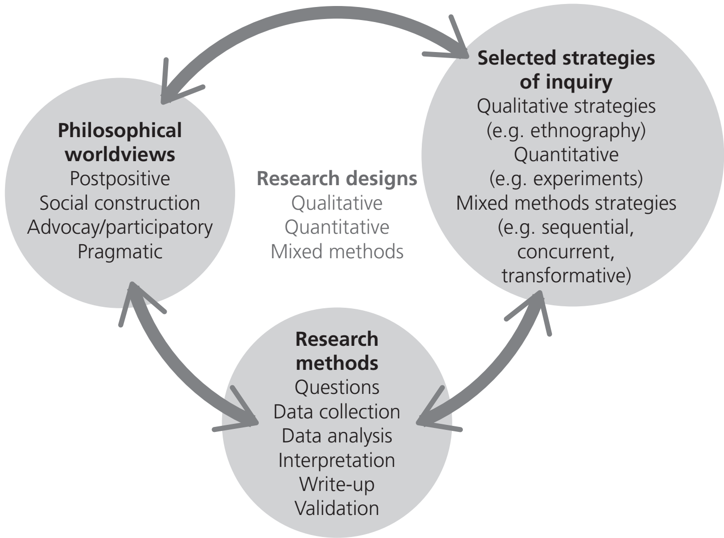

Figure 3.1 Three components of the research design: philosophical assumptions, strategies of inquiry, and specific methods of data collection, analysis and interpretation (adapted from Creswell, 2009, p. 24).

3.1 Pragmatic worldview

The basic set of beliefs that guided my research inquiry is a pragmatic worldview, which is real-world practice-oriented, problem-centred, pluralistic and focused on consequences of actions (Morgan, 2014). I subscribe to the idea that a reality exists external to our mind, but recognise that the knowledge resulting from different worldviews and approaches are complementary. Pragmatism is not bound to only one view on reality because questions about the nature of reality are less central (Morgan, 2014). Some may subscribe to the idea that there is a reality external to the mind and true knowledge independent of human existence, and others to the view that knowledge is socially constructed. However, it is essential to pragmatism that the knowledge produced must be useful, that is, guiding behaviour that leads to anticipated outcomes.

3.2 A mixed methods strategy of inquiry

Mixed methods research can broadly be defined as "research in which the investigator collects and analyses data, integrates the findings, and draws inferences using both qualitative and quantitative approaches or methods in a single study or a program of inquiry" (Tashakkori & Creswell, 2007, p.4). The main reason for combining both quantitative and qualitative data was because of the nature of the research problem. Both numeric data and participants' detailed views were merged to develop a more complete understanding of the current lighting situation, user needs and wants**,** and to identify predictors of technology acceptance.

The mixed methods strategies used in the project were both concurrent (quantitative and qualitative data are converged or merged in the analysis of the problem) and sequential (findings in one method are expanded on in another method) (Creswell, 2009). Methods ran parallel involving one primary method (*Light at Home survey*) and the embedding of a secondary method (*My Home Lighting*), which can be described as a concurrent embedded strategy (Creswell, 2009). Methods also ran in sequence (*My Window Openings,* preceded by the initial phase of the *Light at Home survey* and *My Home Lighting*). The purpose was to provide additional coverage regarding electric lighting, daylight and darkness in the home (Morgan, 2014). In the final study, *My Light Profile*, quantitative and qualitative data were collected at the same time, i.e. questionnaires followed by exit interviews.

3.3 Research methods

The research design is shown in Figure 3.2. As a first step in this mixed methods project, a questionnaire survey was used to obtain descriptive data regarding lamp purchasing behaviour and indoor lighting characteristics (*Light at Home survey*). At the same point in time, residents' experiences with their home lighting were explored using observer-based environmental assessments and qualitative photo-elicitation interviews with participants at home (*My Home Lighting*). Later, residents' experiences with daylight and their window openings were explored in a similar way to the home lighting interview study, but with a new set of participants (*My Window Openings*).

In a second step, with another set of participants (with the exception of two who had previously participated in the initial study, *My Home Lighting*), a validated questionnaire was used to measure the relationship between participant characteristics, pre-determined predictors, and behavioural intention to use a new lighting system (*My Light Profile*). Participants completed a questionnaire after a demonstration of a prototype of the home lighting system, in a full-scale model of a studio apartment. On the same occasion, reasons for participants' willingness/unwillingness to use the lighting system were explored using qualitative interviews with participants to understand the data at a more detailed level.

I visited the participants in their own environment to experience their lighting on site (*My Home Lighting* and *My Window Openings*). It was a natural consequence of recognising the bodily bases of mind and meaning (embodied cognition) and the importance of contextual factors (ecological perspective) described in the previous chapter. Visits in the field also made it easier for participants to both show and talk about their use of luminaires and window openings. When research in the field was not possible, the setting moved to a full-scale model of a studio apartment (*My Light Profile*). A full-scale model has the advantage of allowing movement within the space, which is not possible using two-dimensional simulations, e.g. still images projected on a screen. Benefits of using full-scale models are discussed further in the appended paper, see Appendix A8.

I used both open- and closed-ended questions (the former in interviews and the latter in questionnaires). Asking only closed-ended questions would have increased the risk of missing valuable information. Methods included both predetermined approaches (*My Light at Home survey, My Light Profile*) and emerging approaches (*My Window Openings*).

Quantitative methods were selected for analysing factors that influence residents' lamp purchasing behaviour and indoor lighting characteristics (e.g. the number of lamps and placement in the home in the *Light at Home survey*). The survey allowed for a larger sample size, and comparison between different groups in the sample and with previous result from 12 countries in the EU (PremiumLight Project Consortium, 2014). A quantitative method was also chosen for statistically testing, with available questionnaire instruments, predictors of user acceptance of an early prototype of a personalised home lighting system (*My Light Profile*).

Qualitative methods were preferred for exploring residents' experiences with their home lighting (*My Home Lighting*) and window openings (*My Window Openings*) for two reasons: 1) theory and research on lighting and window openings in the home is lacking (Morse, 1991), and qualitative methods are useful for collecting rich, contextual data, and 2) a holistic approach is needed to obtain information that might otherwise be missed (Creswell, 2009; Groat & Wang, 2013).

Purposes

Conceptual framework

Research questions

Taking an experience-centred approach to lighting, the broad focus of this thesis is on human-environment interaction and user acceptance of technology in the home.
The aim is to increase understanding of how residents use their lighting from natural and fabricated sources, what they want from it and when they do not want it.
The aim is also to evaluate a new personalised home lighting system in terms of comfort and intention to use the system.

Theoretical approach to motivation and needs
Goal Framing Theory (GFT).[1]
Basic Needs Theory.[2]

Theoretical approach to user acceptance of technology
Unified Theory of User Acceptance of Technology (UTAUT).[3]

RQ1 What lights do Swedish residents have in their homes, and what factors influence their illumination choices?

RQ2 How do residents perceive and use daylight and their window openings during the day and night?

RQ3 How willing are residents to use a sensor-based and energy-efficient home lighting system aimed at improving health, in terms of daily rhythm and sleep quality?

[1] Lindenberg and Steg, 2007; Steg et al., 2014; Steg et al., 2015.
[2] Deci and Ryan, 2004.
[3] Venkatesh, Thong and Xu, 2012.
[4] Secondary data collected by the Nordic Museum in Stockholm were also included.

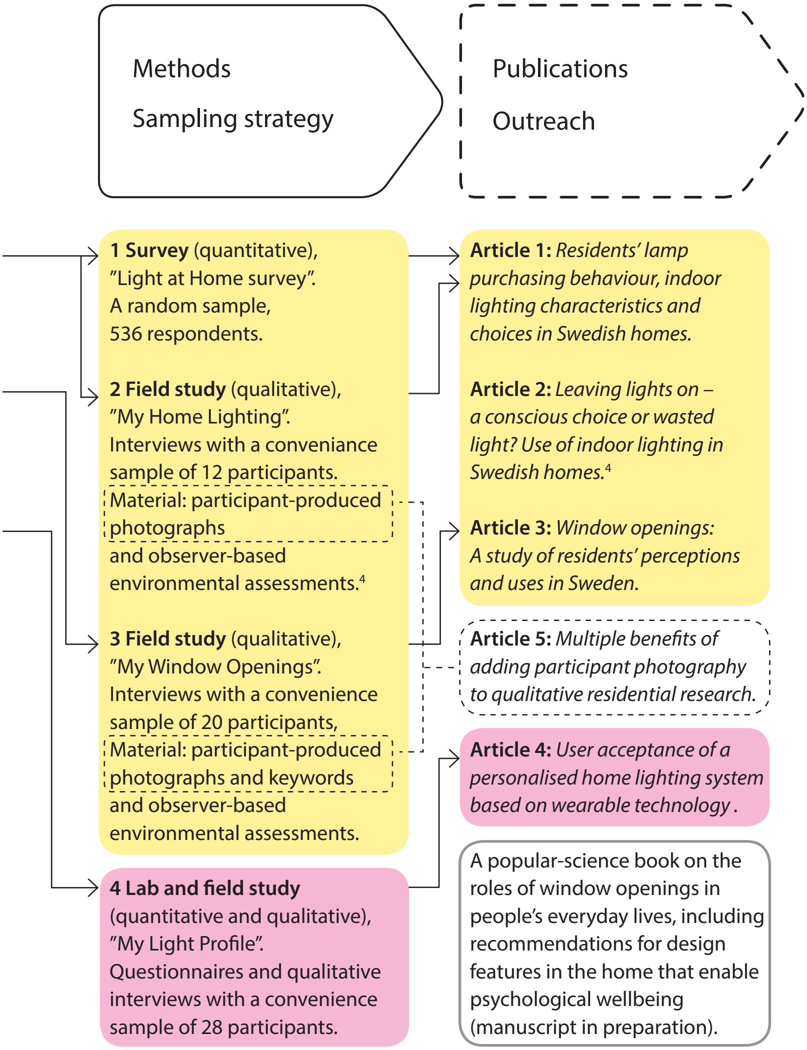

Figure 3.2 Graphical overview of the research design which is centred around the research questions.

Qualitative interviewing was chosen over, e.g. observation or reviewing text, because it is useful for exploring user needs and understanding perceptions of individuals (Mitzner et al., 2016). Individual interviews were preferred to group interviews, sine this yielded a greater depth of information, even though it meant smaller samples. Face-to-face interviews (instead of over the phone) were chosen because they include non-verbal cues. Interviews were held in residents' homes to enable observations of participants' homes and follow-up questions relevant to the actual setting, and because a natural setting provides a more relaxed environment. Questions in all interview studies were open-ended and included follow-up questions asking the participant to clarify or provide more detail.

It was essential for me as interviewer, inquiring about people's experiences of light, to personally experience the environment, because both focused and peripheral perception are central when spatial qualities and light are involved. Merely looking at two-dimensional images and interviewing the participants away from their homes would not have been adequate. A photo-elicitation technique, including participant-produced photographs in combination with interviewing (*My Home Lighting* and *My Window Openings*) (Gerhardsson, 2019), was used to encourage participants to talk and reflect, and thereby obtain more information (Harper, 2002; Rose, 2007).

As outlined in Figure 3.2, the data collected for the thesis included: 1) questionnaire survey data and questionnaire data from the lab, 2) qualitative data from face-to-face interviews held in the field facilitated by participant-produced photographs, 3) participant-produced keywords and captions to their images, 4) observer-based environmental assessment (OBEA) forms completed in the field by the researcher, 5) secondary archival textual data collected by the Nordic Museum (to support the primary data), 6) questionnaire data obtained in a laboratory setting after test trials in the field, and 7) exit interviews following the completion of a questionnaire. The purpose of using OBEA forms was to check the number of luminaires and window openings, to record interior features relevant to the research questions, and to form an impression of the home before carrying out the interview.

Each source of data has its own merits and is linked to either different research questions or parts of a single overall question (Creswell, 2009; Gifford, 2016; Morgan, 2014; Robson & McCartan, 2016). For example, the first research question, *"What lights do Swedish residents have in their homes and what factors influence their illumination choices?"*, required a quantitative survey method to enable generalisation of the findings to the population from which the sample was drawn. But to address the second part of the question, qualitative interviewing of a small sample was expected to give insights into what might facilitate or hinder their desired lighting.

Data were integrated in the reported findings, e.g. 'factors influencing residents illumination choices' (choices of lamp technologies were obtained from *the*

Light at Home survey, and inhibitors and enablers of the preferred home lighting were obtained from the interview study, *My Home Lighting*). Quantitative and qualitative data in the acceptance study (*My Light Profile*) were integrated in the findings regarding technology acceptance. The interview data helped understand the reasons for the physical and psychological comfort/discomfort of wearing the devices needed in the personalised home lighting system.

Table 3.1 shows an overview of the type of data in each study, motivations for the selected technique, and how the results of different methods have been integrated.

Table 3.1 Combinations of quantitative and qualitative mixed methods approaches (adapted from Whitehead & Schneider, 2013).

Combination	Study	Motivation for the selected techniques and how results were integrated
Quantitative + qualitative	*The Light at Home survey + My Home Lighting*	In a first step, a survey was conducted that served as a quantitative foundation. Qualitative interviews were held in parallel to provide complementary information about factors that limit or facilitate residents' choices of lamps and luminaires. Qualitative data were also used to deepen understanding about participants' perceptions of luminaires and what residents' want from their lighting, which may not be easily quantified. Two separate samples were used in each study. Data were analysed separately and results were integrated in the interpretation phase of the study and reported in the journal article (Gerhardsson et al., 2019; Gerhardsson et al., 2020).
Qualitative	*My Window Openings*	At a later stage, qualitative interviews were held with a new set of participants. The reason was to provide complementary information about the contribution of window openings to the lighting situation (daylighting and room darkening). The study was partly informed by the previous qualitative interview findings (e.g. the frequent use of window luminaires). Findings were integrated with the findings of the preceding studies in the thesis.
Quantitative + qualitative	*My Light Profile*	In a second step, questionnaires and qualitative interviews were used in a full-scale model of an apartment. A valid questionnaire instrument was available for testing predictors of user acceptance of an early prototype of a personalised home lighting system. The interview data helped increase understanding of the reasons for the physical and psychological comfort/discomfort of wearing the devices needed. Data were analysed separately, integrated and reported in the journal article (Gerhardsson & Laike, 2019a).

3.3.1 Reliability, validity and generalisability

To ensure *reliability,* i.e. the consistency of the analytical procedures, and to avoid concerns about personal and research method biases that may have influenced the findings, validated scales were used to measure technology acceptance (*My Light Profile*) (Venkatesh et al., 2012). When validated scales could not be used, Cronbach's alpha was used to measure internal reliability, e.g. questionnaire items measuring 'physical comfort' (*My Light Profile*).

To ensure consistency in the qualitative research, the following procedures were applied. Procedures apply to all studies that included qualitative interviewing. When the procedure only applied to a single study, it is shown in parentheses.

- Procedural protocols were followed to ensure that I was consistent on home visits (*My Home Lighting, My Window Openings*) and when conducting exit interviews after the participant had completed the questionnaire in the full-scale model (*My Light Profile*).
- Interview transcripts were carefully checked during transcription.
- Definitions of codes were recorded in code books to keep track of the meaning of codes during the analytical stage, and coding decisions were recorded in order to be clear and transparent, i.e. maintaining a decision-trail (Noble & Smith, 2015, p. 34).
- Intercoder agreement was established based on whether a colleague and I agreed on codes used for the same passage in a random selection of interview transcripts (*My Home Lighting*). Also, identified themes were discussed (*My Window Openings, My Light Profile*).

Validity involves the precision at which the findings accurately reflect the data. One limitation lies in the self-report data of the *Light at Home survey*, e.g. regarding the number of lamps in the rooms and lighting behaviour, such as whether new energy-efficient lamps are switched on for the same number of hours, and the frequency of turning off the lighting in non-occupied rooms. However, several findings in the *Light at Home survey* confirm those of the PremiumLight market survey (Kofod, 2013). Previous research has established that the items in Questionnaire 2 used in the lab study (*My Light Profile*) accurately reflect independent and dependent variables, e.g. 'performance expectancy' and 'behavioural intention to use the technology' (Venkatesh et al., 2012).

Ecological validity is considered to be high, as questions addressed actual behaviour in the participants' everyday lives and not in hypothetical situations, and data were collected in the settings where such behaviours naturally occur (Steg et al., 2013). For example, questionnaires in the *Light at Home survey*, which included counting of lamps (type and location), were completed in respondents' homes. Interviews asked participants about preferences and use of their lighting and window openings in their homes instead of asking about general lighting or window preferences based on constructed environments in a laboratory setting.

Regarding *qualitative validity*, or truth value (Noble & Smith, 2015, p. 34), I reflected in research diaries on such personal experiences that might result in methodological bias, and presented participants' perspectives clearly and accurately. Being an architect by profession, one potential bias might be over-interpreting findings and giving environmental factors disproportional weight in the thematic analysis. On the other hand, my architectural knowledge and practical experience directed my attention to features in participants homes and details in their views I might otherwise have missed.

I recognise that coding is the result of interpretation. Explicit details in participants' views are easier to code but implicit meanings and identified patterns are results of the researchers' interpretation. A content-based coding was applied in the qualitative research, i.e. codes were not determined before data collection to avoid forcing data into pre-determined codes.

When findings were reported in journal articles, they included detailed descriptions when the format of the journal allowed for extended findings sections. Settings and multiple views among the participants were reported, which makes their accounts more realistic. Interviews in the field and observer-based environmental assessments of physical conditions in participants' homes added to the validity of findings, e.g. the opportunity to check the number of luminaires and window openings that were reported (*My Home Lighting, My Window Openings*).

Generalisability concerns the transferability of the findings to other populations, settings and applicability in other contexts. One limitation of the *Light at Home survey* is the response rate (27%), which could be biased towards socially desirable answers, thereby affecting the generalisability of the findings. However, the respondents in the *Light at Home survey* properly represented the national population in terms of dwelling type. In terms of housing tenure type (i.e. home ownership) there was an over-representation of tenant-owned and owner-occupied dwellings compared to the municipal and national level. Generalisability of the results from the questionnaire in the study on technology acceptance (*My Light Profile*) may be limited because of the non-probability sample and sample size.

Analytical generalisations in qualitative research similarly concern the applicability of findings to other contexts, settings or groups. The purpose of the interviews was to provide a rich thematic description of the data set and obtain thick data, i.e. enough data to achieve data saturation (Guest et al., 2006; Fusch & Ness, 2015) The sample was intentionally diversified in terms of age, gender and household size to obtain a wide range of experiences. However, only residents living in multi-dwelling buildings were included, ensuring a relatively homogeneous sample and a smaller number of participants since they were analysed as a single group. Structured interviews with open-ended questions were chosen to ensure that questions central to the topic would be the same across all interviews. It is believed that the identified themes reflect what Swedish residents want from their home lighting and window openings, and findings can be applied to other settings, such as one- or two-dwelling buildings in urban areas, in a Swedish context. The findings of the study on home lighting were partly supported by secondary findings (archived comments and images collected by the Nordic Museum). The motivation for using secondary data was to see whether findings of the primary data set could be applied to a broader group of residents in multiple Swedish cities. However, secondary data only addressed window luminaires but still supported five of nine sub-themes identified in the primary data.

3.3.2 Overview of conducted studies

This section provides an overview of the conducted studies – *Light at Home survey, My Home Lighting, My Window Openings, My Light Profile* – including the setting, participants, data collection strategies, data analysis procedures, and how findings were reported (see Table 3.2–3.5).

Table 3.2 Overview of the quantitative 'Light at Home survey'.

Light at Home Survey	
Description	The aim of the study was to describe the current lighting situation in Swedish homes using a quantitative method. A multiple-choice questionnaire using a large sample (*N* = 536) was chosen to identify the motives behind residents' lamp purchases, to describe the lighting characteristics of homes and enable statistical generalisations.
Research question	What lights do Swedish residents have in their homes, and what factors influence their illumination choices?
Unit of analysis	Individuals.
Population	Adults in the municipality of Lund, aged 18–80.
Time dimension	Cross-sectional.
Sampling	A random sample of 2,000 people was drawn by the State Personal Address Registry from the adult population of Lund.
Data collection	
Technique	Self-administered paper-and-pencil questionnaire.
Time period	02-11-2015 — 27-11-2015.
Number of individuals	*N* = 536 (female 51% and male 49%).
Response rate	27% (after one postal reminder).
Data analysis	Descriptive statistics and calculation of statistically significant relationships between nominal values, such as housing tenure or dwelling type, and other variables, for example the number of lamps or choice of lamp technologies. Software tool: IBM SPSS Statistics for Windows, version 23.

Table 3.3 Overview of the qualitative interview study 'My Home Lighting'.

My Home Lighting	
Description	The aim of the study was to deepen the understanding of residents' experiences with their lighting and choices of luminaires, using a qualitative approach. Interviews, held in homes and with 12 participants, were chosen to increase understanding of participants' perceptions and uses of their home lighting, and to deepen understanding of what specifically limits or facilitates residents' choices of lamps and luminaires.
Research question	What lighting do Swedish residents have in their homes, and what factors influence their illumination choices?
Unit of analysis	Individuals.
Population	Selection criteria: Swedish speaking adults, 18 years or older, living in multi-dwelling buildings in the metropolitan area of Malmö.
Time dimension	Cross-sectional.
Sampling	Convenience sample. Only residents living in multi-dwelling buildings were included, ensuring a relatively homogeneous sample and a smaller number of participants since they were analysed as a single group.
Data collection	
Technique	Primary data: Structured interviews with open-ended questions and photo-elicitation, and observer-based environmental assessments. Participants were offered single-use cameras if they had no camera phones. Secondary data: archived text comments of window luminaires at the Nordic Museum in Stockholm.
Time period	Primary data: 1-10-2015 — 30-11-2015. Secondary data was collected by the museum in November 2015.
Number of individuals	Primary data: *N* = 12 (female 50% and male 50%), aged 26–76. Secondary data: *N* = 61, 77% female and 23% male, aged 24–75.
Data analysis	Thematic analysis 1: perceptions of character of electric lighting and use. Thematic analysis 2: key factors influencing residents' interior lighting choices. A content-based coding was applied, i.e. codes were not determined before data collection.

Table 3.4 Overview of the qualitative interview study in the field 'My Window Openings'.

My Window Openings	
Description	The aim of the study was to explore the role of window openings in homes: their contribution to the lighting situation and residents' dwelling experiences during the day and night, using a qualitative approach. Interviews, held in homes and with 20 participants, were chosen to increase understanding of participants' perceptions and uses of their window openings.
Research question	How do residents perceive and use daylight and their window openings during the day and night?
Unit of analysis	Individuals.
Population	Selection criteria: Swedish speaking adults, 18 years or older, living in multi-dwelling buildings in the metropolitan area of Malmö.
Time dimension	Cross-sectional.
Sampling	Convenience sample. Only residents living in multi-dwelling buildings were included, ensuring a relatively homogeneous sample and a smaller number of participants since they were analysed as a single group.
Data collection	
Technique	Structured interviews with open-ended questions and photo-elicitation, observer-based environmental assessments and text data (keywords assigned by the participants to their photographs of the window openings). Participants were offered single-use cameras if they had no camera phones.
Time period	17-03-2017 — 24-05-2017
Number of individuals	*N* = 12 (female 50% and male 50%), aged 24–93.
Data analysis	Thematic analysis: dimensions of dwelling comfort relating to window openings. A content-based coding was applied, i.e. codes were not determined before data collection.

Table 3.5 Overview of the mixed-methods study in the field and laboratory 'My Light Profile'.

My Light Profile	
Description	The aim of the study was to conduct user experience evaluations of an early prototype of a personalised home lighting system, including body-worn loggers. A mixed methods approach was used. A convenience sample *N* = 28) wore the devices for 23 hours in the field and were given a demonstration of the lighting system components in a full-scale model of an apartment. Participants reported their acceptance of the lighting system and experience of physical comfort and visual appearance of the body-worn loggers on questionnaires. Interviews were also held to provide insights on how more acceptable wearable technology could be developed, and to increase understanding of the reasons behind participants' perceptions and evaluations of the lighting system.
Research question	How willing are residents to use a sensor-based and energy-efficient home lighting system aimed at improving health, in terms of daily rhythm and sleep quality?
Unit of analysis	Individuals.
Population	Selection criteria: Swedish speaking adults, 18 years or older.
Time dimension	Cross-sectional.
Sampling	Convenience sample.
Data collection	
Technique	Self-administered questionnaires (1 and 2) with closed-ended questions and structured interviews with open-ended questions.
Time period	05-04-2016 — 16-05-2016
Number of individuals	*N* = 28 (female 50% and male 50%), aged 22–76.
Response rate	—
Data analysis	Descriptive and inferential statistics (predictor variables of technology acceptance). Software tool: IBM SPSS Statistics for Windows, version 23. Thematic analysis of qualitative data: dimensions of wearable comfort. A content-based coding was applied, i.e. codes were not determined before data collection.

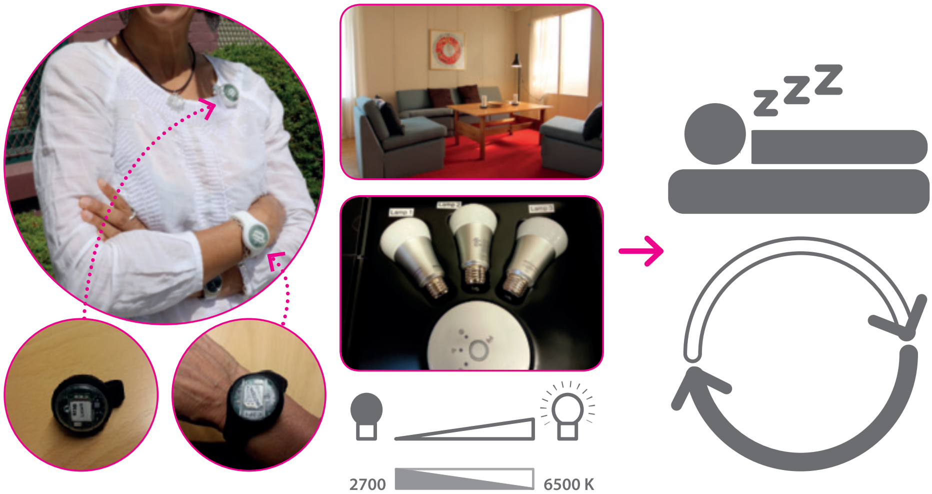

Figure 3.3 The prototype of the sensor-based home lighting system comprises, two loggers, three LED light bulbs (Philips Hue, tunable white, 8,5 W, 600 lumen) and a Philips Hue Bridge. Most people will need bright white light in the morning and dim warm light in the evening to maintain circadian rhythm and sleep timing.

3.3.3 A prototype for a personalised home lighting system

The study *My Light Profile* concerned user experience evaluations of an early prototype of a personalised home lighting system. The prototype, based on energy-efficient LEDs and wearable sensors, was developed to test whether electric lighting can improve daily rhythm and sleep quality (see Figure 3.3). The system, including the app for producing the lighting schedule, the hub and the loggers, was developed by the Lighting Research Center, Troy, New York (Jones et al., 2016).

The lighting system shown in Figure 3.4 requires information about the person's light exposure and activity patterns, which are recorded by two body-worn loggers with built-in sensors (Figueiro, 2013). The loggers, worn on the body but involving no interaction with the user, must be worn continuously, depending on the regularity of the user's daily behaviour. Prior to use, the wearer enters the preferred sleeping and waking time in a mobile phone app. Information collected during the day and night is transmitted to the mobile phone app, which produces a lighting schedule that adjusts the desired timing of the circadian system. In the home, the phone 'talks' to a hub (Raspberry Pie) via the wireless home network, and delivers high or low circadian stimulation lighting when the person enters the room. Wall-mounted beacons (iBeacons), using Bluetooth Low Energy, identify the location of the user, providing they carry the mobile phone when moving between rooms. Transmitted radio signals from the beacons are picked up by an app on the mobile phone, and ZigBee-enabled LED-lamps change the intensity and colour temperature automatically.

3.4 Ethical considerations

Studies involved collecting data from people in their homes about their experiences on non-invasive topics, such as lighting behaviour. No approval from the Ethical Review Board was needed, since the studies did not include interventions or potential risk of unintentional physical or psychological harm. Nevertheless, research involving people requires careful ethical considerations in all stages of the research (APA, 2017; Creswell, 2009; Kvale & Brinkmann, 2009; Swedish Research Council, 2017).

Ethical issues enter early in a research project in terms of what problem to address, whether the investigation will be beneficial for the people being studied, and policy relevance (described by Stokols (1993) as 'social validity'). Related to this are the socio-political consequences of the knowledge produced (Kvale & Brinkmann, 2009). The main goal of the thesis is to contribute to lighting in homes that saves energy and improve people's health and wellbeing.

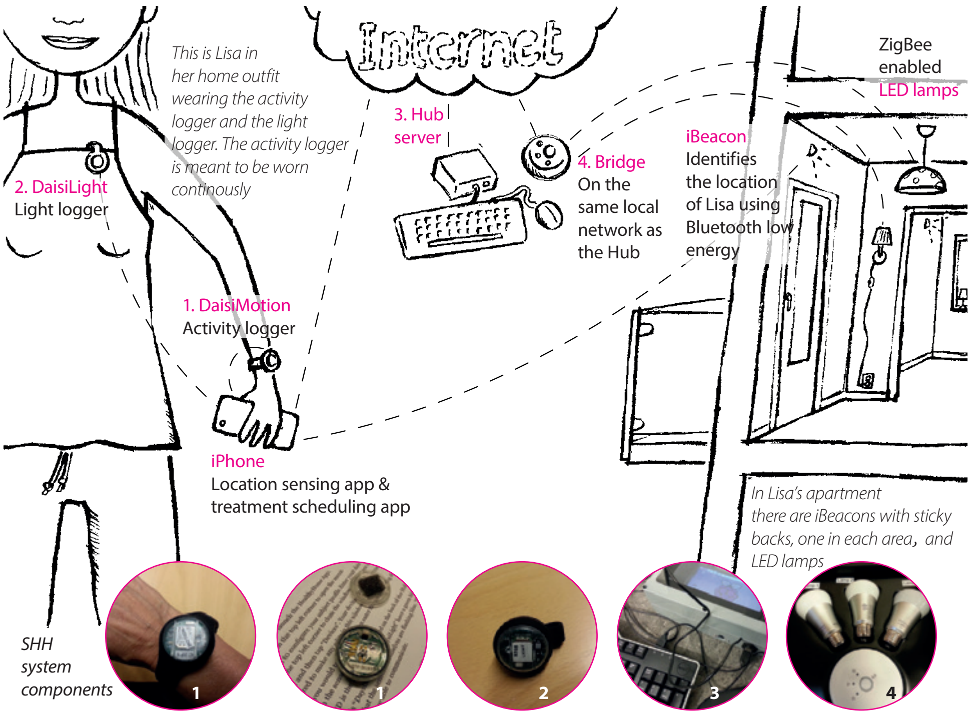

Figure 3.4 Illustration showing how the sensor-based home lighting works and the components included in the Swedish Healthy Home (SHH) lighting system.

Study participants all received written information about the purpose of the study in advance. Invitation letters to participate included a link to more information about the research programme 'Swedish Healthy Home', which included three of the studies (*Light at Home survey, My Home Lighting, My Light Profile*). Participants were informed that they could end their participation at any time without any consequences, if they wished. All of them gave verbal consent. Minimum age limit was 18 and only healthy adults participated in the interviews. Older participants were allowed to be assisted by friends or family when taking photos of their luminaires and window openings.

Consideration was taken to participants' time and the site in the interview studies (*My Home Lighting, My Window Openings*). When booking the home visits, participants were asked to suggest a convenient time. I was always mindful about not disrupting the physical setting in the home after recording features and taking measurements (*My Home Lighting, My Window Openings*).

Anonymity and confidentiality of the participants were protected in the survey and interview transcripts (e.g. survey participants who returned the questionnaires could not be identified, and interview participants were given identification numbers when transcribing and coding).

Participants in the interview studies received either three lottery tickets or a movie voucher. Participants in the lab study received a small reimbursement on completion.

Reports were written following the principles of scientific reliability, honesty, respect, accountability (ALLEA, 2017): reporting accurately about the research procedure and findings, acknowledging the work by other researchers, not disclosing participants identities, disclosing funders for research, providing copies of the reports or journal manuscripts for those participants who asked for them and taking responsibility for the research and its wider impacts.

Other ethical issues include the re-use by other researchers of collected data stored in third-party repositories (e.g. Swedish National Data Service, SND). One way to safeguard against the use of data for completely different purposes is to opt for restricted data access to survey data.

4 Results

This chapter summarises the main findings reported in the appended journal articles/manuscripts. It also includes previously unreported findings from collected survey data, because they have relevance for residents' experiences and behaviour relating to light and darkness.

4.1 Light at Home survey

The survey study aimed to describe the current lighting situation in Swedish homes, such as residents' lamp purchasing behaviour and indoor lighting characteristics, and resulted in the main findings shown in Figure 4.1 (Gerhardsson et al., 2019).

- Two goals guide residents' energy-efficient lamp choices – hedonic and normative goals.
- The average Swedish home is characterised by a large number of lamps (*M* = 39).
- Apartments had 29 lamps (0.36 lamps/m^2) and houses had 50 lamps (0.35 lamps/m^2).
- Rented apartments had fewer lamps in the kitchen and bathroom than tenant-owned apartments.

Figure 4.1 Main findings of the survey study *Light at Home*.

4.1.1 Lamp purchasing behaviour

Survey results showed that light emitting diode (LED) lamps are currently accepted by many domestic consumers: 67% of respondents always or often buy LED lamps, 52% always or often buy compact fluorescent lamps (CFLs), 33% always or often buy halogen lamps, and 22% always or often buy general lighting service (GLS) lamps (respondents could choose multiple options). Reasons for always or often buying energy-efficient lamps (CFLs, LED lamps and halogen lamps), were grouped as either hedonic, gain or normative goals. Hedonic goals ('They last a long time and I don't have to replace them very often') and normative goals ('They save energy') were equally frequent for CFL consumers and LED consumers. For these consumers, purchase price (gain goal) mattered less. For consumers who never or seldom bought CFLs, major goals were hedonic ('It takes too long for the lamp to warm up', 'The lamps size does not fit in my luminaire', 'The quality of light is not acceptable'). For consumers who never or seldom bought LED lamps, goals were economic ('They are too expensive') and hedonic ('The lamp size does not fit in my luminaire', 'The quality of light is not acceptable').

When respondents ($N = 508$) last replaced a traditional GLS lamp that burned out, the most common replacement was an LED lamp (36%). Others replaced it with a CFL (20%) or a traditional GLS lamp (20%). A small number replaced the burned out GLS lamp with a halogen lamp (13%). A larger proportion (33%) of respondents in the age group 75–80 yr replaced it with another GLS lamp, χ^2 (12, $N = 503$) = 25.46, $p = .013$.

Respondents were asked to rate six performance factors on a four-point scale ('Not important' to 'Very important' or 'I don't know'). On average, the most important performance factor was 'lamp quality' (colour tone), followed by 'lamp lifetime' and 'energy efficiency', 'purchasing cost' and 'lamp design'. The least important was 'dimmability'. However, there were significant differences between groups who used no dimmers, one or two, and three or more dimmers. Dimmability was rated as important or very important by 4% among those in the first group, 33% by those in the second, and 78% in the third group, χ^2 (8, N = 482) = 261.33, $p < .001$.

4.1.2 Lighting characteristics

The final section of the questionnaire included an account of lamp types (CFL, LED, halogen or GLS lamps). The average number of lamps per home was 39. Apartments in multi-dwelling buildings had 29 lamps (0.36 lamps/m^2) and one- or two-dwelling buildings had 50 lamps (0.35 lamps/m^2), so the size of the home explains the difference in total number of lamps. Rented apartments had fewer lamps per home (24 lamps/home, 0.33 lamps/m^2) compared to tenant-owned apartments (33 lamps/home, 0.39 lamps/m^2). An analysis of variance (ANOVA) showed that the difference between the number of lamps in rented and tenant-owned apartments was statistically significant regarding the kitchen, $F(3, 413)$ = 15.949, p <.001, and the bathroom, $F(3, 426)$ = 33.998, p <.001. In the kitchen there were 4 and 6.9 lamps respectively, and in the bathroom 2 and 4 lamps respectively.

Lighting control is an essential component of a home lighting system in that it allows the users to manually or automatically turn on or off their lights, or to adjust light intensity. More than half of the respondents, 62%, used one or several dimmers in their homes. The use of dimmers varied significantly with dwelling type: 52% of respondents in multi-dwelling buildings reported using at least one dimmer compared to 76% in one- or two-dwelling buildings, χ^2 (4, N = 505) = 49.16, p < .001. Variation also occurred between housing tenure type: 36% in rented dwellings reported using at least one dimmer whereas 72% used at least one in tenant-owned and owner-occupied dwellings, χ^2 (4, N = 505) = 67.83, p < .001.

4.1.3 Lighting behaviour

Respondents (N = 513) who had changed traditional GLS to CFLs or LED lamps were asked whether they had changed their user habits. A majority (77%) reported no change in behaviour, with the new lamps switched on for the same number of hours. Twelve percent reported 'the new lamps are switched on for longer than before, as the consumption is less'.

A recurrent recommendation in energy conservation campaigns is to turn off the lighting in unoccupied rooms. Most of the respondents (57%, N = 301) answered that they sometimes turn off lights when nobody is in the room, 26% (N = 140) answered that they always turn off lights, and 17% (N = 90) seldom or never turn off lights.

A majority (89%) reported never using any special light to wake them up or make them more alert, see Figure 4.2(a). Blocking out light, such as streetlighting and natural light, at night and early in the morning can influence sleep quality. A majority (76%) always or frequently use blinds, roller blinds or other solutions to darken the bedroom when they sleep, see Figure 4.2(b).

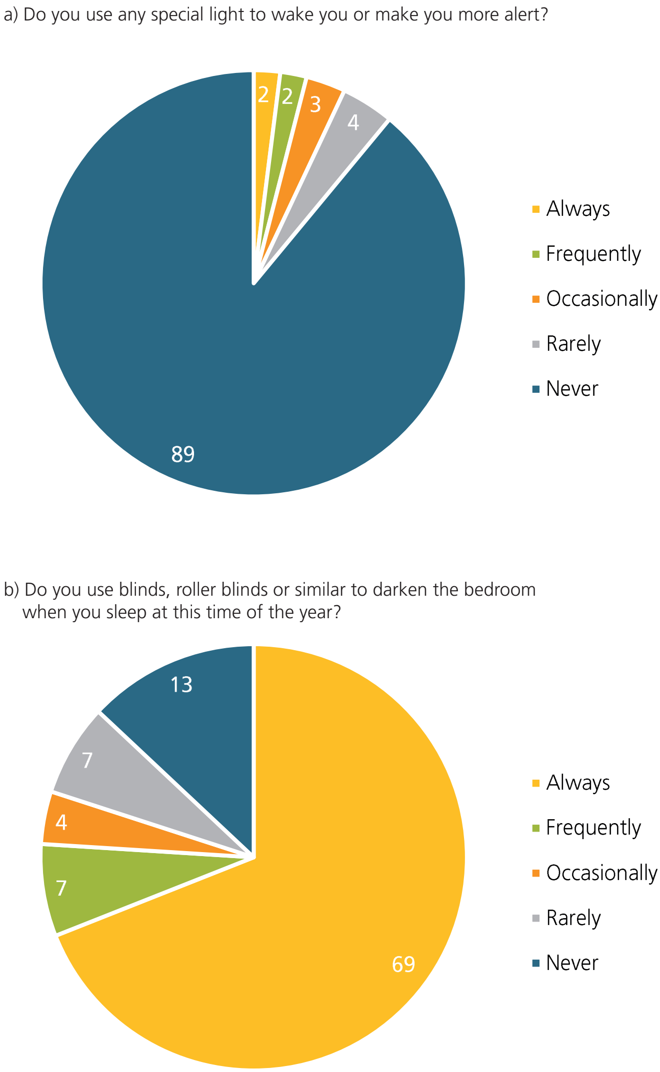

Figure 4.2 Pie charts showing light-related behaviour in the morning and evening: (a) the use of special light for awakening or increasing alertness, e.g. dawn simulators (*N* = 534), (b) room darkening (*N* = 535).

A set of questions asked about the time spent at different places in the morning on a typical day to find out potential places for mounting luminaires with circadian-effective light, see Figure 4.3.

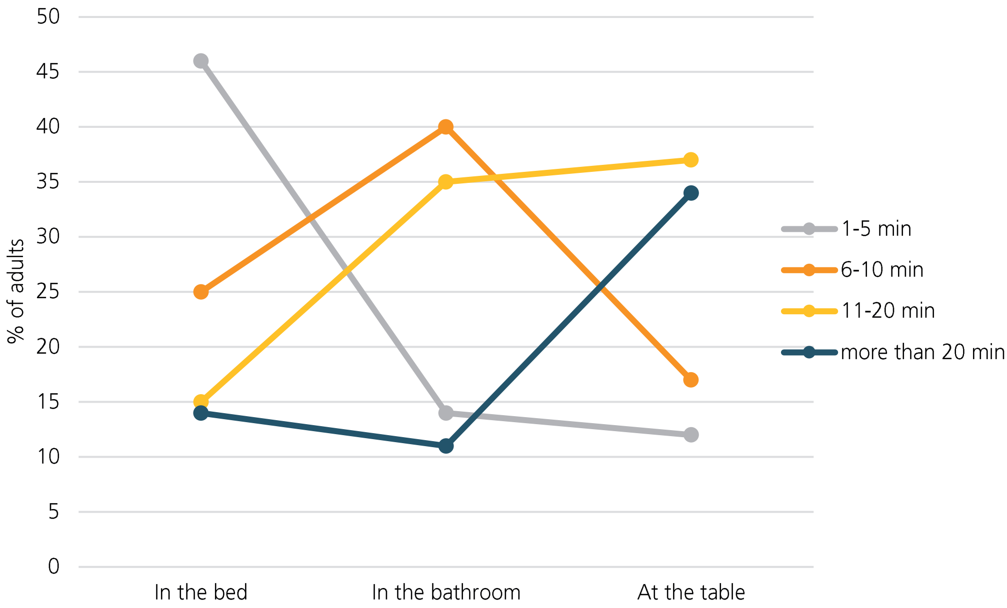

Figure 4.3 Line chart showing the time spent at different places in the morning after a night's sleep: in bed after wake time, in the bathroom and at the table. A majority (71%) spent at least 11 minutes at the table in the morning, of whom 34% spent more than 20 minutes at the table.

Burning candles is a common Scandinavian cultural practice that contributes to the lighting situation in homes, for example, by creating a particular mood in the room. Half of the respondents (51%) used candlelight 'very frequently' or 'frequently', 34% answered 'occasionally' and 15% reported that they 'rarely' or 'never' burn candles. The primary reasons for burning candles were 'Because it creates an atmosphere' and/or 'Because it looks nice'.

4.1.4 Daylight outdoors and indoors

Respondents were asked to report how important daylight was when they chose their home, see Figure 4.4. Half of the respondents (54%) reported daylight to be important, but there was a significant difference between those who lived in rented homes (41%) and tenant-owned homes (59%), χ^2 (2, N = 507) = 12.74, p = .002.

As illuminance is much higher outside than inside a building, respondents were asked: 'How much time did you spend outdoors during a normal day this week?' Results, shown in Figure 4.5, reveal that reported outdoor time ranged between 0 and 11 h between 06:00 and sunset (M = 2.75, SD = 2.05, *Median* = 2). More people spend at least half-an-hour outdoors in the afternoon/evening than other times of the day.

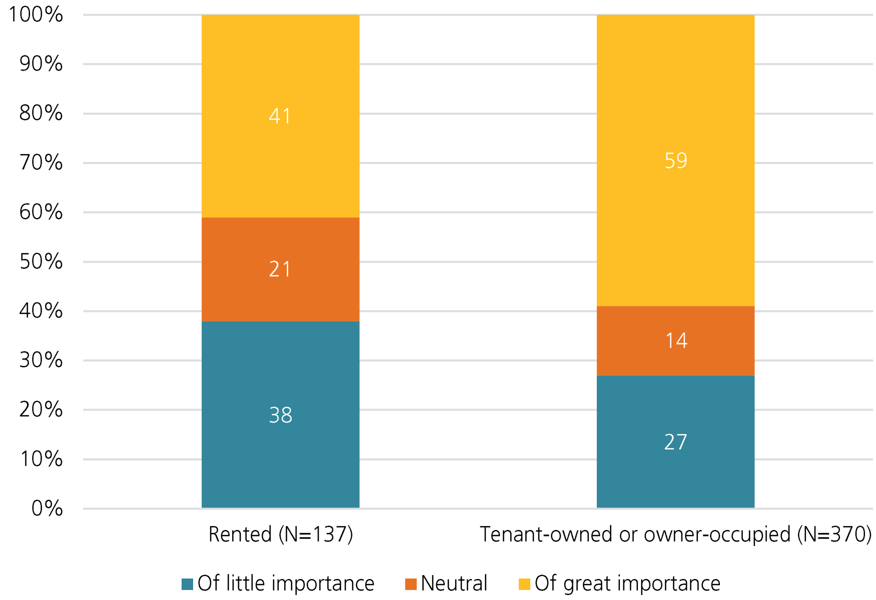

Figure 4.4 The importance of daylight to residents when they chose their home. Respondents rated the importance on a seven-grade response scale from 'little' to 'great importance' (*N* = 507).

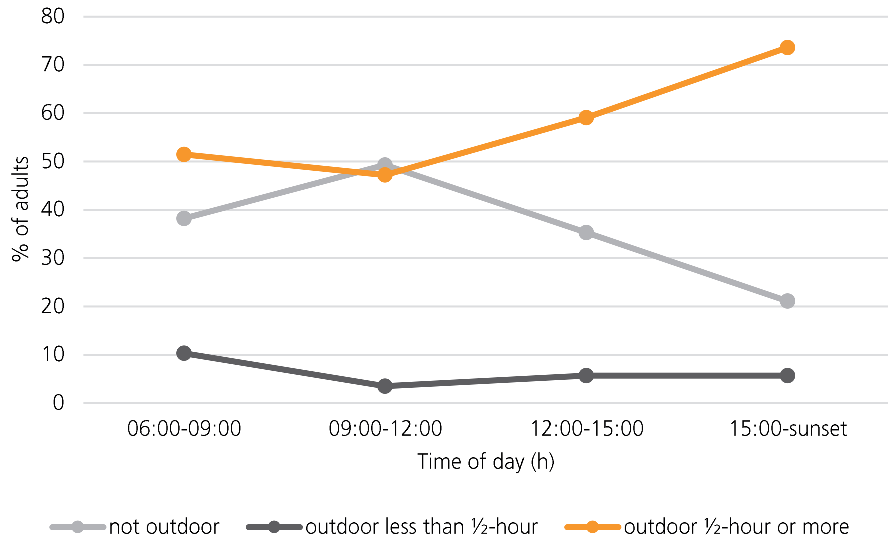

Figure 4.5 Respondents' self-reported time spent outdoors at different times are shown grouped as 0 hours, less than ½-hour or ½-hour or more (*N* = 513). For example, in the afternoon after 15:00, 6% of the respondents spent less than 30 minutes outdoors, while 73% spent 30 minutes or more.

4.2 My Home Lighting

This interview study aimed to deepen the understanding of residents' experiences with lighting and their choices of luminaires, and resulted in the main findings shown in Figure 4.6 (Gerhardsson et al., 2019; Gerhardsson et al., 2020).

Thematic analysis 1 of primary and secondary data (exploring residents' perceptions of the character of their electric lighting and use):

- What they want related to behavioural goals, psychological wellbeing and social needs.
- Lights left on in unoccupied rooms can serve a purpose for the residents.
- Reasons include visual or aesthetic comfort, personal safety or people outside.

Thematic analysis 2 of primary data (exploring key factors influencing residents' interior lighting choices):

- An individual may know what lighting they want but still not have it in their home.
- Both individual characteristics and situational factors influence residents' lighting.
- The indoor environment enables or restricts certain lighting choices and actions.
- Availability of lighting products also affect luminaire choices and visual comfort.

Figure 4.6 Main findings of the interview study *My Home Lighting*.

4.2.1 Thematic analysis 1: Perceptions of character of electric lighting and use

Character words used by participants when describing their lighting were either pragmatic – 'adequate lighting', 'watch-TV-lighting', 'functional/utility lighting', 'general lighting', 'point lighting', or hedonic – e.g. 'cosy lighting', 'dull lighting', 'bright and nice'. When lay people talk about lighting and luminaires, they do not use the same vocabulary as lighting experts, but some lay terms are quite similar to those used by experts. All participants were aware of the general principles of good lighting – expressed by the participants as 'functional/utility lighting', 'general lighting', and 'point lighting'. Participants were aware of the weaknesses of and possible improvements to their home lighting. However, some participants also commented on the difficulties of replacing existing luminaires or getting new ones, or replacing burned out lamps.

The coding for how residents use their home lighting in different ways in varying situations, and their choices of luminaires resulted in nine sub-themes (see Table 4.1) identified by the researchers. The participants' accounts of how and when they use their lighting suggest that luminaires and home lighting have the following

Table 4.1 Sub-themes in the thematic analysis: Capabilities of home lighting and luminaires. Character attributes, or goals, describe the capabilities of luminaires, and examples are drawn from the interview transcripts.

Character attributes	Capabilities of luminaires as suggested by their apparent characters	Examples drawn from the interviews (interviews with participant X)
Pragmatic	To enable vision	When opening the cupboard, finding the books on the shelf, eating, breast feeding, passing through the hall to the bathroom, putting on outdoor clothes in the entrance hall, watching TV without glare from light sources in the room, moving around to avoid tumbling. (All participants)
Pragmatic	To facilitate visual tasks	When putting on make-up, reading, writing, playing board games with the grandchildren, preparing food, doing the dishes, changing nappies at night, making the bed, tying shoes, doing desk work, doing crafts, sewing, pressing plants. (All participants)
Pragmatic Hedonic	To display objects	A wall-mounted ceramic piece of artwork, paintings, a collage of family photos, glass art. (P2, P5, P11)
Pragmatic Hedonic Social	To send a message	That someone is at home, that guests are expected. (P4, P10)
Hedonic Social	To support a particular atmosphere – *place*	Creating a cosy atmosphere by lighting candles when expecting guests, using luminaires, e.g. a table luminaire on the dinner table or a wake-up light or table lamps in the windows, turning on luminaires at dusk, avoiding dark rooms, leaving luminaires on because it is cosy when returning home, lighting a table luminaire in the window to make it pleasant, dark spaces look gloomy and dull, string lights, using a bedside luminaire to create cosy lighting. (P1, P2, P3, P4, P5, P6, P7, P8, P9, P11, P12)
Hedonic	To shape the architectural *space* with indirect lighting	Pointing a floor-standing luminaire toward the ceiling or the wall, using top shelf lighting hidden from view to illuminate walls and ceiling. (P1, P2, P3, P4, P5, P6)
Hedonic	To offer a visual aesthetic experience with appealing luminaires, lit or unlit – *solids* – or with light-dark patterns on *surfaces*	Comments on the appearance of luminaires, lamp shades and the lamp base, e.g. neat, sweet, nice, attractive, suitable and uniform style, wooden details, colour, beautiful design. Comments on decorative patterns of light and shade on the walls. (P1, P2, P3, P4, P6, P7, P8, P9, P10, P11, P12)
Pragmatic Hedonic	To maintain or change rhythmicity – *time*	Using a wake-up light in the morning, a bunny night light in the child's bedroom. (P6, P12)
Hedonic	To evoke memories and serve as valuable mementos – *past time*	Inherited ceiling mounted luminaires. (P4, P6, P12)

capabilities: to enable vision; to facilitate visual tasks; to display objects; to send a message; to support a particular atmosphere; to shape the architectural space with indirect lighting; to offer a visual aesthetic experience with appealing luminaires, lit or unlit, or with light-dark patterns on surfaces; to maintain or change rhythmicity; and to evoke memories and serve as valuable mementos.

Four capabilities of home lighting and luminaires – 'to enable vision', 'to facilitate visual tasks', 'to support a particular atmosphere', and 'to offer a visual aesthetic experience' – represented the most common sub-themes, and were found in 11 or all 12 interviews. Essential elements for all nine sub-themes were identified within the first seven interview transcripts. The full range of thematic discovery took shape within the first eight transcripts, so after the eighth transcript, no new themes were identified.

There were several reasons for turning on luminaires and leaving them on in unoccupied rooms, connected to behavioural goals, such as safety, or psychological wellbeing or social needs. One participant (P11) leaves at least one luminaire on in the hallway to avoid tumbling. Another reason for leaving the luminaire on in the hallway, which also relates to safety, was given by participant P4: *"to give the impression that someone is home – when no one's at home"*. Reasons linked with psychological wellbeing were given by participant P11, who had lights turned on in unoccupied rooms to make the dwelling homelier. Other comments also related to visual comfort and concerned lighting visible from other rooms. Reasons can also involve social needs – the luminaires are kept on for people outside the home, to make visitors feel welcome or to make people outside feel secure. It can be reassuring to know that there are people inside the buildings.

Consequently, lights left on in unoccupied rooms can serve a purpose for the residents, such as providing safety, avoiding visual or aesthetic discomfort, and making the home inviting or benefitting people outside.

4.2.2 Thematic analysis 2: Key factors influencing residents' interior lighting choices

In the qualitative analysis, comments from interviews were grouped according to five key factors influencing residents' lighting choices (see Table 4.2) – 1) individual characteristics and experiences, 2) the social situation, 3) activities performed, 4) the physical setting, and 5) time. Two factors, individual characteristics and the physical setting, were interpreted as being the most important, since all participants addressed their lighting preferences and certain limitations of the built home environment. The other three factors were discussed by fewer participants.

Table 4.2 Key factors influencing residents' lighting choices, and what specifically limits or facilitates their choices of lamps and luminaires and their preferred lighting.

Factor*	Characteristics	Examples drawn from the interviews
Individual characteristics and previous experiences (11)	Individual lighting preferences and knowledge of action strategies; reasons behind the choices of lamps, such as effort, cost, or environmental concern, and luminaires	– Aesthetic concerns prevent residents from mounting ceiling luminaires (e.g. visible electric cords), or having the appropriate task lighting because the lamp shade dims the light, or from adjusting the hanging height of pendants, – preference for warm light, – effort prevents residents from changing unwanted or burned out lamps, or replacing temporary luminaires, – cost, in terms of limited available time, prevents residents from making changes, – residents in rented homes have to bear the cost of any desired changes regarding e.g. dimming control or additional luminaires in the bathroom other than standard options, – waste of resources to change fully functioning lamps even though the colour tone is wrong.
Activities performed (4)	Different activities performed in the same room in home environments	– Different lighting needs depending on the type of activity: preparing food, doing the dishes, eating, sewing, reading or watching TV. Standing activities require one type of lighting and sedentary or recumbent another, – conflicts between different activities in the same room, such as having a pleasant lighting at dinner or bright general lighting for other activities in the kitchen, or using the dinner table for visually demanding tasks, such as pressing plants, – in a room which is not used much, lighting is not a priority.
Physical setting (12)	The physical environmental qualities of homes and what the physical setting permits	– Weather conditions outside, – the orientation of the building determines daylight access, which in turn affects the need for artificial lighting, – inward-opening windows restricts the use of table luminaires on the window sill or pendants, – beams across the ceiling and centrally located ceiling roses (from which a luminaire is supposed to be suspended), and pre-installed ceiling light hooks conflict with the furnishing, – material conditions for drilling holes and installing hooks, – distance between and the number and height above floor of electrical outlets, – availability of dimmers and wall switches, and the number of luminaires controlled by one switch, – fixed luminaires provided by the landlord, – transparency of the shower curtain allows more or less light in the shower space, – colours of interior surfaces affect the reflection of light, – luminaire designs with visible lamps reduce lamp type choices, – lamp shades provide too dim light or too cool light.
Social situation (7)	What others in the household want, privacy issues, and what lighting producers and providers can offer domestic consumers	– Reducing the lighting in the evening so people outside cannot see in, – a bed partner wanting to sleep while the other wants to read in bed, – certain luminaires are lit only when having guests, – dinner guests with different lighting preferences: some want bright light while others want candlelight, – different lighting behaviour: one turns off lights when leaving the room while another one leaves all lights on, – difficulty in finding the appropriate luminaire, – marketing trends and new technologies.

Time (5)	The time of day and year, life circumstances, ageing	– Preference for dim light in the morning when brushing your teeth, but bright light in the evening, – availability of daylight will affect the use of electric light, – when living temporarily in a home you avoid drilling holes to mount luminaires, – raised awareness with age of what light you prefer, – older residents need higher light levels (sometimes in conflict with aesthetic preferences of certain luminaires).

* Numbers represent the prevalence of the themes across the participants, e.g. '12' signifies that all 12 participants referred to the particular theme (key factor).

4.3 My Window Openings

This interview study aimed to explore the role of window openings in homes: their contribution to the lighting situation and residents' dwelling experiences during the day and night, which resulted in the main findings shown in Figure 4.7 (Gerhardsson & Laike, 2019b).

- Window openings relate to three dimensions of dwelling comfort and basic needs.
- The physical dimension relates to physical needs and involves practical utilities.
- The psychological/aesthetic dimension relates to psychological wellbeing.
- The social dimension concerns interactions between residents and people outside.
- Provision of air, task light and daily rhythm is essential but not sufficient.

Figure 4.7 Main findings of the interview study *My Home Lighting*.

4.3.1 Perceptions and use of daylight and window openings

Participants were asked to imagine a windowless situation, which immediately triggered spontaneous emotional reactions and evaluative statements. Initial exclamations of surprise, or more reflective responses by some participants, were linked with light, enclosure and visual intrusion. When participants were asked to elaborate on their initial responses, multi-layered descriptions of the impact of window openings evolved.

Keywords assigned by the participants to their images can be divided into four major groups. The most frequently mentioned words relate to 'illumination', e.g. *light, shadows, sun, morning sun, morning light, dark, evening reflections, light from the south*. Equally common were keywords relating to a 'view out', e.g. *movement, nature, people, seasons, trees, good morning world, car park, neighbours, city, openness to the sea and seaside promenade*. The third main group concerns 'air and sound' and examples of keywords are *air exchange, traffic noise, ventilation, practical, heat, calm*.

The final group reflects 'view into the home', e.g. *shielded, observing*.

The thematic analysis of participant interviews resulted in three dimensions of dwelling comfort relating to either physical needs, psychological wellbeing or social connection (see Figure 4.8). The physical dimension concerns physical needs and the provision of practical utilities, such as cool air, noise blocking, task light and daily rhythm, i.e. a 24-hour cycle of light and darkness. The psychological/aesthetic dimension involves the window opening supporting visual delight, ambient light, health and enjoyment, e.g. spatial brightness, indoor pleasantness, improved mood, perceived spaciousness, and visual privacy. The social dimension reflects the interaction, mediated by the window opening, between residents and people outside – e.g. observation, direct communication, or visual cues. Empirical examples of such comfort qualities are provided in tabular form, see Tables 4.3–4.5. Essential characteristics of all comfort qualities, were identified within the first nine transcripts. After the ninth transcript, no new comfort qualities were identified.

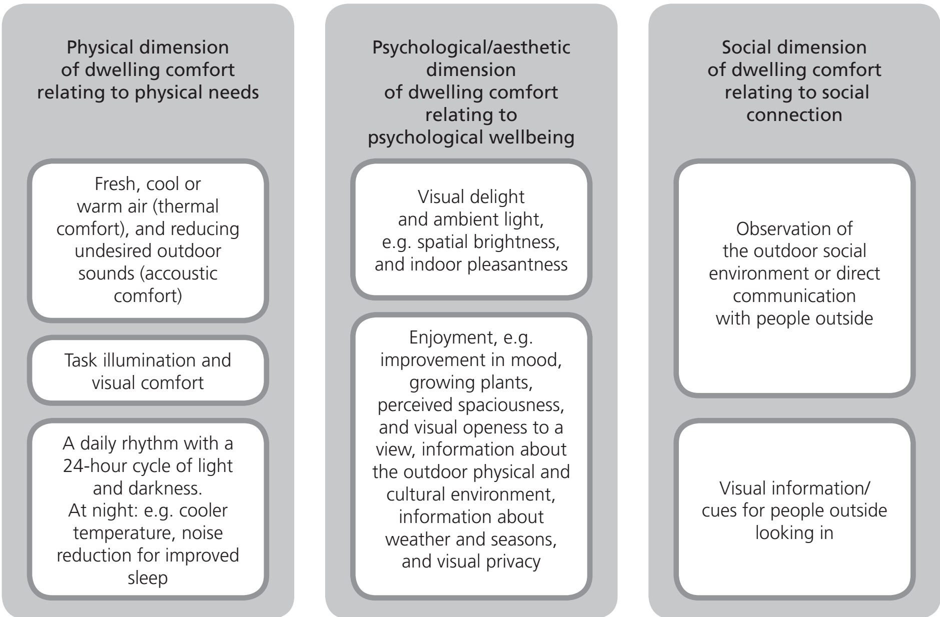

Figure 4.8 The roles of window openings in the home. The thematic analysis of participant interviews resulted in three dimensions of dwelling comfort, relating to physical, psychological/aesthetic or social needs and desires.

Table 4.3 The physical dimension of dwelling comfort described by comfort qualities and empirical examples.

Physical dimension of dwelling comfort relating to window openings		
Comfort quality*	Description	Examples
Indoor air quality and thermal comfort (20)	Characterised by fresh air, cooling and heating, and involves natural ventilation, passive cooling and solar heat gain.	Opening the windows for ventilation; to improve ventilation because air inlets are not sufficient in summer; or to lower the indoor temperature.
Acoustic comfort (9)	Characterised by avoidance of disturbing or undesired outdoor sounds.	Undesired sounds, such as seagulls being noisy early in the morning, traffic, waste collection trucks.
Visual task performance (11)	Characterised by daylight illumination in terms of adequate lighting to make the completion of a task easier.	Daytime cleaning with daylight; reduced daylight on the task area because of dark bookshelves, and the location of the desk. *"No, it could be much better [light]. There's no light there during the day. It's darker than my room. We have many lamps there to make it really light. He builds with Lego and needs light, so there are many things that …"* (P9) *"It depends on what I'm going to do. If I'm just going to make a sandwich, I don't turn the light on. If I'm going to cook dinner and read a recipe, I'd turn it on. And in the morning, I turn it on."* (P15)
Visual comfort (13)	Characterised by daylight illumination which minimises uncomfortable visual contrast, glare and reflected glare.	Reflected glare from bright external surfaces, e.g. a newly installed copper roof, white exterior walls of adjacent buildings; reflected glare from the television screen making it difficult to see. *"Of course, I sometimes wonder if I should have the bed some other way, and the desk. It's a bit uncomfortable to sit facing the light, because you get blinded. If you have it from the side, you might have been able to work a bit better. /…/ It's the white walls there, and the sun shines on them. So it gets quite white here."* (P5)
Sleep hygiene (20)	Characterised by daily rhythm through light/dark exposure. Avoidance of disturbing light and noise during sleep, and maintaining a cooler temperature during the night.	Problems with darkening during the day after a night shift; wearing a sleep mask; waking up with daylight; having the bedroom window open to reduce the temperature; the feel of fresh air. *"So that you can stick your nose out [from the duvet] and so it will be a bit chilly. These are types of things that can be a problem when you sleep with a new person – if you don't have the same views."* (P11) *"The only place I make it dark is my bedroom, because I can't sleep when it's light. /…/ It gets dark but, in the summer, it's a problem. I want it dark here. Even darker than I can make it now."* (P3)

* Numbers represent the prevalence of the themes across the participants, e.g. '20' signifies that all 20 participants referred to the particular theme.

Table 4.4 The psychological/aesthetic dimension of dwelling comfort described by comfort qualities and empirical examples.

Psychological/aesthetic dimension of dwelling comfort relating to window openings		
Comfort quality*	Description	Examples
Spatial brightness (20)	Characterised by illumination and enabling an adequately daylit room (ambient lighting).	The whole room has to be bright; plenty of light; contrasts; colour nuances affected by the weather; variation that makes daylight more vivid and less sterile.
Indoor pleasantness (10)	Characterised by illumination and enabling visual appearance of the window, objects, people and interior surfaces of the room.	Avoiding direct sunlight to preserve a nice tablecloth on the kitchen table or a wall; unshielded windows because mullions and glazing bars are carefully moulded.
Improvement in mood and health (4)	Characterised by illumination.	*"Nevertheless, you feel good from the light you get every day. There was a question about if there was no window. Then I thought that, if there wasn't a window, it would have been difficult – so it's still the light."* (P13)
Growing and maintaining indoor plants (4)	Characterised by illumination.	Growing pot plants; starting seeds; planting avocado seeds; growing grass for the cat.
Perceived spaciousness (15)	Characterised by a view out, and suggesting visual openness or enclosure produced by an interior. It has less to do with illumination because the feeling of enclosure can be experienced at night without much light from the outside. View distance may affect the perception of spaciousness more than illumination through the window opening. Imagine, e.g., translucent glazing, a light-coloured tent fabric with no transparent 'windows', or thick fog.	*"[Windows] I think are very important. I've always had them. I've lived in houses in Trelleborg and there it [window] was really big. Up on M-[road]it was also big. But there, the houses were so close together that I didn't get the same feeling of space and light like I do here. It was a much more shut-in feeling, even if I lived in a big house."* What do you think was the reason for that? *"That the houses were too close together. The neighbours were so close. So I'm very happy now that I've come up a bit, and light filters in from all directions."* (P9)
Visual openness to a view (17)	Characterised by a view out that has certain qualities regarding view content, view distance, and view elements.	Seeing nature outside; looking out through the window; trees moving in the wind; garden; clouds; the sun's path across the sky; birds; the park; the city scape; people; too dense and close to adjacent houses.
The outdoor physical and cultural environment (9)	Characterised by a view out onto the physical environment, urban culture or cultural heritage, and enabling sensory information, such as hearing urban sounds.	*"Above all this way, but it's because here is a big street – it's Drottninggatan out there. To be able to come home in the afternoon, and open up and lie down, have a cup of coffee and doze off a bit to the sound of cars and buses – I like that."* (P19)

Seasonal changes and weather conditions (14)	Characterised by a view out and enabling sensory information from the outside, such as sound, or to be able to open the window and feel the wind and outdoor temperature.	Vegetation that tells the time of year; the sound from frogs and toads during summer nights; be able to check the weather; rain falling on hard surfaces.
Visual privacy (15)	Characterised by a view in that is perceived as intrusive.	People outside watching when working in the kitchen, or dancing with the grandchildren; translucent glass for privacy; people outside seeing the programme on the TV; preferring privacy when sitting down.

* Numbers represent the prevalence of the themes across the participants, e.g. '20' signifies that all 20 participants referred to the particular theme.

Table 4.5 The social dimension of dwelling comfort described by comfort qualities and empirical examples.

Social dimension of dwelling comfort relating to window openings		
Comfort quality*	Description	Examples
Observation of the outdoor social environment, or communication with people outside (13)	Characterised by view out and enabling sensory information, such as voices or dogs barking, and communication..	Checking whether a neighbour's car is in the car park to see whether they are home; checking for intruders through the window facing the car park; calling out to someone; watching her son playing football with friends outside.
Visual information/cues (9)	Characterised by non-intrusive view in, and requires visual openness enabling inhabitants to provide visual cues for people outside.	Choosing interior window treatments depending on how others perceive them, e.g. vertical blinds or curtains instead of venetian blinds; creating a pleasing window display for people outside with flowerpots and lamps on the windowsill. *"It's like a screen of indoor residential lighting and street lighting that gives a feel of living in a city. I think that's nice."* (P9)

* Numbers represent the prevalence of the themes across the participants, e.g. '20' signifies that all 20 participants referred to the particular theme.

Participants living in multi-dwelling buildings from different construction periods were asked about any desired changes regarding their window openings. Here are some examples: larger or additional windows, mounting window coverings (blinds, curtains or exterior shading), windows without mullions to increase the glazing area, a lower windowsill, or improving visual privacy without reducing daylight too much. One reason for wanting larger windows and glazing is to increase daylight, but some residents desired no change because they valued the wall area.

4.3.2 Factors involved in residents' dwelling experiences relating to window openings

These findings, based on interviews and keywords, are significant in several respects, which will be discussed in the following section. Findings show that a window opening (including the transparent glazing and shading devices) is linked with one or more dimensions of dwelling comfort depending on multiple factors (see Figure 4.9). The following examples drawn from the interviews illustrate each factor:

- *the cultural context* – e.g. disliking visual intrusion when sitting down (home setting), having electric lights in the window opening (common practice in Sweden),
- *the situation* – e.g. blinds left down during the day because it requires some effort to pull them up (e.g. state of the individual), disliking visual intrusion watching the TV (activity),
- *the social environment* – e.g. blinds left down because neighbours show similar behaviour, disliking closed blinds or curtains during the day because it gives the wrong signal (social environment and/or cultural context),
- *individual characteristics and experiences* – e.g. being able to overview the outdoor social environment because you are an anxious person (personality trait),
- *the physical environment* – design features of the window openings (see Appendix A5, The Window Opening Inventory) may directly influence the individual, or indirectly, through the activity performed. For example, house cleaning (activity) during daylight hours because light is plentiful (design features) leading to improved task performance (individual response).

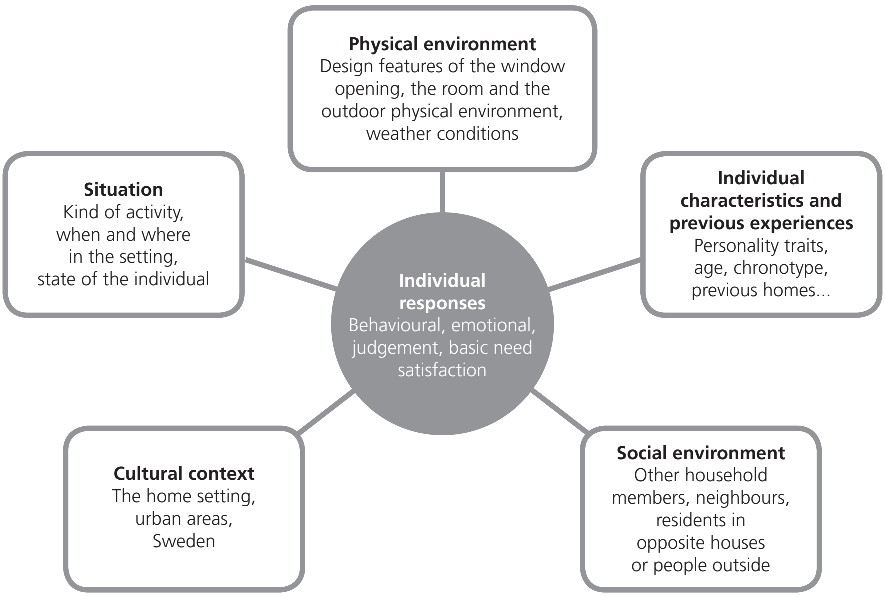

Figure 4.9 A visualisation of the multiple factors involved in residents' dwelling experiences relating to their window openings.

4.4 My Light Profile

This combined lab and field study aimed to evaluate an early prototype of a personalised home lighting system that included body-worn loggers. The study resulted in the main findings shown in Figure 4.10 (Gerhardsson & Laike, 2019a).

- Half of the participants were positive to using the lighting system in the future.
- 'Physical wearable comfort' explained 36% of the variance of 'behavioural intention'.
- Expectations of better performance during the day explained 51% of the variance.
- Interviews identified feelings of comfort or discomfort when wearing the devices.

Figure 4.10 Main findings of the interview study *My Light Profile* that looked at factors predicting user acceptance of a dynamic home lighting system, and analysed reasons behind participants' evaluations of the lighting system.

4.4.1 User acceptance based on statistical analyses

The final section in Questionnaire 2 measured acceptance of technology using 17 items that have been found to strongly predict technology acceptance in a consumer context – the extended Unified Theory of Acceptance and Use of Technology (UTAUT2) (Venkatesh et al., 2012). Two variables, habits and price value, were excluded due to the short test period, and because participants were evaluating a prototype not available on the market, and therefore with no commercial price. The level of agreement was expressed on a 7-point Likert scale ('Strongly disagree' to 'Strongly agree').

The three items 'I intend to use the system in the future', 'I intend to use the system at every opportunity in the future', and 'I plan to increase my use of the system in the future' were merged into the dependent variable 'behavioural intention to use the home lighting system', since Cronbach's alpha of .91 suggested a correspondence. Half (50%) of the participants gave an average score of 4.3 or higher on the 7-point Likert scale (N = 28, M = 4.1, SD = 1.6).

The mean value of the following independent variables of the Unified Theory of Acceptance and Use of Technology were close to 4 on the 7-point Likert scale: 'performance expectancy' (N =27, M = 4.3, SD = 1.4), 'social influence' (N= 28, M = 3.7, SD = 1.7) and 'hedonic motivation' (N= 27, M = 4.4, SD = 1.5). This suggests that participants, on average, were neutral, or slightly positive, to the idea that the technology would benefit them in performing certain activities. Participants did not perceive that significant others believed the participants should use the technology. Participants were neutral, or slightly positive, to the enjoyment of using the lighting system.

The remaining independent variables, 'facilitating conditions' (N= 27, M = 5.9, *SD* = 1.2) and 'effort expectancy' (*N*= 28, *M* = 5.5, *SD* = 1.0), were rated higher on average, indicating that participants perceived that there are resources and support available for using the system, and the degree of ease using the technology is high. Average scores for the outcome variable 'behavioural intention to use the home lighting system' were close to 4 (*N*= 28, *M* = 4.1, *SD* = 1.6). About two-thirds of participants would recommend others to use the home lighting system (*N*= 28, *M* = 5.2, *SD* = 1.4), with 68% answering 5 or higher on a 7-point scale from 'No, absolutely not' to 'Yes, absolutely'.

A hierarchical multiple regression was conducted with 'behavioural intention to use the home lighting system' as the dependent variable. The model showed that, of the selected five determinants of the UTAUT2, two ('performance expectancy' and 'social influence') predicted participants' willingness to use the lighting system. However, 'social influence' made a small and non-significant contribution and was therefore excluded in the final model (see Figure 4.11).

Both 'physical comfort' and 'performance expectancy' accounted for 86% of the variance in 'behavioural intention to use the home lighting system'. 'Performance expectancy' was the most important factor, accounting for 50.6% of the variation in 'behavioural intention to use the home lighting system', and this change in R^2 was significant, $F(3, 20) = 24.90$, $p < .001$. Physical comfort factors of the light logger and the activity watch made a considerable contribution, explaining 35.8%, and this change in R^2 was also significant, $F(2, 23) = 6.41$, $p = .006$. 'Physical comfort' was entered at stage one, as it seemed logical to assume that the comfort of carrying the wearables is a prerequisite for accepting the home lighting system. Surprisingly, the visual appearance of the loggers – colour, shape, material, size, design and durability – added nothing to the variance.

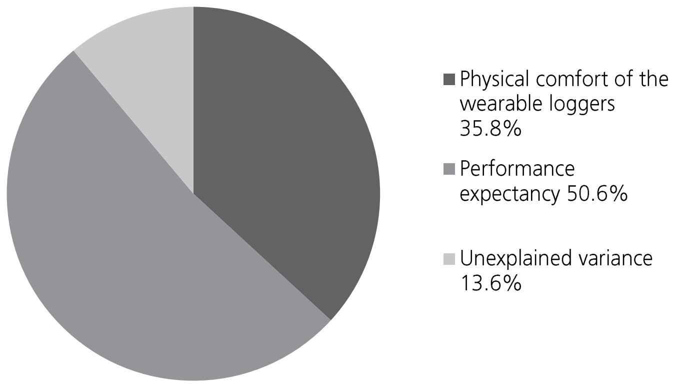

Figure 4.11 Visual depiction of variance in 'behavioural intention to use the home lighting system', as predicted by 'physical comfort' of the light logger and the activity watch, and 'performance expectancy'. Fourteen percent of the variance was unaccounted for (*N* = 26).

4.4.2 User evaluations and acceptance based on the interviews

The qualitative interview data were analysed using a set of four of six dimensions included in the Comfort Rating Scales (Knight & Baber, 2005). The remaining dimensions were not relevant for the kinds of devices used in this study. Two dimensions or themes relate to psychological comfort – *emotion* (concerns about appearance and relaxation) and *anxiety* (worry about the device, safety, reliability, e.g. worries about the safety of wearing the device and concerns as to whether the wearer was using it correctly or whether it was working correctly). The third and fourth dimensions are linked with physical comfort – *attachment* (physical feel of the device on the body, attachment) and *movement* (the device physically affects movement).

Two additional dimensions were identified that reflect participants' experiences with the wearables and carrying the mobile phone in the home: *value concerns* and *changes to routines*. The former addresses cognitive and not only emotional concerns about personal values concerning lifestyle, the environment or ethics, but also relates to self-identity (perceptions about abilities, flaws, status, and worth).

Themes and examples from the interviews are shown in Table 4.7. 'Movement' was interpreted as the most critical factor for understanding how willing participants were to use the system. This was based on theme prevalence across the interviews. The next most critical factors seemed to be 'attachment' of the loggers and 'anxiety' relating to the light logger and the mobile phone.

Table 4.7 Examples from the interviews illustrating the dimensions of wearable comfort of the light logger and the activity watch, or carrying the mobile phone.

Dimension of comfort*	Description of dimension	Examples concerning the wearable devices or the mobile phone (participant ID followed by '+' indicating a positive attitude to using the system, '–' indicating a negative attitude, and no sign indicating neutrality)
Emotion (Psychological erceptions of comfort) (6)	Appearance and relaxation, e.g. wearer worries about how they look wearing the device and feelings of being relaxed.	*"I think the light logger is a pain. People maybe wonder what it is."* (P5–) *"In that case, I wouldn't like to have one [light logger] that's so visible. I'd rather have something more discreet, I can imagine."* (P7+)
Anxiety (Psychological perceptions of comfort) (16)	Safety and reliability, e.g. worries as to the safety of wearing the device and concerns as to whether it is being used correctly or it is working appropriately.	*"It was very easy to wear. The only thing you have to think of was to not to hide it, like when you switch to a jacket and scarf."* (P6+) *"The activity watch was just there, but with the light logger I was thinking: Is it at the right angle, is it standing up? You had to think a bit about it."* (P10+)
Attachment (Physical perception) (16)	Non-harmful sensation, e.g. physical feel of the device on the body, and the attachment of the devices.	*"The only thing was that, if I took this off [thick jumper] then I'm wearing a very thin shirt, and then it [light logger] hangs down a bit. Then I changed [clothes] so that it wouldn't weigh down so much."* (P2–) *"[The light logger] was very simple. Yesterday, I was wearing a shirt, and then it was constantly resting against my collar bone. It felt as if it was pushing."* (P10+) *"I felt it [activity watch] was a bit of a nuisance at night. If you're not used to it…"* (P16)
Movement (Physical perception) (22)	Conscious awareness of modification to posture or movement. The device gets in the way when carrying out normal movement patterns.	*"[The light logger] feels as if I always have to be adjusting it so that it's sitting properly and so that it's not bending."* (P5–) *"No, I never have my own mobile on me. I leave it on the desk or somewhere at home."* (P3+)
Value concerns (Cognitive concerns) (4)	Conflict with personal values.	*"Being human is just being a consumer. I don't like looking at myself… When I look at myself with this equipment, and so the technology was going to log me and feel where I was, what I needed. That makes me sad, unfortunately."* (P11)
Changes to routines (14)	Wearing the device requires a change to routines and restrictions as to what clothes to wear.	*"Perhaps if you had everything in an activity watch. The problem is you have to remember to move the light logger all the time."* (P3+) *"Something that was a bit of a problem was the telephone. Yesterday, I was wearing a dress. When you have a dress, you don't have any pockets. So then I have it on the table, and this was ok as long as you were sitting at home by the computer."* (P9+)

* Numbers represent the prevalence of the themes across the participants, e.g. '28' signifies that all 28 participants referred to the particular theme.

5 Discussion

This thesis contributes to the knowledge about what residents want from their indoor lighting, luminaires and window openings during the day and night, and what prevents them from having what they want.

The outcome of the research reveals that the scope of indoor lighting in Swedish homes may be broader than has been shown in the existing research literature on home lighting. The use of electric lighting reflects, for example, embedded memories, sleep and waking routines, and communication with light. The findings identify the potential effects of a windowless situation in dwellings; in addition to the absence of daylight, the loss of both sensory information and local social interaction.

A supportive indoor physical environment is essential for fulfilment of residents' needs and their enjoyment, such as the appropriate technical infrastructure, a windowsill deep enough for a table luminaire, and easy installation of curtain rods and room-darkening solutions. However, such environmental indoor design features are largely dependent on the decisions made by housing developers and landlords. Residents may lack knowledge about how to achieve the desired lighting situation. For example, it may not be an easy task to find a luminaire and the light source that will produce the desired effect in a particular room, despite knowing the general principles of good lighting.

Residents might be aware of the effect of light on mood and for alerting the mind, but seem to know less about light as a time giver for setting the body clock to avoid circadian disruption that can lead to a reduction in sleep quality. (The circadian aspect of light was not mentioned when interviewees were asked about how they use their lighting and window openings.) More information about the multiple benefits of light and guidance on how to achieve these benefits in people's everyday environments may help. What must be communicated is that daylight with the appropriate shading is the most sustainable indoor lighting option when available, electric light is supplemental, and more advanced lighting technology could be added (provided energy for lighting use does not increase).

Another original contribution relates to the understanding of how users may respond to lighting technology involving wearable devices to support the regulation of circadian rhythm. These findings can help identify possible problems in the individual measurements of light/dark cycles and sleep/wake patterns needed in a personalised home lighting system.

The scope of residential indoor lighting should be expanded to include the effect of indoor lighting on the outdoor environment after daylight hours, as well as the effect of building design and technologically advanced home lighting systems on residents' everyday lives. Together, these components have significance for the sustainable development goals 'Sustainable cities and communities (goal 11) and 'People's health and wellbeing' (goal 3).

5.1 Lighting characteristics and factors influencing illumination choices

The combination of survey and interviews shed new light on the goals guiding people's lighting choices and behaviour. The qualitative findings contributed the additional information needed to understand key factors that influence residents' illumination choices.

Reasons for purchasing LED lamps and CFLs are because they last a long time and need replacing less often (hedonic goal) and because they save energy (normative goal). Purchasing cost (gain goal) has little impact on consumers' decisions on what to buy. The identified goals directing domestic consumer lamp choices confirm the conclusions of other studies investigating reasons for environmentally responsible behaviour, namely that environmental concerns influence behaviour mostly in situations when costs and inconvenience are low (Diekmann & Preisendörfer, 2003; Gatersleben et al., 2002). In other words, low-cost decisions such as buying low-energy lamps will favour a normative goal.

The most important performance factors rated by consumers when they purchase lamps are lamp quality (colour tone), lamp lifetime, and energy efficiency. Less important are purchasing cost, lamp design and dimmability. Providing information about the colour tone to consumers is therefore essential to avoid dissatisfaction with new lamp technologies. Consumers may also be sensitive to any perceived deviations from the expected colour tone. (Light sources of the same Correlated Colour Temperature, which is often stated on the lamp package, can have different chromaticity.) Also, dimmability may be an appreciated feature with the increased use of dimmable lamps, provided they perform well without visible flicker.

As expected, a prominent lighting characteristic is the large number of lamps in an average Swedish home, which is supported by previous survey findings of Swedish homes compared to other countries (PremiumLight Project Consortium, 2014). However, rented apartments have significantly fewer lamps in the kitchen and the bathroom, and fewer lamps in total, than tenant-owned apartments. Also, the use of dimmers as a way to control lighting varies significantly with housing tenure type. The interviews suggest that one reason for not mounting additional luminaires could be the tenant's obligation to repair any holes or to cover the costs of repair when they move. Another reason could be uncertainty about the duration of residence. The cost of installing dimmers in rented apartments lies with the tenant. The findings regarding both the number of lamps and dimmers suggest that housing tenure, not only dwelling types, should be considered in future studies of home lighting.

It is generally known that Swedish homes have low light levels, rather than plentiful general lighting provided by ceiling-mounted luminaires. It might be inferred that low light levels and uneven light distributions are what residents prefer, but findings from the interviews suggest that there are several inhibitors of residents' desired home lighting. Residents who know what lighting they want may not have it for various reasons.

The first group of reasons concern individual characteristics, e.g. having the knowledge to choose the proper light source or luminaire to produce the desired effect. Motivation also plays a role, e.g. choosing not to replace a broken lamp may be because of the effort involved. Not wanting to change lamps where the whiteness is perceived to be too cool or too dim may be explained by environmental concerns, i.e. not wanting to waste fully functional lamps. So, a resident may avoid taking action and making the desired changes because of lack of knowledge, a desire to reduce effort (hedonic goal/emotional state), or environmental concerns (normative goal). The identified reasons might explain why people have low light levels in their homes – one of the questions raised in the most recent review of research on windows in homes (Veitch & Galasiu, 2012).

Other groups of reasons for residents not having the lighting they want are context-specific (see Figure 5.1): what the physical setting permits (e.g. available

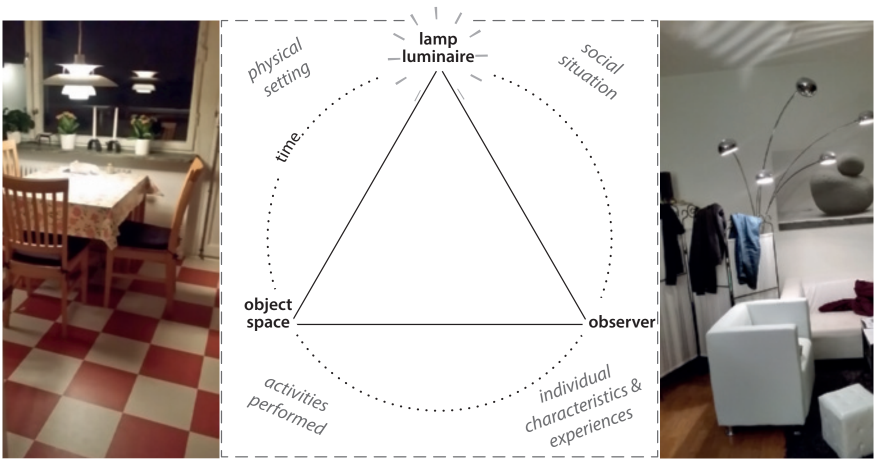

Figure 5.1 Factors influencing residents' indoor lighting choices and uses. A lighting experience is always multi-facetted because it involves the light source and luminaire, surfaces of objects and space reflecting the light, and the observer. The preferred lighting and use of luminaires are influenced by the individuals' characteristics and experiences, the activity performed by the individual, the physical setting, the social situation and time. (Photos taken by two of the participants in the study *My Home Lighting*.)

outlets), the social situation (what others in the household want or what the market can provide), the activity performed in a room, and time (e.g. time of day, life circumstances, ageing).

Motivation is very much about someone wanting some change in themselves or in the environment (Baumeister, 2016; Reeve, 2016). So, what causes residents to turn on their luminaires or change their lighting conditions? Interview findings and the analysis of archival data collected by the Nordic Museum suggest the following reasons: to see, show and tell, shape the room and touch our feelings. Using lighting to see, e.g. to find the way or facilitate visual tasks, is linked with behavioural goals. The other reasons relate more to psychological wellbeing, such as using display lighting to show a piece of artwork or family photos, to send a message that someone is at home, using indirect lighting to illuminate the ceiling and define a space, or to support a particular atmosphere. Additional reasons are to evoke memories embedded in the luminaires and to maintain rhythmicity (sleep and waking routines, e.g. using a night lamp or a wake-up light).

Motives linked with aesthetic experience and psychological wellbeing, rather than visual task performance, are also reflected by residents' reasons for burning candles – a well-known Scandinavian practice. According to the survey findings, half of the respondents burn candles frequently. The most common reasons are because it creates an atmosphere and/or because it looks nice. In other cultures, however, religious reasons might be more common.

In view of the frequent energy conservation campaigns over the years, it is surprising that only 26% of the respondents always turn off lights in unoccupied rooms in the home. One explanation is habitual behaviour. Such recurring behaviour can be defined as follows (Klöckner & Verplanken, 2013): when the intended goals of an action are reached, and the behaviour leads to the intended outcomes, the behaviour will probably be automatically repeated in the next similar situation. The findings suggest that leaving lights on in unoccupied rooms could be because of the following goals: aesthetic experience (to avoid visual or aesthetic discomfort), caring about others (making the home inviting or benefitting people outside), health (to avoid tumbling), or feeling good.

The finding that lights left on in unoccupied rooms may not necessarily be wasted light has implications for how to frame messages about energy reductions in energy conservation campaigns. I propose a shift from 'energy-saving' to 'mindful' lighting behaviour, which implies being kind to oneself, people and the planet. 'Mindful', or being aware, is linked to mindfulness, which is rooted in Buddhist teachings and entails respect for the needs of others and oneself (Williams & Kabat-Zinn, 2011). 'Mindful' sends the message that we have to pay attention to what we need in the present moment, avoid automatic behaviour, and also reflect on the environmental and ethical consequences of our behaviour. In other words, a shift from habits to intentional behaviour.

5.2 Window openings play several roles in residents' everyday lives

Window openings in the home serve as a different kind of illuminant. The findings show that residents appreciate their window openings because they contribute to their dwelling comfort in many ways. One dimension relates to physical needs and involves practical utilities. Window openings provide, e.g. air, task lighting and daily rhythm (a 24-hour cycle of light and darkness). A second identified dimension of dwelling comfort (the psychological/aesthetic) relates to psychological wellbeing, e.g. spatial brightness, indoor pleasantness, improved mood, perceived spaciousness, and visual privacy. A third dimension (the social) concerns interactions between residents and people outside, e.g. observing people outside and using visual cues.

Although physical need satisfaction is essential, it is not sufficient. How residents interact with and what they expect from their window openings might reflect underlying 'basic psychological needs', which include three components: *competence*, *autonomy* and *relatedness* (Deci & Ryan, 2000). I propose that this concept can be applied to the home and residents' exchanges with the outdoor physical environment, as well as the social environment through the window openings. Some of these interactions reflect the need for *relatedness*. For example, by following proper 'window blind etiquette' people show that they care for others or want to be accepted by others.

Autonomy is represented by participants' own decisions on when to adjust daylight controls (blinds, curtains, external shades) to improve sleep, daylight or privacy. Even if others are indirectly involved in 'window blind etiquette', residents may endorse such values, and chosen actions will still be an expression of the self. Autonomy would also enable individual screening in a multi-dwelling building, e.g. attaching tinted film on a balcony glass railing to prevent visual intrusion, without needing to obtain permission from the landlord or the tenant owners' association. Other studies have also linked dwelling comfort to the ability to manage the home as desired (e.g. Ellsworth-Krebs et al., 2019).

Linking residents' experiences with their window openings to *competence* is not as apparent, since Deci & Ryan (2000) regard competence as a felt sense of confidence and a very strong desire to affect and gain control of the environment, rather than a skill or capability. However, related to mastery and control is knowledge. Findings in the present study show that residents seem to lack adequate knowledge about how to improve indoor light conditions. Residents may not be aware of the consequences of certain design choices for brightness and the distribution of light, for example the effects of displayed objects on the windowsill, window coverings, curtain fabrics, colour and finishes.

In their review of the physiological and psychological effects of windows, daylight and view at home, Veitch and Galasiu (2012) concluded with several questions for future research. The findings of this thesis address some of them, for example, factors preventing residents making more or better use of daylight to meet their visual needs, or when residents use shading devices and why. The findings show that there may be conflicting goals, such as the desire for adequate task lighting or spatial brightness on the one hand, and visual privacy or wanting to preserve a tablecloth on the kitchen table on the other. Shading devices, either blinds or curtains, can be closed to avoid reflected glare from bright external surfaces, e.g. a newly installed copper roof or white exterior walls of adjacent buildings, or because reflected glare from the television screen makes it difficult to see.

The thesis has also identified additional factors that seem to be central for why residents want windows: for manual ventilation, passive cooling for better sleep quality, feeling the air temperature, experiencing desired sounds and providing visual information for people outside. Findings show that window openings in homes significantly contribute to multiple dimensions of dwelling comfort, not merely the provision of daylight, so multiple use of windows justifies the additional cost for investment and maintenance. (A description of conflicting goals in architectural design can be found in, e.g. Leslie et al., 2012.)

The findings suggest that residents may not be aware of the design features with greatest impact on daylight conditions in the room. When participants were asked about any changes they would like to see regarding their window openings, they mentioned, e.g. larger or additional windows, mounting window coverings, windows without mullions to increase the glazing area, a lower windowsill, or improving visual privacy without reducing daylight too much. One reason for wanting larger windows and glazing is to increase daylight. No one suggested moving the protruding balcony above the window openings, which indicates limited awareness about the effect of obstructions above the window opening on the provision of daylight.

Responsibility for the design of the building configuration lies with the architects and their clients. Unlike balconies constructed in recent decades, a common feature of multi-dwelling buildings designed according to the principles of functionalism in the 1930s, 1940s and 1950s is the placement of the balcony. Instead of blocking the windows, balconies were placed in front of the balcony door and the exterior wall to avoid too much obstruction of the visible sky (for examples, see Appendix A4).

5.3 Willingness to use a sensor-based dynamic home lighting system

The findings from the *Light at Home survey* indicate acceptance of LED lamps among residents. Findings in another study (*My Light Profile*) suggest that residents may be willing to use a personalised home lighting system to improve sleep at night and performance during the daytime.

The theory used to identify factors predicting user acceptance of the sensor-based home lighting system was developed for a consumer context (Venkatesh et al., 2012). However, 'Habit' and 'Price value' were not considered, since the system was a prototype and not yet available on the market. The independent variables 'performance expectancy', 'effort expectancy', 'social influence', 'facilitating conditions', and 'hedonic motivation' relate to several types of motivation, such as better performance during the day (goal), effort (hedonic goal/emotional state) or enjoyment (positive affect). Caring about health (value) in terms of sleep quality is one variable that could have been included, but was instead addressed in the interviews.

Interview findings also show that the wearable devices of the evaluated prototype need to be further developed to avoid psychological and physical discomfort. With these comfort issues in mind, it is believed that sensor-based home lighting systems could be useful for certain groups, for example, night-shift workers and people with insufficient exposure to daylight. However, for some, such a system may not be the solution for improving health and sleep quality because of conflicting personal values, e.g. not wanting to be dependent on technology. These insights could be transferred to similar types of wearable technology and technological systems in the home, involving either wearable devices or the continuous use of a mobile phone.

5.4 Reflections on the application of theory

Embeddedness characterises both the perspective of embodied cognition and the ecological perspective, which were useful for taking a holistic approach, i.e. to consider the variety of factors that might influence people's behaviours relating to light and darkness in the home. In contextual research, embeddedness reflects the idea that a particular phenomenon is thought to be embedded in a surrounding set of events (Stokols, 1987; Clayton et al., 2016). In the present setting, this approach helped identify essential sources of situational influence on residents' behaviour in the analyses of the interviews. For example, how life changes (e.g. moving to a new home, ageing, divorcing, becoming a widow) and temporal factors (behaviours during both day and night, in different seasons) impacted on arrangements in the home relating to lighting and window openings, and choices of luminaires.

The Framework to Understand Motivation and Emotion can be regarded as an umbrella, framing different types of internal motives identified in the conducted studies (see Table 5.1). Motives were identified either in the interpretative phase of the interview studies or when categorising response options in questionnaires. For example, the thematic analysis in the interview study, *My Home Lighting*, revealed aesthetic experience, caring for others or feeling good as reasons for wanting lights turned on in unoccupied rooms. Such reasons reflect internal motives, e.g. positive affect and relatedness (a basic psychological need).

Practical goals, such as managing visual tasks, can explain why residents use light from either luminaires or window openings. Similarly, expectations of performing better during the day can explain why residents would be willing to use a personalised home lighting system that improves daily rhythm and sleep quality. Nevertheless, residents' use of their electric lighting and window openings seem to be motivated by additional outcomes, such as health and psychological wellbeing. The outcomes, in turn, originate from internal states where needs, cognition and emotions play fundamental roles. The relative importance of an individual's needs and goals to each other will influence their choices, as will socio-environmental conditions. The home is undoubtedly much more than a serviceable shelter or a 'machine for living'.

Table 5.1 Examples of different motivations for light-related behaviours in the home identified in either the interviews or questionnaires.

Reasons for certain light-related behaviours in the home	Motivation	Illustration from study findings
Why leave lights on in unoccupied rooms?		
Aesthetic experience	Positive affect	It looks dull when adjoining rooms are completely dark.
Caring about others	Relatedness	Luminaire in the window is turned on for people outside.
Feel good	Hedonic goal (emotional state)	It is nice when you come home, and the window luminaire is turned on.
Why have open curtains or blinds to admit daylight?		
Health benefits (good mood)	Positive affect	Daylight makes you feel good and alert.
For enjoyment	Hedonic goal (emotional state)	A room with plentiful light increases comfort.
Why use a personalised home lighting system based on sensors?		
Health benefits	Value	To improve sleep quality.
Performance expectancy	Goal	When sleep quality improves you will perform better during the day.

To summarise, the applied theories were helpful for gaining a broader perspective on behaviour relating to light and darkness in the home, and for analysing and sorting residents' experiences in ways that have not been attempted in previous lighting research.

5.5 Strengths and limitations

The theoretical approach to motivation and the mixed-methods strategy of inquiry, where findings were fully integrated when reporting the findings, enabled a more complete picture of the lighting situation in homes and increased understanding of the underlying motives for residents' light-related behaviours.

However, we still do not know the current electricity use for lighting (which affects potentials for further energy savings). There is always a risk of rebound effects when more energy-efficient technologies are introduced, for example, installing and using a larger number of luminaires or leaving the existing luminaires turned on for longer periods. We still do not know which luminaires are used the most in the home – ceiling-mounted, wall-mounted, floor-standing luminaires, or table luminaires.

Illuminance levels on task and at the eye from electric light sources are anticipated to be low in Swedish homes, but technical measurements are lacking. Differences between age groups should be further investigated (Charness & Dijkstra, 1999), and between residents with different cultural backgrounds. Obtaining measurements of daylight conditions are more complicated because comparisons between cases require an overcast sky (following the CIE requirements for calculating the daylight factor). Such difficulties could be handled but would require an extended data collection period and participants with a high level of tolerance and patience.

One limitation of the *Light at Home survey* questionnaire was the response format in the section asking about lamp purchasing behaviour. One option with respect to saving money was included (initial purchase cost expressed as 'the price is affordable'), but not saving money through use. The response options could not be changed to enable comparison between results and the PremiumLight market survey (PremiumLight Project Consortium, 2014). In future studies, it would be desirable to alter the response options to express even better different hedonic, normative and gain goals.

One limitation of the study of the personalised home lighting system (*My Light Profile*) is that it only measured behavioural intention to use the system based on a validated questionnaire, but not actual use. Another reflection is the study could have included additional questionnaires to obtain self-reported chronotype and current sleep quality (e.g. Chronotype Questionnaire (MCTQ) and Karolinska Sleep Questionnaire), to establish statistical associations between such independent variables and the dependent variable (participants' willingness to use the lighting system). Further studies aiming at improving daily rhythm and sleep quality should be conducted in real-world apartments where most residents, depending on their needs, will experience bright white light in the morning and dim warm light in the evening to maintain a regular daily rhythm. They will have to wear sensors continuously for a longer time and change or re-charge the batteries. Another option is to perform real-world interventions with a circadian-effective lighting schedule but without body-worn sensors.

5.6 Implications for research

Future quantitative survey research on dwelling/residential/home comfort, such as post-occupancy evaluations, should take a broader perspective on dwelling comfort and consider all three dimensions – the physical, psychological/aesthetic and the social. The findings in the thesis suggest that existing questionnaire instruments need to be further developed to include additional variables linked with physical needs (enablers for sleep quality), psychological wellbeing (e.g. spatial brightness, indoor pleasantness, improved mood, perceived spaciousness, and visual privacy), and social needs (possibilities for observing and showing the appropriate visual cues).

The main message to the lighting, chronobiology and light therapy communities is the importance of an enabling physical home environment. To date, extensive testing of how to entrain an individual's daily rhythm in their natural living environment is lacking, despite current knowledge of the factors involved (light intensity, spectrum, timing, duration and light history). However, the physical environment can be more supportive of residents' individual need for a regular 24-hour exposure to light and darkness through increased flexibility.

Another message, for both research and practice, addresses surveys and energy conservations campaigns directed at residents, in which 'never leaving lights on in empty rooms' is considered to be an indicator of pro-environmental behaviour. The findings in the thesis, however, suggest that lights left on in unoccupied rooms in the home may not necessarily be wasted light, because they can serve a purpose for the residents in a Swedish context. Future energy conservation campaigns directed at residents could include 'turn off the light when it's not needed' rather than 'turn off the light in empty rooms'.

5.7 Implications for practice

Responsibility for home lighting also lies with housing developers and lighting producers. The findings highlight the importance of a supportive indoor physical environment for achieving residents' desired patterns of light and darkness. Such enablers in dwellings include the appropriate technical infrastructure (e.g. number and placement of electrical outlets), preparation for easy mounting of window treatments (e.g. multiple layers of curtains and blinds for control of daylight and visual intrusion), and external shades to improve the thermal climate during summer. A dimming function allows residents to control and adjust their lighting according to preference and situation, but requires consideration of the type of dimming technology. For example, simply replacing wall switches with smartphone app controls is not recommended, because dependency on a smartphone for regulating light is not conducive to universal design and to those who prefer to relax in the home without digital distractions.

Design and construction always involve trade-offs and compromises. When home buyers and tenants are better informed about health benefits linked with a regular pattern of light and darkness, they might prioritise health-oriented design solutions rather than other optional extras.

I end by circling back to technological solutionism and whether technology is the answer to any difficulty in peoples' everyday lives. Poor sleep and circadian disruption can be regarded as a social problem with biological origins. Humans are day active by nature, but social obligations and people's doings disturb a natural daily rhythm. Advanced sensor-based lighting applications are not the only solutions to address such problems in the home, as both no- and low-tech solutions are already available. For example, engaging in healthy lighting behaviour (e.g. increased exposure to daylight outdoors and better use of daylight indoors), and applying non-sensor-based lighting technologies in the home with variable intensity and colour temperature that can be adjusted by the user through easy manual control.

However, certain problems can be addressed more effectively at societal level rather than individual level, and there are a number of recommendations (see, e.g. Chattu et al., 2019), such as delayed school starting times for adolescents, abandoning daylight saving time (Roenneberg et al., 2019b), limiting the amount of time workers spend in shift work, and restricting certain types of shift work by legislation.

5.8 Concluding remarks

The thesis is a first attempt to examine user experience and behaviour relating to lighting, luminaires and window openings during the day and night in Swedish homes. It has identified multiple motivations behind residents lighting behaviour and choices. The findings suggest that researchers and practitioners must consider the following key points, of which the first might seem obvious but still is not:

- user needs and experiences when developing new lighting technologies,
- wearable comfort when lighting systems involve body-worn devices,
- window openings need multiple layers for shading, daylight distribution and privacy control,
- rethinking what is looked upon as wasted light in the home.

Suggested questions for future studies are: To what extent does residential indoor lighting impact on the outdoor lighting environment and 'urban comfort', e.g. feeling secure outside? What do inhabited dwellings, mediated by illuminated window openings, do for social community attachment?

6 Sammanfattning

Avhandlingen handlar om användares upplevelser och beteende kopplat till belysning, ljusarmaturer och fönsteröppningar i svenska hem. Syftet är att förstå hur boende använder ljus från både naturliga och tillverkade ljuskällor, vad de vill med sitt ljus och när de inte vill ha det. I Sverige uppger ungefär 40% av den vuxna befolkningen att de har mer problem med nedstämdhet, trötthet eller brist på energi under höst och vinter. En tredjedel får inte tillräckligt med sömn. Även om de exakta orsakerna inte är fastställda visar forskning att ljuset vi utsätts för under dagen har stor betydelse för dygnsrytm och sömnkvalitet, som i sin tur påverkar både sinnesstämning och prestation.

Det finns fler skäl till att intressera sig för ljus och mörker i hemmet som är ett relativt outforskat ämne. Ca 65% av dygnet tillbringas i bostaden och 90% inomhus, och den snabba utvecklingen av ny belysningsteknik för hemmiljöer riskerar att försumma användarnas grundläggande behov och önskemål. Ett ytterligare skäl är konsekvenser kopplade till ökad förtätning i städerna där byggnadernas höjd och placering påverkar den synliga himlen och därmed dagsljuset inomhus. Det finns dessutom anledning att specifikt undersöka hemmiljöer på nordliga breddgrader där dagarna är korta under en stor del av året.

Baserad på enkät- och intervjumaterial från tre av fyra olika forskningsstudier tecknar sig följande bild av den nuvarande ljus- och mörkersituationen i svenska hem. När svenskar köper ljuskällor värderas ljusfärg (färgtemperatur) högt. Dimbarhet värderas högt bland de som redan har flera dimrar (men 36% av hemmen saknar helt dimrar). Det genomsnittliga hemmet kännetecknas av många ljuskällor (i genomsnitt 39 st) men kök och badrum i lägenheter med hyresrätt har ungefär hälften så många ljuskällor som lägenheter med bostadsrätt. Just kök och badrum tillhör de få rum där flertalet ljusarmaturer är fasta och installerade av hyresvärden. Övriga ljusarmaturer väljs av de boende till skillnad från vissa andra länder. Intervjuerna visar att belysning i hemmet är kopplad till praktisk nytta, psykologiskt välbefinnande och sociala behov (t ex att se, visa upp eller kommunicera något, forma rummet och skapa atmosfär). Till och med tänd belysning i ett tomt rum kan fylla en funktion för de boende, t ex bidra till visuell eller estetisk komfort, ett mer inbjudande hem för gäster, hemtrevnad, säkerhet och för att visa omtanke om andra människor utanför huset. Knappt en tiondel använder någon typ att belysning för att vakna eller bli pigg, tre fjärdedelar använder däremot ofta eller alltid någon typ av mörkläggning när de sover.

Fönsteröppningar i hemmet, som också kan betraktas som ljusarmaturer, fyller flera funktioner i vardagslivet. De möjligör vädring, naturlig platsbelysning och en daglig rytm. Fönsteröppningar stödjer dessutom psykologiskt välbefinnande (visuell fröjd och trivsel i form av t ex allmänljus i rummet, rymlighet, utblick, avskildhet utan insyn) och tillgodoser sociala behov (kontakt med människor utanför och uppsikt).

Den fysiska miljön (t ex placering av uttag, en tillräckligt djup fönsterbräda för en fönsterarmatur, montagevänliga tak och väggar) är särskilt viktig för att åstadkomma den belysning som de boende önskar men även utbudet av ljusarmaturer på marknaden och individens kunskap om hur man går till väga för att skaffa sig den belysning man vill ha.

Avhandlingen blickar även framåt och utvärderar en belysningsprototyp för hemmet som ska främja en hälsosam dygnsrytm och bättre sömn. I en av forskningsstudierna undersöktes viljan hos 28 deltagare att använda det nya systemet som förutsätter att personen använder bärbara sensorer för att registrera ljusexponering (intensitet och våglängd) under dagen samt personens aktivitet och vila. Deltagaren bar en ljussensor på kragen och en aktivitetsklocka på armen under ett dygn i sin egen vardagsmiljö och fick därefter en demonstration av belysningssystemet i en fullskalemodell. Hälften av deltagarna skulle kunna tänka sig att använda belysningssystemet i framtiden, om de bärbara sensorerna är bekväma att bära, eftersom man förväntade sig att prestera bättre.

Avhandlingens fyra studier pekar också på vad såväl forskare som praktiker bör ta särskild hänsyn till:

- användarnas behov och upplevelser när ny belysningsteknik utvecklas,
- komfort när det gäller belysningssystem som bygger på bärbar teknik,
- att fönsteröppningar kräver flera lager (t ex utvändiga solskydd, persienner, gardiner) för att reglera sol och dagsljus, få mörkt och hindra insyn,
- att tänd belysning i tomma rum i hemmet kan fylla en funktion och inte behöver räknas som ljussvinn.

Fastighetsutvecklare, hyresvärdar, arkitekter och belysningstillverkare har ett stort ansvar även om boende i svenska hem väljer flertalet ljusarmaturer.

7 References

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Appendix

A1. Interview guide: 'My Home Lighting'

Introductory questions:
A. Can you tell us how old you are and how many people live in your household?
B. Do you work with or have you worked with anything to do with lighting?
C. Do you know approximately when the house was built?

Main question:
Now we'll turn to the pictures in the album that you have taken. Can you tell us a little bit about why you've chosen the luminaires and how they are used? I suggest that we do it room by room, in the same order you took the pictures.

Follow-up and additional questions:

1. Do you have any sort of automatic sensor, for example a presence sensor or daylight sensor?
2. Do you have a dimmer in the flat?
3. When is the lamp switched on? When you are eating, watching TV, when you are spending time with each other (conversation and with guests), during sedentary activities (reading, working at the computer, sewing, doing crafts), when you are sleeping/resting?
4. [Multi-person household] Do you agree on how the lighting should look or how bright it should be? If you have different needs, how do you resolve the differences?
5. Have you changed anything in terms of lighting since you moved in? Age can, for example, affect how much light you want.
6. What changes would you make if you could change your lighting? Which rooms? What stops you from making the changes?
7. Are you satisfied with your daylight?
8. Do you make use of daylight during the day? For example, by not switching on electric lights or keeping blinds up and not drawing dark curtains.
9. Do you turn off the lights when no one is in the room? If you do not do this, why not?
10. Can you black out the bedroom?
11. Do you black out the room every night?
12. Have you thought of anything else about lighting that I haven't covered?

Intervjuguide: Min hembelysning

Inledande frågor:
A. Kan du berätta hur gammal du är och hur många som bor i hushållet?
B. Jobbar du eller har du jobbat med något som har med belysning att göra?
C. Vet du ungefär när huset byggdes?

Huvudfråga:
Nu går vi över till bilderna i albumet som du har tagit. Kan du berätta lite om varför du har valt lamporna och hur de används. Jag föreslår att vi tar rum för rum, i den ordning du tog bilderna.

Uppföljningsfrågor och tilläggsfrågor (ifall de inte har tagits upp tidigare):

1. Har du någon automatisk styrning, t ex närvarostyrning eller dagsljusstyrning?
2. Har du dimmer i lägenheten?
3. När är lampan tänd? När du äter, tittar på TV, när du umgås (samtal och med gäster), vid stillasittande aktiviteter (läsning, datorarbete, sy, pyssla), när du sover/vilar?
4. [Flerpersonshushåll] Är ni överens om hur belysningen ska se ut och hur ljust det ska vara? Om ni har olika behov, hur löser ni det?
5. Har du ändrat något när det gäller belysningen sedan du flyttade in? Åldern kan t ex påverka hur mycket ljus man vill ha.
6. Vilka förändringar skulle du göra om du fick ändra på din belysning? Vilka rum? Vad hindrar dig från att göra ändringarna?
7. Är du nöjd med ditt dagsljus?
8. Utnyttjar du dagsljuset på dagen? T ex genom att låta bli att tända den elektriska belysningen eller låta persiennerna/rullgardinerna vara uppe och inte dra för mörka gardiner?
9. Släcker du när ingen är i rummet? Hur kommer det sig att du inte gör det?
10. Har du möjlighet att mörklägga sovrummen?
11. Mörklägger ni varje natt?
12. Har du kommit på något annat om belysning som jag inte har tagit upp?

A2. Setting: 'My Home Lighting'

The multi-dwelling buildings where data were collected (photos taken by the author).

A3. Interview guide: 'My Window Openings'

Introductory questions:
A. Can you tell us how old you are and how many people live in your household?
B. Do you know approximately when the house was built?
C. Do you work with or have you worked with anything to do with architecture or design?

Main question:
Now we'll turn to the pictures in the album that you have taken. I suggest that we do it room by room, in the same order you took the pictures. Imagine the window opening has been blocked up and there is no window anymore. How would it affect your use of the room and your dwelling – during the day and night?

Follow-up and additional questions:

1. [Multi-person household] Do you agree on how to use the windows? If you have different needs, how do you resolve the differences?
2. Have you changed anything in terms of how you use the windows or their design since you moved in, such as natural ventilation habits, curtains and window treatment, room darkening…
3. Do you need to open the windows? In which rooms? For what reasons?
4. What changes would you make if you could change the window opening? Which rooms?
5. Are you satisfied with your daylight?
6. Do you make use of daylight during the day? For example, by not switching on electric lights or keeping blinds up and not drawing dark curtains.
7. Would you be satisfied with a screen emitting the same kind of light as daylight?
8. Do you have any room without a window? What is your experience of such a room?
9. Have you ever stayed in a windowless hotel room? How did you experience that?
10. Do you occasionally need to darken the rooms, such as the bedroom at night?
11. Do you black out the room every night? [Multi-person household] Do you have the same needs?
12. Is there anything preventing you from getting the desired room darkening? Do you use a sleep mask?
13. How is your sleep in general (do you feel rested when you wake up, do you get enough sleep)?
14. Would you describe yourself as a morning or an evening person?
15. How frequently do you clean your windows? Why do you clean them?

16. Through which window do you look to check the weather?
17. How is the indoor temperature affected by the windows in summer?
18. Can you hear any characteristic sounds from outdoors?
19. Have you thought of anything else about your window openings that I haven't covered? (Orientation, view, view content, visual intrusion, privacy, enclosure, natural ventilation, noise…)

Intervjuguide: Mina fönsteröppningar

Inledande frågor:
A. Kan du berätta hur gammal du är och hur många som bor i hushållet?
B. Vet du ungefär när huset byggdes?
C. Jobbar du eller har du jobbat med något som har med arkitektur och design att göra?

Huvudfråga:
Nu går vi över till bilderna i albumet som du har tagit. Jag föreslår att vi tar rum för rum, i den ordning du tog bilderna. Föreställ dig att fönsteröppningen är igensatt och att öppningen saknas. Hur skulle det påverka din vistelse i rummet och ditt boende – på dagen och på natten?

Uppföljningsfrågor och extrafrågor på slutet (ifall de inte har tagits upp tidigare):
1. [Flerpersonshushåll] Är ni överens om hur fönstren används? Om ni har olika behov, hur löser ni det?
2. Har du ändrat något när det gäller din användning av fönstren sedan du flyttade in? T ex gardinuppsättning, mörkläggning, vädringsvanor…
3. Har du behov av att kunna öppna fönstren? I vilka rum? Av vilken anledning?
4. Vilka förändringar skulle du göra om du fick ändra på fönsteröppningarna? Vilka rum?
5. Är du nöjd med ditt dagsljus?
6. Utnyttjar du dagsljuset på dagen? T ex genom att låta bli att tända den elektriska belysningen eller låta persiennerna/rullgardinerna vara uppe och inte dra för mörka gardiner?
7. Skulle du nöja dig med t ex en skärm som gav samma typ av dagsljus?
8. Har du något rum som du vistas i som saknar fönster? Hur upplever du det?
9. Har du någonsin bott i ett fönsterlöst hotellrum? Hur upplevde du det?
10. Har du någon gång behov av att mörklägga? T ex sovrummen på natten?
11. Mörklägger du/ni varje natt? Om hushållet består av två eller fler). Har ni samma behov?
12. Finns det något som hindrar dig från att få önskad mörkläggning? Använder du ögonmask?

13. Hur är din sömn normalt (känner du dig utsövd när du vaknar, tycker du att du får tillräckligt med sömn)?
14. Är du morgon- eller kvällsmänniska (morgonpigg resp kvällspigg)?
15. Hur ofta tvättas fönstren? Av vilken anledning putsas de?
16. Vilket fönster tittar du ut genom när du vill kolla vädret?
17. Hur påverkas innetemperaturen av fönstren på sommaren?
18. Hör du några karaktäristiska ljud?
19. Har du kommit på något annat om dina fönsteröppningar som vi inte har kommit in på? (T ex betydelsen av väderstreck, utblick, utsiktsmotiv, insyn, avskildhet, inhägnad, vädring, ljud…)

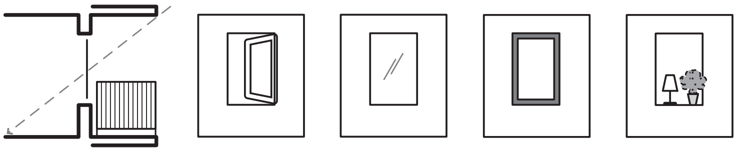
A4. Setting: 'My Window Openings'

The multi-dwelling buildings where data were collected (photos taken by the author). (Next page.)


1912
1929
1935
1941
1942
1944
1945
1947
1949
1959
1959
1967
1969
2000
2001
2002
2005
2007
2011

A5. The Window Opening Inventory

Design features of the window opening, the room and the outdoor setting representing the physical environment. Each feature influences one or more comfort qualities. This on-site inventory sheet was developed from the observer-based environmental assessment (OBEA) forms completed in situ by the author. The aim was to produce a quick tool for on-site evaluations of design features that influence rest, view and daylight conditions in each room in the dwelling.



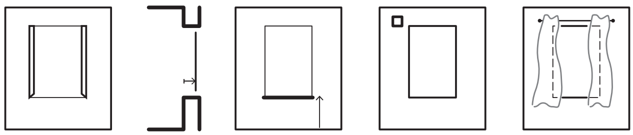
A. External shading devices
__ balcony
__ roof overhang
__ fixed shades (e.g. trellis, louvres)
__ movable shades (e.g. awnings, roll shades)

B. Window type
__ fixed
__ pivot
__ sliding
__ sash
__ inward opening
__ outward opening

C. Glazing type
__ transparent
__ translucent
__ pattern
__ stained
__ low solar heat gain

D. Window bars and glazing frames
__ light
__ intermediate
__ dark
__ moulding

E. Objects in the window opening
__ plant
__ luminaire
__ other
__ no objects



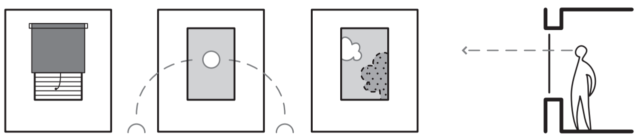
F. Window reveal angle
__ splayed <90°
__ at right angle (90°)

G. Window revel depth
____ cm

H. Windowsill height
__ 0 cm
__ <65 cm
__ 65–105 cm
__ >105 cm

I. Ventilation
__ wall vent
__ trickle vent
__ louvre window
__ air supply duct
__ air exhaust duct

J. Curtain fabric and coverage (open position)
__ light
__ intermediate
__ dark
__ translucent
__ opaque
__ upper
__ side
__ lower
__ none

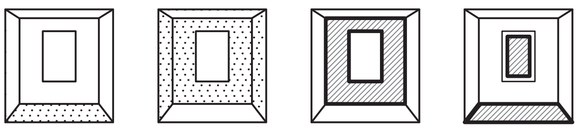


K. Room darkening/ internal shading
__ Venetian blinds
__ roller blinds
__ pleated blinds
__ blackout curtains
__ folding shutters

L. Window orientation
__ N
__ E
__ S
__ W
__ NE
__ SE
__ SW
__ NW

M. View content
__ sky
__ greenery
__ building
__ wall
__ grass
__ ground
__ water
__ street/path
__ people
__ urban wildlife
__ cityscape
__ landcape

N. View distance
__ very short (<10 m)
__ short (10–59 m)
__ medium (60–199 m)
__ long (200–1000 m)
__ very long (>1000 m)



O. Reflectivity of floor surface
__ low
__ intermediate
__ high

P. Reflectivity of wall surfaces
__ low
__ intermediate
__ high

Q. Ratio of window area to inside window wall area
A_{window}/A_{wall}
____ %

R. Ratio of window glazing area to floor area
$A_{glazing}/A_{floor}$
____ %

A6. Interview guide: 'My Light Profile'

1. Do you work, or have you worked, with anything to do with lighting?
2. What is the lighting like when you wake up? When do you switch on lights? A lot of light, or not much? Do you prefer warm or cold light? In the bathroom? At the breakfast table?
3. What is the lighting like before you go to bed? Do you have digital screens near your face before you go to sleep, e.g. tablet, mobile phone or laptop? Do you need to darken your room at night? Can you?
4. Do you make use of daylight if you are at home, for example, by having venetian blinds or roller blinds pulled up or down? Why?
5. How did you experience wearing the light logger for a day? Did you encounter any problems? If so, what? For example, did you remember to attach the logger to your collar as soon as you got up?
6. How did you experience wearing the activity watch for a day? Did you encounter any problems? If so, what? I see that you are wearing a wristwatch…
7. Did you have the mobile phone on you or nearby all the time in the home? How did you experience that? Why?
8. What's your view on radiation from mobiles or from equipment that uses Bluetooth Low Energy to send data?
9. Could you imagine using this equipment for a longer period if you experienced better sleep quality by adapting the lighting at home to your needs? For longer than a month? *Supplement from 27 April 2016:* If not, is it because of the equipment? What is your sleeping like normally? Do you feel rested when you wake up, do you feel you've had enough sleep? Are you a morning or an evening person?
10. Can you think of anything else about your experience of wearing the equipment that I have not covered or that was not covered in the questionnaire? Any concerns or hopes?
11. Do you give your consent to photos of the loggers on your clothes being used in future publications and presentations of the technology?

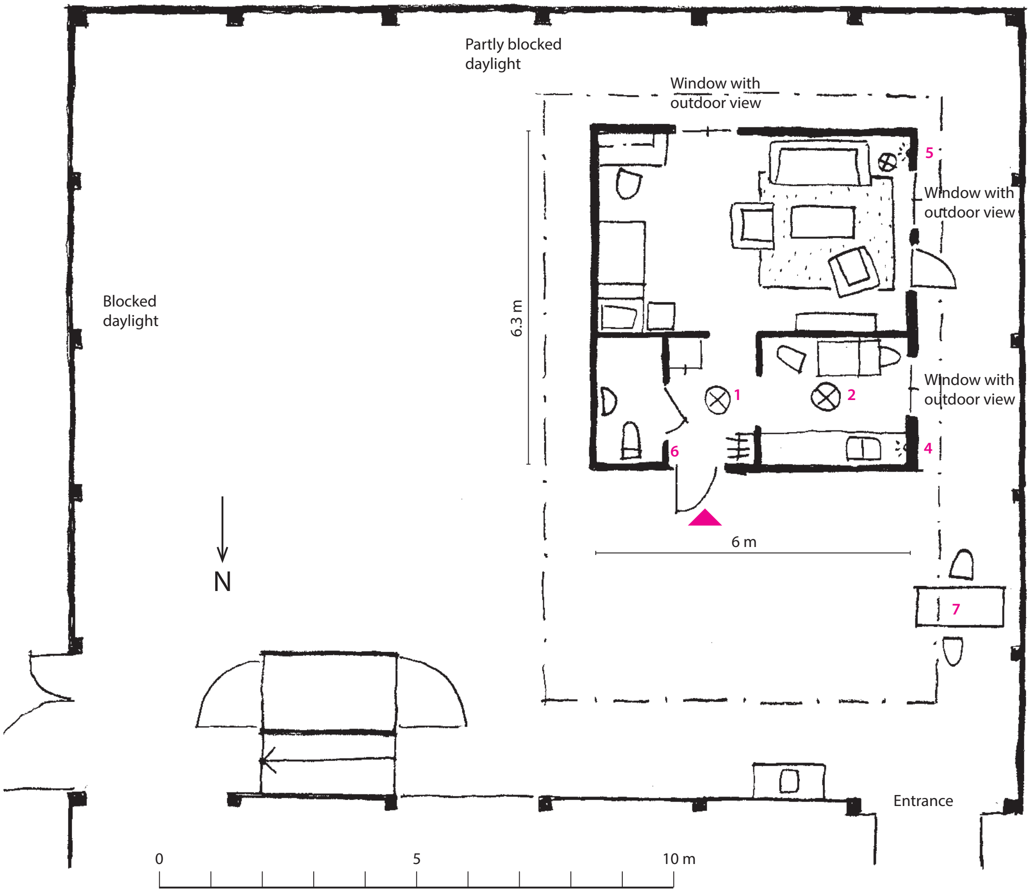
Intervjuguide: Min ljusprofil

1. Jobbar du eller har du jobbat med något som har med belysning att göra?
2. Hur är ljuset hemma hos dig när du har vaknat? När tänder du? Mycket ljus eller lite? Föredrar du varmt eller kallt ljus? I badrummet? Vid frukostbordet?
3. Hur är ljuset hemma hos dig innan du går och lägger dig? … Har du någon digital skärm nära ansiktet innan du lägger dig, t ex surfplatta, mobil eller laptop? Behöver du mörklägga sitt sovrum på natten? Har du möjlighet?
4. Utnyttjar du dagsljuset på dagen om du är hemma? T ex genom att inte ha

nerdragna persienner eller rullgardiner? Hur kommer det sig?

5. Hur upplevde du att det var att bära ljusloggern under en dag? Stötte du på några problem? I så fall vilka? Kom du t ex ihåg att sätta den på kragen på morgonen direkt när du steg upp?
6. Hur upplevde du att det var att bära aktivitetsklockan under ett dygn? Stötte du på några problem? I så fall vilka? Jag ser att du använder en vanlig armbandsklocka…
7. Hade du mobiltelefonen på dig eller intill dig hela tiden i hemmet? Hur upplevde du det? Hur kommer det sig?
8. Hur ser du på strålningen från mobiler eller från utrustningen (som använder lågenergi Bluetooth för att skicka data)?
9. Kan du tänka dig att använda den här utrustningen under en längre tid om du fick uppleva bättre sömnkvalitet genom att belysningen hemma anpassas till dina behov? Längre än en månad? *Tillägg från 160427:* Om inte, beror det på utrustningen? Hur är din sömn normalt? Känner du dig utsövd när du vaknar, tycker du att du får tillräckligt med sömn? Är du morgon- eller kvällsmänniska (morgonpigg resp kvällspigg)?
10. Har du kommit på något annat som rör din upplevelse av att bära utrustningen som jag inte har tagit upp eller som inte framgår av enkäten? Någon oro eller förhoppning?
11. Godkänner du att fotot på loggarna på dina kläder används i framtida publikationer och presentationer av tekniken?

A7. Setting: ‘My Light Profile’



Full-scale model of a studio apartment
Floor area: 38 m^2
Size: Studio apartment with a separate kitchen (the large room serves as bedroom and living room)
Room height: 2.4 m
Light: Daylight and electric lighting (Philips Hue, three LED light bullbs, tunable white, 8,5 W, 600 lumen), **1** ceiling light, **2** ceiling light, **3** floor lamp, **4** iBeacon, **5** iBeacon, **6** iBeacon which was removed after day 1, **7** desk, where the participant filled out the first questionnair on day 1 and received instructions for the devices to be worn for 24 hours



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Löfbergs
Skånegott





A8. Benefits of bringing the real world to the lab: Investigating lighting behaviour in homes using a full-scale model

This is a modified version (supplemented with references) of the peer reviewed extended abstract presented at the CIE Expert Tutorial and Workshop on Research Methods for Human Factors in Lighting, 13–14 August 2018, Copenhagen, Denmark. Author: Kiran Maini Gerhardsson.

Objective

To evaluate the first prototype of a personalised home lighting system, it was decided to use a full-scale model of a studio apartment in the laboratory of the School of Architecture at Lund University. The home lighting system is based on LEDs, wearable sensors and a mobile phone app to produce lighting tailored to the individual's needs. Drawing on participant interviews (N = 28), which were held in the full-scale model, the purpose of this paper seeks to highlight the benefits of using a three-dimensional representation at full-scale.

Studying real-world problems that involve people's behaviour do not always allow research in their natural environment. Researchers must therefore choose other methods to simulate real-world settings (for an extensive overview, see Stokols, 1993). One option is to use a two-dimensional visual representation of the real-world environment, e.g. photography prints or static (still images) or dynamic visual simulations on a flat screen that captures motion. A second option is a 3D-simulation with special glasses. A third is to create the desired environment using either small-scale or full-scale physical models (see appended Table 1 for an overview of environmental simulation techniques).

Studies have indicated that static colour and dynamic simulations are as effective as on-site responses when investigating rooms, buildings, plants or landscapes (Stamps, 2016). Other studies have shown that images, regardless of the presentation mode (e.g. 2D or 3D) and image type (photograph or virtual rendering), can represent the appearance of actual daylit corridor spaces (e.g. brightness and contrast) reasonably well (Cauwerts, 2013). However, the appearance of space (pleasantness and enclosedness) was poorly reproduced using images. One limitation of that study was the age of the participants ranging from 18 to 25, since they may be less sensitive to glare. Another limitation was the type of space in which people either stand or move.

Each approach has merits and limitations but, in lighting research, the effects produced by lighting, such as visual comfort, must be considered. The lighting situation is always influenced by the light source and the luminaire, the surfaces of the space reflecting the light, and the observer perceiving the light (individual characteristics and previous experiences). Neuroimaging studies have found that sensorimotor systems are engaged when humans experience the environment around them, and when viewing images or other people (Arbib, 2017). Both mind and body can be activated, e.g. emotions and facial expressions.

However, images have several limitations. Firstly, images projected on modern screens used in simulations cannot reproduce glare unless the screen is extremely bright, which makes evaluating simulated lighting situations difficult. Secondly, flat images cannot capture well enough how lighting is influenced by spatial and surface characteristics. Thirdly, 2D-simulations or photographs on a flat screen do not enable a full mind-body experience since physical movement within the space is not possible.

Methods

Both quantitative and qualitative data were collected during April and May 2016 using a convenience sample (N = 28, 50% female, median 41 yr). Each participant was engaged for a 24-hour trial in the field and for one hour in the lab. On the first day, the participant received the wearable sensors, which measured light exposure and rest and activity patterns. After 24 hours the participant returned to the lab and was given a demonstration of the new home lighting system in a full-scale model of a studio apartment (floor area 38 m^2). A small self-service breakfast buffet was included in the 'kitchen'. The participant completed a questionnaire addressing the comfort of wearing the sensors and the participant's willingness to use the home lighting system in the future.

To cross-check the assessment and to provide supplementary information, the trial ended with a structured interview with open-ended questions, lasting 10–30 minutes. The interview questions addressed lighting behaviour in the participant's home: which lights were turned on in the morning and evening (including digital screens), the use of daylight and shades, and the darkening of the bedroom at night. The interview involved the participant giving a detailed description of the home environment. The interviews were analysed thematically to provide a deeper understanding of factors influencing their willingness to use the home lighting system or not. Additional themes were the lighting vocabulary used by participants, the effect of available daylight on participants' use of electric light, and methodological insights.

Results

The results relevant to this paper concern the methodological insights. The physical setting, where the interview took place, enabled participants to describe better their home environment. Eleven participants made comments comparing their own home characteristics and those of the full-scale model in terms of:

- room layout and furnishing,
- size of window openings,
- participant-designed blackout screens in the bedroom,
- thickness, transparency or colour of curtain fabrics,
- type of luminaire: floor-standing or ceiling mounted,
- size of luminaires,
- placement of floor-standing luminaires,
- design of floor-standing luminaires,
- colour tone of lamps (cooler or warmer, bluish or yellowish).

Participants who gave poor descriptions of their home environment were encouraged to compare to the objects and materials in the full-scale setting.

An unexpected benefit of the physical setting was the less formal atmosphere created by the homelike appearance of the full-scale model. It is reasonable to assume that interviews conducted in a homelike environment, seated on a sofa or in an armchair, might make participants more relaxed. Participants were surprisingly open about their everyday behaviours, e.g. sleep habits, clothing or no clothing at night.

Discussion and conclusion

As several participants, unrequested, used objects or materials in the full-scale model for comparison when describing features of their own home, it is suggested that a three-dimensional representation at full-scale might elicit more information from the participants. Even though the setting does not fully correspond to a residential environment, there are differences between looking at a place and being in a place. In participants' appraisal of a place, lack of colours and textures, on the walls and the ceiling, is not necessarily a problem.

Previous research studies have used systematic evaluations of 2D- and 3D-simulations, and real settings. A Swedish study investigated participants' assessment of four different car interiors, both real cars and photographs on a computer screen using the Semantic Environment Description method (Karlsson, 2003; Laike, 1999). A real prototype car interior was also compared to a virtual reality (VR) simulation using a head-mounted display. Results showed that the evaluation between the real situation and the visual representation differed in terms of 'unity', 'complexity', and 'enclosedness'. For example, 'complexity' in the real environment was perceived as lower than in the VR situation and 'unity' was perceived as higher. A more recent Swedish study, exploring the reliability of colour and light appearance in 3D-models, showed that colour variations and shadows in renderings have improved, but contrast effects and inter-reflections between angled surfaces are still incorrectly represented (Stahre Wästberg et al., 2015).

To illustrate the limitations of images on a flat screen, watching a movie at the cinema may serve as an example. Movie scenes on a large screen can evoke strong sensations, for example, sudden noises. But have you ever been blinded by, for example, the sun in a science-fiction movie?

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Table 1 Simulation techniques for physical environments. Techniques are categorised by the author according to perceptual and visual qualities of simulations (partly inspired by Lawrence, 1993).[1]

Simulation techniques for physical environments							
Display features and interaction character-istics	Artwork and illustrations (drawings, sketches, paintings)	Photos (print, screen)	Videos	Computer generated models		Physical models	
				2D-simulations	3D-simulations VR[4]	Full-scale	Small-scale
Static (e.g. still image)	X	X		X			
Dynamic (e.g. motion picture)			X	X	X		
Flat surface	X	X	X	X			
Enclosed space					X	X	(X)
Abstraction[2]	modernism, 'semantic perspective'[3], perspective drawings (e.g. isometric)						
Realism[2]	'old master' oil paintings, linear perspective			photorealistic renderings with raytracing to simulate natural flow of light	photorealistic	limitations to colour, texture, daylight, view	limitations to colour, texture, daylight, view
Level of physical interaction	passive, (eye movement)	passive, (eye)	passive (eye)	passive/ active (eye)	active (body)	active (body)	intermediate (eye and head)
Interaction with other people				X (using avatars)	X (CAVE systems)[5]	X	

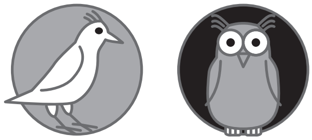
[1] Not included: graphics (schematic diagrams, icons and symbols), maps, technical drawings, sculptures.

[2] Different styles of pictorial rendering.

[3] Relative size of objects are varied according to their symbolic importance.

[4] Virtual reality (VR).

[5] A cave automatic virtual environment (CAVE). Projectors are directed to at least three of the walls of an empty room shaped as a cube.



Applying a mixed methods strategy of inquiry, the thesis identifies multiple motivations behind residents' lighting behaviour and choices, and indicates what must be considered by researchers and practitioners:

- User needs and experiences when developing new lighting technologies.
- Wearable comfort when lighting systems involve body-worn devices.
- Window openings need multiple layers for shading, daylight distribution and privacy control.
- Rethinking what is looked upon as wasted light in the home.

The conclusion is that the indoor physical environment can be more supportive of residents' need for a regular 24-hour exposure to light and darkness. In Swedish homes, where residents choose and mount most of their luminaires, responsibility for home lighting also lies with housing developers and lighting producers.

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